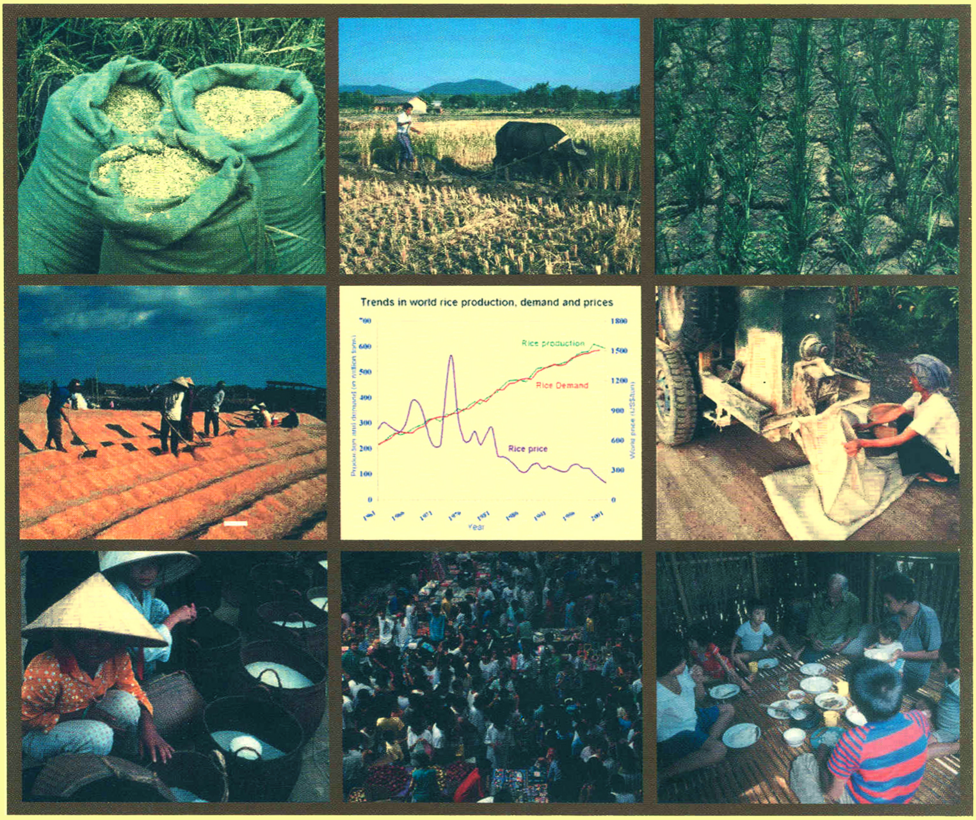
Developments in the Asian Rice Economy



Edited by M. Sombilla,
M. Hossain, and B. Hardy

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2002
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Foreword

Over the past five decades, development and growth in Asia have surpassed those in other developing regions as more Asian countries have recorded faster growth and social change. Japan has emerged as the second largest economy in the world. China, South Korea, and parts of Southeast Asia became economic powerhouses. Indeed, rising incomes and reduced poverty have brought newfound prosperity and confidence to many parts of Asia.

But, despite this growth and prosperity, rice is still looked upon as the pillar for further improvement of food security in the region. It is still the primary means of livelihood among rural households since most of the 1.3 billion members of the agricultural labor force in Asia who cultivate land almost always include at least one rice crop.

The population of Asia has expanded from about 1.7 billion in the 1960s to the current 3.4 billion. The greater portion of this population depends on rice for its staple food and source of energy. It is expected that another 1.5 billion people will be added to the region in the next 15 to 20 years. Rice will thus remain a significant part of the Asian diet as most of the population increase will come from the low-income countries.

The importance given to rice by many governments indeed contributed much to the sector's remarkable production growth. But government support is now waning and other factors are seriously affecting the commodity's production performance. Yet, some countries still need to import rice to meet the domestic consumption of their population. Increasing production to approach rice self-sufficiency remains their paramount goal. Like households, countries feel more secure about being able to produce their own rice requirements. Foreign exchange earnings are dearth in these countries, so that, if given a choice, they would channel these for purposes other than for importing rice.

For the rice-exporting countries, maintaining their position in the world rice market provides the impetus for further increasing rice production. To them, the goal is not just to have an excess rice supply but good-quality excess rice. Thailand has done well in maintaining its niche in the high-quality rice market. However, competition is around the corner with the rebound of Vietnam and the emergence of India as major exporters, especially in the last decade, and the prospects of Cambodia and Myanmar to produce a surplus beyond their domestic needs.

Many of these developments will greatly depend on the interaction of many factors. Government policymakers in general and farmers in particular ought to understand how trends in rice supply, demand, and trade change with economic growth, political development, and demographic changes. This is the main reason for the country studies found in this book. We owe it as a service to our rice-producing and -consuming countries to provide them with an update on the emerging trends of rice supply and demand so that they will be able to plan more rationally. We therefore hope that the information provided in this book will be of great use to our valued clientele.

RONALD P. CANTRELL
Director General
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Preface

Rice is most closely associated with the South, Southeast, and East Asian countries, extending from Pakistan to Japan. Of the 26 major rice-producing countries that account for 96% of global production, 18 are located within the region. Rice continues to be the major source of livelihood, especially in the rural areas, and the main staple food of the population. In most Asian countries, therefore, government development agendas have always been geared toward achieving self-sufficiency in rice.

Short-run trends in the world rice price have strongly influenced national policies for the domestic price and public investments in support for rice production and marketing. Investments in irrigation and research, for example, rose sharply as the world rice price peaked in the mid-1970s. This period was followed by more than a decade of low and stable world rice prices. This led to complacency among policymakers and a slackening of investments in research, irrigation, and other factors that promote productivity growth in the rice sector. Now, concern is growing, particularly in the scientific community, that rice production may not keep pace with the growth in demand because of increasing population. Large numbers of the predominantly rural poor in Asia still cannot afford an adequate diet. Increasing their purchasing power depends on productivity increases in agriculture, particularly in rice, and this must be achieved in the face of rising costs and growing shortages of resources.

Total rice production at the beginning of the 21st century was about 590 million tons. This is about 200 million t or 1.5 times more than the production in the late 1970s. It is projected that, over the next 25 years, another 200 million t more rice will be needed to feed the world. The task of reaching this level looks more difficult to achieve than it proved to be over the past 25 years. In all likelihood, this amount of rice will have to be grown on roughly the same amount of arable land. Demographic and environmental changes-the increasing rate of urbanization, climate change, accelerating erosion of the agricultural base, among others-will constrain the achievement of higher productivity. Technologies and production systems will have new dimensions(in production in a sustainable manner to protect the environment and promote social stability. The problem of reconciling cheap food for poor urban consumers and improving the income of rural households will continue to haunt government officials and practitioners.

Medium- and long-term projections of rice supply, demand, and prices are key information needed to guide national policy decisions and investment plans. In close collaboration with researchers and scientists from national agricultural research and extension systems (NARES), the International Rice Research Institute (IRRI), based in the Philippines, and the International Food Policy Research Institute (IFPRI), based in Washington, D.C. (USA), embarked on a collaborative research project to undertake policy analysis and projection studies on supply, demand, and trade of rice in some of the major rice-producing countries. The objective of the project was to make an in-depth analysis of the changing structure and dynamics of rice supply and demand and to institutionalize the research and policy analysis capacity and projection work as a core research activity in selected NARES. With financial support from the Japanese government, and from core funds of IRRI and IFPRI, the project started with the following countries selected to participate: Thailand, Vietnam, Indonesia, Philippines, Malaysia, Myanmar, Japan, South Korea, Taiwan (China), Bangladesh, India, Nepal, and Pakistan.

This book includes papers presented at the workshop on Medium- and Long-Term Prospects of Rice Supply and Demand in the 21st Century held at IRRI headquarters in Los Baños, Laguna, Philippines, on 3-4 December 2001. Each country paper includes the following sections:

- Growth in production and rice productivity: an analysis of total factor productivity in rice production
- Changes in policy regime that affect the rice industry
- Scope for further improvement in policies to induce further production growth
- Challenges to increasing supply
- Determinants of demand and supply parameters: medium- and long-term projections of rice demand and supply.

In addition to the country papers, presentations were made on various thematic subjects to assess the potentials of rice production vis-à-vis the international market, analyze its prospects in the international market, and determine its environmental sustainability.

The first section of the book presents a global perspective of the rice sector. Chapter one presents the developments of the rice economy in Asia as these have been influenced by the structural transformation of the region from an agricultural to industrial society. This is followed by an assessment of the world rice market in the years ahead by analyzing projection results to 2025 produced by the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) for supply, demand, trade, and prices under various scenarios.

The second section presents the rice sector development and prospects of the two largest rice producers in Asia, and in the world, China and India. The rest of the country studies are grouped on the basis of their net position in terms of rice supply and demand balances. Net rice importers include Indonesia, Bangladesh, and the Philippines. Supply and demand prospects of these countries make up the third section of the book. Those for the net exporting countries are presented in the fourth section. The dynamics of the rice supply and demand relationship in the newly industrialized economies of Asia are slightly different from those that are considered developing countries. Supply and demand analyses of these countries are presented in the fifth section. The sixth section includes studies that determine the comparative advantage of rice cultivation in various countries, while the seventh section assesses the effects of climate change on rice production. It also assesses the opportunities for increasing production in intensive rice-based systems, for which the wheat-rice system in the Indian Punjab was analyzed.

The final section presents some issues that arose from the workshop and their implications for rice research strategy and policies.

The transformation of the Asian rice economy and directions for future research: the need for increased productivity*

R. Barker and D. Dawe

Following World War II, growing concern about the pending food crisis in Asia led to support among international donors and national policymakers for the so-called Green Revolution technology—improved seeds, expanded irrigation, and the increased use of chemical fertilizer. For almost two decades, from the mid-1960s to the mid-1980s, rice production grew at close to 3% per annum. Slower growth since the mid-1980s has been influenced by both supply and demand factors: sharply lower prices for rice, environmental degradation and overexploitation of soil and water resources, and a decline in per capita consumption with the rising incomes in some regions.

The major structural transformation in Asia's rice economy over the past three decades has been part and parcel of the process transition toward an industrial economy. Indicators of this transformation are a decline in percentage gross domestic product and labor force in agriculture, a decline in population growth rate, a decline in percentage calories from rice in the diet, the change in rice production practices (many of which had existed for hundreds of years), the decline in percentage of farm income from rice, and a decline in the percentage of households below the poverty line.

The comparative advantage in rice production appears to be shifting back to Asia's major river deltas, where water is plentiful and labor is cheap. Many countries will face, on the one hand, pressure from the World Trade Organization to engage in free trade and, on the other, domestic pressure to protect the rice industry.

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*This is a modified version of Barker R, Dawe D (2001): "The Asian rice economy in transition," in Rockwood WG, editor: *Rice research and production in the 21st century: symposium honoring Robert F. Chandler, Jr.*, published by the International Rice Research Institute, Los Baños, Philippines. p 45-77. Copyright International Rice Research Institute. 2001.

These changes raise issues concerning the future directions for rice research. Rice remains the dominant food crop in Asia and a major source of livelihood for many poor consumers and producers. With declining financial support for research and the rising cost of resources—labor, land, and water—priority areas must be clearly identified. Increasing rice productivity continues to be the foundation of rural development in Asia and a key component of sustainable poverty alleviation.

Following World War II, concern grew about the food problem in Asia. The population was growing at close to 3% per annum and potential for further expansion of cultivated area was limited. Attention focused on the need to increase the yield of rice, the primary dietary staple.

Food security achieved by the Green Revolution was but a critical first step in Asia's transition from an agricultural to an industrial society. In the 1960s, two-thirds of the labor force and one-third of the gross domestic product (GDP) for most Asian countries were in agriculture. As those economies grew, agriculture became an ever-smaller portion of the total economy. This is the normal pattern of development (Timmer 1988). Rice remains the dominant staple in the Asian diet, however, and the most widely grown crop. It contributes one-third to one-half of agricultural value added and 40–50% of the calories consumed by people in much of the region (Hossain and Pingali 1998). The introduction of new technologies and growth in production continue but at a much slower pace. More than a decade of low and stable world rice prices has led to complacency among policymakers and a slackening of investments in research, irrigation, and other factors that would promote productivity growth in the rice sector. There is concern, particularly in the scientific community, that rice production may not keep pace with the growth in demand because of population.

The well-to-do consumers are diversifying their diets and rice-farming households are looking for new sources of income to compensate for low returns to rice production caused by the decline in price. But large numbers of the predominantly rural poor in Asia still cannot afford an adequate diet. Increasing their purchasing power depends on productivity increases in agriculture, particularly in rice, and this must be achieved in the face of rising costs and growing shortages of resources, particularly water.

We describe the transition in the Asian rice economy from several dimensions. We examine in turn

- the trends and sources of growth in rice production,
- the trends in technological change: its beneficiaries, impact on poverty alleviation, and negative effects on environment and health,
- diversification in consumption and production away from rice, and
- the shift in comparative advantage and expanding world rice trade.

Then we discuss the challenge that faces the international community, national policymakers, and researchers to continue to increase the productivity of rice and to ensure adequate supplies for those who cannot afford an adequate diet.

Trends and sources of growth in production and productivity

The growth in rice production over more than three decades since the release of the first high-yielding rice variety, IR8, in 1966 and the factors explaining that growth are well documented (Barker and Herdt 1985, Hossain and Pingali 1998, Pingali et al 1997). Today, concern is general in many quarters about the slowdown in rice production growth and the potential implications for food security and poverty alleviation. How was it possible to achieve a 3% per annum growth in Asian rice production for more than two decades, a growth rate far exceeding what had ever been achieved previously?

Political imperatives and climatic shocks

In the post-World War II era, the concern of the West regarding the deteriorating food situation in Asia and its implications for political stability was driven to a large degree by cold-war politics. Among the governments of Asia and the West and the international development agencies the priority was clear—*increase cereal grain production in Asia*. A consensus gradually emerged as to how to get the job done as the pieces of the Green Revolution technology began to fall into place.

Two weather events, which have now come to be known as *El Niño* and *La Niña* (which lead to drought or flood in many parts of the world), served to catalyze the commitment to the food security goal. The first of these occurred in the mid-1960s in the Indian subcontinent, where a shortfall in grain production threatened famine. The second occurred in 1972, resulting in a shortfall in crop production, leading to a sharp rise in world rice prices (Fig. 1) and forcing Thailand, the world's largest rice exporter, to ban exports for several months in 1973.

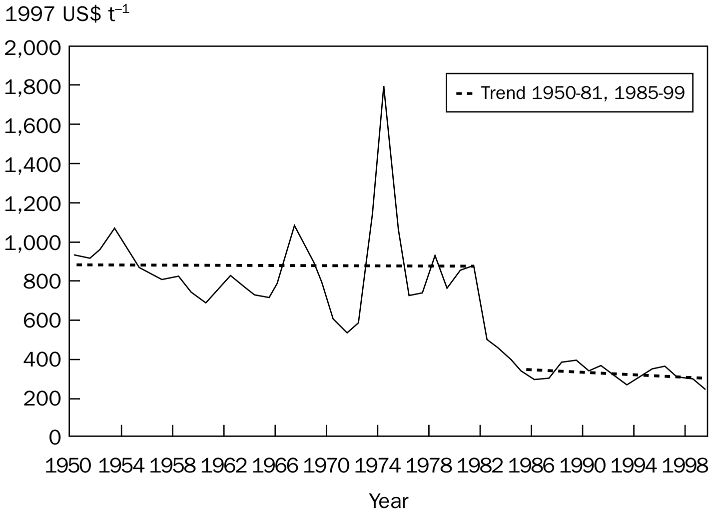

Fig. 1. Real world rice prices (100Bs, F.O.B. Bangkok).

Technological advances

The so-called Green Revolution is most commonly associated with the development of the modern semidwarf varieties (MVs) of rice and wheat. However, two other critical components of the Green Revolution technology are fertilizer and irrigation. With the new varieties, and with these other two factors, a steady stream of technological improvements has contributed to rice productivity growth. Because the inputs were highly complementary, efforts to apportion the share of the output growth to each have proved difficult. An analysis by Herdt and Capule (1983) suggested that the MV effect, fertilizer effect, irrigation effect, and other factors (a residual) contributed almost equally to growth in production. Included in "other factors" would be the extraordinary investment of the West in human capital development in Asia. This often overlooked investment helped to provide the policy and institutional changes needed to facilitate the development and spread of the new technology. This would help to account for the speed with which these technologies spread.

Varietal improvement. When IRRI began operations in 1962, no one would have predicted that a breakthrough in rice yield potential could be achieved in just four years. The serendipitous early discovery of the dwarfing gene in the Taiwan collection led to the release in 1966 of the first semidwarf variety, IR8. Traditional tall varieties (about waist high) yielded a biomass consisting of 80% straw and 20% grain, while the grain-to-straw ratio in the semidwarfs (about knee high) was 50/50. These shorter, stiffer straw varieties gave a higher yield response to fertilizer without lodging at harvest time. Equally important, the new varieties matured in just 120 d or less compared with 150 d for the traditional varieties. The release of IR8 established a yield ceiling in open-pollinated rice in the tropics that has lasted to this day. (Hybrid rice developed in China in the 1970s raised the yield ceiling by 15%, but suitable varieties for adoption in the tropics have yet to be developed.)

The susceptibility of IR8 to pests and diseases quickly shifted the emphasis to breeding for resistance. The release of IR36 a decade after IR8 (1976) marked another milestone, characterized by the development of the second generation of insect- and disease-resistant MVs. It was estimated in the early 1980s that more than 10 million hectares were planted to IR36 (IRRI 1982). However, this led to concerns that the genetic base of the new varieties was too narrow, thus increasing the downside risk of widespread crop loss in a single year (Evans 1986). The release of IR64 in 1985 with more than 40 landraces in its ancestry provided insurance against risk of this nature. Throughout the entire period from the release of the first high-yielding varieties (HYVs), the quality of grain steadily improved.

To date, drought and the effects of El Niño and La Niña weather conditions remain the major source of year-to-year variation in crop production. Breeding for marginal environments with frequent droughts or adverse soil conditions is more complex. Some researchers argue that, aided by biotechnology, the greatest potential for productivity gains (and poverty alleviation) in the future lies in the rainfed environments (Hossain 1999). Others anticipate that a future breakthrough in the yield ceiling will continue to favor the irrigated areas and that these areas will produce an ever-larger share of the world's rice (Otsuka 2000). We will return to this issue later in the paper.

Advances in fertilizer technology. Since the advent of the Green Revolution in the 1960s, chemical fertilizers have had a central place in transforming farm production in Asia. Asian fertilizer consumption has risen from 7 million nutrient (N, P, and K) tons in 1965 to 17 million in 1975, the year of the "fertilizer crisis," to 39 million in 1985 and 69 million in 1995, essentially doubling every ten years. The extraordinary growth in fertilizer consumption, more than 7% per year for three decades, was due to a steady decline in the price of fertilizer (Fig. 2) and learning by farmers about the benefits of fertilizer when used with MVs.

The major factor explaining this reduction in cost has been a stream of discoveries in applied chemistry and mechanical engineering relating to the production of superphosphates, phosphoric acid, and, above all, ammonia, which is converted into nitrogen fertilizer (Tomich et al 1995). One of the most dramatic developments occurred in 1963 just before the Green Revolution. The shift from piston to centrifugal compressor tripled the optimum plant size for manufacturing urea, thus further lowering the cost of production. Given the speed of technological change and the sophistication and capital-intensive nature of the technology, the developed countries have a comparative advantage in fertilizer production. Some Asian countries, ignoring this fact and seeking to become self-sufficient in fertilizer, have constructed plants, often with assistance from the developed countries, that are obsolete almost the day they are completed.

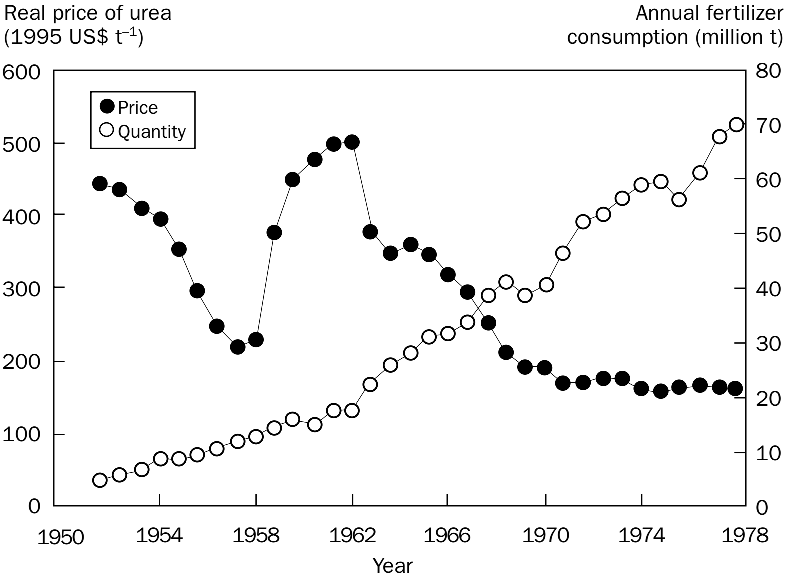

Fig. 2. Relationship between world price of urea and total fertilizer consumption in Asia, 1961-96.

Technological advances in irrigation and water management. Technological advances in irrigation can be divided between (1) those relating to the development of surface water or canal irrigation systems largely through public investment and (2) those relating to the exploitation of groundwater largely through private investment. Before World War II, Asian irrigation was dominated by so-called run-of-the-river systems by which water was diverted by barrages (artificial obstructions) to provide supplemental irrigation to ensure the main wet-season crop. Advances in the technology of large dam and reservoir construction in the western United States before World War II became the foundation for surface irrigation system development in Asia in the post-World War II period. High rice prices justified the substantial investment in large public-sector irrigation systems in the 1970s. But the subsequent decline in rice prices, rising construction costs, and growing opposition of the environmentalists have led to a sharp decline in investments since the mid-1980s (Rosegrant and Pingali 1994).

In contrast, advances in technology and declining costs have resulted in a continuing rapid expansion of tubewells (and, more recently, in other microirrigation technologies such as sprinkler and trickle irrigation). In India, for example, well over half of the total area irrigated is served by tubewells, whereas, in China, irrigation using power (both tubewells and lifting water from rivers and drains) accounts for more than 60% of total irrigation. Farmers, often reluctant to pay irrigation fees for unreliable deliveries of canal irrigation water, are willing to pay full cost for pump irrigation that can increase rice yields or facilitate the shift from rice to higher valued crops. The boom in the adoption of groundwater technologies began first in the semiarid areas of Asia. Improved technology, often coupled with government subsidies, led to a decline in the cost of pumping and encouraged the spread of groundwater technology into the monsoon areas. However, unregulated expansion of tubewells is leading to a serious overexploitation of groundwater, particularly in the semiarid regions that include two of the major breadbaskets of Asia, the Punjab and the North China Plain.

Growth in production and yield

Figure 3 shows the growth in rice production and yield for the Green Revolution years (1967-85) and for the pre- and post-Green Revolution years. Following a rapid growth in production of close to 3% in the Green Revolution period, the growth rate declined by almost one-half. Table 1 illustrates the considerable variation over time and space in the rate of adoption of the new technology and growth in production. Insular Southeast Asia, China, and other select regions such as the Indian Punjab were the early beneficiaries of the Green Revolution technology. By 1980, 50% or more of the rice area in these regions had been planted to the MVs (Herdt and Capule 1983). In other parts of Asia, including Bangladesh and eastern India, adoption has been much more recent and growth in yield has been more rapid after 1985. Vietnam has shown a strong growth in land area and yield since 1985. Surprisingly, Thailand, the world's largest exporter of rice, has had the lowest rate of MV adoption among all major Asian countries, approximately 15% in 1995. Yield growth and fertilizer con-

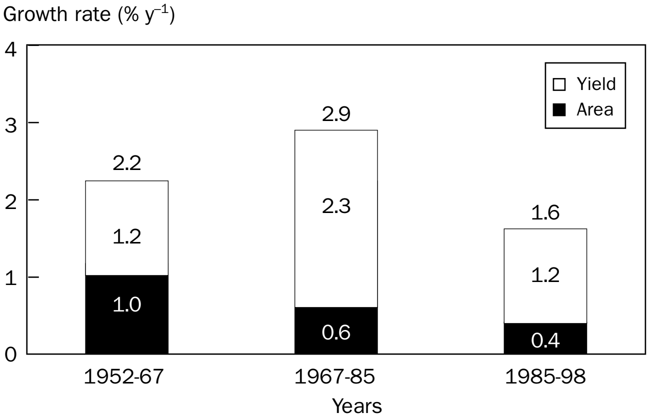

Fig. 3. Changes by area and yield toward production growth in Asia, 1952-67 to 1985-98.

Table 1. Average compound growth (% per year) in rice area, yield, and production for Asia and selected countries or regions, 1951-66, 1966-85, and 1985-2000.[a]

		1951-66	1966-85	1985-2000
Asia	Area	1.4	0.6	0.4
	Yield	1.2	2.5	1.1
	Production	2.7	3.1	1.6
Early adopters				
China	Area	1.1	0.5	–0.6
	Yield	1.9	2.8	1.1
	Production	3.0	3.3	0.5
Indonesia	Area	1.6	1.5	1.2
	Yield	–1.4	4.3	0.6
	Production	0.2	5.8	1.7
Philippines	Area	1.7	0.3	1.3
	Yield	0.9	3.1	1.6
	Production	2.7	3.4	2.9
Punjab (India)	Area	6.2	9.7	2.3
	Yield	4.6	5.4	0.4
	Production	11.1	15.7	1.6
Late adopters				
Bangladesh	Area	1.0	0.5	0.2
	Yield	1.2	1.4	2.8
	Production	2.3	1.9	3.0
Vietnam	Area	1.7	0.9	1.9
	Yield	1.8	1.9	2.9
	Production	3.5	2.9	4.9
West Bengal (India)	Area	0.5	0.6	1.1
	Yield	3.2	1.8	2.9
	Production	3.8	2.6	3.9

continued on next page

Table 1. continued

		1951-66	1966-85	1985-2000
Low adopter				
Thailand	Area	1.5	1.9	0.6
	Yield	2.2	0.8	0.7
	Production	3.7	2.7	1.3

[a]Calculations are based on harvested area and rough rice production. Yield is mentioned in rough rice production per ha of harvested rice. The conversion ratio of rough rice to milled rice is 52% for Indonesia and 66% for Bangladesh. Harvested area is 95% of sown area. Calculations are based (except for Indian states in 1951) on three-year averages centered on each of the years shown, e.g., data for 1951 are an average of numbers from 1950 to 1952. Growth rates for Indian states in the last column are for 1985-96.
Sources of underlying raw data: for 1950-52, Rose (1985) and Bansil (1990). For 1965-67, IRRI (1995). For 1984-86, IRRI (1995). For 1999-2001, FAO.

sumption have also been low as Thailand has chosen to expand rice area and continue to grow low-yielding but high-quality export varieties.

Much of the variation in the timing of MV adoption has been associated with developments in irrigation and water management. Investments in large irrigation schemes occurred in the 1970s and early 1980s in many parts of Asia and the expansion of the dry-season rice area gave a major boost to production. The boom in groundwater development, mentioned previously, led to the gradual spread of tubewell technology into the delta areas. Deepwater rice area has declined and there is a higher concentration of production of both rice and other crops in the dry season (Dawe et al 1998). The ability to apply high levels of fertilizer under more favorable growing conditions has boosted production in many of these delta areas.

The rice area in Asia has remained almost constant since the mid-1980s. The continued expansion of tubewell irrigation has resulted in a major portion of new irrigated area being used for crops other than rice (Dawe et al 1998). However, the portion of the rice area that is irrigated increased between the late 1970s and the early 1990s from 51% to 56%. This was the result of a decline in both upland and deepwater area, a trend that will probably continue.

What explains the slowdown in growth?

What explains the slower growth in production, area, and yield since 1985? The most obvious cause is the dramatic drop in world rice prices from 1981 to 1985 (Fig. 1). Marking the successful introduction of Green Revolution technologies, supply grew more rapidly than demand. Over the past 15 years, world prices have remained remarkably stable, allaying earlier fears that the adoption of Green Revolution technology would result in greater yield and price variability. A new equilibrium in supply and demand seems to have been reached at a lower price and slower growth rate.

The slower growth is influenced by both supply and demand factors. On the supply side, in many areas of Asia, the yield gains from the adoption of the new technologies have been almost fully exploited and, typically in these areas, intensification of rice production has been leading to the overexploitation and degradation of soil and water resources. It is no longer possible to sustain production growth at 2.5–3% per year. In addition, with sharply lower domestic rice prices and rising wage rates, farmers have found it far less profitable to produce rice. Simultaneously, the growth in demand for rice has been declining in many areas because of both a rise in incomes and fall in the rate of population growth. The factors that have contributed to slower growth and the implications for rice research are discussed in more detail in the sections that follow.

Productivity, poverty, and sustainability

The words "poverty alleviation" and "poverty eradication" have only recently become the pronounced goal of national governments and international donor agencies. Yet, there was certainly an implicit belief that success in raising rice production in Asia and increasing farm incomes would have a positive impact on poverty alleviation by averting famine and providing food security for millions of people. Michael Lipton, an early critic of the Green Revolution (Lipton and Longhurst 1989, p 400), wrote more recently that, "If social scientists had in 1950 designed a blueprint for pro-poor agricultural innovation, they would have wanted something like the modern varieties: labor-intensive, risk-reducing, and productive of cheaper, coarser varieties of food staples" (Lipton 1999). Even better would have been a range of modern varieties benefiting less-favored, rain-parched areas. But, if initial emphasis had been given to the marginal areas, such emphasis could not have produced enough extra food in the 1960s and '70s to avert disaster.

A recent article in *The Economist* states that "the Green Revolution's tool kit probably saved more than a billion people from starvation" (*The Economist*, 25-31 March 2000). However, even today, despite convincing evidence to the contrary, a large share of public opinion views the Green Revolution as having made the rich richer and the poor poorer. This fact notwithstanding, legitimate concerns exist about the benefits and costs associated with the Green Revolution in the past and, more particularly, with future technological change in agriculture. In the next two sections, we look at the plus side of the ledger—how the increase in rice productivity has helped the poor. In the third section, we discuss the negative effects of Green Revolution technology and issues related to sustainability in the growth of rice production.

How has the increase in rice productivity helped the poor?

Research that leads to an increase in the productivity of rice contributes to poverty alleviation through pathways that lead to benefits for rice producers, agricultural laborers, and consumers. Initially, higher productivity results in higher profits for farmers and more employment, particularly for agricultural laborers and for those in farm-related businesses. The early adopters benefited the most because, initially, the growth in production was too small to affect the rice price. Subsequently, as the adoption of new technologies spread and rice prices fell, the farmers with the largest marketed surplus suffered the largest decline in income.

Because of the large size of the rice economy and the importance of rice in the Asian diet, productivity gains in rice compared with any other agricultural commodity grown in Asia have the widest potential impact on poverty reduction. The lower prices for consumers are the inevitable result of growth in production that outstrips growth in demand. Lower rice prices for consumers benefit the poor—including the urban poor, rural landless, and nonrice farmers—disproportionately because rice makes up as much as 70% of their total calorie intake. A lower rice price stimulates employment in the industrial and service sectors of the economy, drawing labor out of agriculture. For many economies, the structural transformation has not been smooth, particularly where slow growth in the nonfarm sector fails to create sufficient jobs to employ the surplus agricultural labor. However, this transformation in the economy, described in more detail in the following section, is essential for long-term poverty alleviation.

As the modern varieties spread, initial concerns focused on equity rather than on productivity effects on poverty reduction. Large farmers and landowners were seen to be benefiting at the expense of small farmers, tenants, and the landless. More than two-thirds of the published research on what MVs do to the poor focused on this issue (Lipton 1999). Evidence is convincing, particularly in the case of rice (where nearly all farms are small), that, in those environments where MVs have been widely adopted, the benefits have accrued to the well-to-do and poor alike (Barker and Herdt 1985, David and Otsuka 1994). The poor consumers, for whom rice represents a much larger share of total calorie consumption, have often benefited disproportionately.

The new technology did favor irrigated areas over marginal environments. A study of the effect of modern rice technology on income distribution on the basis of case studies in seven Asian countries concluded that factor and product market adjustments largely counteract the potentially adverse effects of differential MV adoption across production environments (David and Otsuka 1994). For example, either seasonal or permanent labor migration to irrigated areas has been a common phenomenon in Asia.

It is scientifically more difficult to develop varieties for unfavorable production environments. However, a pro-poor strategy must target those unfavorable environments with potential for success. This is illustrated by recent gains in production in the river delta areas of eastern India, Bangladesh, and Vietnam made possible by the introduction of low-cost irrigation technologies (2–5-hp pumps and treadle pumps) and a change in cropping pattern that allowed a shift from low-yielding deepwater rice to MVs. In contrast, there is a general consensus that crops other than rice normally would be better suited to most upland (nonpaddy) areas.

Measuring the effect on poverty alleviation

The period from 1965 to 1985 saw a large decline in poverty (as measured by the number of people below the dollar-a-day poverty line) based on rising crop yields, employment, and public agricultural research effort, but this process has stalled since then (Lipton 1999). Table 2 shows the decline in people below the dollar-a-day poverty line from 1970 to 1990 for six East and Southeast Asian countries. The majority of the poor are in the rural areas, where the decline in poverty has been most dramatic.

Table 2. Absolute poverty (1970-90) for six East and Southeast Asian countries (China, Indonesia, South Korea, Malaysia, Philippines, Thailand).

	Number of absolute poor (millions)			Incidence of poverty (%)		
	1970	1980	1990	1970	1980	1990
Total	377	289	152	35	23	10
Rural	351	265	132	40	27	12
Urban	26	24	20	13	9	5

Source: Lipton (1999).

The decline in percentage of people below the poverty line in South Asia has been equally dramatic. This is best illustrated in a study conducted by Datt and Ravallion (1998a). The research is based on surveys of poverty and consumption conducted periodically by the National Sample Survey for the 15 major states in India from 1957-58 to 1990-91. The study links the reduction in rural poverty to growth in farm productivity in India through a statistical model that incorporates wage effects and food price effects. They find a downward trend in the squared poverty gap (SGP)[1] index over time, while there is an upward trend in yield. There is an 88% (negative) correlation between the two trends, but there was a considerable lag, with the decline in poverty not occurring until after 1975.

In a separate study based on the same data, Datt and Ravallion (1998b) identify factors that explain why some Indian states have performed better than others. They conclude that, although the trend rate of growth of average farm yields is important, starting endowments of physical infrastructure and human resources—higher irrigation intensity, higher literacy, and lower initial infant mortality—all contribute to higher long-term rates of poverty reduction in rural areas. With the exception of Bihar and Assam, the rice-growing states have performed at or above the average in rural poverty reduction.

In contrast to Southeast Asia, the absolute number of the poor in South Asia has continued to grow. For example, the number of people below the dollar-a-day poverty line in South Asia was estimated to be 495 million in 1990 and 522 million in 1998 (World Bank 2001). The number of rural poor in India in 1994 was still nearly 250 million, essentially unchanged from 1970 despite data showing that the incidence of poverty in rural India had fallen from 55% to 37% over the same period (Fan et al 2000). India exports rice, whereas large segments of the population still lack the purchasing power to obtain an adequate diet.

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[1] The poverty gap (PG) is the average distance of the population below the poverty line—defined in this study as the level of average per capita expenditure to achieve a nutritional norm of 2,400 calories per person per day. For the squared poverty gap (SPG) index, the distances below the poverty line are squared so that the index penalizes inequality among the poor.

Government policies can play a critical role in ensuring household food security, but they frequently add to the problem. For example, high support prices for grain in India have led to a huge surplus of grain stocks and India is now one of the largest exporters of rice in the world market (Meenakshi and Banerji 2001). The support price programs help neither producers, who do not receive the support price for their sales, nor low-income consumers, who can buy better quality rice at market prices lower than that offered by the government. More importantly, as is so often the case with floor prices for grains, the support prices are unsupportable as the government eventually finds the financial expenditures to be overly burdensome and discontinues purchases.

Negative effects and sustainability

The intensification and rapid growth in rice production have led to a growing number of environmental and health problems and raised questions about our capacity to sustain growth in production for the foreseeable future. Pingali et al (1997) provide a comprehensive analysis of these problems and their environmental and health effects.

The various problems affecting sustainability of production were a result of the intensification process embedded in Green Revolution technology. The new technology led not only to an increase in yields, but, with the development of irrigation, made it possible to grow two or three crops of rice where only one had grown before. As the ecology of the rice field changed, a range of environmental problems emerged gradually over time. Solutions have been found with varying degrees of success but have often proved to be only temporary. A continuing research effort has been needed simply to maintain yield potential (so-called maintenance research).

Following the initial release of the MVs, serious pest and disease problems occurred—most notably, brown planthopper and tungro virus. This resulted in the development of more insect- and disease-resistant varieties (e.g., IR36) and in the very successful efforts of the FAO to mount a campaign in integrated pest management, IPM (FAO 1990). Perhaps as a result of these efforts, rice pesticide sales per unit of cultivated rice area began to decline substantially in the early 1990s in many developing Asian countries. But pesticide use is still large and increasing in some countries (e.g., China). These chemicals have had negative effects on human health (Pingali et al 1994), livestock, and fish culture. Clearly, some of the emerging problems or side effects have extended well beyond those related simply to rice cultivation.

Subsidies for nitrogen fertilizer helped lessen the risk to farmers of adopting a new technology and increased yields, but these higher yields have sometimes led to the mining of other soil nutrients such as phosphorus and potassium (Pingali and Rosegrant 2001). Compensation for these induced deficiencies may now require large quantities of imported fertilizer, since phosphorus and especially potassium fertilizers are produced largely outside Asia. There has also been some concern regarding a possible deterioration in soil quality, reflected in yield declines in several long-term experiments with continuous cropping of rice. Recent research has shown this problem to be less widespread and severe than originally thought, however (Dawe et al 2000, Tiongco and Dawe 2002).

One of the more recent and less tractable problems to arise relates to the management of water resources. Until recently, most people believed that we would always have enough water to grow food, to drink, and to support industry. However, many countries and regions have entered a period of severe water shortage (Seckler et al 1998, Barker et al 1999). Many of the water problems such as salinity, waterlogging, and overexploitation of groundwater are largely confined to the semiarid regions. However, these regions include two of the major breadbaskets of Asia—the Punjab and the North China Plain—where rice and wheat are commonly grown in rotation. Furthermore, the growing scarcity and competition for water will be pervasive, extending well beyond the semiarid regions and profoundly affecting the way we value and use water resources.

A common perception is that, in rice production, enormous quantities of water are being "wasted." However, the rice plant consumes about the same amount of water as other cereal grains. Much of the water that is "lost" from one farmer's rice field is used elsewhere, perhaps in the next farmer's field, perhaps as return flow, or through groundwater extraction farther down the basin.

This fact notwithstanding, most irrigation systems in monsoon Asia have been poorly designed, managed, and maintained (Pingali et al 1997). Through better management practices at the farm and system level, there appears to be ample scope for increasing the productivity of water (Guerra et al 1998) although further research is needed to determine whether farm-level gains in productivity translate into gains at the basin level (Perry 1999). Research interest is growing in integrated water resource management (IWRM), which focuses on the allocation of scarce water resources at the basin level among competing uses—irrigation, municipal, industrial, hydropower generation, and environment—and on the competing complementary relationship between canal and groundwater development in the basin.

In summary, the gradual emergence and recognition of problems related to the intensification of rice production have broadened the rice research agenda. Maintenance research to ensure the sustainability of rice production to meet future demands is a continuing process that extends beyond the initial focus on higher yields and productivity to assess the potential effect of productivity gains on the environment, health, and poverty alleviation.

Agricultural and structural transformation

All countries are striving for a successful transformation—the gradual evolution of an economy from one based primarily on agriculture to one in which the large majority of labor and output are in the industrial and service sectors (Timmer 1997). Diversification and commercialization of agricultural systems are part and parcel of the process of transformation. But, for such a transformation to take place, there must initially be a rise in agricultural productivity to generate food surpluses and free up labor and other resources needed to support growth in the nonagricultural sector. Whether through the improvement in rice production following the Meiji restoration (1868) in Japan, the introduction of high-yielding Ponlai varieties in Taiwan, China, in the 1920s, or the spread of the Green Revolution technology in South and Southeast Asia in the 1960s and '70s, the starting point has been much the same, that is, for most Asian economies, the initial step in this transformation has been an increase in land and labor productivity in rice production.

Table 3 depicts this structural transformation in the Asian economies. Over the past 30 years, the share of GDP and the percentage of the labor force in agriculture have been declining, more rapidly in South Korea; Taiwan, China; Indonesia; Malaysia; and Thailand, and more slowly in the Philippines and Sri Lanka. Because of the slow absorption of labor into the nonfarm sectors in these last two countries, a substantial portion of the labor force has looked overseas for work and remittances have become a significant foreign exchange earner and source of household income.

For most Asian countries in the 1990s, GDP in agriculture was 25% of total GDP, but 50% or more of the labor force remained in agriculture. The two- or three-to-one ratio of the share of the labor force in agriculture to the share of GDP from agriculture suggests that labor productivity is higher in the nonagricultural sector and that labor will continue to be pulled toward the more productive nonagricultural sector.

The demographic transition

It is somewhat of a paradox that the success in increasing rice productivity leads not only to further changes in production practices but also to a gradual decline in the importance of rice in both consumption and as a source of farm household income. This is accompanied by both diversification of consumption and production and the

Table 3. Percent gross domestic product (GDP) and labor force in agriculture, 1960s and 1990s.

Region/country	GDP in agriculture (%)		Labor force in agriculture (%)	
	1960s	1990s	1960s	1990s
East Asia				
China (mainland)	40	21	82	70
South Korea	37	7	66	18
China (Taiwan)	28	3	56	10
Southeast Asia				
Indonesia	54	17	75	57
Malaysia	30	13	60	25
Philippines	26	22	62	43
Thailand	40	11	84	64
Vietnam	–	40	–	70
South Asia				
Bangladesh	53	31	86	61
India	47	26	75	62
Sri Lanka	28	23	56	47

Sources: World Bank, World Development Report (various issues), and Council of Agriculture, Taiwan, China.

move from a largely subsistence to a commercial or market-oriented agriculture. In the sections below, we describe the changes, beginning with the demographic transition.

Historically, structural transformation has been accompanied by demographic transition (Tomich et al 1995). In the first phase of the transition, mortality rates decline but fertility remains high and the rate of population growth rises significantly. In the second phase, rapid population growth ends as population growth declines to levels nearer the greatly reduced mortality rate.

Table 4 shows the trend in annual growth in population for East Asia, Southeast Asia, South Asia, China, and India for two time periods. Although the decline has been most dramatic in China, clearly South and Southeast Asia are rapidly entering the second stage of the demographic transition. Because of the downward trend in population growth and rising incomes, we can expect the growth in demand for rice to decline. However, the growth in the labor force will remain high in the immediate future and finding gainful employment for this expanding workforce will be the major concern of most governments. The greatest pressure will occur in South Asia, where, as noted in the previous section, the number of people below the poverty line has increased in recent years.

Changes in food consumption patterns

There is an inherent desire for diversity in dietary patterns among most populations of the world. For many of the poor in Asia, rice remains the priority in the diet, composing 70% or more of the calories supplied. But, as incomes rise, the proportion of rice in the diet declines, giving way initially to wheat and more gradually to the consumption of livestock and other products. For most of Asia, this means a growing level of imports and the challenge is to find agricultural exports to offset this import bill.

Table 5 ranks countries according to the percentage decline in rice as a portion of the calories supplied in the diet from 1965 to 1995. The rate of decline is clearly associated with the rate of economic growth, with Myanmar experiencing no decline at all and, at the other extreme, Japan experiencing a decline of 50%. There is also a strong association between the decline in rice consumption per capita and the rise in incomes.

Table 4. Annual population growth (%) in Asia, 1965-70 and 1995-2000.

Region or country	Years	
	1965-70	1995-2000
East Asia (excluding China)	1.5	0.5
Southeast Asia	2.5	1.5
South Asia (excluding India)	2.7	2.2
China	2.6	0.9
India	2.3	1.7

Table 5. Change in percentage of calories from rice in total per capita calorie supply for Asian countries ranked by percent change from 1965 to 1995.

Country	Percentage calories from rice		Per capita income adjusted for purchasing power parity (current international $)	Changes in percentage calories from rice	
	1965	1995	1995	Change	% Change
Asia	38	33	–	–4	–12
Japan	42	23	11,718	–19	–45
Malaysia	49	31	4,285	–19	–38
South Korea	51	34	4,025	–17	–33
Thailand	69	47	2,096	–23	–33
Philippines	44	38	2,047	–6	–13
China	37	34	907	–4	–10
Sri Lanka	43	39	1,195	–4	–9
Vietnam	72	68	–	–5	–6
Bangladesh	76	73	543	–3	–4
Nepal	37	37	582	–1	–2
Cambodia	76	76	–	0	0
India	33	33	724	0	1
Myanmar	73	76	–	3	4
Indonesia	47	51	1,285	4	8

Source: For percentage calories from rice, FAOSTAT (2001). For per capita income, World Bank, World Development Report.

Changes in farming practices

Earlier, we indicated how the spread of the semidwarf high-yielding varieties had brought a visible change to the rice fields. More visible changes have followed. At first, labor inputs increased. But, as the rate of growth in yield has declined, the demand for labor in the nonagricultural sector has grown, albeit not uniformly across the region. The growth in labor productivity, caused initially by the increase in rice crop yields, is now being achieved largely through the adoption of labor-saving technology.

This rising and then falling trend in labor input reflects the fact that, in the early stages of the agricultural transition in Asia, labor was in surplus. The Green Revolution technologies created jobs by increasing the labor requirements for a single crop, by making it possible in many areas to grow two crops of rice, and by producing employment off the farm in a host of farm- and nonfarm-related activities. As the transition proceeds and the demand for labor in the nonfarm sector grows, wage rates rise and demand grows for labor-saving technologies at the farm level. With more than 50% of the total labor force still in agriculture, there is a danger that the adoption of labor-saving technologies may move faster than the ability of the nonfarm sector to absorb labor. The temporary setback in demand for nonfarm labor as a consequence of the Asian financial crisis in 1998 illustrates this point. Lipton (1999) cautions that the top priority for antipoverty research should be to raise yields in ways that substantially raise the demand for labor. Yet, many regions are experiencing real increases in wages and declines in labor availability in many rice-farming areas (Estudillo and Otsuka 2001, Kikuchi et al 2000). Thus, the appropriate adoption of labor-saving technologies is largely a matter of timing. As economies grow, the point is reached where there is no longer a surplus but a shortage of labor in the agricultural sector.

The speed of adoption of these labor-saving technologies has varied by region, but the unmistakable trend is marked by the gradual disappearance in many regions of practices and techniques that have been used for centuries in rice production. Although the pace of change varies from region to region, the tractor is gradually replacing the water buffalo for land preparation, direct seeding of rice is replacing transplanting, particularly in the dry season, herbicides are replacing hand weeding, and the mechanical thresher is replacing traditional hand threshing of paddy.

Indeed, the traditional Philippine song, "Planting rice is never fun, work from morn to setting sun; cannot stand, cannot sit, cannot rest for a little bit," seems to have been a harbinger of things to come. Although the youth no longer look to rice farming as a way of life, those left behind to tend the rice fields are adopting new practices to lighten the burden and increase the productivity of their labors.

Changes in sources of rural household income

Rice is becoming a smaller part of the total economy and for rice farmers it also is becoming a smaller share of household income. For the Philippines, studies by Estudillo and Otsuka (2001) based on surveys from 1966 to 1994 in Central Luzon and by Hayami and Kikuchi (2000) of a Laguna Province village over three decades document the direction of this change (Fig. 4). The share of income from rice fell from 50% in the 1970s to 15% in the 1990s. The share of income from other farm activities fell, but more gradually, and, by the 1980s, it exceeded income from rice. The income from nonfarm activities rose from 10% to more than 60%.

Surveys identifying sources of household income were conducted in six villages in two locations in Thailand in 1987 and 1994 (Isvilanonda et al 2000) and in four

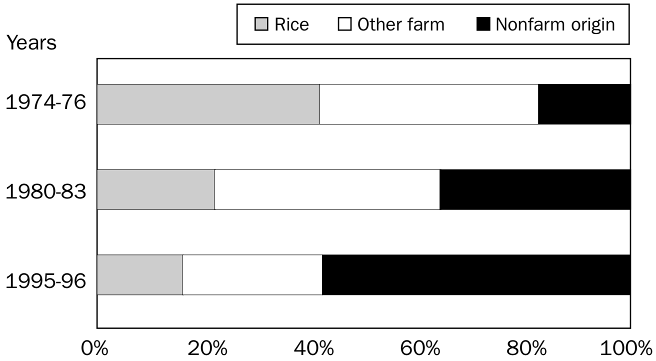

Fig. 4. Change in percent income from rice, other farming, and nonfarm activities in a Laguna village, Philippines. (Adapted from Hayami and Kikuchi 2000.)

villages in the Philippines in 1985 and 1997 (Hossain et al 2000). The villages represented three rice-growing ecosystems—irrigated, rainfed, and upland. Table 6 summarizes the results. Despite the shorter period of time, the pattern is much the same as in the Laguna village. The importance of rice as a source of household income declines and nonfarm income increases in all three rice-growing environments.

One needs to be cautious about generalizing from these village case studies, particularly as regards the speed and magnitude of change. For example, the location of the village has much to do with opportunities for nonfarm employment. A sample survey was conducted in Bangladesh consisting of 1,245 rural households in 1988 and 1,316 rural households in 1995 (Hossain 1998). The pattern of change was similar but more gradual, with the share of income from rice falling from 28% to 24% and the share of income from nonagricultural activities rising from 37% to 46%.

Diversification in the agricultural sector

Successful agricultural development requires the diversification of agriculture away from the staple crops such as rice for which demand gradually declines. For smaller countries, diversification must be associated with the development of export markets. Diversification of agriculture can occur at the farm level or in the agricultural sector as a whole, with different regions of a country specializing in different crops (Timmer 1997).

By and large in Asia, the diversification of rice farms to crops other than rice has been difficult. This is because the surface irrigation systems have been designed and managed to provide an adequate supply of water for rice but not to provide water when needed for nonrice crops. The systems are said to be "supply-driven" rather than "demand-driven." For the former, farmers tailor their cropping to the time of the irrigation deliveries. For the latter, the amount of irrigation water delivered is tailored to the crops that farmers choose to grow. A notable exception has been Taiwan, China

Table 6. Change in percent income from rice, other farming, and nonfarm selected villages in the Philippines and Thailand (Marciano et al 2001, Isvilanonda and Hossain 1998).

	Irrigated		Rainfed		Upland	
Philippines	1985	1997	1985	1999	1985	1999
Rice	42	29	55	41	25	17
Other farming	18	6	26	10	42	22
Nonfarm	40	65	19	49	33	61
Thailand	1987	1995	1987	1995	1987	1995
Suphan Buri						
Rice	56	21	53	17	53	27
Other farming	36	31	27	18	8	36
Nonfarm	8	48	20	65	39	37
Khon Kaen						
Rice	46	8	28	8	30	19
Other farming	10	5	14	7	19	32
Nonfarm	44	87	58	85	51	49

(Levine et al 2000). There, the irrigated area remained fairly constant from the mid-1960s to the mid-1980s. But, during this period, the area in rice and sugarcane fell by almost 50% and was replaced by fruits, vegetables, and feed grains, allowing the value of agricultural production to continue to rise and the value of exports—including livestock—to contribute significantly to foreign exchange earnings. The ability of farmers to make these crop adjustments was due in large measure to the major government investments in land consolidation and in irrigation and drainage infrastructure during the 1950s and ’60s that allowed water to be rotated at the 10-ha level. Many Chinese irrigation systems have been designed with the same high degree of infrastructure articulation and of water control and management needed to facilitate diversification from rice to other crops.

For much of the rest of Asia, however, diversification of irrigated agriculture is largely occurring through private farmer investment in tubewells and, more recently, in microirrigation systems such as sprinkler, surge, and trickle irrigation. As noted earlier, groundwater irrigation has been growing more rapidly than surface irrigation in several countries and the cost of these microirrigation technologies has been falling rapidly. Large sections of the new irrigated area are not being cropped with rice (Dawe et al 1998). The initial exploitation (and now overexploitation) of groundwater occurred largely in the semiarid regions but is now gradually spreading to the monsoon areas.

Several Asian countries have been successful in developing nonirrigated crops for export. Following an initial success in developing rubber exports, Malaysia in the 1970s and ’80s captured 80% of the world’s palm oil market. Although Thailand remains the world’s largest rice exporter, it successfully developed export markets in cassava, maize, and sugar. Vietnam has become the world’s second largest exporter of rice, but also the second largest exporter of coffee. The share of total crop area devoted to rice has declined in all three of these countries since the early 1960s by 10 to 20 percentage points. Yet, in countries such as Indonesia and India, little change has occurred over time.

The world rice market, changing comparative advantage, and domestic rice policies

High and unstable world rice prices in the 1960s and ’70s provided a major incentive in Asian importing countries to adopt Green Revolution technology and strive for rice self-sufficiency. Major investments in irrigation gave those countries and regions outside of the major river deltas of Asia at least a temporary comparative advantage in producing rice. For political reasons, the collapse of exports from Myanmar, Cambodia, and Vietnam added further uncertainty to the world market. But, the successful adoption of the new technologies and the growth and maturation of the Asian rice economies have dramatically changed the picture.

The world rice market

The opening of the Suez Canal in 1856 promoted the development of rice exports from the major river deltas of Southeast Asia—the Irrawaddy, Chao Phraya, and Mekong. The dominance of Myanmar, Thailand, Cambodia, and Vietnam in the world rice trade continued until after World War II, providing a major source of foreign exchange earnings for these countries. World trade remained small as a portion of total world production—3–5%.

Through the 1950s to the mid-1960s, rice export prices remained stable. However, the withdrawal of Myanmar, Cambodia, and Vietnam from the export market and a shift in policies in Thailand and the rice importers led to wide fluctuations in world prices beginning in the mid-1960s. The rice importers adopted policies to stabilize their domestic prices, thus shifting instability to the world market. From 1961 to 1980, the coefficient of variation in world rice prices was 30%, while the coefficient of variation for domestic rice prices in most Asian countries was less than half of that (Siamwalla and Haykin 1983).

A combination of factors led to a surge in per capita rice production from 1981 to 1985. This resulted in the sudden plunge in world rice prices to less than 50% of their previous levels (Fig. 1). One might ask why the slow, steady upward trend in per capita production before the early 1980s had not led to a much earlier decline in world prices. The most likely reason is that Asian countries were much poorer in this earlier period, which meant that the income elasticity of demand was relatively high. Thus, growth in rice production had to keep pace not only with population growth but also with income growth, that is, increases in per capita production were necessary to keep world prices constant in real terms. As the economies have grown, population growth has declined (Table 4) as has the importance of rice in diets (Table 5). Future growth in demand is projected to be roughly equal to the now lower rate of population growth (Rosegrant et al 1995).

For the last 15 years, world rice prices have remained low and relatively stable. The greater importance of irrigation in rice production and improved pest and disease resistance in modern varieties has tended to reduce variability in production per capita. The reemergence and strengthening of the commercial orientation of major rice-exporting nations and the move toward freer trade and increasing integration will improve the performance of the world rice market. In addition to Thailand and Vietnam, Cambodia and Myanmar may possibly become important players once again in the near future.

Finally, from 1995 to 1999, a sharp increase in world market rice exports occurred. Average world exports in 1990-94 were 14.3 million metric tons and in 1995-99 22.5 million metric t. Although growth has been steady in demand for exports in Africa and Latin America, this sudden spurt was due to a doubling of demand in oil-exporting countries and tripling of demand among Asian importers—largely because of shortfalls in production in Indonesia and the Philippines in 1998. Whether or not this volume of trade will be maintained or continue to grow will depend on the continuing growth in demand outside of Asia, and on the decision of Asian importers regarding the level of protection to provide to domestic rice production.

Comparative advantage

The introduction of new technology increased the comparative advantage in rice production for many of the Asian importing countries. Asia's total imports of rice declined from an average of more than 4.5 million metric t in 1965-75 to approximately 3 million metric t in 1985-95. In the former period, Asian imports represented approximately half of world trade, whereas in the latter period they represented only 25%. More recently, Asian imports have once again been on the rise, but it remains to be seen whether this trend will continue.

With the recent fluctuations in exchange rates, assessing comparative advantage is becoming a more difficult task. Thus, what is said below should be regarded as a hypothesis that needs further testing. Since the early 1980s, it appears that many Asian importers have begun to lose their comparative advantage. This would include, in particular, the island economies of South and Southeast Asia, which were among the early beneficiaries of the Green Revolution technology. Recent studies of economic comparative advantage have been conducted in the Philippines (Estudillo et al 1999) and in Sri Lanka (Kikuchi et al 2000). Both studies show an upward trend since the 1980s in domestic costs of rice production, largely because of an increase in wage rates. The domestic cost of production per metric ton of rice has risen above the level of the cost of importing a ton of rice. For these countries, the benefit-cost ratios no longer justify the investment in new irrigation facilities on economic grounds.

In contrast, the comparative advantage in the deltas, which include some of the traditional exporting countries, has been strengthened. Recent improvements in water management and the exploitation of groundwater have facilitated the introduction of Green Revolution technology and accelerated growth in rice yields in Vietnam, Bangladesh, and West Bengal (India). These were among the late adopters in part because the appropriate technology for managing water was not at hand, and for other reasons as well (e.g., Vietnamese market-economy liberalization began only in 1990). The sharp devaluation of the Thai currency during the Asian crisis helped to maintain Thailand's position as the world's largest exporter of rice. In summary, low wage rates coupled with plentiful water appear to give the deltas a strong comparative advantage in rice production.

Domestic rice policies

Domestic rice policymakers face two decisions—at what level to set the domestic rice price and how to ensure price stability. Setting the level of the domestic rice price became a more difficult political issue when world rice prices fell substantially in the mid-1980s. The more developed Asian rice-producing countries have all made essentially the same choice in recent years: keep domestic prices above world rice prices. Japan and South Korea currently have very high nominal rates of protection and provide the most dramatic examples of this choice (Table 7). This choice may have been due in large part to the substantial appreciation of the national currency (the yen and won), since higher real domestic rice prices have been only a minor contributor to higher nominal rates of protection (Timmer 1993). Thus, whether other countries

Table 7. Nominal protection rate for rice in nine Asian countries, 1960-95 (David and Huang 1996, IRRI 1995).

Country	1960-70	1970-80	1980-88	1988-95
Japan	70	148	443	496
South Korea	17	65	243	431
Taiwan (China)	–12	6	101	246
Philippines	31	–3	6	39
Bangladesh	68	51	32	18
Indonesia	–	3	27	18
Sri Lanka	36	42	–4	8
Thailand	–28	–28	11	5
India	19	–5	–3	–17

follow the path of high protection taken by Japan and South Korea may depend on what happens in the future to world rice prices and exchange rates.

It is not clear how this conflict between high protection for rice and increased trade liberalization will be resolved. Although the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) was a major milestone for international agricultural trade, no Asian rice producers have yet made major binding international commitments in the direction of allowing equilibration between world and domestic prices. Perhaps the most significant commitments have been made under the Association of Southeast Asian Nations (ASEAN) Free Trade Agreement (AFTA). Indonesia and Malaysia agreed to end nontariff barriers (NTBs) on rice by 2010 with a maximum tariff of 20% for intra-ASEAN trade. The Philippines has also agreed to remove NTBs by that date, but with an as yet unspecified maximum tariff. These agreements could have major effects on rice producers and consumers in those countries, especially since the world's two leading rice exporters (Thailand and Vietnam) are members of ASEAN. Yet, there remain safeguard provisions whose effects could in principle be quite important. Large domestic protection for the traditional Asian rice importers would retard the development of a vibrant international market for rice. Given the recent surge in subsidies for U.S. rice production, rice export subsidies in Thailand and India, and the imposition of a rice tariff in Indonesia, the prospects for liberalized rice trade in the near future are very uncertain.

Ensuring domestic rice price stability has become an easier task in the past decade for at least two reasons. First, world rice prices were more stable during the past 15 years than they were from 1965 to 1980. In fact, world rice prices were more stable than world wheat and maize prices from 1985 to 1999, which was not true in the earlier era when the world rice market gained a reputation for severe instability. Second, even after accounting for the setback caused by the recent economic crisis, most countries in the region have experienced significant economic growth and structural transformation during the past 30 years. As a result, the importance of rice to consumers, producers, and the macroeconomy is correspondingly less.

Nevertheless, rice price instability will not go away as a problem in the eyes of policymakers. For one, with the increased liberalization of financial markets, free trade in rice would expose consumers and producers not only to instability on world rice markets but also to exchange rate instability. More important, for many poor consumers and farmers, rice still constitutes a substantial share of their expenditures (for net buyers) or income (for net sellers). Large sudden price movements will profoundly affect the effective purchasing power of these poor individuals and there is a legitimate role for government to smooth such fluctuations (Dawe 2001).

The challenges ahead

Asia's transition from an agricultural to an industrial society is well advanced. Despite the setback caused by the Asian financial crisis in 1998, economic development and the structural transformation appear to be back on course. Growth in agriculture has supported industrial growth. Incomes have risen and population growth rates have declined, accompanied by a gradual decline in per capita demand for rice. There have been significant gains in poverty reduction. Rice prices have been low and stable for more than a decade.

The declining budgets for research suggest that many donors are asking why they should continue to invest in rice research. Alternatively, what investments are needed to ensure sustained rural economic development? These are reasonable questions that deserve serious consideration.

Why continue investing in rice research and related technological developments?

The short answer to this question is sustainability and poverty reduction. As noted earlier, the intensification of rice production and rapid growth in output have been achieved at a significant cost in environmental degradation and pollution. The engine of agricultural growth has slowed or stalled. How much of this is due to declining prices, to the near full exploitation of existing technological potential, or to environmental degradation? For example, what will be the effect of overexploitation of groundwater and falling water tables in the Punjab and North China Plain on Asian food supplies? We don't know the answer to questions such as these. But we face a "Catch 22" (see Heller 1962). At today's low world food grain prices, it doesn't seem to pay to invest in research and development that will lead to sustainable gains in productivity in the future. But, given the long gestation period for most research and development efforts, failure to invest could lead to higher food prices and even erase some of the gains in poverty reduction achieved in the past.

A second, more compelling and challenging reason for investing in research and development relates to the need to extend productivity gains and poverty reduction to those segments of Asian society and the rest of the developing world that have not benefited from the Green Revolution. The projected number of people in South Asia who cannot afford an adequate diet will still be large for the foreseeable future. Under the baseline assumptions of the IMPACT model of the International Food Policy Research Institute (IFPRI), which projects a slight decline in world rice prices by 2020, there will still be more than 50 million malnourished children below the age of six in India and Bangladesh at that time, accounting for nearly half the population in that age group (Rosegrant et al 1995). If world rice prices were to rise, the situation would be much worse. If we ignore this issue, then a large segment of Asian society will fail to participate in economic development.

We emphasize that poverty will be reduced in the future as it was in the past by sustained growth in agricultural productivity. But the link between "poverty alleviation" and "productivity growth" seems to be poorly understood. Lipton (1999), referring to what he calls "mission creep" in the Consultative Group on International Agricultural Research (CGIAR), reports that investments to increase productivity fell from 74% of total investment in 1972-76 to 39% in 1997-98. Yet "poverty eradication" is now the main theme of the CGIAR. If the CGIAR is to make progress toward this goal, international agricultural research centers must attempt to ensure that budget reductions do not further erode research on productivity.

What are the prospects for further gains in rice productivity?

Major advances in varietal improvement designed to break the yield ceiling established by IR8 include a new plant architecture and the development of hybrid rice that is adaptable to the tropics (Dawe 1998). Compared with current modern varieties, the new plant type (sometimes referred to as "super rice") will have fewer tillers but these tillers will have longer panicles bearing more grains, plus sturdier stems and deeper roots to support the increased grain weight. The grain-bearing panicles will also sit lower relative to the tops of the leaves to reduce shading and enhance photosynthetic activity.

Hybrid rice will give a yield advantage of about 15–20% over inbred lines. Hybrids have been grown for 20 years in China and until recently covered half of China's rice-growing area. It appeared that hybrids were poised to spread rapidly in India, but consumers have regarded the quality as inferior to that of popular inbred lines and the price has been discounted by more than 10% (Janaiah and Hossain 2001).

Whether the above technologies will have a major effect on production and productivity is uncertain. However, biotechnology—tissue culture, gene mapping, gene transfer, etc.—has now become an important avenue for advances in plant breeding. Owing to the advent of molecular mapping and the ability to scan the genomes of wild species for new and useful genes, we may now be in a position to unlock the genetic potential of these germplasm resources (Tanksley and McCouch 1997). For rice, for example, exotic germplasm is a likely source of new and valuable genes capable of increasing yield and a source of other complex traits important to agriculture.

However, the ability to capture intellectual property rights has led to rapid private-sector investments in biotechnology and, in some instances, a virtual buyout of public-sector research capacity at universities. The concern is that the priorities of the private firms are likely to draw funding away from important crop improvement work that would benefit the developing countries and in particular the poorer segments of their economies (Herdt 1998).

The Rockefeller Foundation, over the past 15 years, has been supporting biotechnology research on rice by more than 50 researchers from advanced and developing countries. These and other interested researchers have met every 18–24 months to review progress, exchange experiences, and make arrangements for training opportunities in one another's facilities. More than 400 scientists from developing countries have been trained at the PhD or postdoctoral level in this effort. The recent development of varieties fortified by vitamin A and iron demonstrates the potential of such work not only in improving yields and insect and disease resistance, but also in improving nutrition and health. In efforts to ensure public-sector support for research in rice biotechnology, rice scientists face yet another obstacle—the growing public concern about genetically engineered plants.

A new priority area for research

With the decline in funding for research, those areas with potential for increasing productivity must be carefully targeted. As pointed out earlier, scientists disagree on the potential for increasing productivity in irrigated as opposed to rainfed areas (Hossain 1999, Otsuka 2000). The need for productivity increases is clear in both areas, however. Many poor people in Asia are rice farmers, but in many of these countries even larger numbers of poor people are net consumers of rice. Thus, it is crucial to raise productivity in the less favorable environments, where poor farmers live, and in the favorable environments, which supply rice for the urban poor and the rural landless. Pingali et al (1997) suggest that a pro-poor research prioritization should partition research resources fifty-fifty between the irrigated lowland environments and less favorable rice-growing environments.

Gains in productivity in the past have typically come from increasing yield per hectare. Because land was frequently the most limiting resource, a change in yield per hectare provided a good proxy for a gain in productivity. However, as other resources have become scarce, productivity must be examined in a broader context. For example, do gains in yield per hectare translate into higher net returns for a farm where labor and management are in short supply (Barker et al 2001a)?

A constraint even more critical than land or labor in many regions is the growing scarcity of and competition for water. Water scarcity is likely to dictate a major change in our research priorities in the future and yield per cubic meter of water will become an increasingly important yardstick in measuring productivity gains. Past gains in water productivity have come indirectly from yield increases since no additional water was used to grow MVs relative to what was used for traditional varieties. Most of the increases have resulted from improvements in the harvest index, which is now approaching its theoretical limit (Richards et al 1993).

The human cost of drought in rainfed areas (e.g., Pandey et al 2000) and the increasing need for water-use efficiency in irrigated areas give great urgency to breeding crops and developing management practices to enhance tolerance of water stress (Bennett 2001). Making headway in this new priority will require close interaction among scientists in several disciplines, including plant breeding, plant physiology, genomics, hydrology, agronomy, and economics.

This relatively new priority area addresses the need to increase water productivity in both the unfavorable rice-growing environments and the irrigated lowlands. Progress is already being made on both fronts. The West Africa Rice Development Association

(WARDA) has developed a variety based on an *Oryza glaberrima* × *O. sativa* cross for upland areas and it is now being adopted in rainfed rice areas. The early development of the crop canopy in this variety reduces wasteful evaporation of water from the soil surface and competition for water from weeds. At two irrigation sites in China, IRRI and the International Water Management Institute (IWMI) are working with Chinese colleagues on the project "Growing More Rice with Less Water" (Barker et al 2001b). In April 2002, IRRI will host a conference bringing together researchers working on a variety of water-saving management practices to share knowledge and identify further research needs.

Looking to the future

The major trends in economic development described in this paper will continue. These are (1) a continued decline in population growth, (2) a gradual decline in agriculture's share of GDP and the labor force, (3) a shift in consumption patterns away from rice to higher valued crops and livestock products and the related commercialization of agriculture, (4) a growing scarcity and rising value of resources such as land, water, and labor, and (5) a declining dependence on rice as a source of farm income. During this period, the terms of trade have turned against agriculture in general and rice and other cereal grains in particular, aided in large measure by the continued high level of supports and subsidies for agriculture in the developed countries.

As we speculate on the future, several unresolved issues and questions remain. Not all are answerable; however, some should dictate the directions for future rice research. These questions are the following:

- What is the potential for increasing the productivity (not just yield per hectare) of rice in the irrigated lowlands and rainfed uplands?
- What effect will the growing scarcity and competition for water have on rice supplies and food security?
- How will productivity gains affect environment, health, and poverty alleviation?
- How will the rising cost of resources—land, labor, and water—shape research priorities?
- How will intellectual property rights and concern about genetically engineered plants affect the research environment?
- How can we ensure that those who lack purchasing power for an adequate diet will receive the benefits of further gains in rice productivity?
- Should there be a shortfall in rice production, what is the likely supply response to an increase in rice price?
- Who has the comparative advantage in producing rice and to what degree should those countries without a comparative advantage subsidize their rice producers?
- What is the future of the world rice market and of efforts to liberalize trade?
- What are the projections for domestic demand for rice?
- What effect will climate change have on rice production?

Without attempting to answer these questions, we conclude as follows. For the foreseeable future, rice will continue to be the dominant crop in Asia and an important source of employment for the rural labor force. Thus, increasing rice productivity continues to be the foundation for rural development and a key component in a strategy for national food security and sustainable poverty alleviation.

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Section **ONE**

China's rice economy and policy: supply, demand, and trade in the 21st century

J. Huang, S. Rozelle, R. Hu, and N. Li

Rice is the most important food crop in China. China's rice is also the largest component and most dynamic part of the world rice economy. The purpose of this paper is to examine trends in China's rice economy and policies governing the agricultural sector and predict China's future involvement in world rice markets. The study shows that, while the rice sector has been heavily penalized by price and marketing policies as well as macroeconomic policies such as the overvaluation of domestic currency, rice productivity has gained substantially from productivity-enhancing investment such as agricultural research and irrigation. Projections show that, under the most plausible expected growth rates in the important factors, China's grain imports will rise over the projection period. But, rice trends are in stark contrast to those of feed grains. Increasing maize imports arise mainly from the accelerating demand for meat and feed grains. The expected increasing rice exports will offset part of the increase in feed grain imports.

The most important difference among the projections for rice supply, demand, and trade is in the sensitivity of predictions to the simulation assumptions. Different rates of agricultural investment create some of the largest differences in production and trade. Most major demand factors—urbanization, income growth, and market liberalization—are pushing China's consumers to reduce rice demand over the next 20 years. With a significant change in agricultural policy in response to China's entry into the World Trade Organization, supply will not only be able to keep up with demand, but also rice exports will be enlarged. China is expected to become a major player in the world japonica rice market in the coming decades.

Rice is the most important food crop in China's agricultural economy. During the last three decades, rice sown area was about 27–29% of total grain sown area in the country and rice production accounts for 41–45% of total grain production (Table 1). Moreover, rice makes up 40% of calorie intake in China (Huang and Rozelle 1996). China's rice is also the largest component of the world rice economy. Since 1970,

Table 1. Importance of China's rice economy, 1970-99.

Item	1970	1980	1990	1999
		(%)		
Rice in China's grain economy				
Area	27	29	29	28
Production	45	44	42	41
China's rice in world rice economy				
Area	24	23	23	20
Production	36	38	38	34

Sources: National Statistical Bureau of China and USDA, ERS.

China's rice area has accounted for nearly one-fourth of the world's sown area and more than one-third of its rice production (Table 1). The rise in the rice supply in China during the 1970s and '80s is one of the most remarkable success stories in science and technology and policy-making. Several factors contributed to the sharp increase in production (Huang et al 1996, Fan 1991). Technology changes, increasing availability of water, inorganic fertilizer, and other farm chemicals have kept rice production growth exceeding population growth. Institutional change also stimulated production, particularly in the early reform period, 1979-94 (Lin 1992, Huang and Rozelle 1996).

Future gains, however, may not have as many sources and may rely mostly on further technological breakthroughs. High input levels in many countries and diminishing marginal returns mean that increasing inputs will not provide large increases in output. Water shortages and increasing competition from industry and commercial cash crops do not provide much hope for large gains in area and yield from investment in water control. Institutional change in many cases provides only one-time changes and has been shown to be largely exhausted in China (Huang and Rozelle 1996). In the future, many have predicted that almost all gains will have to come from second- and third-generation Green Revolution technologies (Pingali et al 1997, Huang et al 1999). However, our recent studies show that the growth rate of investment in agricultural research and extension declined significantly in 1985-95 and an increase restarted only in the late 1990s (Huang et al 2000, Rozelle et al 1997, Huang and Hu 2001).

On the demand side, as markets develop, the patterns of demand change. But pressure moves in many directions. Better retail markets provide consumers with more choices. For example, northerners can get better japonica rice and southerners have access to high-quality indica and japonica rice. Market development and urbanization have also been shifting food consumption from staple food grains including rice to meats, fruits, vegetables, and other foods (Huang and Rozelle 1998). Within the same commodity, for example, demand for high-quality rice has been rising as income growth and urbanization expand (Huang 1994, Huang and Rozelle 1995). As labor markets expand, northern rural migrants will consume more rice as they enter urban society and move to southern regions; southern migrants to urban and northern regions, on the other hand, will eat less. Changes in both demand and supply side factors are expected to have significant effects on the rice economy in China (Fan et al 1994).

China's recent entry into the World Trade Organization (WTO) has led to a wide debate on its effects on both the domestic and global economy. The WTO entry affects all areas of the economy, but is widely expected to have a particularly dramatic effect on agriculture and hence rural areas. One reason is because the reforms in China over the past 23 years largely ignored trade policies for key farm products; therefore, much remains to be done. The other reason is that China has committed itself to major changes in farm trade policies by 2005—commitments that are far greater, and much faster, than any other developing country committed itself to in the Uruguay Round Agreement on Agriculture (Anderson et al 2001).

The effect of meeting those commitments on agriculture will directly affect China's farm sector plus its food, feed, and fiber processors as well as consumers of food and beverages. However, the effects are not clear in many aspects. Some claim that these effects will be substantial. Imports of numerous farm products are expected to increase significantly (Li et al 1999) and this will put downward pressure on the prices received by China's farmers. Others argue that the effects of China's entry into the WTO may not be large but modest (Anderson and Peng 1998, Huang et al 2000).

In contrast to maize, wheat, and soybean, which are adversely affected in domestic production and imports by trade liberalization, various debates seem to have led to a consensus that China's joining the WTO may help the country further develop a strong rice sector.[1] Its exports are projected to rise and domestic production will expand (Huang and Chen 1999). Less consensus on the effect of trade liberalization on the rice economy is the extent of this effect and the effect on various rice varieties and farmers' income. A careful examination of China's rice economy suggests that the sector remains difficult to predict since it defies categorization (i.e., conventional and hybrid rice, indica and japonica rice). The potential for future productivity increases is difficult to gauge by studying other developing countries since more of China's rice area is irrigated than in any other main producing nation, and its own research system, which has traditionally produced some of the world's most advanced wheat technology, is in disarray (Huang 2001). Demand structure has been changing. All of this will have a significant effect on rice production, farmers' income, and rice trade. Although China's net exports have been less than 1% of domestic production, its share of total world rice exports typically ranges from 10% to 20%. The future performance of China's rice sector is of critical importance to the welfare of China's domestic population and could have pervasive effects on world food markets.

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[1] This consensus appears in the discussions of all workshops and seminars held recently in China and abroad.

The overall goal of this paper is to further explore the special features of China's rice economy and to increase the understanding of its domestic rice sector and its future participation in global markets. It also seeks to establish a more comprehensive, transparent, and empirically sound basis for assessing the future growth of China's rice supply, demand, and trade needs. To meet this goal, the first section assesses the trends in China's rice economy and examines a series of factors, beyond income and prices, that may have an important effect on Chinese grain demand and supply. This discussion also necessarily entails a close look at China's domestic and marketing policies and the effect on the rice sector of recent measures to liberalize its grain market. A supply and demand projection model for China's agriculture is developed. In this model, a series of important structural factors and policy variables is accounted for explicitly, including urbanization and market development on the demand side and technology, agricultural investment, environmental trends, and institutional innovations on the supply side. After reviewing the baseline assumptions and forecasts, the results of the baseline projections are presented. Then, alternative scenarios are examined under different rates of growth in income, population, and investment in research and irrigation, and policy implications are derived from the alternative scenarios.

Rice production

Growth trend

The growth of agricultural production in China since the 1950s has been one of the main accomplishments of the nation's development policies. Except during the famine years of the late 1950s and early '60s, the country enjoyed rates of production growth that outpaced the rise in population. Even from 1970 to 1978, when much of the economy was reeling from the effects of the Cultural Revolution, grain yield grew at 2.8% per annum (Table 2, rows 1–3). After accelerating to 5.8% per year in the early reform period of 1978-84, grain yield growth slowed to 1.8% in the 1984-95 decade and to 1.2% only in the late '90s (Table 2).

Rice production in China also has grown steadily throughout the last several decades (Table 2). In the 1970s, rice yields increased at about 2% annually. The growth rate accelerated to 5.1% in the early reform period (1978-84). Although the growth rate slowed somewhat after the mid-'80s, rice yields are still among the highest in the world, reaching 6.3 t ha^{-1} by the late '90s (NSB 2001). These successes have depended on the government's continual effort to modernize the nation's rice economy (Hu et al 2000). But, unlike wheat (which maintained its sown area) and maize (which increased its sown area significantly after the mid-1980s), rice producers saw a decline in the sown area at 0.6% per year from 1970 to 1995. Rice production and yield growth rates fell behind the average for overall grain in each of the subperiods since the mid-1980s.

Table 2. Growth rates (%) of rice and total grain production, sown area, and yields in China, 1970-1999.

Commodity	Prereform	Reform period		
	1970-78	1978-84	1984-95	1995-99
Grain				
Production	2.8	4.7	1.7	1.9
Sown area	0.0	–1.1	–0.1	0.7
Yield	2.8	5.8	1.8	1.2
Rice				
Production	2.5	4.5	0.6	1.6
Sown area	0.7	–0.6	–0.6	0.3
Yield	1.8	5.1	1.2	1.3
Wheat				
Production	7.0	8.3	1.9	2.1
Sown area	1.7	0.0	0.1	0.1
Yield	5.2	8.3	1.8	2.1
Maize				
Production	7.4	3.7	4.7	3.2
Sown area	3.1	–1.6	1.7	2.9
Yield	4.2	5.4	2.9	0.3
Cash-crop sown area	2.4	5.1	2.1	3.5

Notes: Growth rates are computed using regression method.
Sources: NSB (1980-2000) and MOA (1980-2000).

Structural changes in production

A yield increase has been the central goal of crop research and technology policy. China developed and extended its first fertilizer-responsive, semidwarf rice varieties in the early 1960s before the rest of the world had been introduced to Green Revolution technology. By the early ’80s, more than 98% of China’s rice area was planted with improved varieties (both conventional high-yielding varieties and hybrid rice cultivars, Huang and Rozelle 1996). Disease-resistant varieties were developed and extended throughout the late 1970s and ’80s.

One of the largest breakthroughs in rice yield, the development of hybrid rice, was made by Yuan Longping in Hunan Province in the early 1970s (Lin 1991). In 1976, China began to extend F_1 hybrid rice varieties for use by farmers. With a potential 15–20% yield advantage over conventional high-yielding varieties, the area under hybrid rice expanded rapidly from 4.3 million ha in 1978 to 15.9 million ha in 1990, increasing from 12.6% of rice sown area to 41.2% (Huang and Rozelle 1996). The share of hybrid rice in total rice area reached a historical high in the early 1990s (Table 3), when more than half of the rice in China was hybrid rice.

However, the high-yield goal of research and extension policies has faced a growing challenge since the early 1990s. After 1993, when the rice retail market was liberalized, hybrid use fell because of concerns about quality. Our estimates show that the

Table 3. Structural changes (%) in rice production in China, 1980-2000.

Year	Area shares by		Shares by region		Hybrid rice area share[a]
	Indica	Japonica	South	North	
1980	89	11	94	6	14
1985	88	12	93	7	26
1990	84	16	90	10	49
1995	79	21	89	11	52
2000	73	27	86	14	50

[a]Hybrid rice area reached a peak in 1991-92 and accounted for about 54% of total rice area. Conventional (nonhybrid) rice area share = 100% – hybrid rice area share.
Source: The authors' survey.

share of hybrid rice area declined from its peak level of 54% in 1991-92 to 50% in 2000 (Table 3). Increasing demand for high-quality rice is also believed to have a significant effect on rice production by region and type of rice, indica and japonica (Table 3). Rice area expanded rapidly in North China, a major japonica production area. North China's share of rice sown area grew from less than 6% before the 1980s to 10% in 1990 and 14% in 2000. Several provinces that were traditionally indica rice producers in the lower part of the Yangtze River Basin, such as Jiangsu, Zhejiang, Shanghai, and Anhui, have now become major new japonica producers. Rising rice production in North China and shifting rice production from indica to japonica cultivars in the Yangtze River Basin have raised the share of japonica rice area from 11% in 1980 to 16% in 1990 and 27% in 2000 (Table 3).

The nature of technological change

By the early 1980s, China's research and development system for agriculture reached its peak. In part as a consequence of past investments, reform era breeders have turned out a constant stream of varieties (Table 4). Since 1982, rice farmers in China have used about 400 "major" varieties each year (Table 4),[2] which implies that farmers in each province use around 25 major rice varieties per year. However, this number varies greatly across regions, ranging from less than 10 in Hebei to around 50 in Guangdong. Hu et al (2000) showed that historic investment priority, fortunate breakthroughs, and the availability of international germplasm have all contributed to the activities of plant breeding programs and spread of rice varieties in China.

China's breeding efforts have also enhanced the quality of its seed stock. Using experiment station yields of each major variety during the year that the variety was certified, two measures of quality were developed: a "yield frontier" variable and an

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[2] A "major" variety in our sample is any variety that covers at least 10,000 *mu* (or 667 ha) in a province. Since our database is built on this concept, we do not have full coverage. In fact, the proportion of area covered by "major" varieties exceeds 90% in each province.

Table 4. Major variety, yield frontier, and total factor productivity (TFP) of rice in the 16 major rice-growing provinces and agricultural research investment in China, 1981-99.

Year	Rice variety number	Average increase in yield frontier[a] (kg ha^{-1})	Adopted yield potential[b] (kg ha^{-1})	Output index[c]	Material input index[c]	Labor input (days ha^{-1})[c]	Total input index	TFP index[c]
1980	–	–	–	99	103	567	97	109
1981	–	–	–	100	101	485	93	120
1982	379	460	402	112	108	393	87	138
1983	333	468	414	118	111	364	87	146
1984	380	509	415	122	113	345	84	156
1985	424	512	424	115	116	330	80	154
1986	419	515	431	117	119	325	79	157
1987	373	552	438	117	124	317	78	158
1988	381	577	449	115	136	318	80	151
1989	365	590	455	123	141	315	82	158
1990	412	595	463	127	143	312	82	163
1991	395	595	465	123	144	296	78	165
1992	403	601	476	121	144	290	74	169
1993	392	603	475	117	142	285	70	179
1994	416	605	476	116	167	271	74	169
1995	391	611	483	121	170	287	77	170

[a]The yield frontier is the highest experiment station yield of a variety that has been extended to the field. The variable is nondecreasing in the sense that, if in some subsequent year the highest-yielding variety has a lower yield, the previous period's yield is maintained. [b]Adopted yield potential is the average experiment station yields of all varieties being adopted by farmers. [c]The base year of all indices is 1979 (1979 = 100).
Source: Hu et al (2000).

"adopted yield potential" variable.[3] The yield frontier, which is created by using the highest yield of any one major variety in the field in each province during a given year, is a measure of the ultimate yield potential of the current technology used by farmers in each province. The other variable, adopted yield potential, is the average of the experiment station yields of all major varieties that have been adopted by farmers.

According to the above two measures, China's research system has created a steady stream of high-quality technology (Table 4). The yield frontiers for rice moved up at 2.3% per year from 1980 to 1995, most likely because of the development of hybrid cultivars. Farmers, however, have not always chosen (or perhaps been able to choose) the highest-yielding varieties. The average adopted yield potential of major varieties in the sample area has risen at the annual growth rate of 1.4% during the reforms

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[3] "Yield frontier" is defined to be nondecreasing. If a major variety (defined in note 2) used by farmers in the field has the highest yield one year, it is assumed that the yield frontier in that province has reached that yield level and will not fall, even in the rare case that farmers have stopped using that variety and all other varieties have lower certified yields in the following years.

(Table 4). When compared with the farmers' actual yields in 1980, the difference is 31%, a gap that is not high by the standard of developing countries (Pingali et al 1997). In part reflecting the rapid rise in material inputs (see discussion above), the gap fell from 31% to 14% from 1980 to 1995.

The gap between adopted yield potential and actual yield for rice is small when compared with that of other rice countries. In 1987, China's gap was only 1.0 t ha^{-1} (or 15%); similar (although not exactly comparable) gaps ranged from 5 t ha^{-1} (or 65%) in the Philippines to 3.5 t ha^{-1} (or 58%) in India (Pingali et al 1997). Relatively low yield gaps may imply that further gains in realized total factor productivity of rice in China may be more difficult since most of them must come from increases in the creation and adoption of new varieties.

The gap between the yield frontier and adopted yield potential has grown (Table 5). This has several different implications for China's future yield growth. High-yielding varieties may not be moving out into the field because of some physical, policy, or infrastructure constraint. On the other hand, it could be that farmers are finding other varieties with lower yields that are more effective in increasing their profits. The large changes in the rice market (Rozelle et al 2000, Luo, 1999) and increasing demand for high-quality rice (there is a trade-off between high yield and better quality) may partially explain the fact that the gap between the yield frontier and adopted yield potential has grown substantially.

Growth of TFP

Rice output increased by 20% in 1982-95 (Table 4). Divisia indices of aggregated inputs, including land, labor, fertilizer, and other material inputs (see Hu et al 2001), actually fell, but this is due mainly to the decline in labor in the early reform period and sown area later. Material inputs including fertilizer, pesticides, and other factors rose sharply. Aggregated data show that the material inputs increased annually at 32%.

Although the mobilization of inputs has been a major part of the increase in rice during the last 20 years, China's future rice supply increases may not be able to rely on inputs as much as in the past. High levels of fertilizer and pesticide use in many regions of the country mean that a larger expansion of these inputs in the future may

Table 5. Experiment station yields (yield frontier and adopted yield potential), actual yields, and yield gaps in 16 major rice-growing provinces, 1980-95.

Item	1980 (t ha^{-1})	1995 (t ha^{-1})	Annual growth rate (%)
Yield frontier	6.6	9.1	2.3
Adopted yield potential	6.1	7.2	1.4
Actual yield	4.2	6.2	2.1
Percentage gap between adopted yield potential and actual yield	31%	14%	

Source: Hu et al (2000).

not be expected. Other correlates of development, such as rising wage rates, environmental awareness, and resource limitations, mean that pressure will be on farmers to reduce inputs even more. When countries near input plateaus, further growth in output must begin to rely more on technological change, thus increasing the importance of our understanding of the record of total factor productivity (TFP) in the past and the factors that have contributed to its rise.

The TFP of rice was at about the same level in 1990 as it was in 1984. There is great discussion in China over what has caused yield slowdowns during this period, a debate that usually focuses on land rights, commodity pricing policy, the availability and price of inputs, and the structural transformation of the rural economy (i.e., the expansion of rural industries, rising wages, and rural income diversification). Regardless of the ultimate reason for the slowdown, policymakers aware of food security were concerned. TFP began to rise again in the 1990s. The productivity of rice rose by more than 20 percentage points from 1990 to 1993, but fell in the mid-1990s.

Rice consumption and trade

Consumption growth trend

On a per capita basis, the average resident in China consumed about 93 kg of rice per year in the 1990s (Table 6). Rural consumers, on average, consumed 104 kg per capita, much more than their counterparts in urban regions, who consumed about 65 kg in the '90s.

After reaching a record level in the late 1980s (of 95 kg), urban residents' per capita rice consumption experienced a slightly declining trend (Table 6). Rural villagers' rice consumption continued to increase, but growth slowed down in the mid-

Table 6. Rice supply and use food balance sheet in China, 1980-99.

Item	Units	1980-84	1985-89	1990-94	1995-99
Area harvested	1,000 ha	33,312	32,232	31,654	31,283
Yield	t ha^{-1}	3.33	3.75	4.04	4.38
Production	1,000 t	110,961	121,023	127,794	136,957
Stock change	1,000 t	–1,652	–2,297	–2,865	2,072
Net import	1,000 t	–621	–288	–803	–912
Import	1,000 t	159	518	183	630
Export	1,000 t	780	806	986	1,542
Consumption	1,000 t	111,992	123,032	129,855	133,973
Food use	%	83	84	84	84
Feed use	%	7	7	7	7
Seed use	%	3	2	2	2
Industry use	%	2	2	2	2
Waste	%	6	6	5	5
Per capita food	kg person^{-1}	92	95	94	92
Urban	kg person^{-1}	81	74	67	64
Rural	kg person^{-1}	95	102	104	104
Self-sufficient level	%	99	98	98	102

Source: CAPSiM database and authors' estimates.

1980s and stagnated after the mid-'90s. Because per capita consumption in rural areas is much higher than in urban areas, the share of the urban population in total consumption has declined for average consumers since the early '90s. Therefore, for the rice sector, the total increase in demand is mainly driven by population growth and the structural change in the economy such as urbanization and food market expansion in rural areas and changes in food consumption patterns in favor of meat over staple foods, including rice (Huang and Rozelle 1998).

Structure of rice consumption

Although rice has been widely used as feed in many parts of South China, which accounted for 6–7% of total rice use in China, it is expected that this share will decline in the future as China gradually phases out its compulsory grain procurement policy, a policy that has provided an incentive for farmers to produce lower quality but higher yielding rice. Liberalization of the maize economy and improvements in market infrastructure and the interregional transportation system will facilitate the shift from rice to maize as feed for livestock in this rice production region.

Seed use, industry demand, and waste in postharvest processes all together account for about 10% of total rice consumption. The share of direct and indirect food (i.e., processed food such as rice cakes and noodles) consumption, which accounted for 84% of rice consumption (Table 6), is expected to rise in the future.

Demand shifters

Income shifts and demand. On the demand side, recent changes in the urban economy have made urban consumers almost entirely dependent on markets for their consumption needs. In this sector, prices and income changes have been and will most likely be the fundamental forces driving consumption pattern changes. Urban incomes rose steadily at nearly 8% per year in the early years of reform (Table 7). In the early reform era, rising incomes meant an increasing demand for most food products, including rice. Real income per capita for urban residents continued to rise in recent years, jumping 6–7% from 1985 to 1995.

At the current average level of income for most urban residents, rice consumption rises only marginally with new increments in income (Garnaut and Ma 1992, Fan et al 1995); the income elasticity of urban rice demand was around 0.10 in the mid-1990s (Huang and Bouis 1995) and is expected to approach zero in the coming years.

Although rural income has grown slowly since the mid-1980s (Table 7), demand for rice has increased (Fan et al 1994, Halbrendt et al 1994). The rice demand expenditure elasticity estimated by the authors was 0.15 for rural residents, which was slightly higher than that for urban dwellers. Our work shows, however, that, as incomes rise in cross-section samples, the elasticities of urban and rural residents fall (Huang and Rozelle 1995). It is expected that income of the urban and rural populations will grow over the next several decades and that growth in demand for rice will fall and eventually become negative.

Table 7. Income, population growth, urbanization, and food market development in China, 1980-99.

Year	Per capita income (yuan in 1999 price)		Population growth rate (%)	Ratio of urban to total population	Rural food market development index[a] (%)
	Rural	Urban			
1980	616	2,062	1.38	19	31
1985	1,193	2,605	1.56	24	42
1990	1,380	3,217	1.46	26	45
1995	1,702	4,713	1.06	29	48
1999	2,210	5,854	0.88	31	57

[a] The rural food market development index is measured as the share of food expenditure purchased from the market. The exchange rate was 8.28 yuan = US$1 in 1999.
Source: NSB (1989-2000) and rural household income and expenditure surveys.

Rural market liberalization. Rural consumption markets are also less complete. Farmers in many areas face limited choices in their consumption decisions since many products they desire on a daily basis, such as meat and fresh fruit, are not always available, even as their incomes rise. In a sample of households drawn from the national household income and expenditure survey by the authors, a strong and significant correlation was found between the level of consumption of primarily purchased goods, such as meat and fruit, and the level of market development holding income and prices constant (Huang and Rozelle 1998). Discontinuous free markets, lack of refrigeration, and generally high transaction costs for procuring food affect the consumption patterns of rural consumers. While changes in rural markets have been rapid, in 1999 Chinese farmers still purchased only 57% of the food they consumed (Table 7). As markets develop and activity in rural consumption markets increases, consumption patterns will be affected, apart from changes in income and prices.

Population growth. The annual growth of China's population declined considerably in the past two decades. The family planning policy apparently contributed to this drop in population growth. The annual population growth rate fell from about 1.5% in the 1980s to less than 1% recently (0.88% in 1998, Table 7). An updated estimation of population growth by the United Nations indicates that the annual growth of China's population will fall further to about 0.65% in 2010 and that China will reach zero population growth by 2030 or so (UN 2000). While the declining growth of population will lead to less pressure on domestic food production to meet growing demand, because of the size of the country, the average annual increase in the total population is estimated to be more than 9 million and nearly 8 million in the first and second decades of the 21st century, respectively.

Urban migration. Across Asia, as countries urbanize, consumer behavior changes dramatically (Huang and Bouis 2001, Huang and David 1993, Bouis 1989). China's urban dwellers consume much less rice and other staples (especially those that require intensive preparation) and more convenience foods. Hence, as the population in China shifted from rural to urban areas, rice consumption typically fell.

The ratio of urban to rural residents in China is changing rapidly; the share of the urban population in the total population increased from 19% in 1980 to 31% in 1999 (Table 7).[4] The impact of this population shift on food grain demand in China has been documented by Huang and Bouis (1995). Since rural rice demand currently exceeds urban demand, China's future migrations will dampen rice consumption.

Rice trade trend

International trade for rice in China is minimal and did not change much in the past two decades. Total rice production rose to about 137 million t in 1995-99, which was more than use. China imports high-quality indica rice but also exports high-quality japonica and medium- to low-quality indica rice. On average, China has been a net exporter and the amount of net rice exports ranged from about 0.5 to 1 million t (Table 6), less than 1% of domestic production.

Policy intervention and WTO membership

Government investment policy

China is a country in rapid transition from a socialist system to one in which an increasing proportion of its goods and services, including food, is being allocated by market forces (Sicular 1991, Rozelle et al 1997b). It is also a country that is rapidly developing. China's government, however, far from giving up its activist role in the economy, remains deeply involved in guiding the nation's development process. Many forces arising from these development and transition processes may be affecting China's rice economy. Any attempt to accurately forecast future rice supply and demand trends must account for these major economic forces.

Technology. On the supply side, many sharp transitions are under way. Above all, technological change needs to be considered explicitly, since it has been the engine of China's agricultural economy, in general, and for fine grains, such as rice, in particular (Stone 1993). Robust growth in the stock of research capital has in part been responsible for these dramatic changes. There is concern, however, that China's system may be suffering from neglect after more than a decade of reform (Pray et al 1997). Real annual expenditures on agricultural research fell from 1985 to 1990, before resuming real growth (Huang and Hu 2001). The slowdown in growth in annual investments in the late '80s resulted in slower growth in the overall stock of research in the '90s. The recent increase in government commitment to invest in agricultural research is most welcome and should be encouraged and continued in the future.

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[4] This measure does not include a big part of the temporary migrant community (the so-called floating population). In the short run, this part of the population must be ignored since little is known about its consumption patterns. Moreover, there is no reason to expect that, by adding it to the urban population at this time, its effect on urbanization would increase. It may be that its consumption patterns are more rural than urban in the temporary living conditions. But, to the extent that a part of these residents end up staying in cities permanently, they will almost certainly eventually adopt some urban habits.

Irrigation investment. China's progress in water control has been another major source of productivity gain (Wang 2000). Irrigated area increased from less than 18% of cultivated area in 1952 to more than 50% in the late '90s (NSB 2001). In the initial years, most construction was based on both locally organized small-scale projects and publicly financed large-scale surface projects (Stone 1993). In the late 1960s and '70s, tubewell development drove the expansion of irrigated area construction, especially in the North China Plain maize-wheat region. Development of the nation's water control infrastructure continued during the 1980s as the government launched many new medium- and larger-scale water control projects (Stone 1993). Even though pump set numbers stagnated in the '80s, the overall quality of water control equipment has been continually upgraded (MOWR 1999). Significant expansion of rice area in northeast China, the region of rice (japonica) with the fastest growth in China, would not have been possible without irrigation development in the region in the '90s. Irrigation has also been a major factor influencing land and labor use in the cropping sector in the 1970s and '80s as better water control stimulated the increase in double-cropped area (Stone 1993).

Although local residents contributed much of the labor for China's irrigation development, public irrigation expenditures financed a large part of the construction of the national water control network. Irrigation investment and the stock of facilities have followed patterns similar to those for research (Rozelle and Huang 1998). The investment in irrigation facilities has been by far the largest component of total construction investment in agriculture (Wang 2000). It is several times higher than investment in agricultural research. Real annual expenditures on irrigation rose rapidly until 1975, before beginning a ten-year decline. However, in 1985, annual expenditures began to grow again and reached an all-time high in the early '90s (Wang 2000). Changing agricultural strategies and periods of fiscal control, however, have made public expenditures on water control follow a more variable path.

Marketing and pricing policies. Price and market reforms associated with China's policy shift from a socialist to a market-oriented economy began with nonstrategic commodities such as vegetables, fruit, fish, livestock, and oil and sugar crops. The early reforms aimed to raise farm-level prices and gradually deregulate the market. As the right to private trading was extended to include surplus output of all categories of agricultural products after contractual obligations to the state were fulfilled, the foundations of the state marketing system began to be undermined (Rozelle et al 1997b).

After record growth in agricultural production in 1984 and 1985, a second stage of price and market reforms was announced in 1985 aimed at radically limiting the scope of government price and market interventions and further enlarging the role of market allocation. Other than for grains and cotton, the intention was to gradually eliminate the planned procurement of agricultural products, with government commercial departments being required to buy and sell in the market. Because of the sharp drop in the growth of agricultural production and food price inflation in the late 1980s, however, implementation of the new policy stalled. Mandatory procurement of grains, oil crops, and cotton continued. To encourage farmers to raise productivity and sell to the government, contract prices were raised over time, but by less than the rate of inflation. After agricultural production and prices stabilized in 1990 to 1992, another attempt was made in early 1993 to abolish the compulsory quota system and sales at low prices to consumers. Both the state distribution and procurement systems were substantially liberalized, but the policy was reversed when food price inflation reappeared in 1994. Since then, several new policies have been implemented and government grain procurement once again has become compulsory. A provincial governors' grain responsibility system was introduced in 1994-95, aimed at encouraging greater grain self-sufficiency at the provincial level. Furthermore, a controversial policy in the grain marketing system began in 1998. Under the 1998 policy, individuals and private companies were prohibited from procuring grain from farmers (who must deal solely with the commercial arm of grain bureaus and the grain reserve system), but they were allowed to operate in wholesale and retail markets. Grain quota procurement prices were set above market prices, which meant a transfer in favor of those farmers able to sell at that price (Huang 1998, Lu 1999). Not surprisingly, stocks started to accumulate and procurement and market prices had to come down relative to international prices in 2000.

Despite these periodic cycles in the reform process, the proportion of retail commodities sold at market prices has kept rising. According to Lardy (2001), the share for agriculture was just 6% in 1978 but had risen to 40% by 1985, 79% by 1995, and 83% by 1999.

What have these policies together with macro and trade policies meant for nominal rates of agricultural protection in China (the percentage by which domestic prices exceed prices at the country's border)? Table 8 shows our recent estimates based on quota and negotiated procurement prices and on wholesale market prices since 1985 for selected agricultural commodities. The requirement that farmers submit a mandatory delivery quota at below-market prices has represented a lump-sum tax on farmers and a lump-sum subsidy to the consumers lucky enough to gain access at below-market value to that procured grain (Sicular 1995). From 1990 to 1997, the average price they received for compulsorily delivered grains and soybean was from one-eighth to one-third below the border price. Rice was most heavily penalized by the quota procurement policy. In the late 1990s, although those prices for wheat, maize, and soybean were above the border price, the rice price was still below the border price.

Negotiated procurement prices were somewhat higher, of course, but still below wholesale market prices. Wheat and soybean, China's main imported farm commodities, have received a more favorable treatment than rice. That is true not only in each price category but also in that a higher proportion of rice production is procured at the low quota procurement price. More recent estimates by Huang and Rozelle (2001), which take quality differences into account more carefully, suggest that there is less protection in place than Table 8 implies (Table 9). In particular, wheat wholesale prices may be no higher and possibly even lower than the import prices of similar-quality grain, and high-quality japonica rice has been heavily taxed while high-quality indica rice has been highly protected.

Table 8. Nominal protection rates (NPR) for grain, China, 1978 to 2000.[a]

Years	Quota procurement price				Negotiated procurement price				Wholesale market price			
	Rice	Wheat	Maize	Soybean	Rice	Wheat	Maize	Soybean	Rice	Wheat	Maize	Soybean
NPR at official exchange rate												
1978-79	–42	15	12	2	–6	72	65	22	10	89	92	40
1980-84	–43	–3	–15	13	2	50	28	25	9	58	46	44
1985-89	–30	4	–13	–13	–5	34	17	15	–4	52	37	39
1990-94	–37	–14	–35	–32	–16	14	–7	7	–7	30	12	26
1995-97	–23	–12	–14	–22	–4	6	3	8	–1	19	20	19
1998-2000	–3	10	22	33	–16	9	19	39	–6	26	32	49
1998	2	16	33	8	–16	5	26	37	–6	22	40	37
1999	–6	22	30	53	–19	12	20	59	–9	30	33	67
2000	–4	–7	2	38	–13	9	11	21	–2	26	23	44
NPR at "black market" real exchange rate												
1978-79	–61	–23	–26	–32	–37	14	10	–19	–27	26	28	–6
1980-84	–53	–20	–30	–6	–16	23	5	3	–11	30	20	19
1985-89	–46	–21	–33	–32	–29	–1	–12	–12	–27	11	2	5
1990-94	–50	–31	–48	–45	–33	–9	–26	–15	–26	5	–10	0
1995-97	–25	–15	–17	–25	–7	3	0	5	–4	15	16	15
1998-2000	–6	6	17	28	–19	5	14	34	–9	21	27	44
NPR at effective real exchange rate												
1978-79	–73	46	–48	–52	–56	–20	–23	–43	–49	–12	–10	–34
1980-84	–73	–54	–60	–47	–52	–30	–40	–41	–49	–26	–32	–32
1985-89	–69	–54	–61	–61	–58	–42	–48	–49	–57	–34	–40	–38
1990-94	–70	–59	–69	–67	–60	–46	–55	–49	–56	–38	–46	–40
1995-97	–45	–38	–38	–45	–32	–25	–27	–24	–30	–16	–15	–16
1998-2000	–26	–16	–7	2	–36	–17	–9	6	–28	–4	1	14

[a]Border prices are average prices of exports (rice and sometimes maize) or imports (wheat, soybean, and sometimes maize) for the varieties that are comparable with domestic grains. Data for 2000 are for the first 6 months of that year.
Source: Huang (2001).

In sum, despite substantial efforts to liberalize the price and market structure of the agricultural sector, producers of major agricultural commodities continue to be penalized by commodity-specific policies of procurement. When the effect of the overvaluation of the domestic currency is also taken into account, the situation is even worse. It is therefore not surprising that many farm families have invested their surplus funds and labor in nonfarm activities rather than back into agriculture (Huang 2001). Much of that investment has gone to township and village enterprises (TVEs), whose employment, output, and exports have boomed. Despite the migration of farm workers to rural industrial and service activities (not to mention to urban jobs such as in construction), the average farm size and the share of farm household income from farming have fallen steadily since the late 1970s. Whether that tendency is accentuated or reduced by entry into the WTO depends on the consequent reform's effect on farm relative to nonfarm incentives.

Table 9. Nominal protection rates (NPR) of cereal grain in China in 2001.

Variety or quality		Comparable domestic price		Border prices (US\$ t^{-1})		NPR (%)
		Yuan t^{-1}	US\$ t^{-1}	C.I.F.	F.O.B.	
Estimated at official exchange rate						
Rice	Thai super-quality rice	3,690	446	380		17.3
	High-quality japonica	2,930	354		398	–11.1
	Medium-quality indica	1,519	184		185	–0.5
Wheat	US DNS (super quality)	2,350	284	190		49.4
	Canadian #3	1,800	218	181		20.1
	Australian soft	1,625	196	175		12.2
	U.S. hard red	1,550	187	169		10.8
	UK	1,350	163	145		12.5
	China, high quality	1,350	163	145		12.5
	China, medium quality	1,250	151	140		7.9
	China, low quality	1,100	133	133		–0.1
Maize	Common variety	1,150	139		105	32.3
Estimated at estimated “real” exchange rate in China in 2001[a]						
Rice	Thai rice 5% broken	3,690	366	380		–3.6
	High-quality japonica	2,930	291		398	–26.9
	Medium-quality indica	1,519	151		181	–16.6
Wheat	US DNS	2,350	233	190		22.8
	Canadian #3	1,800	179	181		–1.3
	Australian soft	1,625	161	175		–7.8
	U.S. hard red	1,550	154	169		–9.0
	UK	1,350	134	145		–7.6
	China, high quality	1,350	134	145		–7.6
	China, medium quality	1,250	124	140		–11.4
	China, low quality	1,100	109	133		–17.9
Maize	Common variety	1,150	114		105	8.7

[a] The estimated “real” exchange rate is 10.075 in 2001, while the official exchange rate is 8.2771. It is roughly estimated as the official exchange rate in 1994 × ($CPI_{China\text{-}2001}/CPI_{China\text{-}1994}$)/($CPI_{US\text{-}2001}/CPI_{US\text{-}1994}$). CPI = consumer price index.

Other factors. In addition to research, water control, and relative price changes, institutional changes, wage trends, and environmental factors may also affect agricultural output. Leaders first implemented decollectivization policies in the late 1970s, focusing first on poorer regions of the nation and then gradually extending the policy to the whole country. By 1980, 14% of villages had returned land-use rights to farm households, a figure that moved rapidly upward in the early ’80s, reaching and staying at 99% of villages in 1984. McMillan et al (1989) and Lin (1992) argue that these reforms are responsible for most of the growth in the early reform era, though these were one-time effects that were exhausted by the mid-’80s.

Trends in environmental degradation, including erosion, salinization, and loss of cultivated land, show that the agricultural land base may be receiving considerable stress: erosion has increased since the 1970s, although in a somewhat erratic pattern. This and other factors (e.g., salinization) have been shown to affect the output of grain, including rice and other agricultural products in several recent studies (Huang and Rozelle 1995, 1996, Huang et al 1996).

Increasing opportunities in the noncropping and off-farm sectors have led to large shifts in labor-use patterns (Table 4). After putting increasing amounts of labor into grain production in the 1950s, ’60s, and early ’70s, labor use in all crops fell substantially from 1975 to 1994 (SPB 1988-95). Rice farmers use less than half the prereform levels of labor; on a person-day per hectare basis, labor fell from more than 600 person-days in 1978 and 567 person-days in 1980 to 270–280 in the mid-1990s (Table 4). Higher wages attracted tens of millions of workers to the industrial and commercial sectors during the reform period and some of the biggest flows came out of the highest-producing rice provinces: Sichuan, Yunan, Guizhou, and Jiangxi.

The characteristics inherent to China’s developing and transitioning rural economy have both facilitated and constrained labor mobility. The labor-intensive nature of Chinese farm management practices (without great investments in an expensive capital stock) allows labor to enter and exit the cropping sector without incurring high start-up or close-down costs. Employment opportunities in local township and village enterprises and the rapid expansion of the self-employed labor force may make the flow of labor between agriculture and industry more fluid. At the same time, natural barriers, such as moving costs (which exist within all economies), impede flows. China’s factor markets also still contain several structural imperfections, such as employment priority for local workers, housing shortages, and the urban household registration system (Lin 1991). One of the costs of these kinds of barriers is that they may slow down the movement of factors among alternative economic activities, thus reducing the efficiency of the sector’s producers.

China’s commitments in agriculture upon entry into the WTO

Many analysts had been expecting China to become ever more dependent on agricultural imports in the course of the economy’s rapid industrialization over the past 20–25 years. Some researchers (e.g., Brown 1994) have even suggested that China could deprive the rest of the third world of food. China has sustained being a net exporter of rice, meat, fish, fruits, and vegetables (Anderson et al 2001). Its net agricultural imports have not grown significantly in the past. How much of that is due to government policies that constrain domestic demand, including import restraints by state traders, is a moot point that has led China’s trade partners to insist on there being some imports of key farm products following entry into the WTO and some importers other than just state trading enterprises.

In its WTO Protocol of Accession, China has agreed to have no agricultural export subsidies and to limit its domestic support to farmers to 8.5% of the value of production (compared with 10% for other developing countries). The import market access commitments China has made to WTO members look substantial on paper. Tariff-rate quotas (TRQ) will be retained only on wheat, rice, maize, edible oils, sugar, cotton, and wool. Specific details for grain, cotton, and edible oil are summarized in Table 10.

Table 10. Tariff rate quota (TRQ) of agricultural products.

Product	TRQ (million tons)		Tariff (%)		Quota for nonstate-owned enterprises (%)
	2002	2005	At quota	Above quota	2000-05
Wheat	7.3	9.6	1	65	10
Maize	4.5	7.2	1	65	25–40
Rice	2.6	5.3	1	65	50
Cotton	0.743	0.894	–	–	67
Soybean oil	1.7	3.2	9	121	50–90

Rice will have a global TRQ of 2.66 million t, growing with annual increments to 5.32 million t by 2005, at a tariff of 1% (with the out-of-quota bound tariff falling from 114% to 65%). Given the nature of China's rice demand, supply, and trade balance and rice's nominal protection rate (NPR) presented above, it is expected that this TRQ for rice may not be a binding condition in the coming years. Wheat, a major imported commodity in China, will have a global TRQ of 7.3 million t, growing with annual increments to 9.6 million t by 2005, at a tariff of 1% (with the out-of-quota bound tariff falling from 114% to 65%). Maize, a currently exported commodity with an export subsidy that reached 30–40% of border prices in 2000-01 and was phased out in January 2002, will have a global TRQ of 4.5 million t, growing with annual increments to 7.2 million t by 2004, at a tariff rate of 1% (with the out-of-quota bound tariff falling from 114% to 65%).

In addition, there is to be a tariff-only regime on other agricultural and food products whereby the tariff rates will be cut upon entry and phased down to the much lower bound rates by 2005. State trading monopolies will also gradually disappear (except for tobacco) because China has agreed to allow an increasing degree of competition from private firms in the importing and exporting of farm products.

Projection of rice demand, supply, and trade

To project the likely demand, supply, and trade and evaluate the effects of trade liberalization on China's agriculture in the future, we apply an existing agricultural policy simulation and projection model (CAPSiM) developed and maintained by the Center for Chinese Agricultural Policy. CAPSiM is a partial equilibrium model or sectorwise general equilibrium model (considering all cross price effects for both demand and supply equations). In the projection or policy simulation, prices can be determined endogenously or exogenously. CAPSiM explicitly accounts for urbanization and market development (demand side), technology, agricultural investment, environmental trends, and competition for labor and land use (supply side), as well as the price responses of both demand and supply. Details of the model description can be found in Huang and Li (2000) and Huang and Chen (1999).

Defining projection scenarios

Baseline scenario. Population growth rates in the projection period (2000-20) are from the United Nations' most recent demographic predictions. The shares of urban population will rise from 31% in 2000 to 34% in 2005 and 43% in 2020. The baseline per capita income growth rate is forecast to average about 3% to 4% in the rural sector, which would decline over the projection period. The per capita income growth assumption for the urban sector ranges from 4.0% to 4.5% per year.

The NPR of fertilizer price is assumed to fall from the current 15% to zero by 2005 and then follow the world trend projected by the World Bank. The opportunity costs of land for crop production and labor for the whole agricultural sector are assumed to grow by 1% and 2%, respectively, in 2000-20.

The annual growth rates of research and irrigation expenditure in real terms are assumed to be 4.0% and 3.5%, respectively, in the future. Erosion and salinization are expected to continue to increase at a steady but slower pace than in the past.

China's WTO entry commitments in the agricultural sector discussed in the last section are imposed in the baseline. It is assumed that the current NPRs will drop to zero (when considering the changing Chinese imports or exports that will have effects on the border prices, and these are simulated through the GTAP model, which links CAPSiM with GTAP). The TRQ for major agricultural commodities for 2002-05 are incorporated into the simulation as a constraint to imports. Meanwhile, we assume that China's agricultural market will be fully liberalized after 2005.

Alternative scenarios. To evaluate the effects of China's joining the WTO, we assume that the current trade policy (tariff and nontariff restrictions) would remain and that domestic prices would be determined at the domestic demand and supply balance, while all other assumptions under the baseline were maintained. To explore how important agricultural research on China's future grain and rice economy will be, we further assume that the annual growth rate of the agricultural research expenditure will increase from 4% (baseline assumption) to 6%.

Results of baseline projections

According to the analysis, per capita rice consumption in China crested in 1999. From a base-year high of 91 kg, rice consumption per capita starts to decline at a very slow rate in the first 10 years of the forecast period, before falling in 2020 to 84 kg (Table 11). The average rural resident will consume greater amounts through 2010. Urban rice consumption per capita peaks in 1999 and declines over the whole projection period. Aggregate rice demand per capita drops faster than either rural or urban demand because the total demand for the product falls as migration occurs.

Although per capita rice demand is falling in the projection period, total rice demand continues to increase through 2020 mainly because of population growth. By the end of the forecast period, aggregate rice demand will reach 142 million t (Table 12). Total grain demand is projected to increase by about 30% (Table 12). Rice will fall from a share of about 32% of total grain use to only a little more than 26%.

Baseline projections of the supply of rice show that China's producing sector produces slightly more than the increase in demand. The surplus of the rice balance is

Table 11. Projected annual per capita grain and rice consumption under baseline scenario, 1999-2020.

Item	Per capita rice food consumption (kg)			
	Base year (1999)	2005	2010	2020
Grain				
National average	190	191	189	180
Rural	220	224	225	221
Urban	121	121	121	119
Rice				
National average	91	90	89	84
Rural	104	104	105	103
Urban	60	58	57	55

Source: Author's estimates.

Table 12. Projections of grain production, demand, and net imports under various scenarios, 2005-20.

Scenario	2005	2010	2020
Baseline: WTO regime			
Grain: production (million t)	457	476	507
Net imports (million t)	11	28	49
Demand (million t)	468	504	556
Self-sufficiency (%)	98	94	91
Rice: production (million t)	143	147	154
Net imports (million t)	–4	–6	–12
Demand (million t)	137	141	142
Self-sufficiency (%)	104	104	109
Alternative one: without WTO entry			
Grain: production (million t)	461	486	527
Net imports (million t)	–5	–4	–4
Demand (million t)	456	482	523
Self-sufficiency (%)	101	101	101
Rice: production (million t)	141	144	147
Net imports (million t)	–2	–2	–3
Demand (million t)	139	142	144
Self-sufficiency (%)	101	101	102
WTO regime + increase in agricultural research expenditure[a]			
Grain: production (million t)	457	476	522
Net imports (million t)	11	27	35
Demand (million t)	468	504	557
Self-sufficiency (%)	98	94	94
Rice: production (million t)	143	147	157
Net imports (million t)	–4	–6	–16
Demand (million t)	137	141	141
Self-sufficiency (%)	104	104	111

[a] The annual growth rate of agricultural research investment is assumed to increase from 4% to 6%.
Source: Authors' projections.

expected to increase after 2000. Rice production is expected to reach 147 million t in 2010 and 153 by 2020, about 10% higher than in the base year.

Under the projected baseline scenario, the initial widening gap between the forecast annual growth rate of production and demand implies a rising surplus. Rice exports increase somewhat in 2000-05 from about 4 million t per year to 6 million t, and reach 12 million t (about 9% of domestic consumption or 8% of domestic production) in 2020 (Table 12).

Alternative projections

To test the sensitivity of the results to changes in the underlying forces driving the supply and demand balances, several alternative scenarios are run, altering the baseline growth rates of the key variables, including income, population, and investment in technology. The results (not shown in the tables) indicate that the population growth rates and urbanization are the most important factors that will affect rice consumption. The effect of income is small as the income elasticities are low for rice in the whole projection period.

Perhaps the most important supply-side simulation result shown in Table 12 is the effect of investment in agricultural research on rice production and trade balances. The variation caused by changing the growth of investment assumption is hardly surprising given the large contribution that agricultural research—and the technology it has produced—has made to agricultural productivity in recent years (Huang and Rozelle 1996, Huang et al 1996). Increases in the rate of growth in investment in agricultural research from 4% to 6% per year are projected to reduce China's grain imports by about 15 million t in 2020 (Table 12, comparing baseline with the last scenario) and more than 20 million t in 2025 (not shown). Rice exports will rise from 12 to 16 million t by 2020.

Hence, high continuing levels of grain imports could be expected only if there were a continued decline in the growth of agricultural investment, and if the government did not respond with countervailing policy measures as imports rose. Such a scenario could unfold only if the government were unwilling or unable to undertake policies to stimulate growth in food production. However, agricultural research and irrigation investments have already recovered in recent years as China prepares to join the WTO.

Tables 12 and 13 also show that, although China could achieve self-sufficiency in almost all agricultural products and could even be a net exporter of grain, as occurred in the late 1990s, the costs of implementing a grain self-sufficiency policy in the future would be very high. For example, under a nearly "closed economy," China's domestic maize price would double in 1999-2020, while the WTO scenario produces a decline in maize price of more than 20% in the sample period (Table 13). A similar story is found in soybean and other edible crops. This could dampen and hurt the benefits of livestock expansion from trade liberalization. Rice seems to be the only grain that is projected to benefit from China's entry into the WTO.

Table 13. Major agricultural price (yuan kg^{-1}) changes under alternative scenarios, 1999-2020.

Product	1999	2005	2010	2015	2020	Price change in 1999-2020 (%)
Without WTO entry						
Rice	2,070	2,048	2,034	1,969	1,874	–9
Wheat	1,449	1,441	1,428	1,382	1,319	–9
Maize	1,220	1,669	1,939	2,197	2,448	101
Soybean	3,112	3,360	3,677	3,853	3,852	24
Oil crop	8,558	8,266	8,823	9,315	9,683	13
Sugar crop	3,526	4,151	4,387	4,611	4,798	36
Pork	14,010	14,887	15,238	15,834	16,660	19
Beef	14,674	14,370	14,710	15,236	15,629	7
Mutton	17,399	15,667	15,120	14,685	14,286	–18
Poultry	11,042	11,179	11,189	11,205	11,478	4
Eggs	6,583	6,358	6,450	6,558	6,702	2
Milk	3,164	2,306	2,112	1,964	1,856	–41
With WTO entry						
Rice	2,070	2,088	2,090	2,091	2,092	1
Wheat	1,449	1,253	1,254	1,254	1,253	–14
Maize	1,220	968	968	969	970	–21
Soybean	3,112	1,971	1,973	1,974	1,975	–37
Oil crop	8,558	7,268	7,272	7,276	7,279	–15
Sugar crop	3,526	2,438	2,440	2,442	2,444	–31
Pork	14,010	15,426	15,434	15,433	15,433	10
Beef	14,674	14,798	14,802	14,808	14,808	1
Mutton	17,399	17,128	17,133	17,140	17,140	–1
Poultry	11,042	11,506	11,508	11,507	11,507	4
Eggs	6,583	6,550	6,551	6,551	6,551	0
Milk	3,164	2,333	2,334	2,334	2,334	–26

Sources: Authors' estimates.

Conclusions

The purpose of this paper was to examine the trends in China's rice economy and policies governing the agricultural sector, review the current trends in supply, demand, marketing, and trade, and then, on the basis of more comprehensive and structurally sound models, predict China's future involvement in world grain markets. The authors' framework includes a demand-side model that, in addition to the effects of income and population trends (as well as income response parameters that vary as income levels rise), accounts for the effects of urbanization and the changing level of the development of rural consumption markets. The supply response model considers the effect of prices, public investment in research and irrigation, institutional change, and environmental factors.

The study shows that, while the rice sector has been heavily penalized by price and marketing policies as well as macroeconomic policy such as the overvaluation of the domestic currency, rice productivity has gained substantially from productivity-enhancing investment such as agricultural research and irrigation. The projections show that, under the most plausible expected growth rates in the important factors (most of which are broadly consistent with the major projection models at the World Bank and International Food Policy Research Institute), China's grain imports will rise over the projection period. But, rice trends are in stark contrast to those of feed grains (maize) and soybean. Increasing maize imports arise mainly from the accelerating demand for meat and feed grains. The expected increasing rice exports will offset parts of the increase in feed grain imports and make the total amount of grain imports less than 50 million t by 2020.

The most important difference between the projections for grain imports and rice exports is in the sensitivity of the predictions to the simulation assumptions. There is considerable range in the projections for total grain (mostly maize) and rice when baseline assumptions are varied in both the short and long run. Different rates of agricultural investment create some of the largest differences in expected imports, but this is what should be expected from the factor that has the largest marginal output response. For rice projections, slight changes in assumptions result in predictions of China having large variations from the baseline results. Most of the major demand factors—urbanization, income growth (and low or negative expenditure elasticities), and market liberalization—are pushing China's consumers to reduce rice demand over the next 20 years. With a significant change in agricultural policy in response to China's WTO entry, supply will be able to keep up with demand and rice exports will increase. Hence, if China's grain imports were to grow to the high level predicted by others in the coming decades, this is not going to be because of the demand for rice (or wheat).

On the basis of the results presented in this paper and other work by the authors, for total grain as a whole, it appears that China will neither empty the world grain markets nor become a major grain exporter. Although China will become a more important player in world grain markets as an importer in the coming decades, its importance will primarily be in world feed markets. In contrast, China may continue to export rice. Over the long run, if the baseline assumptions hold and the structural parameters used in this study are and remain reliable, China may become one of the world's leaders in rice exports.

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Medium- and long-term prospects of rice supply and demand in the 21st century in India

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This paper assesses the total factor productivity (TFP) of rice grown in various regions of India and examines the sources of productivity growth and marginal rates of return to public investment in rice research. The paper also projects the supply and demand of rice in the 21st century in India. The results of the study highlight a spectacular increase in rice yield from 1.1 t ha^{-1} in 1967-71 to 1.9 t ha^{-1} in 1997-99. The TFP index has risen at 0.9% per annum and has contributed one-third of production growth. A decelerating tendency in TFP growth is observed. The cost per unit of rice has declined steadily. The cultivation of basmati rice has benefited farmers in the northern states of India. Demand for rice will be met in the future with a marginal surplus for trade. To maintain the surplus status of rice, the study emphasizes the need to strengthen efforts to increase production by maintaining or increasing TFP through public investment in irrigation, infrastructure development, research, and efficient input use. More than half of the required growth in yield to meet the demand target must be met from research efforts in developing location-specific and low-input-use technologies with emphasis on the regions where current yield is below the required national average yield. All efforts need to concentrate on accelerating growth in TFP while conserving natural resources and promoting the ecological integrity of the agricultural system.

Rice is an important food grain that is produced and consumed worldwide. India contributes 23% of the total world rice production. The public investment in irrigation, other rural infrastructure, and research and extension, together with improved crop production practices, has added 43 million t of rice from 1970 to 1999. The 62% incremental rice production that came from small farmers (less than 2-ha farm size) underlines the impressive role of smallholders in the Green Revolution process (Singh and Kumar 2001). In the years to come, higher economic growth as well as the sizable increase in population, despite decelerating population growth, will increase rice demand. Rice is a highly export-competitive commodity in India. The net trade of Indian rice will probably increase in the near future, especially the high-value segment of basmati rice. Rising demand will continue to put increasing pressure on the ever-shrinking and degrading land and water resources. Steps to improve rice productivity to meet the growing domestic demand and to produce an exportable surplus for the world rice market require an in-depth analysis of rice productivity, supply, and demand. This paper examines rice productivity and its implications for food security with the specific objectives (1) to assess total factor productivity (TFP) growth for rice in different regions of India, (2) to examine the sources of productivity growth and estimate the returns to public investments in rice research, and (3) to assess the medium- and long-term prospects of rice supply and demand in India. This paper on TFP is an extension of the work of Kumar and Rosegrant (1994, 1997) and Jha and Kumar (1998). It uses more recent data and has developed a simultaneous model for identifying the sources of TFP growth and an extended supply analysis methodology with a more realistic approach.

The data

The farm-level data on yield and the use of inputs and their prices from 1971-72 to 1997-98 collected under the "Comprehensive scheme for the study of cost of cultivation of principal crops," Directorate of Economics and Statistics (DES), Government of India (GOI), were used in the analysis of TFP and supply projections. The missing year data on inputs and their prices were predicted using interpolations based on trends of the available data. The time-series data on area, yield, production, irrigated and high-yielding variety (HYV) area for the rice crop, and source-wise area irrigated were taken from the various published reports of the DES (GOI). Crop production across the country is diverse and agricultural production and the use of inputs depend on the physical environment, which includes factors such as soil quality and climate. State-wise time-series data were aggregated into four regions: the eastern region covering the states of Assam, Bihar, Orissa, and West Bengal; the northern region, which includes Haryana, Punjab, and Uttar Pradesh; the western region covering Gujarat, Maharashtra, Madhya Pradesh, and Rajastan; and the southern region comprising Andhra Pradesh, Tamil Nadu, Karnataka, and Kerala. The share of the hills region (Himachal Pradesh and Jammu and Kashmir) in rice production was marginal and was therefore not included in the analysis. The data on research and extension stock investment compiled by Evenson (for details see McKinsey et al 1991) and updated by Kumar (1999) were used. The national sample survey (NSS) data of various rounds covering 1983-93 on the consumption pattern were used in projecting rice demand. The population projections for India given in the state of world population of the United Nations Population Fund were used (UNFPA 1998).

Growth in area, yield, and production

Changes in cropping patterns represent responses to changing economic, technological, and institutional factors. Land constrains Indian agricultural production. An increase in crop area and production is strongly associated with the crop's relative profitability. Farmers allocate their land among alternative crops in order to maximize their expected return. India has also experienced considerable changes in rice area, production, and yield since the Green Revolution began. Levels of yield, the adoption of modern varieties, irrigation, and price policy have been some important factors that have influenced changes in the cropping pattern. Rice yield increased spectacularly from 1.1 t ha^{-1} in 1967-71 to 1.9 t ha^{-1} in 1997-99. The extension of irrigation facilities has brought about drastic changes in the cropping pattern that replaced coarse cereals with high-yielding and high-value crops such as wheat and rice. From 1967 to 1999, rice area increased 0.6% annually and the output showed an increase of 2.8%, mainly because of yield growth (Table 1). The northern states, which were not traditionally rice-growing states, have contributed more to the growth of rice yield and production. The share of rice from the northern region was merely 12% in 1970 but increased to 28% of the total rice production in 1999 (Table 2). From 1967 to 1999, rice production in the northern region increased at 5.7% annually, with nearly two-thirds of this increase being contributed by yield gains. The rice area, production, and yield growth attained were highest in 1973-81. In the following decade, the rate of production increase declined to 5.2% per year, with yield gains still showing a high growth of 4.0% annually, which further declined to 3.2% during 1991-99, while area and yield growth decreased to 1.9% and 1.3%, respectively. In the southern region, growth in production was 2.5% during 1973-81, 3.5% during 1982-

Table 1. Annual compound growth rates (%) in area, production, and yield of rice, India.

Region	Item	1967-99	1967-72	1973-81	1982-90	1991-99
Eastern	Area	0.2	–0.0	–0.4	1.2	0.6
	Production	2.2	0.1	0.3	6.8	2.1
	Yield	2.0	0.1	0.7	5.6	1.5
Western	Area	0.7	0.7	1.2	0.2	0.5
	Production	2.3	–1.2	2.8	2.0	1.0
	Yield	1.6	–2.0	1.5	1.8	0.5
Northern	Area	2.0	1.3	4.4	1.1	1.9
	Production	5.7	5.9	9.0	5.2	3.2
	Yield	3.7	4.6	4.6	4.0	1.3
Southern	Area	–0.2	–0.6	0.2	–0.3	0.2
	Production	1.9	2.8	2.5	3.5	1.4
	Yield	2.1	3.4	2.4	3.8	1.2
India	Area	0.6	0.3	0.8	0.7	0.7
	Production	2.8	1.4	2.8	4.7	2.1
	Yield	2.2	1.2	2.0	4.0	1.4

Table 2. Share (%) of region in rice area and production, India.

Region	TE[a] 1970		TE 1980		TE 1990		TE 1999	
	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.
Eastern	46	43	43	36	43	36	42	35
Western	17	13	18	12	18	12	18	11
Northern	15	12	18	20	20	25	22	28
Southern	22	31	21	32	19	27	18	26

[a]TE = triennium ending. Area = total area under rice.

90, and 1.4% during 1991-99 and virtually all of it came from yield increases as the proportion of rice area under modern varieties and irrigation increased. It is encouraging that the eastern region realized high growth rates in production (6.8%) and yield (5.6%) during 1982-90. This growth declined steeply during 1991-99. The eastern region accounted for the highest share (35%) in total production in the triennium ending in 1999. Although the western region faced irrigation constraints, an increasing trend in production was observed. The gains in rice output have come essentially from a steady increase in yield. A steady growth in yield was observed in the 1980s and '90s, despite the decline in capital formation. Part of the explanation lies in the significant lag between investments in irrigation, research, education, extension, etc., and realization of the potential created. A decelerating growth in area, production, and yield has now been observed in all the regions. The scope for area expansion is limited. The deceleration in technological components might have slowed production growth (Kumar 2001).

Growth in inputs

From 1967 to 1999, rice area under irrigation and modern varieties exceeded 85% of the total cultivated area in the southern region. The growth in planting of modern varieties in the northern region has been similar, but the irrigated area under rice was slightly lower (75%). The adoption of modern varieties and irrigation has been slower in the eastern and western regions (Table 3).

The average fertilizer use was near or at the recommended dose in the northern and southern regions versus 57 kg in the western region and 46 kg in the eastern region (Table 4). Where relatively high levels of input use have already been attained, the growth in the use of fertilizer and its marginal contribution to yield increases are expected to be lower in the future, especially in the northern and southern states. The eastern and western regions have lagged behind the northern and southern regions with respect to the application of fertilizers and adoption of HYV technology, and a further growth in input use and rice yield in the eastern areas could occur. The use of organic manure was in a small quantity and also has shown a declining trend.

The use of labor-saving technologies, especially tractors, expanded rapidly and replaced animal labor (Table 5). The most prominent change occurred in animal labor, whose growth declined by as much as 11.6% per annum in the northern region

Table 3. Trends in area under irrigation and modern varieties of rice, India.

Region	Irrigated area (%)				Modern variety area (%)			
	TE[a] 1970	TE 1980	TE 1990	TE 1996	TE 1970	TE 1980	TE 1990	TE 1996
Eastern	29	30	29	32	6	27	45	65
Western	18	21	23	27	7	35	57	68
Northern	29	43	61	75	13	56	83	87
Southern	82	84	85	86	24	73	84	88
India	38	42	45	50	11	43	62	74

[a]TE = triennium ending.

Table 4. Trends in fertilizer use in rice cultivation by region, India.

Region	Organic manure (quintals ha^{-1})			Chemical fertilizer (kg nutrient ha^{-1})		
	TE[a] 1975	TE 1985	TE 1995	TE 1975	TE 1985	TE 1995
Eastern	22	18	20	11	28	46
Western	6	13	10	20	24	57
Northern	23	27	20	68	87	184
Southern	51	65	38	81	129	174
India	26	26	20	33	54	86

[a]TE = triennium ending.

Table 5. Trends in labor use in rice cultivation by region, India.

Region	Human labor (h ha^{-1})			Animal labor (h ha^{-1})		
	TE[a] 1975	TE 1985	TE 1995	TE 1975	TE 1985	TE 1995
Eastern	834	978	998	225	248	203
Western	599	587	675	144	148	138
Northern	871	802	591	112	82	26
Southern	1,074	1,143	1,164	172	146	62
India	855	904	900	191	182	142

[a]TE = triennium ending.

and by 2.5% in the southern region. The traditional labor use in other regions seems to be high. Human labor use did not decline except in the northern region.

Evidence on the use of inputs revealed that the existing level of application of modern inputs is relatively low in the eastern region. A further spread of inputs in this region, or to new areas where the existing level of application is relatively low, would contribute to a rise in the productivity per unit of input and ensure a more equitable distribution of benefits. This is followed by the increased investment in minor irrigation, including pump sets and bamboo tubewells, and increased use of fertilizer. There is great scope for a further increase in yield and production in the eastern states through a substantial investment in flood control and in minor irrigation. The eastern region occupied 42% of the total rice area in the country and contributed 35% of the country's total rice production. Any slight improvement in productivity in the eastern region will contribute significantly to the domestic rice supply in India.

Real cost of production, price, and profit

The nominal cost[1] per unit of rice production showed an upward trend despite the rapid growth in yield caused by technical change.[2] However, we need to ascertain whether the increase in nominal unit cost of production came mostly from an increase in prices of farm inputs at a rate higher than the rise in productivity or from a higher use of inputs in real terms for obtaining the same yield. This question was examined by assessing the cost of production at constant prices (base year 1981-82). Annual growth rates of the real cost of production, real rice price, and real profit were computed and are presented in Table 6.[3]

The unit cost of production of rice has decreased steadily in real terms, at –1.6% in eastern India, negligible in western India, –1.1% in northern India, and –3.2% in southern India. Modern variety adoption; investment in irrigation, infrastructure, and research; and subsidies appear to have lowered the unit cost of rice production. From the results, it appears that, in the later period of fast growth of modern variety adoption in the southern region, there was a sharp decline in the unit cost of rice production. Thus, the adoption of modern varieties and public policies has lowered the unit cost of production and rice prices in real terms. The real price in the northern states did not decline because of the adoption of high-priced basmati rice. The increasing

Table 6. Annual rates of growth (%) in real cost of production, price, and profit (at 1981-82 price) in rice production, India, 1971-72–1997-98.

Region	Real cost[a]	Real price	Real profit
Eastern	–1.57**	–1.37**	4.83**
Western	–0.07 ns	–0.80**	0.70 ns
Northern	–1.10**	0.74**	11.00**
Southern	–3.29**	–1.12**	7.69**
India			
1971-85	–1.21**	–2.34**	2.5 ns
1985-97	–1.51**	0.31***	7.00**
1971-97	–1.64**	–1.00**	5.81**

[a] ns = nonsignificant; ** = 1% level of significance, * = 5% level of significance, and *** = 10% level of significance.

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[1] Cost includes all cash and kind expenses actually incurred, rent paid, interest on owned and borrowed capital, and imputed value of family labor.

[2] Detailed statistics are available in the reports of the Commission for Agricultural Costs and Prices for the crops sown during various seasons, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India.

[3] The unit cost of production was deflated by an input price index series to obtain the real cost per unit of output. The real price is computed by deflating the rice price received by farmers with the wholesale consumer price index. Real profit is measured as net profit in rice-equivalent terms.

trends in real profit are evident in all the regions. The annual growth in real profit was estimated to be 11% in the northern region, followed by the southern region (7.7%) and eastern region (4.8%). The cultivation of basmati rice benefited the northern region farmers substantially. In all the regions, the decline in the real cost of production was more than the declining trend in real price. The results inferred that farmers and consumers have shared the benefits of higher production efficiency and lower prices, respectively.

Total factor productivity growth

The Green Revolution phase is characterized by widespread variety turnover and the adoption of improved varieties was made possible by agricultural research and policy support. This brought about boosted productivity growth per unit of land, which resulted in steady output growth for crops. The first "post-Green Revolution" phase saw continued growth in returns to land through intensification of chemical input use and labor input per hectare. The second "post-Green Revolution" phase began when input use was high, and further gains in productivity largely depended on increased efficiency of input use. The process of intensification of agriculture is central to achieving sustained growth in output. Conceptually, the increased use of inputs, to a certain extent, allows the agricultural sector to move up along the production surface by increasing yield per unit of land. Efficient input use may also induce an upward shift in the production function to the extent that a technological change is embodied in their use. The TFP concept, which implies an index of output per unit of total factor input, measures these shifts or increases in output properly, holding all inputs constant.

The Divisia-Tornqvist index (see Christenson 1975, Diewert 1976) is used in this study for computing the total output, total input, and TFP for rice using state averages based on farm-level data for 1971-97 for 15 states of India. Rice grain and straw are included in the output index. The inputs included in the input index are land, seed, manure, fertilizer, pesticide/herbicide, human labor, animal labor, machine labor, and irrigation. The total output, total input, and TFP indices are calculated as

Total output index (TOI) and total input index (TII):

$$TOI_t/TOI_{t-1} = \Pi_j \left(Q_{jt}/Q_{jt-1}\right)^{(R_{jt} + R_{jt-1})1/2}$$

$$TII_t/TII_{t-1} = \Pi_i \left(X_{it}/X_{it-1}\right)^{(S_{it} + S_{it+1})1/2}$$

Input price index (IPI):

$$IPI_t/IPI_{t-1} = \Pi_i \left(p_{it}/p_{it-1}\right)^{(S_{it} + S_{it-1})1/2}$$

where R_{jt} is the share of output j in the total revenue, Q_{jt} is output j (j = 1 for main product and j = 2 for by-product), S_{it} is the share of input i in the total input cost, X_{it}

is input i, and p_{it} is price of input i in period t. To measure productivity over a long period of time, chaining indices for successive time periods are preferable. With chain linking, an index is calculated for two successive periods, t and t – 1, over the whole period t_0 to T (sample from time t = 0 to t = T) and the separate indices are then multiplied together:

$$\text{TOI}(t) = \text{TOI}(1) \times \text{TOI}(2) \ldots\ldots\ldots\ldots\ldots\ldots \text{TOI}(t-1).$$
$$\text{TII}(t) = \text{TII}(1) \times \text{TII}(2) \ldots\ldots\ldots\ldots\ldots\ldots \text{TII}(t-1).$$
$$\text{IPI}(t) = \text{IPI}(1) \times \text{IPI}(2) \ldots\ldots\ldots\ldots\ldots\ldots \text{IPI}(t-1).$$

Total factor productivity index (TFP):

$$\text{TFP}_t = (\text{TOI}_t/\text{TII}_t)$$

The chain-linking index takes into account the changes in relative values/costs throughout the period of the study. This procedure has the advantage that no single period plays a dominant role in determining share weights and biases are likely to be reduced. The above equations provide the indices of total output, total input, and TFP and input price indices for the specified period t. The aggregate index of input and output at the country level is derived as the weighted average of the state-level index. The state share in total rice area is used as the weight.

The average annual growth rates of output, input, and TFP indices are given in Table 7. The results reveal that, in the northern region, the input index during 1971-97 rose by 4.1%, whereas it rose by 1.7% in the southern region, by 1.9% in the eastern region, and by 2.7% in the western region. With increases in inputs and technological change, output has increased by 5.1% annually in the northern region, followed by the southern region (3.2%), the eastern region (2.9%), and the western region (2.0%). The variation in TFP is due almost entirely to variation in output, as the total input use increased smoothly over time. Overall, the TFP index has risen by around 1.5% annually in the southern region, by 1.1% in the eastern region, and by 1% in the northern region. In the western region, wide variation in the TFP index was observed because of wide fluctuations in weather and the estimated annual growth was negative and statistically insignificant. Productivity growth represents 48% of total output growth in the southern region, 36% in the eastern region, and 20% in the northern region. For the country as a whole, TFP growth was estimated at 0.91%. TFP contributes nearly 30% of the output growth in Indian rice.

TFP growth during the post-Green Revolution period (1985-97) declined from the growth rate estimated for the early period of the Green Revolution (1971-85). This tendency serves to emphasize two points. First, research challenges remain and there is no scope for complacency in the light of the current comfortable food supply situation. Fast growth may not be sustained if further technological improvements do not occur. Second, it is essential for the country to cover a diverse research portfolio. Quality improvements such as basmati rice have added to the value of production. Rice research has helped break the seasonal barrier and expand rice area in north-

Table 7. Annual rates of growth (%) in total input, output, and total factor productivity (TFP) for rice in India, 1971-97.

Region	Total input	Total output	TFP
Eastern	1.86**	2.93**	1.06**
Western	2.68**	2.03**	–0.65 ns[a]
Northern	4.07**	5.10**	1.03**
Southern	1.66**	3.17**	1.51**
India			
1971-85	1.89**	2.87**	0.98**
1985-97	2.50**	3.25**	0.75*
1971-97	2.23**	3.14**	0.91**

[a]ns = nonsignificant; * = 5% level of significance, ** = 1% level of significance.

western India and in the *rabi* season. The new varieties bring stability to rice production by providing tolerance of or resistance to adverse environmental conditions. All these contributions are subsumed under a residual TFP measure. This decelerating process will be examined in more detail below. Some researchers attributed this slowdown to a reduction in growth following the exploitation of early productivity gains from the adoption of modern varieties, the declining trend of investment in agriculture during the 1990s, and, more importantly, the increasing problems of water quality and soil salinity (Joshi and Agrihotri 1982, Joshi and Jha 1991).

The indices of land, labor, and fertilizer productivity and TFP were calculated for the triennium ending (TE) in 1977, TE 1987, and TE 1997 and normalized with respect to the eastern region and year 1997.[4] The results appear in Table 8. Land and labor productivity increased in all the regions and fertilizer productivity declined in all of them. TFP increased in all the regions, except in the northern states in 1995 relative to 1985. Basmati rice is increasing in the northern states. The TFP measurement did not capture the value added by basmati rice cultivation. The notable productivity gains have come from the more efficient use of the existing inputs of land and labor. The increased labor productivity was a result of a reduced use of labor on account of mechanization. Similarly, the increase in land productivity has taken place on account of the increase in land-saving modern inputs, particularly fertilizer and irrigation. It is to be noted that the productivity of fertilizers fell significantly because increasing amounts of fertilizer were being used to maintain current yield levels. This has shifted the concern from simply increasing the levels of fertilizer use to improving its efficiency. Promoting efficient fertilizer practices, improving soil-testing services, strengthening the distribution channel of critical inputs, especially high-quality seeds, and developing the physical and institutional infrastructure will particularly help resource-poor farmers by increasing TFP growth. Yield-based growth

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[4] Data normalization is done to provide a comparative picture across regions.

Table 8. The indices and growth of factor productivity and total factor productivity (TFP) in rice production, India (eastern region = 100).

Region	Index (%)			Decadel changes (%)	
	TE[a] 1977	TE 1987	TE 1997	1977-87	1987-97
Partial factor productivity in Land					
Eastern	61	73	100	20	37
Western	61	62	90	2	45
Northern	60	80	64	33	–20
Southern	56	78	100	39	28
Labor					
Eastern	69	73	100	6	37
Western	66	66	77	0	17
Northern	60	92	82	53	11
Southern	60	78	98	30	26
Fertilizer					
Eastern	592	187	100	–68	–46
Western	382	330	192	–14	–42
Northern	433	363	330	–16	–9
Southern	476	380	394	–20	3
TFP					
Eastern	80	84	100	5	19
Western	76	67	78	–12	16
Northern	71	96	71	35	–26
Southern	73	86	99	18	15

[a] TE = triennium ending.

has rapidly increased nutrient removal from the soil at a rate that has not been matched by balanced growth in the supply of nutrients through chemical and organic fertilizers. The result of the unbalanced application of fertilizers has been a decline in the efficiency of their use over time (Kumar and Desai 1995).

Total factor productivity decomposition

The TFP index varies not only across states but also over time. In this section, we analyze how technologies and infrastructure have contributed to productivity growth. Factors that account for a change in TFP include changes in technology, institutional reform, infrastructure development, human resource development, and others. The crop-related technology changes that are often embodied in the seeds adopted by farmers can be divided into two components: quality and quantity. The former represents either cost reduction or yield improvement technologies, or both, while the latter represents the amount of area in which the technology is adopted by farmers. Distinguishing these two components of technology in assessing their impact on productivity growth is important, as the mechanism by which they affect TFP differs. Quality reflects research output that is determined by investment in research and is an exogenous variable in the TFP equation. The quantity of technology is linked to adoption and is affected by extension, literacy, infrastructure development, as well as on-farm and off-farm characteristics. Adoption is a farmer's choice variable and therefore must be considered an endogenous variable in the TFP model. The empirical specification of the endogenous technology and the determinants of the TFP model are defined as follows:

TFP = f (RES, HYV, RAIN, DUMMY)
HYV = g (RES, EXT, RLIT, RINF, IRRINF, DUMMY)

where RES = research stock of rice crop (Rs ha^{-1} of rice area), EXT = extension stock (Rs ha^{-1} of net crop area), RAIN = July to September rain in mm, HYV = percent of crop area under high-yielding varieties, RLIT = percent of total rural literate population (primary and above education), RINF = rural infrastructure, proxies by percent of villages electrified, IRRINF = irrigation infrastructure, measured as the percent share of irrigated area to total net cultivated area, DUMMY = dummy for region, DE = dummy for eastern states (Assam, Bihar, Orissa, West Bengal), DW = dummy for western states (Madhya Pradesh, Rajasthan, Maharashtra, Gujarat), DN = dummy for northern states (Punjab, Haryana, Uttar Pradesh), and DS = dummy for southern states (Andhra Pradesh, Tamil Nadu, Karnataka) of India.

Cross-section time-series data are used in the estimation of the simultaneous equation model of rice TFP decomposition using the three-stage least squares (3SLS) estimation framework. The econometric estimates of the model are presented in Table 9. The system R-square was high (0.98), indicating the goodness of fit. The estimates of the model were statistically significant. Research, extension, rural literacy, and rural infrastructure (rural electrification and irrigation) were significant determinants that influenced the adoption of modern varieties. The adoption of modern varieties had a significant influence on TFP. Thus, research investment leads to increases in TFP through its impact on variety turnover. Using TFP elasticity and growth rates of each factor, the contribution of each determinant to TFP growth was computed and is presented in Table 10. Rural infrastructure has accounted for 42% of TFP growth, followed by public research (21%), literacy (15%), irrigation infrastructure (14%), and extension (8%).

The ratio of amount spent on extension to research is falling (Pal and Singh 1997). A wide untapped yield potential exists (Siddiq 2000). This, coupled with the complexity of second-generation technologies and heterogeneity of production environments, warrants much more intensive extension efforts. The slowing down in emphasis on extension will further widen the gap in the adoption of technology. Extension services should be strengthened by scaling up investment levels and by improving the quality of extension. The first step in this direction should be to increase the availability of operating funds. This will result in increasing TFP trends and raise the share of extension in TFP growth.

Table 9. Estimated parameters of total factor productivity (TFP) decomposition model for rice, 1971-95.

Variable	TFP equation		HYV equation	
	Parameter estimate[a]	T-ratio	Parameter estimate	T-ratio
Intercept	0.437**	2.7	–0.056	0.3
RES	0.003	0.2	0.074**	4.1
EXT			0.041**	2.2
HYV	0.100**	3.0	–	–
RLIT			0.270**	3.2
RINF			0.386**	9.3
IRRINF			0.286**	5.6
RAIN	0.5425**	25.4		
Dummy				
DW	–0.064	1.2	0.462**	6.7
DN	0.243**	4.6	0.340**	4.6
DS	0.153**	2.9	0.622**	10.6
R-square	0.77		0.89	
System R-square	0.98			

[a]** = significant at 1% level.
Source: Kuchhal (Mittal) (2000), unpublished PhD thesis.

Table 10. Sources of total factor productivity (TFP) growth in rice, India.

Sources	Annual growth (%)	Elasticity of TFP	Share (%) of TFP growth explained
Public research	8.9	0.011	21
Extension	8.6	0.004	8
Literacy	2.5	0.027	15
Rural infrastructure	5.1	0.039	42
Irrigation infrastructure	2.3	0.029	14

Returns to rice research

Using the elasticity of TFP with respect to research stock, one can easily estimate the value marginal product (EVMP) of research stock (R) as

$$\mathrm{EVMP(R)} = b_r \,.\, (V/R)$$
$$V = Q \,.\, \mathrm{FHP} \,.\, \mathrm{STFR}$$

where R is the research stock and V is the value of rice production associated with TFP. Q is rice production, FHP is the farm harvest price, STFP is the share of rice production accounted for by TFP growth, and b_r is the TFP elasticity of research stock. The benefit stream is produced under the assumption that the benefit of investment made in research in period t will start producing a benefit after a lag of five years, produce a benefit at an increasing rate in the next nine years, remain constant for the subsequent nine years, and thereafter decline (Evenson and Pray 1991).[5] The benefit stream is discounted at the rate r, at which the present value of the benefit is equal to one. Thus, r is considered as the marginal internal rate of return to the public research investment.

The returns to public investment in rice research given in Table 11 revealed that, for the period 1973-97, a one-rupee increment in research stock generated on average an additional income of Rs 7.2. The marginal internal rate of return to public rice research is estimated to be 41%. This indicates that the returns to investments in rice research have been highly rewarding. Returns are quite stable over time, ranging from 39% to 43% and reaching a peak during 1986-91. Thereafter, returns to research steadied somewhat.

Supply of rice

The supply model presented in Appendix 1 was estimated for rice.[6] The model was estimated by using three-stage least squares (3SLS) and the seemingly unrelated regression equations (SURE) estimation procedure. Double-log forms were used for all the equations in the system. The model based on SURE estimates presented in Appendix 2 was selected for the analysis in the study as it had a higher adjusted R-square and a lower level of standard errors when compared with the 3SLS. Most of the coefficients in the estimated system were statistically significant at the 5% confidence level (one-tail test) or better. The explanatory power of the estimated system was quite high and statistically significant. The model had the expected sign and supported the trends observed in several previous studies (Kumar and Muruthyunjaya 1989, Chand 1991, Kumar and Rosegrant 1997, Gulati and Kelley 1999).

Table 11. Returns to rice research in India.

Period	Value marginal product (rupees)	Internal rate of return (%)
1973-76	6.7	40.6
1976-81	7.3	41.8
1981-86	7.5	42.1
1986-91	8.1	43.2
1991-97	5.8	38.8
1973-97	7.2	41.5

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[5] The investment of one rupee in year t in research will produce a benefit equal to 0.1*EVMP in year t + 6, 0.2*EVMP in year t + 7, and so on, and it will be 0.9*EVMP in year t + 14. After this, the benefit will be equal to EVMP up to t + 23. Then, the benefit for year t + 24 onward will be equal to 0.9*EVMP and in t – i + 25 it will be 0.8*EVMP, and so on. This gives the benefit stream from research investment.

[6] The cross-section cum time-series data for 1971-96 were used. The averages at the state level were derived from the farm-level cost of cultivation data collected and published under the "Comprehensive scheme for the study of cost of cultivation of principal crops," Directorate of Economics and Statistics, Government of India.

Choice of technique

The choice of technique (irrigation, variety) for the crop is a function of investment decisions of the farmer and the government and this induces the use of inputs and thereby affects yield. The choice of technique is measured as the percent of rice area under irrigation and HYVs. The elasticity of irrigated rice area with respect to the net sown irrigated area was 0.61. The literacy rate, electrification, and irrigation influence the decision on the adoption of modern varieties significantly. All of these variables had expected positive signs. The elasticity of HYVs with respect to rural electrification was the highest (0.48), followed by literacy (0.38) and irrigated area of rice (0.19).

Factor demand function

Human labor. Normalized wages, machine labor charges, and the adoption of HYVs and irrigation significantly influenced the use of human labor. The wage elasticity of human labor demand had the anticipated negative sign. A negative sign of cross-price elasticity with respect to the price of other variable inputs showed that the pair is complementary and a positive sign an indicator of a substitution relationship. The cross-price elasticity in relation to machine labor price was positive and significant. The elasticity of demand for human labor with respect to rice price was positive and mild (0.09). With wage inflation, human labor would be replaced by machine labor. This would induce efficiency in crop production and improve productivity and yield. Irrigation had a positive and significant effect on labor employment. The adoption of modern varieties had an insignificant influence on human labor demand.

Machine labor. Machine labor use is a function of wages, bullock labor charges, machine labor charges, HYVs, and irrigated rice area. The cross-price elasticity of machine labor demand with respect to wages and bullock labor charges was positive and significant, indicating a substitution relationship. The substitution of machine labor for human and bullock labor would take place as a result of an increase in wages for traditional labor. The elasticity of machine labor employment with respect to HYVs and irrigation was positive and significant. Irrigation expansion and the adoption of modern varieties induced the demand for machine labor.

Fertilizer. Chemical fertilizers are the major nutrients in crop production. The own-price elasticity of fertilizer demand had a positive sign but was statistically insignificant. The gradual increase in fertilizer price has not decreased fertilizer use. A complementary relationship of fertilizer use with irrigation, HYVs, and mechanization was strongly visible and had a positive and significant effect in inducing fertilizer use. Fertilizer demand was highly responsive to irrigation and HYVs. Its demand with respect to HYVs was estimated to be positive and significant.

Yield. The structural equation of yield function in the model is specified as a function of farm inputs (human labor, machine labor, fertilizer, farmyard manure), technology and quality of inputs (TFP indices are used to take care of these factors), rainfall, and the dummy for the eastern (control), western, northern, and southern states of the country. Machine labor, fertilizer, and FYM had a significant and positive effect on rice yield. The effect of TFP on yield was positive and strong. The elasticity of rice yield with respect to TFP was estimated at 0.58. TFP seemed to be the most dominating source of yield growth. Organic manure had a positive and significant effect on rice yield.

Regional dummy. A quick glance at the region dummy estimates for rice showed that the eastern region (control) and the southern region dummy coefficients were positive, high, and statistically significant. It can be inferred that the faster rate of growth in rice yield could be achieved from the eastern and southern states of India. The northern states had achieved high growth in yield mainly because of the intensive use of inputs, which may not be cost-effective. These findings confirm earlier findings (Kumar and Rosegrant 1994) that the future productivity gains in rice production will have to be achieved from the eastern and southern regions of India.

Cumulative effects of price and nonprice factors

The cumulative effects of price and nonprice factors on yield were computed by using the estimated model and the formulation presented in Appendix 1. Figure 1 illustrates the process through which yield growth takes place as a result of price and nonprice factors. The cumulative effect of price and nonprice factors on rice yield is presented in Table 12.

Price factors

Wages. Wages have a negative effect on the use of human labor and a positive influence on machine labor and fertilizer. This implies that, with the increase in wages, human labor becomes more costly. Once human labor becomes costly, the process of replacing human labor by machine labor takes place. Mechanization induces fertilizer use and the trade-off between these inputs improves the efficiency of rice production. Hence, the net effect of a normalized wage on yield was positive and estimated to be 0.23.

Bullock labor charges. Higher bullock labor charges will induce a higher use of machine labor as this results in the replacement of bullock labor by machine labor. With a 10% increase in bullock labor charges, the use of machine labor will increase

Table 12. Cumulative effect of price and nonprice factors on rice yield in India.

Variable	Total effect of price and nonprice factors on rice yield (elasticity)
Wages (w/P)	0.23
Bullock labor charges (b/P)	0.10
Machine labor charges (m/P)	–0.23
Fertilizer price (r/P)	0.02
Organic manure (q/ha)	0.04
Net sown area irrigated (%)	0.08
Villages electrified (%)	0.08
Rural literacy (%)	0.06
Total factor productivity	0.58

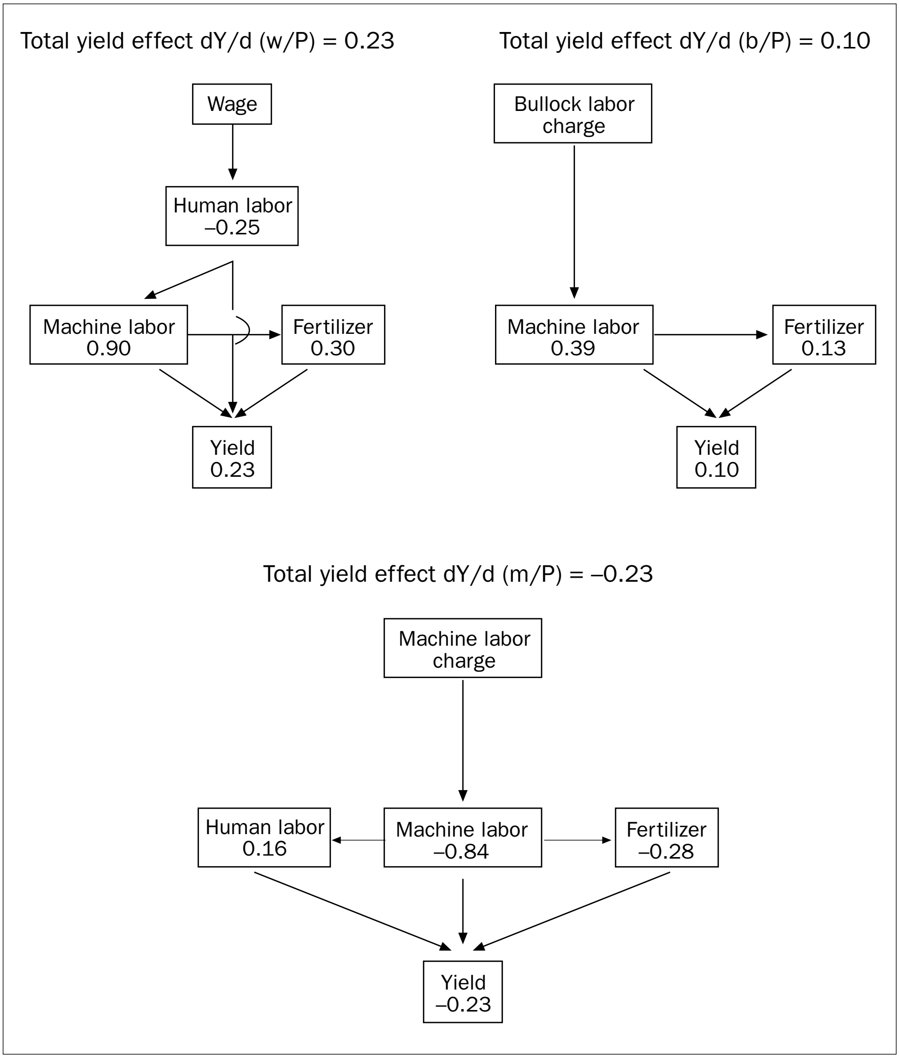

Fig. 1. Effect of factor price on rice yield. Numbers are the elasticities.

by 3.9%. Mechanization induces a higher use of fertilizer. The higher use of machine labor and fertilizer resulted in productivity gains. The cumulative effect of bullock labor charges was estimated to be 0.10.

Machine labor charges. The price elasticity of demand for machine labor was highly negative and significant. With a 10% increase in machine labor charges, the use of machine labor will decline by 8.4%. The high cost of machine labor will result in less use of machines and fertilizer and more use of human and bullock labor. This will result in a net negative effect on yield. The cumulative effect of machine labor charges on yield was estimated to be –0.23%. It is necessary to keep the price of machine labor low and thereby help to induce crop production efficiency in the light of food needs and nutritional household security.

Fertilizer price. Chemical fertilizers are the major nutrients in crop production. Rice and wheat are the technologically advanced crops and their relative profitability is high (Kumar et al 1998). Rice yield elasticity is highly inelastic with respect to fertilizer price. Thus, a reduction in fertilizer subsidy will not affect the use of fertilizer and rice yield.

Nonprice factors

Irrigation. The impact of net sown irrigated area induces the allocation of irrigated land to specific crops. Crop irrigated area induces the adoption of modern varieties. Both yield-enhancing nonprice technologies induce the use of inputs and hence influence yield. As seen in Figure 2, crop irrigation induces the adoption of HYVs, with an elasticity coefficient of 0.11. The irrigated area of the crop and adoption of HYVs induced a higher use of human labor, machine labor, and fertilizer. Among the inputs, irrigation had the highest effect on fertilizer use, followed by machine labor and human labor. The total effect of irrigated land expansion on yield was estimated to be 0.16 for rice. The government investment in irrigation increased the growth of irrigated area at 10% annually, and yield growth of rice would gain at 0.8%.

Literacy effect. Figure 3 illustrates the effect of literacy on yield through the adoption of modern varieties and the higher use of modern inputs. Rural literacy had a significant effect on the adoption of modern varieties. The elasticity of HYVs for rice with respect to literacy was 0.38. The higher use of fertilizer and machine labor was induced through modern varieties of rice as a result of the higher rural literacy rate. However, the effect of literacy on human labor use was negligible and negative. A 10% improvement in the literacy rate would induce growth in rice yield of 0.6%. An increase in yield resulting from an improvement in literacy rate seemed to be small on average but it still had substantial implications for the domestic supply of rice.

Electrification. Rural electrification induced the adoption of modern inputs in the rice crop (0.48). Capital investment in rural electrification in the eastern states increased the use of fertilizer and machine labor and improved the rice supply. Electrification had a mild negative effect on human labor employment. The higher use of modern inputs as a result of rural electrification was responsible for increasing yield growth from its existing level. A 10% increase in rural electrification will correspond to an increase of 0.8% in rice yield.

Total factor productivity. TFP is a significant determinant for yield growth. The elasticity of rice yield with respect to TFP was estimated to be 0.58. Literacy accounted for 15% growth in TFP for the rice crop (Table 10). This implied that literacy, through TFP, would contribute an 8.7% improvement in rice yield growth, which is quite substantial.

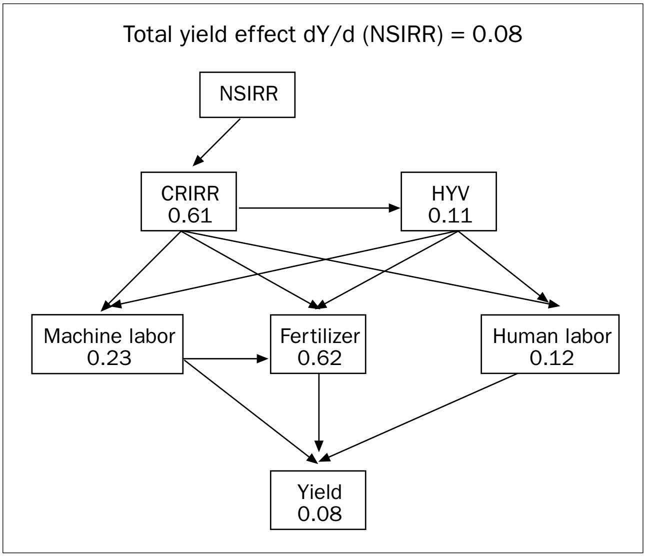

Fig. 2. Effect of irrigation on rice yield.

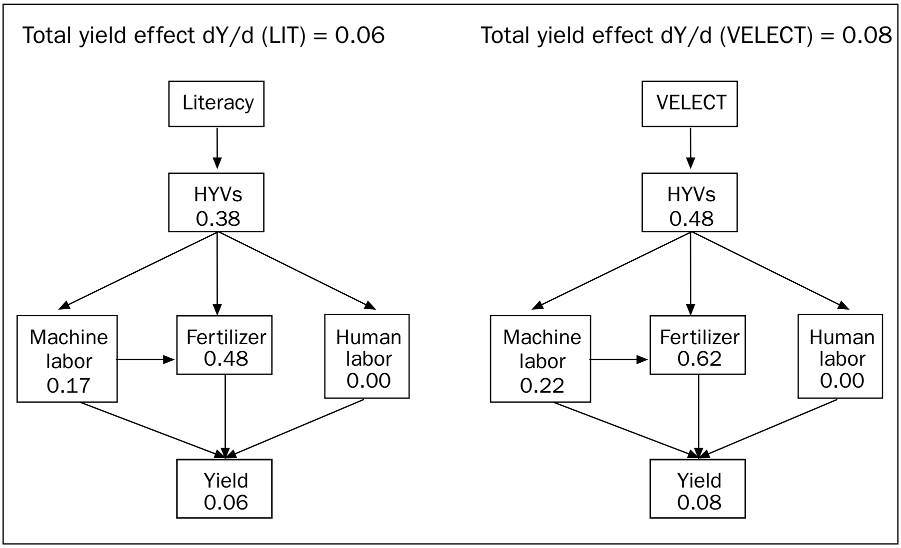

Fig. 3. Effect of literacy and rural electrification on rice yield. Numbers are the elasticities.

Supply growth

TFP, price environment, infrastructure, literacy, and organic manure are the major sources of yield growth (Table 12). The estimated rice yield growth equation in terms of relative changes of exogenous variables could be expressed as

$$\dot{Y} = 0.23\ \dot{(w/P)} + 0.10\ \dot{(b/P)} - 0.23\ \dot{(m/P)} + 0.02\ \dot{(r/P)} + 0.04\ \dot{FYM} + 0.08\ \dot{NSIRR}$$

$$+\ 0.06\ \dot{LIT} + 0.08\ \dot{PVELECT} + 0.58\ \dot{TFP}$$

Yield and area are the sources of output growth. The production growth equation would be

$$\dot{S} = \dot{Y} + \dot{CRAREA}$$

where Y is rice yield per unit of land and w, b, m, r, and P are wage rates, bullock labor charges, machine labor charges, fertilizer price, and crop output price, respectively. NSIRR is the percent of net sown area under irrigation, LIT is the rural literacy, PVELECT is the percentage of total villages electrified, TFP is total factor productivity, CRAREA is rice sown area, and a dot (**.**) represents growth in the corresponding variable. This formulation has the advantage of separating the effect of price and nonprice factors. The first four terms measure the price effects and the other terms measure the contribution of irrigation, literacy, electrification, and TFP to yield growth.

The yield and production (supply) growth equations given above were used to predict the supply of rice under the assumptions given in Appendix 3 for factor and product prices, infrastructure variables, TFP, organic manure, and area growth. Medium- and long-term prospects of rice supply were explored up to 2030 under the following scenarios:

S1 = baseline assumptions as given in Appendix 3
S2 = baseline assumptions without TFP growth
S3 = baseline assumptions without area growth
S4 = baseline assumptions without TFP and area growth

Under these assumptions, the annual growth in rice supply and the sources of its growth were predicted by using the yield and output growth equations (Appendix 4). The projected growth in rice supply is given in Table 13. The results revealed that rice supply would grow at a lower rate than that achieved in the past. The predicted annual growth of rice supply, corresponding to the baseline, would decline from 2.16% in 2000 to 1.71% in 2010 and further to 1.50% in 2030. The projected growth in rice supply would be lower than that achieved during 1991-99. In the absence of TFP growth, rice supply would grow by 1.51% in 2005, 1.41% in 2010, 1.36% in 2020, and 1.31% in 2030. The possibility of area expansion is limited. Under the assumption with no growth in rice area, the supply would grow annually by 1.23% in 2005,

Table 13. Predicted annual growth (%) of domestic rice production in India.

Year	Scenario 1 (baseline)	Scenario 2	Scenario 3	Scenario 4
1995	2.51	1.98	1.95	1.42
2000	2.16	1.73	1.55	1.11
2005	1.87	1.51	1.23	0.87
2010	1.71	1.41	1.08	0.78
2015	1.66	1.39	1.03	0.76
2020	1.60	1.36	0.98	0.74
2025	1.55	1.33	0.94	0.72
2030	1.50	1.31	0.90	0.70

1.08% in 2010, 0.98% in 2020, and 0.90% in 2030. If no serious efforts are made to accelerate TFP growth, we could use the scenario without growth in TFP and rice area. Under this scenario, the rice supply would grow at a smaller rate of about 0.87% in 2005, 0.78% in 2010, 0.74% in 2020, and 0.70% in 2030 vis-à-vis the baseline. The projected growth in rice supply is lower than that achieved during 1982-90 (4.7%) and 1991-99 (2.1%) and much less than what has been envisaged in various five-year plans. In most of the area, the investment in irrigation has remained static or has even fallen. The natural resource base is under severe pressure. It therefore looks difficult to increase the incremental rice output unless large investments in irrigation, infrastructure, literacy, mechanization, research, and extension are made.

Sources of supply growth

As per the long-term perspective (1973-97), the rice supply grew annually at 2.51%. The shares of sources of rice supply growth are presented in Appendix 4. In scenario 1, during 1973-97, prices contributed a maximum share to supply growth (26.3%), followed by area (22.3%), TFP (21.1%), electrification (16.3%), irrigation (7.2%), literacy (5.9%), and FYM (0.9%). A significant decline in the shares of irrigation and electrification in the total rice supply growth was predicted in the projected period. This has occurred because of a slowdown in the growth of net sown irrigated area and village electrification. A declining growth in public investment in canal irrigation was observed. Electrification had reached a high level and in many states almost all the villages were electrified. Price environment is a potentially important instrument in influencing efficiency and investment in agriculture. Unfavorable agricultural terms of trade persist along with favorable technological frontiers. Although this works as a disincentive to invest in agriculture, it has shifted incentives to use available resources efficiently. Price environment induced the replacement of traditional inputs (human labor, FYM, local varieties, etc.) by modern inputs (machines, fertilizer, modern varieties, etc.). The modern inputs have induced efficiency to improve productivity over and above their own contribution as a direct input into production. The price environment, TFP, literacy, and area are the major sources of output growth. Literacy plays an important role in the output supply through the adoption of advanced technology.

Irrigation and electrification induced output growth during the Green Revolution period. These favorable sources of growth have lost their importance in the present scenario.

Supply projections

Sometimes the growth figures are misleading in assessing the actual need of supply. Therefore, a need arises to project supply in physical terms and it is easy to compare with demand. The domestic supply projections for rice are calculated up to 2030 using TE 1999 as the base year. Using the base-year rice production in TE 1999, rice supply is projected under various scenarios (Table 14). It is expected that, in the future, increases in rice production will be only yield-based. The possibility of area expansion is minimal. Therefore, scenarios 3 and 4 will be more realistic in the supply analysis. The domestic supply of rice under scenario S1 (baseline) in 2010 will be about 108 million t. Domestic production will increase to about 127 million t in 2020 and to 148 million t in 2030. Considering the absence of TFP growth, the domestic supply of rice will be 103 million t in 2010, 118 million t in 2020, and 135 million t in 2030. In the absence of area expansion under rice in the medium and long term, the supply is projected at 100 million t in 2010, at 111 million t in 2020, and at 122 million t in 2030. The domestic supply in scenario 4 (without TFP and rice area growth) is projected to be 96 million t in 2010, 103 million t in 2020, and 111 million t in 2030.

A comparison of scenarios S1 and S2 assesses the effect of TFP growth on rice supply (Table 15). The TFP contribution to the rice supply is estimated at 4.6 million t in 2010, 8.6 million t in 2020, and 12.9 million t in 2030. If TFP growth is not maintained, the loss in the domestic supply by 2030 will be 9.5% of the production. The impact of TFP on supply will be substantial. The area response remained one of the important sources of domestic supply. Several states gained in rice area as a result of substitution or expansion or both effects. The impact was substantial in the northern states, where the rice area gained 4.4% annually during 1973-81 and 1.9% in the

Table 14. Projected domestic rice supply (million t), India.

Year	Scenario 1[a] (baseline)	Scenario 2	Scenario 3	Scenario 4
TE 1999	85.7	85.7	85.7	85.7
2000	89.5	88.7	88.4	87.6
2005	98.7	96.0	94.6	91.9
2010	107.8	103.2	100.0	95.8
2015	117.1	110.6	105.4	99.5
2020	127.0	118.4	110.8	103.3
2025	137.3	126.6	116.2	107.1
2030	148.0	135.1	121.6	110.9

[a] Scenario 1 = baseline assumption for price and nonprice exogenous variables. Scenario 2 = baseline assumption without TFP growth. Scenario 3 = baseline assumption without area growth. Scenario 4 = baseline assumption without TFP and area growth.

Table 15. Effect of total factor productivity (TFP) growth on domestic production of rice (million t), India.

Year	Baseline (scenario 1)	Without TFP growth (scenario 2)	Effect of TFP growth
2000	89.5	88.7	+0.8 (0.9)
2010	107.8	103.2	+4.6 (4.5)
2020	127.0	118.4	+8.6 (7.3)
2030	148.0	135.1	+12.9 (9.5)

Table 16. Effect of area growth on domestic production of rice (million t), India.

Year	Baseline (scenario 1)	Without area growth (scenario 3)	Effect of rice area growth
2000	89.5	88.4	+1.4 (1.6)
2010	107.8	100.0	+7.8 (7.8)
2020	127.0	110.8	+16.2 (14.6)
2030	148.0	121.6	+26.4 (21.7)

recent past. All the regions have shown a positive growth in rice area expansion at about 0.6% on average nationally during 1967-99.

A comparison between scenarios S1 and S3 in Table 16 assesses the effect of area on supply. In the absence of area expansion, the loss in rice supply will be 7.8 million t in 2010, 16.2 million t in 2020, and 26.4 million t in 2030, which is about 22% of the total rice supply. This loss needs to be compensated for by increasing productivity and yield. A comparison between scenarios S4 and S1 assesses the effect of TFP and area response and it is estimated to be equivalent to 12 million t in 2010, 24 million t in 2020, and 37 million t in 2030 (Table 17).

Demand projections

Several studies done in the past provide demand projections for rice in 2020. Among the most recent ones, the demand estimates given by Rosegrant et al (1995) provided food projections based on the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). Rice demand for India is estimated at 116 million t in 2010 and 145 million t in 2020. The demand for rice is on the high side considering the rice consumption pattern in India. The study does not account for regional variations in the consumption pattern and changes in income distribution. It uses demand elasticities and technical coefficients synthesized from past studies. The food characteristic demand system developed by Bouis and Haddad (1992), which is based on demand for energy, variety, and tastes of foods, is used to derive the demand elasticities (Kumar 1998). These demand parameters are used to project the demand for rice in 2020 under the assumptions that (1) total income grows at 4%, 5%, or 7% per annum; (2) population grows at 2.0% per annum from 1991 to 1995, 1.9% from 1995 to 2000, 1.8% from 2000 to 2010, and 1.7% from 2010 to 2020; and (3) the pace of urbanization will be consistent with the recent historical trend. Apart from the rice demand for direct human consumption, an increasingly important component is the requirement for feed, seed, industrial use, and wastage. After adding these requirements to the human consumption, the total domestic demand for rice is derived. The results of domestic rice demand predictions corresponding to the three scenarios of growth in gross domestic product (GDP) at constant prices are given in Table 18. The domestic demand for rice will be about 104 million t in 2010 and 122 million t in 2020. During 2000-20, the domestic rice demand would grow at an annual compound rate of 1.78%.

To meet the rice domestic demand, India must attain a per-hectare yield of 2.45 t by 2010 and 2.89 t by 2020. The average national yield must improve over the base year 2000 by 23% by 2010 and by 45% by 2020. This yield improvement requires serious efforts on the part of the national and international agricultural research systems. The emphasis for achieving the required increments in yield must be placed on regions where current yield is low. Greater emphasis needs to be given in the states of Bihar, Orissa, Assam, West Bengal, and Uttar Pradesh (Kumar and Mathur 1996).

Supply-demand gap

Looking at the supply and demand gap of rice in 2000-30 given in Table 19, it appears that the demand for rice will be met in the future with an annual surplus of about 4 million t by 2000, which will grow to about 5 million t in 2030. This will occur if TFP and area growth are maintained at historical levels. Without TFP growth (scenario 2), the demand for rice will exceed domestic production in 2010 and India may experience a deficit of about 3.5 million t in 2020 and 8 million t in 2030. Without rice area expansion during the projected period (scenario 3), the trade deficit will grow to 12 million t in 2020 and to 21 million t in 2030. However, under scenario 4 (without TFP and area growth), the deficit is estimated at about 8 million t in 2010, 19 million t in

Table 17. Effect of TFP and area growth on domestic production of rice (million t), India.

Year	Baseline (scenario 1)	Without TFP and area growth (scenario 4)	Effect of TFP and area growth
2000	89.5	87.6	+1.9 (2.2)
2010	107.8	95.8	+12.0 (12.5)
2020	127.0	103.3	+23.7 (22.9)
2030	148.0	110.9	+37.1 (33.4)

Table 18. Projected domestic demand for rice in India.

Income growth (%)	Domestic demand (million t) 2000	2010	2020	Growth during 2000-20 (%)
4	85.4	103.7	122.4	1.82
5	85.4	103.6	122.1	1.79
7	85.6	103.7	121.9	1.78

Table 19. Supply-demand gap for rice (million t), India.

Year	Supply	Demand	Gap
S1: corresponding to baseline assumption for price and nonprice exogenous variables (Appendix 2)			
2000	89.5	85.6	+3.9
2010	107.8	103.7	+4.1
2020	127.0	121.9	+5.1
2030	148.0	143.0	+5.0
S2: corresponding to baseline assumption without TFP growth			
2000	88.7	85.6	+3.1
2010	103.2	103.7	–0.5
2020	118.4	121.9	–3.5
2030	135.1	143.0	–7.9
S3: corresponding to baseline assumption without area growth			
2000	88.4	85.6	+2.8
2010	100.0	103.7	–3.7
2020	110.4	121.9	–11.5
2030	121.6	143.0	–21.4
S4: corresponding to baseline assumption without TFP and area growth			
2000	87.6	85.6	+2.0
2010	95.8	103.7	–7.8
2020	103.3	121.9	–18.6
2030	110.9	143.0	–32.1

2020, and 32 million t in 2030. This emphasizes the need for strengthening efforts to increase production by maintaining or increasing TFP through public and private investment in irrigation, rural infrastructure development, research and technology development and transfer, human resource development, and the sustainable management of land by the efficient use of water and plant nutrients. The supply position remained easy on account of area expansion with an annual growth rate of 1.9% in the northern region, 0.5% in the western region, 0.6% in the eastern region, and 0.2% in the southern region during 1991-99. The gain in rice area took place as a result of irrigation expansion and the replacement of coarse cereals by rice. Rabi rice area continues to expand significantly, with a higher yield of 2.8 t ha^{-1} than the national average yield of 1.9 t ha^{-1}.

The significant increase in rice yield and production over the past 25 years strongly attests to the productivity of the Indian rice research system. The International Rice Research Institute (IRRI) was a dominant partner of the national research system in earlier years, acting as a direct supplier of improved modern varieties. This has provided the respectable annual TFP growth of 0.91%. Evidence of decelerating TFP growth is seen in Table 7. Technical change has not made much headway across substantial areas. A high yield gap exists across pockets and regions. Under the scenario illustrated in Table 19 (S1), the estimates of rice supply and demand give a reasonable degree of confidence that the supply has been growing at a higher rate than demand, which produced a buffer stock of 10 million t by April 1995. The stock rose further to 14.9 million t in April 2000, despite a deceleration in growth in TFP.

The favorable factors (area, irrigation, fertilizer, and TFP) of past growth may not be available in the future. The supply scenario may not match the rice demand challenges ahead and the country may face a rice trade deficit. All efforts need to concentrate on accelerating growth in TFP, while conserving natural resources and promoting the ecological balance of the agricultural system.

Conclusions

From the foregoing analysis, the broad signals are clear. There is an urgent need to exploit the potential of the eastern region. The northern region shows very high growth in production and yield mainly on account of the intensive use of inputs. Even with the sharp drop in rice prices as a result of technological change and price policy changes, rice research still yields high returns. The technological change in rice production has lowered the unit costs of production and rice prices in real terms and benefited both consumers and producers. The TFP analysis for the later period could not adequately capture the influence of the fast adoption of high-value basmati rice in the northern region explicitly. The productivity of resources can be enhanced further by improving the management of infrastructure as well as by extending it to the less developed areas and by introducing new technologies. It is better to promote the efficient allocation of resources and pay attention to the evolution of cost-reducing innovations. There is also a dire need to improve the efficiency of public investment in irrigation by constructing field channels in the eastern region (Kumar 1977) and other public infrastructure.

The northern region witnessed the Green Revolution as a result of the large-scale adoption of yield-enhancing technologies of rice. There was some spillover effect of improved rice technology in the eastern region. In a liberalized environment, the crop pattern is moving in favor of rice.

TFP growth and a reduction in poverty have strong linkages. All future efforts to improve TFP and arrest the deceleration in TFP growth will lead to a reduction in poverty and hunger among small landholders. Farming systems research to develop location-specific technologies and a strategy to make gray areas green by adopting a three-pronged approach—watershed management, hybrid technology, and small farm mechanization—will accelerate growth in TFP. These are some of the issues examined recently by Singh and Kumar (2001), whose study suggested that it is necessary to make efforts to promote available dry-land technologies. Promoting efficient fertilizer practices, improving soil-testing services, strengthening the distribution channel of critical inputs, especially high-quality seeds, and developing physical and institutional infrastructure will particularly help resource-poor farmers.

The farm situation will be characterized by a reduction in farm labor, a higher use of fertilizer, and mechanization. This would improve efficiency and rice yield. Rural literacy emerged as an important source of growth in the adoption of technology and the use of modern inputs to increase rice yield. Literacy will play a far more important role in the adoption of technology than it did in the past (Mittal and Kumar 2000).

The scope for area expansion is limited. A sustainable solution for food security cannot be found in the manipulation of input and output prices without appropriate adjustments in nonprice factors and production strategies.

Looking at the demand-supply scenarios, it appears that the demand for rice will be met in the future with a marginal surplus for trade. However, a surplus status of rice will not occur until growth in TFP and area are maintained at historical levels. This emphasizes the need to strengthen efforts to increase production by maintaining or increasing TFP through public investment in irrigation, infrastructure development, research, and the efficient use of inputs. The policies that induced efficiency can keep the balance between domestic rice supply and demand. More than half of the required growth in yield to meet the target demand must be met from research efforts by developing location-specific and low-input-use technologies with emphasis on the regions where current yield is below the required national average yield.

Recognizing that serious yield gaps exist and that there are already proven paths for increasing productivity, it is very important to maintain a steady growth rate in total factor productivity. Indian rice deals with global trade. All efforts need to concentrate on accelerating growth in TFP, while conserving natural resources and promoting the ecological integrity of the agricultural system.

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Notes

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Appendix 1

Supply model

Studies on agricultural supply response at the country or regional level have mainly applied duality theory to derive systems of output supply and factor demand equations from the underlying profit function (Lau and Yotopoulos 1972, Sidhu 1979, Janvry and Kumar 1981, Chand 1991). In the application of the dual approach, the technology and levels of quasi-fixed inputs have been treated as exogenous variables that do not allow measurement of the dynamic effect of quasi-fixed inputs, technology, and investments on the supply of commodities. Mundlak (1988) has developed an alternative framework for the choice of techniques in production, which permits a separate determination of optimal input and output combinations along a given production function, and to determine the optimal combination of techniques. The approach provides a structure within which the choice of technique and quasi-fixed inputs are determined endogenously. This approach was used for food supply analysis in Indonesia (Rosegrant and Kasryno 1992) and in India (Kumar and Rosegrant 1997). The results have been close to reality.

Adapting this framework, a simultaneous-equation model is specified in which direct and indirect interactions are explicitly considered. It has three blocks—choice of technique, factor demand, and yield equations—and consists of endogenous variables (yield, human labor, machine labor, fertilizer, crop irrigation, and high-yielding varieties) and exogenous variables [factor product prices, irrigation, human resource development (rural literacy), infrastructure (electrification), geographical location (dummy for regions), agroclimatic factor (rainfall), and quality of inputs and technology (TFP)]. Output supply is derived indirectly through this three-block model.

Specification of supply model

Repetitive exercises in estimating and revising the specification of the simultaneous recursive model (in double log form) were undertaken by using three-stage least squares (3SLS) and seemingly unrelated regression estimates (SURE) estimation procedures. The final form of the structural equations of the model is specified as follows.

Choice of technique

$$\text{CRIRR} = f\,(\text{NSIRR, DUMMY}) \qquad (1)$$

$$\text{HYV} = f\,(\text{CRIRR, LIT, PVELECT, DUMMY}) \qquad (2)$$

Factor demand

$$\text{HL} = f\,(w/P,\ m/P,\ \text{HYV, CRIRR}) \qquad (3)$$

$$\text{ML} = f\,(w/P,\ b/P,\ m/P,\ \text{HYV, CRIRR}) \qquad (4)$$

$$\text{FERT} = f\,(r/P,\ \text{HYV, CRIRR, ML}) \qquad (5)$$

Yield function

$$\text{Y} = f\,(\text{HL, ML, FERT, FYM, TFP, RAIN, DUMMY}) \qquad (6)$$

Identity

$S = Y * CRAREA$

where the variables in the model are defined as follows:

Endogenous: CRIRR = % of cropped area under irrigation (sum of both private and public irrigation); HYV = % of rice area under high-yielding varieties; HL = human labor in hours per hectare; ML = use of machine labor (index); FERT = chemical fertilizers in terms of total plant nutrients in kilograms per hectare; Y = yield in quintals per hectare for rice; and S = domestic supply of rice.

Exogenous: NSIRR = % of irrigated area to net sown area; LIT = literacy rate (% of rural literate population, primary or above education); PVELECT = % of villages that are electrified; w = wage rate (Rs h^{-1} of human labor); b = bullock labor charges (Rs h^{-1} per pair of bullock labor); m = machine labor charges (index); r = fertilizer price (Rs kg^{-1} of total plant nutrients); P = rice price; RAIN = rainfall in the critical production period; DUMMY = region dummy and defined as ERDUMMY = eastern region dummy and it takes the value one if the data pertain to the states of Bihar, Orissa, Assam, and West Bengal, and zero otherwise. WRDUMMY = western region dummy and it takes the value one if the data pertain to the states of Rajasthan, Madhya Pradesh, Maharashtra, and Gujarat, and zero otherwise. NRDUMMY = northern region dummy and it takes the value one if the data pertain to the states of Uttar Pradesh, Haryana, and Punjab, and zero otherwise. SRDUMMY = southern region dummy and it takes the value one if the data pertain to the states of Andhra Pradesh, Tamil Nadu, Karnataka, and Kerala, and zero otherwise. FYM = use of farmyard manure (q ha^{-1}); TFP = total factor productivity index (Tornqvist-Theil index). CRAREA = area under rice (predetermined endogenous variable).

Cumulative effects of price and nonprice factors on rice yield

The cumulative effects of price and nonprice factors on yield were derived from the structural equations 1–6 of the supply model as specified above. The formulations are presented below. These formulations have the advantage of separating the effects of constituent forces on yield growth and help in understanding the process through which yield growth takes place.

Wage effect

$$\begin{aligned} dY/d(w/P) = {} & (\partial Y/HL)(\partial HL/\partial\,[w/P]) \\ & + (\partial Y/\partial ML)(\partial ML/\partial\,[(w/P]) \\ & + (\partial Y/\partial FERT)(\partial FERT/\partial ML)(\partial ML/\partial\,[w/P]) \end{aligned}$$

As seen in the above equation, wages have a direct effect on the use of human labor and an indirect effect on the use of machine labor by substitution, thus inducing fertilizer use through mechanization. Hence, there are greater yield improvement opportunities in moving from traditional to modern inputs such as machine labor and fertilizer.

Bullock labor charges

$$\begin{aligned} dY/d(b/P) &= (\partial Y/\partial ML)(\partial ML/\partial\,[b/P]) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial ML)(\partial ML/\partial\,[b/P]) \end{aligned}$$

The bullock labor charges induce changes in machine labor use and also induce fertilizer demand. Bullock labor price has an indirect effect on yield through the higher use of machine labor and fertilizer.

Machine labor charges

$$\begin{aligned} dY/d(m/P) &= (\partial Y/\partial HL)(\partial HL/\partial\,[m/P]) \\ &+ (\partial Y/\partial ML)(\partial ML/\partial\,[m/P]) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial ML)(\partial ML/\partial\,[m/P]) \end{aligned}$$

Machine labor charges have both direct and indirect effects on yield. The first term measures the effect of machine price on human labor and then yield. The second term measures the direct effect of machine charges on the use of machines and then yield. The third term measures the indirect effect of machine charges on yield through fertilizer.

Fertilizer price

$$dY/d(r/P) = (\partial Y/\partial FERT)(\partial FERT/\partial\,[r/P])$$

The above terms measure the fertilizer price effect on yield through fertilizer.

Net sown irrigation

$$\begin{aligned} dY/dNSIRR &= (\partial Y/\partial HL)(\partial HL/\partial HYV)(\partial HYV/\partial CRIRR)(\partial CRIRR/\partial NSIRR) \\ &+ (\partial Y/\partial ML)(\partial ML/\partial HYV)(\partial HYV/\partial CRIRR)(\partial CRIRR/\partial NSIRR) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial ML)(\partial ML/\partial HYV)(\partial HYV/\partial CRIRR) \\ &\quad (\partial CRIRR/\partial NSIRR) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial HYV)(\partial HYV/\partial CRIRR)(\partial CRIRR/\partial NSIRR) \\ &+ (\partial Y/\partial HL)(\partial HL/\partial CRIRR)(\partial CRIRR/\partial NSIRR) \\ &+ (\partial Y/\partial ML)(\partial ML/\partial CRIRR)(\partial CRIRR/\partial NSIRR) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial ML)(\partial ML/\partial CRIRR)(\partial CRIRR/\partial NSIRR) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial CRIRR)(\partial CRIRR/\partial NSIRR) \end{aligned}$$

This equation captures the effect of irrigation on yield (productivity) through yield-enhancing technologies such as the allocation of irrigated land under the crop, the adoption of improved varieties, and their effect on the use of inputs and thereby on yield.

Literacy

$$\begin{aligned} dY/dLIT &= (\partial Y/\partial HL)(\partial HL/\partial HYV)(\partial HYV/\partial LIT) \\ &+ (\partial Y/\partial ML)(\partial ML/\partial HYV)(\partial HYV/\partial LIT) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial ML)(\partial ML/\partial HYV)(\partial HYV/\partial LIT) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial HYV)(\partial HYV/\partial LIT) \end{aligned}$$

This equation captures the effect of literacy on yield through improved varieties and hence changes in the use of inputs, leading to increases in yield.

Rural electrification

$$\begin{aligned} dY/dPVELECT &= (\partial Y/\partial HL)(\partial HL/\partial HYV)(\partial HYV/\partial PVELECT) \\ &+ (\partial Y/\partial ML)(\partial ML/\partial HYV)(\partial HYV/\partial PVELECT) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial ML)(\partial ML/\partial HYV)(\partial HYV/\partial PVELECT) \\ &+ (\partial Y/\partial FERT)(\partial FERT/\partial HYV)(\partial HYV/\partial PVELECT) \end{aligned}$$

This equation captures the effect of village electrification on yield through improved varieties and changes in the use of inputs.

TFP

$dY/dTFP$ = coefficient of TFP in yield equation

Appendix 2

Joint estimation of supply function, factor demand, and within-crop choice of technique for rice, India.[a]

Variable	Yield function	Factor demand			Choice of technique	
		HL	ML	FERT	HYV	CRIRR
Constant	1.46059** (3.07)	4.59642** (12.73)	2.73718** (3.61)	–1.75468 (1.54)	–0.35205 (1.07)	1.37486** (8.33)
Human labor (h ha^{-1})	–0.10721 (1.56)	–	–	–	–	–
Machine labor (h ha^{-1})	0.23875** (12.77)	–	–	0.33843** (2.72)	–	–
Fertilizer (kg ha^{-1})	0.4664** (3.94)	–	–	–	–	–
FYM (q ha^{-1})	0.03763** (3.40)	–	–	–	–	–
TFP	0.57979** (9.88)	–	–	–	–	–
Price of inputs						
Human labor (w/P)	–	–0.24844** (4.63)	0.89776** (7.16)	–	–	–
Bullock labor (b/P)	–	–	0.38603** (5.31)	–	–	–
Machine labor (m/P)	–	0.15999* (2.19)	–0.83797** (5.63)	–	–	–
Fertilizer (r/P)	–	–	–	0.36646 (1.79)	–	–
HYV area (%)	–	0.02737 (0.80)	0.44705** (6.45)	1.13096** (6.86)	–	–
Crop irrigated area (%)	–	0.19400** (6.35)	0.29036** (4.56)	0.68526** (4.26)	0.18813** (3.66)	–
Net sown irrigated area (%)	–	–	–	–	–	0.60846** (12.25)

continued on next page

Appendix 2. continued

Variable	Yield function	Factor demand			Choice of technique	
		HL	ML	FERT	HYV	CRIRR
Literacy (%)	–	–	–	–	0.37579**	–
					(3.54)	
Villages electrified (%)	–	–	–	–	0.48095**	–
					(11.41)	
Rain (mm)	–0.03029	–	–	–	–	–
	(1.09)					
West region dummy	–0.28278**	–	–	–	0.31174**	–0.24077**
	(6.54)				(4.88)	(3.70)
North region dummy	0.08830*	–	–	–	0.37093**	0.21663**
	(2.03)				(6.12)	(3.36)
South region dummy	0.15803**	–	–	–	0.32079**	1.05061**
	(4.31)				(4.75)	(23.25)
Adjusted R-square	0.83	0.18	0.74	0.55	0.83	0.81
F-statistics	122.24	13.4 4	132.60	70.47	183.47	250.29

[a] No. of observations = 228, HL = human labor, ML = machine labor, HYV = high-yielding varieties, FYM = farmyard manure, TFP = total factor productivity. Asterisks indicate significance level: ** = 1%; * = 5%; w/P = real wages, b/P = real bullock labor charge, m/P = real machine labor charge, r/P = real fertilizer price. Numbers in parentheses are t statistics.

Source: Kuchhal (Mittal) S (2000).

Appendix 3

Baseline assumptions for projecting domestic rice supply, India.[a]

Price and nonprice exogenous variables	Observed annual growth (%)			Predicted annual growth (%)		
	1971-85	1985-97	1971-97	2005	2010	2020
Factor and product prices						
Human labor charges	8.62	12.62	10.36	10.36	10.36	10.36
Animal labor charges	7.49	10.40	8.81	8.81	8.81	8.81
Machine labor charges	10.18	6.29	8.02	8.02	8.02	8.02
Fertilizer price	4.04	5.50	4.50	4.50	4.50	4.50
Rice price	6.16	8.67	7.08	7.08	7.08	7.08
Infrastructure variables						
Net sown irrigated area (%)	3.20	1.09	2.26	0.51	0.23	0.11
Villages electrified (%)	6.56	2.02	5.10	0.87	0.38	0.16
Rural literacy (%)	2.95	2.08	2.46	1.62	1.26	0.98
Supply factors						
TFP	0.98	0.75	0.91	0.62	0.51	0.42
Organic manure	1.66	–1.90	0.59	0.00	0.00	0.00
Rice area	0.66	0.65	0.56	0.64	0.63	0.62

[a] It is assumed that the factor product prices would grow at the rate observed during 1971-97. The growth in the infrastructure variables, total factor productivity (TFP), and rice area will decelerate at the rate observed from 1971-85 to 1985-97. Zero growth is assumed for farmyard manure.

Appendix 4

Decomposition of domestic supply growth for rice, India (% share in total annual supply growth).

Sources of growth[a]	1995	2005	2010	2020
Scenario 1: baseline				
Price	26.3	35.3	38.6	41.1
FYM	0.9	0.0	0.0	0.0
Irrigation	7.2	2.2	1.1	0.6
Literacy	5.9	5.2	4.4	3.7
Electrification	16.3	3.7	1.8	0.8
TFP	21.1	19.3	17.4	15.2
Area	22.3	34.3	36.9	38.7
Annual supply growth (%)	2.51	1.87	1.71	1.60
Scenario 2: without TFP growth				
Price	33.3	43.8	46.7	48.5
FYM	1.2	0.0	0.0	0.0
Irrigation	9.1	2.7	1.3	0.7
Literacy	7.5	6.5	5.4	4.3
Electrification	20.6	4.6	2.2	0.9
Area	28.3	42.5	44.6	45.6
Annual supply growth (%)	1.98	1.51	1.41	1.36
Scenario 3: without area growth				
Price	33.9	53.8	61.1	67.1
FYM	1.2	0.0	0.0	0.0
Irrigation	9.3	3.3	1.7	0.9
Literacy	7.6	7.9	7.0	6.0
Electrification	21.0	5.7	2.8	1.3
TFP	27.1	29.3	27.4	24.8
Annual supply growth (%)	1.95	1.23	1.08	0.98
Scenario 4: without TFP and area growth				
Price	46.5	76.1	84.1	89.1
FYM	1.7	0.0	0.0	0.0
Irrigation	12.7	4.7	2.4	1.2
Literacy	10.4	11.2	9.6	8.0
Electrification	28.7	8.0	3.9	1.7
Annual supply growth (%)	1.42	0.87	0.78	0.74

[a] FYM = farmyard manure, TFP = total factor productivity.

Section TWO

Medium- and long-term prospects of rice supply and demand in Indonesia

Tahlim Sudaryanto, Pantjar Simatupang, Bambang Irawan,
and Dewa Ketut Sadra Swastika

The rice industry remains a strategic sector in the Indonesian economy in terms of its contribution to economic growth, food security, and poverty alleviation. Government policies for the rice sector have changed significantly from “high support and high protection” since the 1970s to “low support and low protection” since the mid-1980s. In line with changes in the policy environment, rice productivity growth has tended to decline. However, under the prevailing world market price, rice farming shows a comparative and competitive advantage. For the medium- and long-term perspective, the Indonesian rice supply cannot meet increasing rice demand, which leads the country to import around 1–3 million tons of rice annually. Under the current policy environment, an appropriate strategy to stimulate rice production is through land development and innovation systems.

The Indonesian economy has experienced a massive structural transformation in the past 30 years. Exports based on foreign capital and natural resource exploitation (oil and forest) enabled the economy to grow rapidly from 1970 to the late 1990s (before the economic crisis in 1997), such that the country was considered a significant contributor to the so-called Asian “economic miracle.” With the Indonesian economy undergoing massive industrialization, the rice industry and the agricultural sector as a whole are no longer considered key sectors, especially in terms of their contribution to total gross domestic product (GDP). Meanwhile, the household consumption structure has also become increasingly diversified. The average rice share in the household expenditure declined significantly. The rice price is no longer the most dominant determinant of national price inflation.

Although its role in shaping Indonesia’s macroeconomic situation has decreased significantly, the rice industry remains a strategic sector in the fight for food security and for improving the well-being of the poorer households in rural areas. Rice remains the major staple food of the population, especially for those in lower income groups. The industry remains the backbone of most rural economies and thus has always been resorted to as the rallying point for movements to alleviate poverty and improve equity. The rice industry thus remains very important both socially and politically. Accordingly, promoting rice industry development remains a high priority for the government of Indonesia.

Understanding the medium- and long-term prospects of rice supply and demand is extremely important in formulating Indonesia's national rice policy. However, being both the world's major rice producer and consumer, Indonesia's rice supply and demand conditions significantly affect world rice market dynamics and hence the markets of other food commodities as well. Understanding Indonesia's rice supply and demand outlook is important for better understanding the medium- and long-term prospects of world rice conditions.

In this paper, we discuss the previous performance and long-term prospects of rice supply and demand in Indonesia. Subjects on the supply side include a historical analysis of growth in production and its sources (yields and harvested area), production efficiency (input use and productivity), and rice-farming competitiveness (comparative advantage). The historical analysis is complemented with analysis on the possibilities for increasing rice supply through land expansion, irrigation investment, and other policy instruments to reach some conclusions on the rice supply outlook. The demand side, on the other hand, includes the historical changes in household consumption and other rice use as well as their basic determinants and outlook. Historical changes in policy regimes that significantly affect the performance of the rice industry are also discussed. The paper also presents quantitative perspectives of rice supply and demand. To some extent, this paper is an updated version of the project report "Medium and Long-Term Projection of Supply and Demand in Indonesia" (Simatupang et al 1995). This project was part of the multicountry studies organized by the International Rice Research Institute (IRRI) and International Food Policy Research Institute (IFPRI) and funded by Japan.

Changes in policy regimes

Realizing the dominant role of the rice industry in the Indonesian economy, the importance of rice and rice farming for national food security, and the strategic importance of rice politically, former President Soeharto rightly decided that promotion of national rice production leading to self-sufficiency was the top priority of his economic development program soon after he took control of the government in the late 1960s. He then outlined a consistent "twin strategy" to develop the rice sector:

1. Short run: rice price stabilization at affordable prices to assure household food security and economic (as well as political) stabilization.
2. Long run: boosting domestic rice production, leading to self-sufficiency.

With strong leadership and determination, the Soeharto administration then set up a comprehensive policy package to implement the twin strategy. First was the land rehabilitation and development program. This program was designed to massively expand rice field area, enhance land suitability for intensive rice farming, and increase potential productivity of the land. With large investment funds provided by the government, this program was very successful in expanding rice field area suitable for intensive rice farming, especially in the 1970s. This was the key factor in the high growth rate of rice harvested area in the 1970s up to the mid-1980s.

Second was the extensive and complete infrastructure development program (irrigation and rural roads). The irrigation development program complemented the land development program in expanding irrigated rice fields. Up to the late 1980s, irrigation water was available free of charge for rice farmers. Irrigation development was instrumental in expanding rice planted area, cropping intensity, and yield. Rural road development was the key factor providing extensive access to agro-inputs and creating efficient rural markets.

Third was support to the agro-industry (agro-inputs, agro-equipment, agro-processing) development program. The government provided various incentives (cheap credit, tax holidays) to promote private investment in this area. Private enterprises in rice processing, agricultural equipment, and pesticide manufacturing grew rapidly. The government built five big fertilizer manufacturing companies to meet the rapidly growing demand for fertilizer. Presently, Indonesia has a surplus of urea fertilizer.

Fourth was the innovation system development program. The government set up a comprehensive rice innovation system throughout the country. At the upstream of the system lies research and institutional development equipped with sufficient human resources, research equipment, and operating budget. The national rice research system has been quite successful in finding new high-yielding rice varieties and rice-farming management practices. The government also constructed a national seed distribution system connecting the research and development institutes and farmers throughout the country. To complete the innovation system, the government then set up a national agricultural extension system. The innovation system has been instrumental in promoting the rapid adoption of the Green Revolution technology that was the main source of rice productivity and production growth since the late 1960s.

Fifth was the provision of rice-farming incentives. The incentives scheme included input subsidies (fertilizer, seed, pesticide), cheap supervised credit, and supported rice prices. The agro-input provision was managed by the government to make this easily accessible to rice farmers. The provision of cheap inputs was instrumental in their rapid adoption and intensive use, which led to the achievement of high yield with the application of the Green Revolution technology. Rice farmers were guaranteed a minimum price (floor price) for the paddy they produced. The paddy floor price contained a significant support element (higher than import parity) and was effectively defended by the government. The incentive scheme was quite alluring for the farmers.

Sixth was institutional development. Almost all rice farms in Indonesia are small in size. The average land size is around only 0.3 ha. Rice group farming is useful for harmonizing farming activities as well as economizing on various empowerment programs conducted by the government. Accordingly, since the late 1960s, the government has promoted the development of farmers' groups consisting of 25–30 farmers in each group. For irrigation management, the government also developed a water users' association. To coordinate the programs, the government set up a nationwide Mass Guidance Supervisory Committee (MGSC). At the national level, the MGSC was directly headed by President Soeharto himself, at the provincial level by the governor, at the regency level by the regent, and at the district level by the head of the district. With a centralized and hierarchical organization, President Soeharto was able to control all national rice policies.

To ensure policy enforcement, President Soeharto then declared that increasing rice production was a "national policy," meaning that it must be supported by all parties. It was also decided that rice production became an indicator of official performance. Increasing rice production was the national priority. The supporting budget was almost unlimited and official attention centered on rice. Farmers were forced to plant rice on their irrigated land.

No wonder the comprehensive and mandatory policy package was very effective in boosting national rice production. Rice production had been growing very rapidly since the late 1960s until the mid-1980s. Rice self-sufficiency was finally achieved in 1984, which was considered a significant achievement. It was beyond anyone's prediction that Indonesia could improve its status from being the largest rice importer in the world. President Soeharto was appreciated by the FAO for his achievement.

The achievement of rice self-sufficiency seemed to be the turning point of the impact of the national rice policies. Since 1984, the effort to increase rice production declined gradually. The policy regime has changed radically from high support and high protection to low support and low protection. As part of the structural adjustment advised by the World Bank and International Monetary Fund, fertilizer subsidies have been phased out since the mid-1980s and were completely abolished in 1998. The budget allocation for infrastructure development has declined. Water irrigation is no longer free of charge. Farmers are free to manage their farms. Rice farming is no longer compulsory even on technically irrigated land. Rice farming is now based on a free-market environment.

The only significant policy that is still in place is the paddy floor price. However, this policy has not been too effective as it has not been sufficiently supported by complementary policies and implemented by concerned public agencies. The tariff rate on rice importation, for example, has been too low (Rp 430 kg^{-1}) to support the paddy floor price, which is at a high price of Rp 1,500 kg^{-1}. At the same time, the volume of rice imports has not been restricted. Nonetheless, the persistent undervaluation of the rupiah provides significant price protection for rice farmers.

Growth in production and productivity

Growth in production

The increase in rice production is the main strategy of the Indonesian government to support the food security program. As a result of the Green Revolution technology established in mid-1960 and support from the government's budget from the "petroleum boom," rice production increased spectacularly from 11.8 million tons in 1970 to 23.7 million t in 1984. During 1970-84, rice production growth averaged 5.23% per year. This growth was more than double the population growth, which enabled the achievement of rice self-sufficiency in 1984. Around 70% of the production growth resulted from the increase in yield per hectare or, in other words, from technology innovation (Table 1).

After the achievement of rice self-sufficiency, rice production growth dropped to 1.99% in 1985-99. The production growth rate almost matched the population growth, which was estimated at around 2% per year. This means that rice production growth was just enough to meet the increase in rice demand caused by the population increase, but not sufficient to fulfill the increase in consumption per capita because of increased income. For this reason, rice imports again increased markedly from 650,000 t in 1986 to 1.0–1.5 million t in 1990-95, reaching a peak of around 5.8 million t in 1998.

The figures above reveal that the problem of rice supply recently tended to increase because of the slowing down of production growth. Such conditions worsened because of the greater variability of the production growth rate. During 1970-84, the coefficient of variation of rice production growth was 91% and it increased to 175% in 1985-99. Evaluation by decade showed a similar tendency, in which instability of production growth, harvest area, and yield during the last decade was much higher than in the previous two decades. This means that the recent food security problem was not only due to the decreasing trend of production growth, but also to the instability of the production growth rate (Simatupang 2000). The two major causes of production growth instability in the last decade were the El Niño events that occurred three times and the economic crisis that started in mid-1997.

Table 1 shows that the lower rate of production growth after the achievement of rice self-sufficiency was due particularly to the decrease in yield growth from 3.79% per year in 1970-84 to 0.80% in 1985-99. Furthermore, during the last decade, yield growth was only 0.35% per year while growth of harvested area was 1.05% per year. These figures also indicate that the source of increased rice production during the last decade was mainly from the increase in harvested area, which came from the expansion of arable land or from increased cropping intensity. This phenomenon is not desirable in the future since the expansion of arable land and irrigation construction

Table 1. Long-term growth of rice production in Indonesia.

Period	Average growth (% y^{-1})			Coefficient of variation (%)		
	Production	Harvested area	Yield	Production	Harvested area	Yield
Before self-sufficiency (1970-84)	5.23	1.39	3.79	91	263	75
After self-sufficiency (1985-99)	1.99	1.20	0.80	175	285	266
By decade						
1970-79	3.94	1.00	2.89	120	360	73
1980-89	5.52	1.83	3.64	73	160	87
1990-99	1.37	1.05	0.35	280	391	697

require a very large investment budget, whereas the capacity of the government to finance this investment is increasingly limited. Therefore, a technology innovation capable of increasing yield potential is the only option to assure sustainability of rice production in Indonesia.

Growth in input use

High-yielding varieties and chemical inputs are the major agricultural inputs that support rice production. Yet, because of constraints of capital and low farmers' accessibility, the use of these modern inputs in the 1960s was relatively low. To support input use and at the same time to improve cultural practices used by farmers, various intensification programs were established. The basic objectives of the government's rice intensification programs were (1) to provide farmers with modern agricultural inputs at affordable prices and (2) to provide access to credit to finance the required investment.

Mass Guidance called Bimbingan Massal (BIMAS) was a rice intensification program proclaimed in 1965-66. This program covered five efforts: the use of good seeds, fertilizer, plant protection with pesticides, better water management, and improved cultural methods. Under this program, farmers were guided by skilled personnel and aided by an adequate supply of inputs and subsidized credit package. Later, in 1979, the BIMAS program was restructured and renamed the Special Intensification Program (INSUS). In the INSUS program, 50–100 farmers were encouraged to operate as a group that was responsible for farm planning and decision making, with extension agents ready to provide required services when needed.

Table 2 shows a spectacular increase in input use intensity, particularly after the INSUS program was implemented. For instance, the use of fertilizer increased from 16.3 kg ha^{-1} in 1972-73 to 255.2 kg ha^{-1} in 1990-91 but decreased slightly to 247.1 kg ha^{-1} in 1997-98. The use of pesticide also increased from 0.46 kg ha^{-1} in 1972-73 to 2.42 kg ha^{-1} in 1997-98. In 1980-89, fertilizer and pesticide use increased at 6.81% per year and 5.69% per year, respectively. In Java, fertilizer and pesticide application was much higher than in off-Java, indicating more advanced technology development in Java. The significant increase in input use, among other things, was caused by the increasing coverage area of the rice intensification program: 47% in REPELITA[1] II (1974-79) and 76% in REPELITA IV (1984-89).

During the last decade, the use of fertilizer was declining outside Java, while in Java it still showed an increase, with a lower rate than in the previous decade. The decrease in fertilizer use might be due to the gradual input subsidy reduction since 1983. Furthermore, in December 1998, the subsidy for fertilizer was abolished because of the economic crisis, which in turn made the price of urea and triple superphosphate increase 64% and 52% vis-à-vis the previous month.

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[1] REPELITA (Rencana Pembangunan Limang Tahun) refers to Indonesia's 5-year development plan.

Table 2. Use of major agricultural inputs in rice farming, 1972-73–1997-98 (kg ha^{-1}).

Year	Java	Off-Java	Indonesia
Seed			
1972-73	40.4	36.4	37.4
1978-79	40.8	40.1	40.2
1984-85	40.2	33.9	35.1
1990-91	39.3	35.1	35.9
1997-98	43.4	42.1	42.4
Fertilizer			
1972-73	56.1	3.4	16.3
1978-79	116.3	32.0	48.9
1984-85	344.2	146.5	186.0
1990-91	397.9	222.8	255.2
1997-98	400.6	208.7	247.1
Pesticide			
1972-73	1.03	0.27	0.46
1978-79	1.64	0.56	0.77
1984-85	3.21	1.42	1.78
1990-91	3.71	1.21	1.71
1997-98	6.70	1.47	2.42
Growth (% year^{-1})			
Seed			
1972-79	0.80	2.21	1.71
1980-89	0.32	0.67	0.59
1990-98	1.80	3.06	2.80
Fertilizer			
1972-79	2.29	4.36	2.51
1980-89	4.05	8.74	6.81
1990-98	0.37	–1.20	0.61
Pesticide			
1972-79	8.68	2.41	3.18
1980-89	9.73	3.38	5.69
1990-98	8.50	4.40	5.60

Source: Central Bureau of Statistics.

Competitiveness of rice production

The gradual decline in the world price of rice from the early 1980s was partly due to the lower import demand as several of the major rice-producing and -consuming countries in Asia achieved self-sufficiency in the commodity. At this lower price level, the question was posed as to whether Indonesia would have competitiveness in producing rice, particularly in the long term. The question is relevant because the low cost of rice production in Indonesia was basically due to the government's intervention through subsidy of fertilizer and seed. One of the effects of the economic crisis in 1997 has been the withdrawal of the fertilizer subsidy. In addition, as the GATT comes into force, any kinds of subsidy and trade barriers to agriculture would be removed in the long term.

A study conducted by USAID/DAI and CASER (Center for Agro and Socio-Economic Research) tried to answer the above question. The study was carried out in five rice-producing regions in and outside Java. The competitiveness of rice production was analyzed by season (wet or dry season) since both productivity and price vary by season. Some results particularly related to the competitiveness of rice are presented in the following section.

Financial and economic profitability. The calculation of financial profitability was based on current prices, while the economic profitability calculation was based on the shadow prices of production inputs and outputs. The production cost was classified into tradable input costs (seed, fertilizer, pesticide) and domestic factor costs (labor, land rent, credit).

With productivity of 4.2–5.1 t ha^{-1} in the wet season and 4.3–5.0 t ha^{-1} in the dry season, the financial revenue of rice farming ranged from US$501 to $568 per hectare (Table 3). The revenue varied across sites and seasons because of the difference in productivity and rice price. In the districts of Majalengka, Klaten, and Sidrap, the

Table 3. Return, cost, and profitability of rice farming in five districts of Java and outer islands.

Item	Java			Outer islands	
	Majalengka	Klaten	Kediri	Sidrap	Agam
Financial value					
Return (Rp 000 ha^{-1})					
Wet season 1999-2000	4,606.3	3,759.7	4,092.6	3,970.0	3,872.7
Dry season 2000	4,199.9	4,958.8	4,517.7	3,871.5	5,001.0
Production cost (Rp 000 ha^{-1})					
Wet season 1999-2000	3,758.7	3,154.4	3,662.9	3,354.6	3,407.9
Dry season 2000	3,649.7	3,386.9	3,749.7	3,298.5	3,980.8
Profit (Rp 000 ha^{-1})					
Wet season 1999-2000	847.6	605.3	429.7	615.3	464.7
	(18.4)[a]	(16.1)	(10.5)	(15.5)	(12.1)
Dry season 2000	550.2	1,571.9	768.0	573.0	1,020.2
	(13.1)	(31.7)	(16.9)	(14.8)	(20.4)
Economic value					
Return (Rp 000 ha^{-1})					
Wet season 1999-2000	3,704.0	3,257.4	3,866.2	3,970.0	3,491.4
Dry season 2000	3,463.0	4,551.5	3,292.3	4,089.2	4,057.5
Production cost (Rp 000 ha^{-1})					
Wet season 1999-2000	3,596.6	3,052.2	3,526.0	3,362.6	3,320.3
Dry season 2000	3,539.2	3,263.4	3,759.8	3,107.8	3,874.9
Profit (Rp 000 ha^{-1})					
Wet season 1999-2000	107.4	205.2	340.2	607.4	171.1
	(3.0)	(6.3)	(8.8)	(15.3)	(4.9)
Dry season 2000	–76.2	1,288.1	–467.5	981.4	182.6
	(–2.2)	(28.3)	(–14.1)	(24.0)	(4.5)

[a] Numbers in parentheses are percentage of profit to gross return (%).

productivity of rice farming in the dry season was higher than that in the wet season, but the rice price was lower, whereas the reverse was true in Kediri and Agam districts.

The financial production cost ranged from $421 to $501 per hectare in the wet season and from $375 to $452 per hectare in the dry season. Around 75% of the production cost was domestic factor cost, which consisted mainly of land rent (30–50%) and labor cost (20–35%). The relatively high cost revealed the scarcity of land, particularly in areas with high population density. Because of the conversion of agricultural land into nonagricultural uses, land rent is expected to increase continuously in the future.

Because of inconsistency in seasonal productivity and seasonal price variation in each district, there was no consistent pattern in the seasonal profitability of rice farming. In some districts (Klaten, Kediri, Agam), the profitability of rice farming might be higher in the dry season than in the wet season, but the reverse was observed in other districts (Majalengka, Sidrap). Financial profit in the wet season ranged from $57 to $113 per hectare and from $62 to $179 per hectare in the dry season. It accounted for around 10.5–18.4% and 13.1–31.7% of the financial return in the wet and dry season, respectively. With an interest rate of 12–15% per year, the profitability of rice farming was only marginally higher than the opportunity cost of capital.

Although positive returns of rice farming based on the financial analysis were established in all districts across all seasons, the economic analysis indicated negative economic returns in Majalengka and Kediri, particularly in the dry season (Table 3). In general, economic profit in rice farming was lower than financial profit, mainly because the shadow price of rice was lower than its actual price. This indicated that the government's policy for the rice industry gave an economic incentive to rice production. The amount of the economic incentive varied across districts and seasons, which was generally higher in the wet season. Hence, location-specific technology development is required to maintain proper economic profitability in rice production.

Comparative and competitive advantages. Table 4 shows that rice farming in five districts had competitive advantages in rice production, shown by the profitability to cost ratio (PCR) value of less than 1. Those five districts also showed comparative advantages except for the dry season 2000 in Majalengka and Kediri. Some factors that promoted comparative advantages in those districts were (1) the availability of

Table 4. Domestic resource cost ratio (DRCR) and profitability to cost ratio (PCR) of wetland rice farming in some districts of Java and outer islands.

Island/province	District	DRCR		PCR	
		Wet season 1999-2000	Dry season 2000	Wet season 1999-2000	Dry season 2000
West Java	Majalengka	0.96	1.03	0.77	0.84
Central Java	Klaten	0.92	0.66	0.80	0.62
East Java	Kediri	0.89	1.19	0.87	0.79
West Sumatra	Agam	0.94	0.95	0.86	0.77
South Sulawesi	Sidrap	0.73	0.82	0.81	0.82
Average		0.89	0.93	0.82	0.77

irrigation infrastructure favorable for rice cultivation, (2) the implementation of more developed technology than in other districts, and (3) farmers' accessibility to an economic infrastructure that was relatively strong. Still, the comparative advantages were relatively marginal, shown by the domestic resource cost ratio (DRCR) values that are very close to 1:0.89 in the wet season and 0.93 in the dry season.

Results of sensitivity analysis showed that the comparative advantage was relatively sensitive to the decrease in productivity and rice price (Table 5).

If productivity or rice price decreased by as much as 23%, those five districts would also lose their comparative advantage in rice production. Both productivity and rice price are critical factors in maintaining comparative advantages in rice production because (1) the rice price in the world market tended to decrease and (2) the productivity of rice farming during the last 10 years grew very slowly (0.35% per year) because of the lack of a technology breakthrough. In such conditions, improvement of efficiency through the application of site-specific technology, rationalization of production input use, and improvement of input and output market institutions are necessary to maintain comparative advantages in rice production.

Effects of the incentive policy. The incentive policy in the food crop sector was basically aimed at protecting farmers and stimulating an increase in rice production and productivity. The policy analysis matrix (PAM) has been applied to evaluate the effects of the policy. The analysis was conducted for various irrigation statuses and

Table 5. Sensitivity analysis of comparative advantage in producing rice.

Item	Java			Outer islands	
	Majalengka	Klaten	Kediri	Agam	Sidrap
Actual productivity (quintals ha^{-1})					
Wet season 1999-2000	48.65	41.97	51.15	45.56	48.46
Dry season 2000	49.59	48.55	47.52	43.61	49.83
Productivity under DRCR = 1 (qt ha^{-1})					
Wet season 1999-2000	37.91	34.09	44.08	39.08	38.40
Dry season 2000	41.78	37.18	39.41	36.99	40.03
Productivity gap (%)					
Wet season 1999-2000	22.1	18.8	13.8	14.2	22.8
Dry season 2000	15.7	23.4	17.1	15.2	19.7
Actual price (Rp kg^{-1})					
Wet season 1999-2000	947.6	894.4	800.0	850.0	819.5
Dry season 2000	845.9	1,025.0	955.5	39.1	775.1
Price under DRCR = 1 (Rp kg^{-1})					
Wet season 1999-2000	741.5	733.4	716.4	732.4	653.6
Dry season 2000	715.4	868.2	793.8	888.6	624.5
Price gap (%)					
Wet season 1999-2000	21.7	18.0	10.4	13.8	20.2
Dry season 2000	15.4	15.3	16.9	22.0	19.4

across seasons. Table 6 presents some indicators aggregated by district and by season.

The nominal protection coefficient on output (NPCO) is more than 1, ranging from 1.06 to 1.37. This indicates that the current government policy on rice had led to a farm-gate price that is around 6–37% higher than the international price. This means that the policy gave benefits to farmers. Yet the government policy in the market of tradable inputs was unfavorable for farmers since those input prices were more expensive by 7–32% than their respective international prices. The tradable inputs policy provided benefits only to farmers in the district of Kediri, where prices paid for inputs were 7% lower than their respective international prices, particularly in the dry season.

In total, government policy in the market of outputs and tradable inputs produced an effective protection coefficient ranging from 1.03 to 1.52, except for the district of Sidrap in the dry season (0.90). This showed that, in the current situation of outputs and tradable inputs markets, rice farmers obtained higher added value, around 3–52%, compared with added value obtained in perfectly competitive market conditions. Hence, we can conclude that the government's policy for the markets of outputs and tradable inputs is fairly effective in protecting the income of most rice farmers, although the policy on tradable inputs (seeds, fertilizers, pesticides) increased their prices and thus made them more expensive. The effect of this policy was not significant on the net return of rice farming because of the relatively low contribution of these inputs to the production cost, which was around 25%.

Table 6. Some indicators of the incentive policy in rice production.

Item	Java			Outer islands	
	Majalengka	Klaten	Kediri	Agam	Sidrap
Nominal protection coefficient on output (NPCO)					
Wet season 1999-2000	1.24	1.15	1.06	1.07	1.11
Dry season 2000	1.21	1.09	1.37	0.95	1.24
Nominal protection coefficient on input (NPCI)					
Wet season 1999-2000	1.13	1.08	1.12	1.32	1.10
Dry season 2000	1.07	1.11	0.93	1.31	1.15
Effective protection coefficient (EPC)					
Wet season 1999-2000	1.27	1.17	1.05	1.03	1.11
Dry season 2000	1.25	1.09	1.52	0.90	1.25
Profitability coefficient (PC)					
Wet season 1999-2000	7.73	2.94	1.27	1.09	2.75
Dry season 2000	–7.39	1.22	–1.65	0.58	5.62
Subsidy ratio to producer (SRP)					
Wet season 1999-2000	0.20	0.12	0.02	0.01	0.09
Dry season 2000	0.18	0.06	0.37	–0.10	0.21

In the current situation of output and input markets (tradable and domestic inputs), the financial profit of rice farming is generally higher than the economic profit, indicated by the profitability coefficient (PC), which is more than 1, except in the dry season in Sidrap. This situation occurred particularly because of the higher output price than the parity price. In addition, farmers also paid a lower production cost than opportunity cost of production. This was shown by the positive value of the subsidy ratio to producer (SRP) from 0.01 to 0.07, except for the dry season in Sidrap.

Long-term competitiveness. Competitiveness was highly dependent on the price in the domestic and world markets. In the wet season of 1999-2000, the farm-gate price of rice was Rp 850 kg^{-1} or \$0.113 kg^{-1}. At the same time, the price parity of imported rice was estimated at Rp 686 kg^{-1} or \$0.091 kg^{-1}, leading to a 24% price divergence. In the dry season, the farm-gate price was higher in local currency at Rp 750, but was slightly lower when converted to US\$ (\$0.107) because of the rupiah devaluation. Thus, the price divergence increased slightly from 24% in the wet season to 25% in the dry season. The price parity of imported rice during that same period was estimated at Rp 754 kg^{-1} or \$0.086 kg^{-1}.

Table 7 shows that rice farming was more competitive in the dry season than in the wet season because of higher prices during the dry season. Total divergences of rice production in the dry and wet seasons were 58% and 60%, respectively. This means that current policy induced a net transfer to farmers of about 58% and 60% of the return to management in rice farming, resulting from import tariff (58.4% and 60.8%), seed subsidy (0.6% and 0.9%), and credit imperfection (–1.2% and –1.4%).

The question is, Can the local farmers compete with foreign farmers in producing rice when all divergences resulting from government intervention are eliminated? IRRI estimated that the long-term world price of rice (25% broken, f.o.b. Bangkok)

Table 7. Competitiveness of rice production in East Java for technical irrigated land.

Item	(Rp 000)	(%)[a]
Wet season 1999-2000[b]		
Return to management	1,738.2	100.0
Protection for rice cultivation	1,057.3	60.8
Seed subsidy	15.2	0.9
Credit imperfection	–24.1	–1.4
Total divergences	1,048.4	60.3
Dry season 2000[c]		
Return to management	2,137.1	100.0
Protection for rice cultivation	1,248.1	58.4
Seed subsidy	16.7	0.6
Credit imperfection	–24.6	–1.2
Total divergences	1,240.2	58.0

[a] Percentage of return to management. [b] Private price of rice (farm level) = Rp 850 kg^{-1}; world price (f.o.b. Bangkok) = US\$170 t^{-1}; exchange rate = Rp 7,500 = US\$1; social price of rice (farm level) = Rp 686 kg^{-1}. [c] Private price of rice (farm level) = Rp 950 kg^{-1}; world price (f.o.b. Bangkok) = US\$150 t^{-1}; exchange rate = Rp 8,800 = US\$1; social price of rice (farm level) = Rp 759 kg^{-1}.

would be about US$200 t^{-1}. In this case, the long-term social advantage was estimated at around $54 to $227.4 (1.2–1.8 million rupiahs) and $166 to $232 (1.3–1.9 million rupiahs) for the wet and dry season, respectively, for various irrigation statuses (Table 8). The share of social profit in social revenue would be about 29–33% for the wet season and 29–31% for the dry season. This means that farmers' profit from rice production was about one-third of total revenue, without any government support. It can be concluded that rice farming in Indonesia is very competitive.

Role of rice farming in household income

Until recently, the government's policy on the rice industry had as the top priority to increase agricultural household income and to support economic growth in rural areas. The question is, How important is rice farming in rural household income which makes the government put so much emphasis on further improvement of the industry?

A study conducted by the World Bank and CASER in 1999-2000 revealed some information on the current situation. The study was carried out in 35 villages. It covered 589 households in Java that came from 13 villages and 971 households in the outer islands from 22 villages. Household samples were drawn based on the village census in accordance with agroecosystem status. Income structure by village category is presented in Table 9.

Average household income in 1995 in rice equivalence was about 2.18 t per year in the wetland villages of Outer Java and 2.4 t per year in those from Java. This increased, respectively, to 3.8 t and 4.1 t per year in 1999. The contribution of agricultural income to total income was dominant compared with that of nonagricultural income in the wetland villages of Outer Java and this increased from 63% to 64%

Table 8. Long-term social profit and breakeven point of the rice price in East Java for various irrigation statuses.

Irrigation status	Long-term social profit[a]		Breakeven point of world price[b]		Actual farm-gate price (Rp kg^{-1})
	(Rp 000)	(%)[c]	(US$ t^{-1})	Farm-gate price (Rp kg^{-1})	
Wet season 1999-2000					
Technical irrigated	1,819	33	133	579	850
Semitechnical irrigated	1,729	32	134	584	850
Simple irrigated	1,694	33	132	575	850
Rainfed	1,230	29	140	610	850
Dry season 2000					
Technical irrigated	1,856	31	135	621	950
Semitechnical irrigated	1,708	30	138	632	950
Simple irrigated	1,700	31	136	622	950
Rainfed	1,326	29	139	639	950

[a] If world price = US$200 t^{-1} (f.o.b. Bangkok), exchange rate = Rp 8,000 = US$1, social and private prices at farm level = Rp 861 kg^{-1} for wet season 1999-2000 and Rp 905 kg^{-1} for dry season 2000. [b] If long-term social profit = 0, exchange rate = Rp 8,000 = US$1 and total divergences = 0. [c] Percentage of social return.

Table 9. Income structure of rural households by agroecosystem in Java and off-Java, 1995 and 1999.

Item	Java		Outer islands	
	1995	1999	1995	1999
Wetland villages				
Household income in rice equivalent (kg $year^{-1}$)	2,439.4	4,085.0	2,184.2	3,805.0
Agriculture share (%)	43.0	50.8	62.5	63.6
Rice farming	8.1	13.6	28.1	21.2
Nonrice farming	24.0	31.9	28.5	34.4
Agricultural labor	10.9	5.2	5.9	7.0
Nonagriculture share (%)	57.0	49.2	37.5	36.4
Dryland villages excluding estate crops				
Household income in rice equivalent (kg $year^{-1}$)	3,835.4	4,306.0	2,858.7	4,697.0
Agriculture share (%)	84.5	73.5	76.3	66.9
Rice farming	0.1	0.1	9.4	7.8
Nonrice farming	75.5	68.4	59.9	51.6
Agricultural labor	8.9	5.0	6.9	7.5
Nonagriculture share (%)	15.5	26.5	23.7	33.1
Dryland villages including estate crops				
Household income in rice equivalent (kg $year^{-1}$)	na[a]	na	2,506.8	4,958.0
Agriculture share (%)	na	na	52.2	56.0
Rice farming	na	na	5.3	5.0
Nonrice farming	na	na	40.1	46.4
Agricultural labor	na	na	6.7	4.7
Nonagriculture share (%)	na	na	47.8	44.0
Coastal villages				
Household income in rice equivalent (kg $year^{-1}$)	3,156.6	4,148.0	na	na
Agriculture share (%)	52.4	49.9	na	na
Rice farming	0.2	0.3	na	na
Nonrice farming	39.0	39.6	na	na
Agricultural labor	13.1	9.9	na	na
Nonagriculture share (%)	47.6	50.1	na	na

[a]na = data not available.
Source: modified from Adnyana et al (2000).

from 1995 to 1999. In Java, the share of agriculture to total income was smaller than that of the nonagricultural sector in 1995 but it grew much faster to surpass it in 1999. Average household income in rice equivalence in the dryland villages as well as in the coastal areas was much higher than in the wetland villages for both periods. Similarly, the relative contribution of agricultural income to total income was also bigger than that of nonagricultural income. For the whole agroecosystem, the contribution of agricultural income to total income in Java decreased from 61.1% in 1995 to 58.1% in 1999, whereas, in the islands outside Java, the contribution decreased from 64.0% to 61.8% (Adnyana et al 2000). However, there was no clear pattern when the analysis was broken down in accordance with agroecosystem status. The contribution of agricultural income in 1995 and 1999 decreased for dryland villages excluding estate crops and coastal villages, but increased for dryland villages including estate crops and wetland villages, in Java as well as in the outer islands (Table 9).

Household income in wetland villages was the lowest compared with that of other villages, in both Java and in Outer Java for the same years. In wetland villages, rice is the main commodity usually grown by farmers. Thus, rice-based households actually were the poorest community group compared with other groups in rural areas. Around 80% of agricultural households in rural areas cultivate rice (Agricultural Census, 1993).

In wetland villages, where rice is the main commodity, the contribution of rice farming was relatively small: 13.6% in Java and 21.2% in Outer Java in 1999. The relatively small contribution of rice farming is basically because the analyzed income structure was constructed for the rural community level, not for the household level.

A study conducted by CASER (2000) showed that the contribution of rice farming to total income became higher when the analysis was executed at the household level. The contribution of rice farming to total household income in Java was around 19.3–34.9% for landowner farmers and 29.1–55.3% for landless farmers, whereas, in the outer islands, the contributions were 24.1–39.9% and 36.7–59.7%, respectively, for the same farmer categories.

Consumption and demand for rice

In line with a decreasing share of rice in household expenditure, per capita rice consumption in the last two decades showed a decreasing trend. This trend occurred in both urban and rural areas. The magnitude of the negative trend in urban areas was higher than in rural areas. This difference might be attributed to the higher per capita income in urban areas than in rural areas.

Similar to that of urban versus rural areas, the decline in per capita rice consumption in Java was more significant than that of outside Java. In Java, per capita rice consumption was decreasing at –2.30% and –1.36% in urban and rural areas, respectively. On the other hand, for off-Java, per capita rice consumption declined at –1.76% and –1.19% in urban and rural areas, respectively. On average, per capita rice consumption in Java decreased from 128.3 kg in 1981 to about 92.4 kg in 1999, or at –1.81% per year. For off-Java, it declined from 138.8 kg in 1981 to about 106.4 kg in 1999, or at –1.47% per year.

In absolute terms, the quantity of per capita rice consumption in urban areas was lower than in rural areas, in both Java and off-Java. For example, in 1981, per capita rice consumption in urban Java was 126.3 kg, whereas in rural Java it was 130.3 kg. In 1999, per capita rice consumption in urban Java was 83.1 kg, whereas in rural Java it was 101.9 kg. Another interesting figure is that per capita rice consumption was lower in Java than outside Java. These two figures indicate that the role of rice as a single staple food in urban areas is diminishing, especially in Java. Food consumption by people in urban areas and in Java is more diversified than for their counterparts in rural and off-Java, who are highly dependent on rice. It is common that the people in urban areas sometimes consume bread for breakfast, and noodles for lunch, especially in Java. This change in food habits reduces the consumption of rice over time.

Table 10 presents more details on per capita rice consumption in rural and urban areas, as well as in Java and off-Java.

As happened in urban and rural areas, per capita rice consumption by income group also showed a negative trend. This phenomenon was observed in all income groups. For the low-income group, average per capita rice consumption declined from 134.8 kg in 1981 to about 97.7 in 1999, or at –1.77% per year. The decline in per capita rice consumption was more significant in Java (–1.89% year^{-1}) than outside Java (–1.67% year^{-1}).

The decline in per capita rice consumption was also happening for the medium income group. In 1981, per capita rice consumption was about 133.0 kg, and then declined to about 103.0 kg in 1999, or at –1.41% per year on average. Per capita consumption growth in Java was –1.77%, while in off-Java it was –1.09% per year.

Similar to what occurred for low- and medium-income groups, per capita rice consumption for the high-income group, for the last two decades, was also decreasing. In 1981, it was 131.8 kg, whereas in 1999 it was 99.2 kg on average, or it grew at –1.57% per annum. The most significant decline was in Java, where it decreased from 126.2 kg in 1981 to about 88.9 kg in 1999, or at –1.93% per year, whereas in off-Java it decreased at –1.25% per annum.

There was no consistent pattern in quantity of rice consumption among income groups. In 1981 and 1996, lower income groups consumed more rice than higher income groups. This is logical and reasonable. Theoretically, the higher income group is concerned more about quality instead of quantity of rice. In addition, the higher income group has a higher purchasing power to buy more diversified food (other than rice), such as vegetables, fruits, meat, and dairy products, which are definitely more expensive.

In contrast, in 1993 and 1999, the average rice consumption for the high-income group was higher than that of the low-income group. In Java, the high-income group consistently consumed less rice than did the low-income group. The higher rice consumption for the high-income group also occurred outside Java. This might be due to the lower income of the people outside Java compared with those in Java. For the lower income group, it is common that, the higher the income, the more rice is con-

Table 10. Per capita rice consumption in urban and rural areas, 1981-99 (in kg).

Year	Urban		Rural		Av	
	Java	Off-Java	Java	Off-Java	Java	Off-Java
1981	126.3	136.5	130.3	141.0	128.3	138.8
1984	110.7	125.9	114.2	136.5	112.5	131.2
1990	107.2	122.0	110.4	142.4	108.8	127.2
1993	103.0	115.2	112.6	129.5	107.8	122.4
1996	96.6	111.8	108.1	123.4	102.4	117.6
1999	83.1	99.1	101.9	113.7	92.4	106.4
Growth	–2.30	–1.76	–1.36	–1.19	–1.81	–1.47

Source: SUSENAS, various years.

sumed. In rural areas, especially for the low-income group outside Java, rice has a high status as a staple food compared with maize, cassava, or sago. Therefore, as income increases, for this group rice consumption also increases. This implies that, to reduce the degree of dependence on rice, there are generally two ways. First, create more job opportunities to increase per capita income from the low level to the medium and high levels. Second, limit population growth so that growth in total rice consumption can be controlled.

Table 11 presents more details on per capita rice consumption by income group.

In aggregate, per capita rice consumption decreased from an average of 133 kg in 1981 to about 98 kg in 1999, or at –1.68% per year. During the same period, population growth was 1.92% per year. Therefore, total household consumption increased from 19.89 million t in 1981 to about 20.64 million t in 1999, or at 0.21% per annum.

Based on the food balance sheet data set, total use of rice during 1981-99 was much higher than total household consumption, as presented in Table 12. The total rice use increased from 20.04 million t in 1981 to about 31.57 million t in 1999, at

Table 11. Per capita rice consumption by income group, 1981-99 (in kg).

Income group	1981	1993	1996	1999	Growth (%)
Low					
Java	129.1	112.2	107.4	91.6	–1.89
Off-Java	140.4	124.3	122.0	103.7	–1.67
Av	134.8	118.3	114.7	97.7	–1.77
Medium					
Java	129.0	110.5	101.0	93.5	–1.87
Off-Java	137.0	125.4	119.1	112.4	–1.09
Av	133.0	118.0	110.1	103.0	–1.41
High					
Java	126.2	111.9	93.9	88.9	–1.93
Off-Java	137.3	133.9	114.1	109.5	–1.25
Av	131.8	122.9	104.0	99.2	–1.57

Source: SUSENAS, various years.

Table 12. Household rice consumption and total use, 1981-99.

Year	Per capita household consumption (kg year^{-1})	Total population (000)	Total household consumption (000 t)	Total use (000 t)
1981	133	149,520	19,886	20,045
1984	120	158,531	19,024	22,567
1990	116	179,829	20,860	26,948
1993	114	189,136	21,562	26,320
1996	108	201,353	21,746	31,572
1999	98	210,591	20,638	–
Growth (%)	–1.68	1.92	0.21	3.07

Sources: SUSENAS, 1981-99, computed; Food Balance Sheet, 1978-99.

3.07% per year. This indicates that the use of rice for other purposes (i.e., food industry, consumers for home stock, etc.) was increasing substantially. This might be one factor causing substantial imports of rice every year.

Possibility of increasing the rice supply

Arable land for rice

Because of the decreasing growth of yield, the expansion of harvested area has become an important factor for the increase in rice production in recent years. The increase in harvested area may happen because of the increase in arable land or the construction of irrigation networks, which enable the increase in cropping intensity. Increasing arable land could only be done on islands other than Java, whereas, in Java, the rice bowl of Indonesia, this cannot occur because of the limited land resource. In general, arable land in Java is more fertile than on other islands.

Total arable land in 1980 was roughly 9.4 million ha, with an allocation of 72% for wetland and 28% for dryland. During 1980-89, total arable land in the outer islands increased on average by 4.56%, whereas in Java it decreased at –0.13% per year. The significant increase in arable land on outer islands was due to the opening of forest area, which was stimulated by the transmigration program. Generally, this land had low fertility and its impact on harvested area was relatively low at 1.96% per year. Since most of the land was not suitable for rice farming, cropping intensity decreased by –2.6% per year in 1980-89 (Table 13).

The opposite occurred in Java, where harvested area and cropping intensity increased even though arable land decreased. This shows that the growth in harvested area in Java was particularly due to the construction of irrigation networks. In this area, new land openings could hardly be conducted because of the limited land re-

Table 13. Long-term growth in harvested area, arable land, and cropping intensity in Indonesia. Estimated by fitting semilogarithmic trend lines with the time-series data.

Period	Average growth (% year^{-1})		
	Harvest area	Arable land	Cropping intensity
1980-89			
Java	1.33	–0.13	1.45
Outer islands	1.96	4.56	–2.60
Total	1.63	2.35	–0.72
1990-98			
Java	0.54	–0.76	1.29
Outer islands	2.18	1.05	1.13
Total	1.36	0.33	1.03
1980-98			
Java	0.76	–0.30	1.06
Outer islands	2.11	2.54	–0.43
Total	1.42	1.28	0.14

source and high population growth. Therefore, economic growth that led to demand for land for the nonagricultural sector has caused land conversion, which made arable land decrease in Java. In the last decade, land conversion increased, resulting in a greater reduction in arable land, which was estimated at about –0.76% per year. The conversion of agricultural land occurred particularly during REPELITA IV (1984-89) at 47,500 ha per year.

Irrigation

The construction of irrigation infrastructure has been the major government strategy to increase rice production and reduce the fluctuation in rice production between the dry and wet seasons. Total wetland in 1980 was 7.20 million ha, consisting of 57% irrigated land and 42% nonirrigated land. During the last two decades, irrigated land increased from 4.14 million ha in 1980 to 4.78 million ha in 1998. Average growth of irrigated land in 1980-98 was 1.01% per year. Growth increased slightly from 0.74% per year in 1980-89 to 1.09% per year in 1990-98 (Table 14).

Most of the irrigated land is located in Java. This is because irrigation construction during 1970-80 focused on Java for three reasons: (1) land in Java was more fertile than on other islands, (2) the supporting infrastructure was more available in Java, and (3) the investment cost for irrigation in Java was cheaper than on other islands. Therefore, it was reasonable that the proportion of irrigated land in Java (70%) was higher than on the islands outside Java (40%). As a result, around 62% of the

Table 14. Growth of irrigated land in Indonesia.

Item	Java	Other islands	Indonesia
Area (million ha)			
Irrigated land			
1980	2.52	1.62	4.14
1985	2.48	1.67	4.15
1990	2.53	1.91	4.45
1995	2.56	2.13	4.69
1998	2.54	2.25	4.78
Nonirrigated land			
1980	0.97	2.09	3.06
1985	0.97	2.37	3.34
1990	0.88	2.88	3.77
1995	0.80	3.00	3.80
1998	0.78	2.94	3.72
Growth (% year^{-1})			
Irrigated land			
1980-89	0.52	1.06	0.74
1990-98	–0.01	2.46	1.09
1980-98	0.15	2.17	1.01
Nonirrigated land			
1980-89	–0.65	4.72	3.26
1990-98	–1.82	0.09	–0.33
1980-98	–1.52	1.91	1.05

Source: Ministry of Public Works.

wetland in Java could be cultivated with rice two times per year, whereas on other islands the percentage was around 31% (Irawan 1998).

The REPELITA V (1989-94) irrigation construction in Java became more difficult because of natural resource constraints. This situation motivated the government to move new irrigation construction to outside Java. The policy change led to a higher investment cost for constructing a new irrigation system. If in 1979-84 the required investment for constructing a new irrigation system had been around 0.8 million rupiahs per hectare at constant 1975-76 prices, in 1989-94 the required investment increased to 1.35 million rupiahs per hectare (Rosegrant and Pasandaran 1990).

The increase in irrigation investment cost, coupled with large losses in government revenues because of declining oil prices, motivated the government to reorient its irrigation development program. In 1979-84, around 23% of the area included in the irrigation development program had been new construction area, but in 1989-93 the proportion decreased to 17%. During the last-mentioned period, around 48% of the area included in the irrigation development program was rehabilitation area, or, in other words, government policy in irrigation development focused more on rehabilitation activity rather than on the construction of a new irrigation system. The change in policy caused the irrigated land in Java during the last decade to decrease because of the higher rate of land conversion than the construction of new irrigated land. As shown in Table 14, the decrease in agricultural land because of land conversion in Java occurred particularly in nonirrigated land, with an increasing rate from –0.65% in 1980-89 to –1.82% in 1990-98 (Table 14).

Technology

Technology development is the major factor for increasing rice production efficiently for particularly densely populated countries. The increase in yield per hectare related to technology development may come from the use of improved varieties or improved farm management. The use of improved varieties enables an increase in production capacity of each unit of cultivated land, whereas farm management improvement could reduce the yield gap between potential and actual yield.

Both aspects of technology have been developed in Indonesia to increase rice production. The improvement of farm management was conducted through the application of the rice intensification program, such as BIMAS and INSUS, which covered "five efforts." The intensification program also introduced seeds of high-yielding varieties to farmers. These seeds are packed in BIMAS or INSUS credit packages. Therefore, the rice intensification program was actually an effort to increase production capacity and to reduce the yield gap between potential and actual yield at the same time.

During 1950-99, as many as 129 improved varieties of rice were introduced to farmers, including 27 varieties developed by IRRI. Only a few of them had become popular, with different types of variety according to the period. During the 1970s, four popular types of improved varieties were adopted by farmers: PB-5, Pelita-I, PB-26, and PB-36. In general, those varieties had a less favorable taste, and they even had a shorter cultivation period and higher yield than the traditional varieties. Those high-yielding varieties were then replaced by IR64 in the mid-1980s because it had a good taste while its cultivation period and potential yield were not significantly different from those of the previous popular high-yielding varieties. In 1990, around 90% of lowland rice area in Indonesia was grown with modern rice varieties (Irawan 1998).

Table 15 shows the succession of the major improved varieties that were popular with farmers. Table 15 reveals that improved varieties adopted by farmers were not significantly different in potential yield, but they matured in a shorter time. Considering that most of the rice area is cropped with modern varieties, a future yield increase can be obtained only by introducing new varieties that have a higher yield. Another option is by improving farm management applied by farmers so that the obtained yield can reach the maximum attainable yield (MAY), which, for tropical areas that include Indonesia, is around 7.2 t ha^{-1} for irrigated wetland (Hossain 1997 as cited by Simatupang 2000).

Recently, some promising rice hybrids with high yield potential and moderately resistant to brown planthopper and bacterial leaf blight have been identified (Budianto 2001). These hybrids should be intensively evaluated for their yield stability, adaptability, and other important characters. Current hybrid rice technology is suitable for irrigated lowlands and requires more labor, especially for seed production. This characteristic is suitable to the situation in Indonesia, which has around 5 million ha of irrigated lowland and relatively high labor scarcity. It is expected that a 10–20% increase in yield potential will be obtained through the breeding program, which has been developed recently.

Projection of rice supply and demand

Supply projection

The supply projection in this study focuses on the ability of domestic production to meet the increasing domestic demand for rice because the sustainability of rice self-

Table 15. Succession of the major improved rice varieties adopted by farmers in Indonesia.

Item	Period			
	1972-74	1975-77	1978-87	1988-now
Variety	PB-5	PB-26	PB-36	IR64
Year of release	1967	1971 1975	1977	1986
Average yield (t ha^{-1})	5.5	5.5 5.0	4.5	5 - 8
Cultivation period (d)	145	135 125	115	115
Taste	Less	Good Less	Less	Good

Source: modified from Simatupang (2000).

sufficiency much depends on domestic production. The production projection is the product of harvested area and the yield projection, while the harvested area and yield projections are estimated by using their elasticities with respect to the dominant explanatory variables. The elasticities used in this projection are those estimated by Altemeier (1991), as presented in Table 16.

By using the above estimated elasticities, CASER (2000) estimated the rice supply projection by using the following formulas:

Area response: $A_{i\,t} = A_{i0}\,(1 + \varepsilon_i\,\rho_i + \Sigma\,\varepsilon_{ij}\,\rho_j)^{\,t}$ (6.1)
Yield response: $Y_{i\,t} = Y_{i0}\,(1 + \xi_i\,\rho_i + \Sigma\,\psi_k\,w_k)^{\,t}$ (6.2)
Supply: $Q_{si\,t} = A_{i\,t} \times Y_{i\,t}$ (6.3)

where $A_{i\,t}$ = area planted to rice in period t, $A_{i\,t-1}$ = area planted to rice in period t – 1, A_{i0} = area planted to rice in period 0 (base year), ε_i = elasticity of area with respect to own price, ρ_i = growth of real own price, ε_{ij} = cross-price elasticity of area with respect to price of other commodity j, ρ_j = growth of other commodity's real price (commodity j), t = time period (years), $Y_{i\,t}$ = yield of rice in period t, Y_{i0} = yield of rice in period 0 (base year), ξ_i = elasticity of yield with respect to own price, ψ_k = elasticity of yield with respect to input prices (labor, urea, triple superphosphate), and w_k = growth of real input prices.

Data from the last 10 years (1988-98) were used in computing the growth of all explanatory variables of equations 6.1 and 6.2, for both Java and off-Java. It was assumed that the last ten years' growth will be more appropriate as a proxy for the next ten years' growth of the variables. The projection of rice harvested area and yield was made for both Java and off-Java by using the 1996 area and yield data as the base year. The projected harvested area and yield of dryland and wetland rice in Java and

Table 16. Area and yield responses with respect to output and input prices.

	Area response		Yield response	
Prices	Wetland rice	Dryland rice	Wetland rice	Dryland rice
Java				
Rice	0.120	0.145	0.212	0.274
Maize	–0.083	0.000	–	–
Cassava	0.000	–0.023	–	–
Urea[a]	–	–	–0.058	–0.078
TSP	–	–	–0.027	0.000
Wage	–	–	–0.126	–0.197
Off-Java				
Rice	0.013	0.171	0.241	0.101
Maize	–0.019	–0.04	–	–
Cassava	0.000	–0.033	–	–
Urea	–	–	–0.044	–0.078
TSP	–	–	–0.025	0.000
Wage	–	–	–0.172	–0.022

[a] TSP = triple superphosphate. Source: Altemeier (1991).

off-Java were used to compute the total rice production in Indonesia simply by multiplying their respective projected area and yield. Assuming a closed market, rice supply is obtained by multiplying the net production by the paddy to milled rice conversion factor, which is 0.62. On the other hand, net production is obtained by subtracting the use of rice for seed and losses from total production, which is 10% (Bulog 1992, 1994). By using this approach, the projected area, yield, and supply of rice in Indonesia are as presented in Table 17.

The total area planted to rice is projected to decline from 11.31 million ha in 1998 to about 11.29 million ha in 2010, or at a growth rate of –0.01% per annum (Table 17). This decline is mainly caused by a decline in wetland area from 9.98 million ha in 1998 to 9.94 million ha in 2010, or at a projected growth rate of –0.04% per year. Although the area planted to rice in dryland is projected to increase by 0.19% per year, the contribution of dryland rice area to the total rice area is relatively small (about 12%). Actually, in Java, where rice is mostly produced, the area planted to rice is projected to decline by 0.02% per year in dryland and 0.09% per year in wetland. Although the area planted to rice in off-Java is projected to grow at 0.26% per year in dryland and 0.02% per year in wetland, its contribution is not sufficient to make the total area planted to rice increase.

Unlike the area projection, rice yield is estimated to increase, in both dryland and wetland, by 0.27% and 0.24% per year, respectively. As a result, total production is projected to increase from 50.19 million t in 1998 to about 51.54 million t in 2010, or at a growth rate of 0.22% per annum (Table 17). Therefore, rice supply is projected to increase from 28.01 million t in 1998 to about 28.76 million t in 2010, or at a growth rate of 0.22% per annum. The next question is whether or not this growing supply of rice will be able to meet the increasing demand. To answer this question, the following section examines the demand projection.

Table 17. The projected area, yield, and supply of rice in Indonesia, 1998-2010.

Year	Area			Yield		Total production (000 t paddy)	Rice supply (000 t)
	Dryland (000 ha)	Wetland (000 ha)	Total (000 ha)	Dryland (t ha^{-1})	Wetland (t ha^{-1})		
1998	1,323	9,983	11,306	2.22	4.73	50,192	28,007
1999	1,326	9,980	11,306	2.23	4.74	50,302	28,069
2000	1,328	9,976	11,304	2.23	4.76	50,412	28,130
2001	1,331	9,973	11,304	2.24	4.77	50,524	28,192
2002	1,333	9,969	11,302	2.25	4.78	50,636	28,254
2003	1,335	9,966	11,301	2.25	4.79	50,747	28,317
2004	1,337	9,962	11,299	2.26	4.80	50,859	28,379
2005	1,340	9,959	11,299	2.27	4.81	50,972	28,442
2006	1,342	9,955	11,297	2.27	4.83	51,085	28,505
2007	1,345	9,952	11,297	2.28	4.84	51,197	28,568
2008	1,347	9,948	11,295	2.28	4.85	51,311	28,632
2009	1,350	9,945	11,295	2.29	4.86	51,425	28,695
2010	1,353	9,941	11,294	2.29	4.87	51,539	28,759
Growth	0.19	–0.04	–0.01	0.27	0.24	0.22	0.22

Source: CASER (2000).

Projection of demand for rice

In a standard form, the demand for a commodity is determined by two factors: per capita consumption and total population. Per capita consumption is determined by its own price, other commodity prices, and per capita income. In a mathematical form, per capita consumption and total demand can be formulated as follows:

$$C_t = f\,(P_t, PS_t, I_t, C_{t-1}) \qquad (6.4)$$

$$D_t = C_t \times Pop_t \qquad (6.5)$$

where C_t = per capita consumption in period t, C_{t-1} = per capita consumption in period t – 1, P_t = own price of a commodity in period t, PS_t = price of other commodity in period t, I_t = per capita income in period t, D_t = total demand in period t, and Pop_t = total population in period t.

By applying the above standard form, Swastika et al (2000) estimated the parameters determining rice consumption using the national CBS data. Table 18 presents the estimated price and income elasticities of demand obtained from their study.

As shown in Table 18, there was a tendency for an increase in per capita income to reduce the per capita consumption of rice. It may be true that, as per capita income increases, one will reduce the quantity of rice but tend to consume a better quality of rice. In addition, the higher income will lead consumers to eat a more noncarbohydrate diet, such as animal protein and fruit. For projection purposes, we used the price and income elasticities of Table 18.

The per capita consumption projection is computed by using price and income elasticities, while the population projection is done by using population growth. The projection of demand for rice is simply the product of per capita consumption and population in each respective year. In a mathematical form, the projection of per capita consumption and population can be formulated as equations 6.6 and 6.7, respectively, while total demand for rice is represented by equation 6.8:

Per capita consumption: $C_t = C_0\,(1 + \eta\,\rho + \gamma\,\pi)^t$ …… (6.6)

Population: $Pop_t = Pop_0\,(1 + r)^t$.............. (6.7)

Total consumption: $TC_t = C_t \times Pop_t$ .... (6.8)

where C_t = per capita consumption of rice in period t, C_0 = per capita consumption of rice in period 0 (base year), η = own price elasticity, ρ = growth of own price (in real terms), γ = income elasticity, π = growth of real income, Pop_t = population in period t, Pop_0 = population in period 0 (base year), r = population growth, and TC_t = total consumption or demand for rice in period t.

Table 18. Price and income elasticities of demand for rice in Indonesia.

Variables	Elasticities		Change in elasticity
	Short-term	Long-term	
Own price	–0.0132	–0.0257	–0.0012
Maize price	0.0762	0.1478	0.0072
Income	–0.1479	–0.2870	–0.0139

Source: Swastika et al (2000).

By using the above equations, the projected per capita rice consumption, population, and demand for rice are presented in Table 19. The per capita consumption of rice is projected to decline from 156.0 kg per year in 1998 to about 155.2 kg per year in 2010, or at a growth rate of –0.04% per year. This decline is thought to be mainly a result of the negative response of per capita income to the quantity of rice being consumed. On the other hand, the total population is still growing at an average rate of 1.2% per year from 1998 to 2010. Therefore, the demand for rice during the same period is projected to grow at 1.16% per year (Table 19). With this projected trend of rice demand, Indonesia is expected to import around 3.2 million t of rice in 2000, which increases to 5.2 million t in 2005 and 6.3 million t in 2010.

Some other studies were made on the projection of supply and demand for rice in Indonesia. The following section will discuss the results of six studies that have been made since 1992: CASER (2000), Sudaryanto et al (1992, 1998), Simatupang et al (1995), Mulyana (1998), and Sanim et al (1999).

CASER (2000) was projecting rice production by using the elasticities developed by Altemeier (1991). These elasticities were applied to the CBS data for 1996 as a base year and to 1988-98 data for the growth of all variables. The results of the supply projection have been discussed in a previous section. Demand was projected to increase from 30.10 million t in 1996 to 33.12 million t in 2000 and about 41.54 million t in 2010. The deficit is projected to increase from 2.22 million t in 1996 to 4.99 million t in 2000 and about 12.78 million t in 2010.

Sudaryanto et al (1992) used the trend to estimate the projection of rice supply and demand. The results of their projection showed that rice production is projected to increase from 48.59 million t of paddy in 1995 to about 52.68 million t in 2000 and 57.15 million t in 2005. It is projected to grow at 1.64% per year. In terms of equiva-

Table 19. Projected per capita consumption and total demand for rice in Indonesia, 1998-2010.

Year	Per capita consumption (kg)	Total population (000 persons)	Total demand (000 kg)
1998	156.00	208,186	32,477
1999	155.89	211,842	33,024
2000	155.85	215,348	33,562
2001	155.80	218,697	34,073
2002	155.75	221,881	34,558
2003	155.70	224,881	35,014
2004	155.64	227,711	35,441
2005	155.58	230,338	35,836
2006	155.52	232,761	36,199
2007	155.45	234,989	36,529
2008	155.37	237,008	36,824
2009	155.30	238,789	37,084
2010	155.22	240,356	37,308
Growth	–0.04	1.20	1.16

Source: Swastika et al (2000).

lent milled rice, net production is projected to increase from 27.11 million t in 1995 to 29.40 million t in 2000 and 31.89 million t in 2005.

On the demand side, they projected that the demand for rice will increase from 30.19 million t in 1995 to about 32.67 million t in 2000 and 36.25 million t in 2005. Therefore, the deficit will increase from 3.08 million t in 1995 to about 3.28 million t in 2000 and 4.36 million t in 2005.

Simatupang et al (1995) used elasticity parameters resulting from a multimarket model for the supply response and the almost ideal demand system (AIDS) for the demand function to estimate the projection of supply and demand for rice. They projected that net rice production (rice supply from domestic production) will be 26.98 million t in 1995, and then increase to 30.06 million t in 2000 and 38.52 million t in 2010. The demand for rice is projected to increase from about 29.00 million t in 1995 to 32.94 million t in 2000 and 42.12 million t in 2010. Therefore, the deficit is projected to be about 2.01 million t, 2.88 million t, and 3.60 million t, respectively, in 1995, 2000, and 2010.

The fourth study made by Sudaryanto et al (1998) used the trends to estimate supply and demand for rice. The results of their study showed that the rice supply from net domestic production is projected to substantially increase, from 31.16 million t in 1998 to about 33.62 million t in 2000 and 40.69 million t in 2005. During the same period, the demand for rice is projected to increase from 34.15 million t in 1998 to 35.03 million t in 2000 and 36.34 million t in 2005. The surprising result from this projection is that, starting in 2002, Indonesia will be self-sufficient in rice, with even an increasing surplus that can be exported, from 0.50 million t in 2002 to about 4.36 million t in 2005.

Mulyana (1998) used elasticities resulting from the Nerlove model for a supply response and the utility function for demand. The results of his study showed that rice production is projected to increase from 48.6 million t of paddy in 1999 to about 56.13 million t of paddy in 2005. In net terms, the rice supply is projected to increase from 26.92 million t in 1998 to 27.83 million t in 2000 and 29.91 million t of milled rice in 2005.

Sanim et al (1999) used the Nerlove model for the supply response of multi-inputs and multi-outputs for food crops and the AIDS for the demand function. They projected supply and demand for rice using elasticities resulting from the abovementioned models. The results of their projection showed that rice production is increasing from 48.60 million t in 1999 to about 56.13 million t of paddy in 2005. In net milled rice, it is projected to increase from 27.12 million t in 1999 to 31.32 million t in 2005, or it is growing at 2.43% per year. The demand for rice is projected to increase from 30.90 million t in 1999 to about 34.80 million t in 2005.

The model as discussed above shows superiority in the following sense: (1) it contains a structural supply and demand equation consistent with economic theory, (2) it enables simulating alternative policy scenarios, (3) and it has been widely used by rice policy analysts in Indonesia. However, in this paper, we also compare it to the results of other studies. Almost all of the studies showed that Indonesia is continuously becoming a net rice-importing country. This is indicated by the continuous projected deficit in rice toward 2010. By considering more moderate results, rice imports are projected at around 1.5–2.0 t in the near future, which will increase to 3–5 million t in the medium to long term. These results remind us that efforts to increase rice production have to be given a high priority. The question is how to do it. The government of Indonesia has implemented many programs to increase rice production in the past. A lot of investment was made in irrigation, land expansion, input subsidy, and price support that is now very difficult to make because of a long economic crisis and the WTO agreements.

Alternatives that might still be reasonable to follow to minimize the rice deficit are (1) limiting the conversion of irrigated and fertile land (especially in Java) into nonagricultural purposes and (2) looking for and using the new sources of production growth. Some sources of production growth can be used, that is, minimizing yield losses, expanding area planted to rice (land expansion), increasing crop intensity and the quality of intensification, and giving more priority to developing high-yielding varieties through research in rice breeding.

In the short run, minimizing yield losses is a promising action program, based on CBS data that yield losses from inappropriate harvesting and handling in 1995 were about 20.5% (Dillon et al 1999). The highest losses occurred during harvesting (9.52%) and threshing (4.78%). If we can reduce yield losses from 20.5% to 15%, this really would make a significant contribution to national production. An alternative technology to minimize yield losses is the use of a sharp sickle and power thresher.

In the medium and long run, the use of potential land for both extensification and improvement of intensification is a prospective action program. The Center for Soil and Agroclimate Research has identified about 10.15 million ha of wetland suitable for rice cultivation. About 7.10 million ha of this are located in nine provinces that have no political problem. If 50% of that potential land can be used gradually within 10 years, its contribution to national rice production will be significant.

Conclusions

This review indicates that, even with the most optimistic projection, Indonesia will remain a rice-deficit country at least over the next 5 years (medium term). Most studies, however, indicate that Indonesia will face an ever-increasing rice deficit in a longer-term perspective. Indonesia will remain the major rice-importing country in the world. The main reason is that on the one hand rice demand continues to rise while on the other hand the rice supply has been slowing down since the late 1980s.

Rice consumption continues to rise primarily because of population growth. The population growth rate is still very high, 1.87% per year, which is much higher than the declining rate of rice consumption per capita at –0.73% per year. This means that direct rice consumption increases at more than 1% per year.

Meanwhile, the rice supply has been slowing down since the mid-1980s. The main reasons for this are (1) the slowdown (declining in recent years) in productivity growth, (2) the decrease in rice field expansion, and (3) cropping intensity is reaching its limits. The phenomenon of productivity slowing down is caused by the overintensification syndrome induced by the long practice of intensive rice farming. The decrease in rice field expansion is due to the increasingly limited government investment in new irrigation construction and land development. The exhaustion of cropping intensity is also related to the limited expansion in irrigated rice fields.

Clearly, a drastic change in policy regime also contributes to the slowing down of rice production. During the late 1960s to mid-1980s, there had been massive policy supports for rice production. Now, however, there is little government support for promoting rice production. The only policy still in place and yet not effective is the paddy floor price.

Rice farming in Indonesia is quite competitive. But, the land size of rice farming is too small and hence is not sufficient as the major source of income for most farm households. For household income, the problem is limited landholdings. For national rice production, the problem is limited production capacity because of limited arable land for rice-farming expansion and rice-farming technology reaching its limits.

The widening rice demand-supply gap is a problem of great concern to the government. Formulating a new comprehensive long-term program to revitalize the national rice industry is needed to deal with such a complex problem. Under the present policy environment, the most important programs are perhaps investment in land development, irrigation systems, and innovation systems (research and development in particular).

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Determinants of rice supply and demand in Bangladesh: recent trends and projections[*]

S. Zohir, Q. Shahabuddin, and M. Hossain

Growth in Bangladesh agriculture has largely centered on the adoption of modern rice varieties through investments in irrigation infrastructure, research, and extension services, and by subsidizing fertilizer prices. This study aims to provide an overview of recent developments in the rice sector of the economy and to develop a perspective of the rice supply and demand balance for Bangladesh in the early 21st century. It gives an overview of food and agricultural policies in Bangladesh, including an assessment of some recent macroeconomic and sectoral policy changes in terms of their implications for production incentives. Sources of growth in rice production and productivity are also analyzed. The projection exercise is based on two independent analyses of rice supply and demand. The supply parameters for the projection are estimated from modeling of the dynamic supply response of rice and substitute crop enterprises. A multistage budgeting demand system is developed and estimated to estimate the demand parameters. Based on these estimates and introducing the concept of no-trade regime, a perspective of the demand-supply balance for 2000-20 is presented in this paper.

Bangladesh, with a population of 129 million in 2001 within a land area of 144,000 km^2, is one of the most densely settled countries in the world. The cultivated land, which reached 9.1 million ha in the late 1960s, started declining in the 1970s under pressure from urbanization, housing needs, and infrastructure development. The agricultural census of 1996 reported total cultivated land at only 8.07 million ha. The land was cultivated on 11.8 million farms, with an average size of 0.68 ha (BBS 1999, 2000).

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Rice, the dominant staple food, accounts for 70% of the calorie intake and 43% of household expenditures (HES 1995-98). It is therefore no wonder that three-fourths of the country's total cropped area is devoted to rice production, with rice accounting for 60% of the gross value of crop produced. Yet, with the exception of 1993-94 and 2000-01, domestic production has never been adequate to meet the country's total demand for rice. The primary policy concern for the agricultural sector has so far been to increase rice production in pursuit of national food security.

Growth in Bangladesh agriculture has largely centered on the adoption of modern rice varieties through investments in irrigation infrastructure, research, and extension services, and by subsidizing fertilizer prices. The land frontier has long been exhausted and cropping intensity (175%) is approaching its limit. The cost of further development of irrigation infrastructure is likely to rise sharply and the relative price of rice compared with that of alternative crops for which farmers could allocate their land may not sustain incentives for a further expansion of rice area. Rice, however, continues to be the main source of livelihood in rural areas. At the same time, the government is concerned about ensuring the availability of cheap rice to improve the livelihood of the vast majority of the urban poor and rural landless and to maintain the comparative advantage in rice production to sustain self-sufficiency. All these reasons provide the rationale for looking at the prospects of the Bangladesh rice economy in the future, based on the evolution and effect of agricultural policies and recent development trends.

This study aims to provide an overview of recent developments in the rice sector of the economy and to develop a perspective of the rice supply and demand balance for Bangladesh in the early 21st century. Since policies on pricing, irrigation, water resource development, research, and extension will critically affect both the supply of and demand for rice, an important focus of the study is the evaluation of these policies. Other specific areas covered by the study are the sources of productivity growth and an estimation of the determinants of rice supply and demand trends.

The second section gives an overview of food and agricultural policies in Bangladesh, including an assessment of some recent macroeconomic and sectoral policy changes in terms of their implications for production incentives. Sources of growth in rice production and productivity are analyzed in the third section. The fourth section estimates the parameters governing the supply of rice based on a modeling of the dynamic supply response of rice and substitute crop enterprises. This section also analyzes consumer expenditure patterns and estimates the parameters governing the demand for rice using a "multistage budgeting demand system." A perspective of the demand-supply balance for 2000-20 is presented in the fifth section based on the analysis in the previous section.

Review of food and agricultural policies

For decades, Bangladesh has strived to attain self-sufficiency in rice production. Since there is little scope for extensive farming, most of the increased production is expected to come from the application of modern agricultural inputs and intensive cultivation methods. While one might intervene in both the output and input market to stimulate growth, policies in the past apparently associated mutually exclusive objectives with two kinds of interventions (Zohir 1994, Hossain 1996): (1) interventions in the output market through government procurement and distribution primarily aimed at stabilization of prices, and ensuring equity in the distribution of agricultural income, and (2) interventions in the input market aimed at stimulating growth in rice production.

Policies affecting the output market

The rice market in Bangladesh is perceived to be spatially integrated (Ravallion 1986, Chowdhury 1992, Mahmud et al 1994, Baulch et al 1998). Concerns have been raised, however, about the lack of temporal integration—both seasonal and annual (Ahmed and Bernard 1989). Annual integration was to be achieved through the stock policy supported by imports and domestic procurement. Two policy instruments used to maintain seasonal price spreads within acceptable limits include the domestic rice and wheat procurement program to maintain floor prices to farmers and open market sales (OMS) to moderate prices for consumers when there is exceptional upward pressure on prices. The government procured up to a maximum of 3.5% of domestic production and, during the peak of the operation in the late 1980s, distributed through government outlets nearly 10% of the domestic demand for food grains. The distribution of rice and wheat under public-sector marketing channels decreased from 2.9 million t in 1988-89 to 1.8 million t in 1999-2000.

The government's procurement program is believed to have been ineffective in maintaining floor prices and thereby ensuring incentive prices for producers. It was, however, relatively successful in containing sudden increase in prices, thereby benefiting rice consumers. From 1977-78 to 2000-01, growers' prices were below procurement prices two-thirds of the time. While seasonal variations in food-grain prices declined in the 1980s compared with the previous two decades (Ahmed and Bernard 1989), they increased again during the 1990s (Hossain et al 2001).

The government retained a monopoly over food-grain imports until August 1992, when private traders were allowed to import rice, initially without import duties. However, variable import duties were reimposed in 1994, but the tariff rates did not exceed 15% from 1994 to 2000. After the disastrous floods in 1998, the private sector imported a substantial amount of rice from India fairly quickly, which helped avert a food crisis.

The impact of government intervention in the output market is typically measured by nominal protection rates (NPR) defined as the percentage by which the domestic price (of, say, rice) deviates from the world (border) price, converted at the official exchange rate. The estimates of the coefficients by several researchers (Rahman 1994, Shilpi 1998, Shahabuddin 2000) show that the domestic price of rice remained within the export and import parity price band, except for 1996-97, when it fell below the export parity price. Since Bangladesh has been a marginal importer of rice (except for 1993-94 and 2000-01), at the import parity price domestic producers faced negative incentives. For most years, the domestic price followed more closely the export parity price.

Fertilizer markets and prices

Fertilizer, irrigation, and improved crop varieties are three important inputs, whose procurement and distribution had once been under the sole control of the Bangladesh Agricultural Development Corporation (BADC), a semigovernment organization. Policy changes since the early 1980s aimed at reducing government interventions as well as subsidies have completely transformed the markets for these inputs (Hossain 1996). Changes in privatizing the marketing system of fertilizer began in 1979 and were pursued vigorously in the early 1980s. Beginning in July 1987, private dealers were allowed to procure fertilizer in bulk at a higher discount rate from factories as well as from the four large BADC supply centers known as transport discount points (TDP). By 1992, BADC withdrew from wholesale trade, allowing the private sector to procure, import (except urea), and distribute fertilizers in domestic markets. Subsidies on phosphate and potash were also eliminated in 1992. The price of urea was also adjusted upward to eliminate subsidy at the export parity price. However, fertilizer subsidies were reintroduced in 1996 following an acute fertilizer crisis in the domestic market during the 1995 boro season. In recent years, the government has been importing some urea as domestic production could not cope with the rising demand. The government virtually overtook the wholesale distribution from the private sector and started operating a buffer stock. Shahabuddin and Dorash (2001) estimated that in 1999-2000 the fertilizer subsidy was about 39% for urea but a negative 23% for triple superphosphate.

Policy changes involving mechanized irrigation

Private-sector participation in the market for irrigation equipment also began during the late 1970s. The private importation and sale of minor irrigation equipment, mostly shallow tubewells, were allowed in 1978-79. However, such imports were subject to the “standardization” requirement (Abdullah 1994) and a groundwater ordinance was introduced to control the placement of shallow as well as deep tubewells. Since 1988, the government has withdrawn all restrictions on the importation of irrigation equipment by the private sector, eliminated import duties on agricultural machinery, and removed restrictions on standardization and placement. Along with these policy changes, subsidies for minor irrigation have been eliminated. More importantly, irrigation management has gone through a gradual metamorphosis: from public ownership with bureaucratic management to public ownership with cooperative management and, finally, to private ownership with private management. However, the government retains control on the management of deep tubewells, which it found difficult to transfer to the private sector. Some subsidy for irrigation is provided through the provision of electricity and diesel, as power for irrigation has become a major input in dry-season rice cultivation.

It is now widely recognized that the adoption of modern varieties of rice, and therefore growth in the crop sector, has been largely dictated by the rapid expansion of area under irrigation in Bangladesh. The recent policies of removal of restrictions on standardization and placement of tubewells had a positive effect on private-sector investment in minor equipment for the expansion of groundwater irrigation in the country. From 1987-88 to 1995-96, the number of shallow tubewells (and private force-mode tubewells) fielded increased from 183,000 to 624,000. This spectacular growth spurt was undoubtedly caused by the increased availability of cheaper Chinese and Korean engines as a result of destandardization and the reduction in import duties. Not only did such policy changes make available to farmers cheaper (even if less durable) brands of engines, but the resulting competition as well as the elimination of duties caused a fall in the prices of standardized brands (Abdullah and Shahabuddin 1993). A vibrant water market has developed under which the owners of shallow tubewells (mostly large and medium farmers) sell water to farmers operating land within the command area of the tubewell.

The seed market in Bangladesh has a dual structure in which major crops such as rice, wheat, jute, potato, and sugarcane are classified as notified crops. For these crops, variety development, evaluation, maintenance, multiplication, quality control, and distribution are done by different public agencies. The private sector's role in the seed business has been restricted to the distribution of nonnotified crops, mainly brand-name hybrid vegetable seeds. In 1999, the government allowed the private sector to import seeds of hybrid rice under the condition that it should produce the seed in the country within the next three years. Recently, some nongovernment organizations (NGOs) have signed an agreement with the Bangladesh Rice Research Institute (BRRI) to obtain breeder seeds so that they can produce the foundation and certified seeds of rice for distribution among their members. As a result, the marketing of the seeds of the recently released high-yielding rice varieties has increased substantially (Hossain et al 2001).

Public investment in agriculture

In spite of the high importance of agriculture in the Bangladesh economy, underinvestment in the sector appears to persist. The share of agriculture in total development expenditure declined steadily from about 40% in 1980-81 to about 20% in 1986-87. The share increased, however, toward the end of the 1980s before declining again during the early '90s. While such fluctuations in shares may largely be attributed to changes in policy toward fertilizer subsidy, declines in real public expenditure as well as in shares of total development expenditure are noteworthy (Agriculture Commission 1999).

Research and extension

Agricultural research in Bangladesh seriously started only after the establishment of the BRRI during the 1970s. However, the allocation of funds to agricultural research rarely exceeded 0.3% of crop-sector gross domestic product. In spite of the very high rate of return from rice research (Dey and Evenson 1992, Hossain 1998), rice's share in total crop-sector research declined from more than one-third during the early 1970s to 18% during the late '90s. The allocation of funds for rice research from the government budget accounts for only 0.08% of the value added from rice production (Table 1).

Table 1. Public-sector investment in agricultural research, 1996-97.

Agricultural subsectors	Investment (US$ million)	Investment as % of income from the sector
Crops	16.41	0.28
Rice	3.02	0.08
Jute	1.47	0.99
Sugarcane	0.90	0.96
Others	11.02	0.64
Fisheries	1.83	0.11
Livestock	0.65	0.05
Forestry	1.06	0.10
Total agriculture	19.95	0.20

Source: GOB (1999).

Extension work in Bangladesh has gone through various phases in both coverage and focus. During the 1970s, specializations were made in establishing individual crop-based extension organizations for almost all major crops. Along with growing emphasis on integrated rural development, extension organizations proliferated in different sectors of rural development activities and created complex problems of cooperation and coordination. With the introduction of modern inputs, the input and credit functions of extension agents became prominent. The basic working approach, however, remained unchanged until the introduction of the training and visit (T & V) system of extension. This system comprised the formulation of location-specific impact points; dissemination of information through contact farmers and group training of local-level extension agents, subject matter specialists, and officers; and monitoring of field extension activities. Recognizing that the T & V system was not functioning satisfactorily, a decentralized group-based extension system with elements comprising the identification of farmer needs and a package of technological options for different groups of farmers, keeping in view their complex livelihood systems, was introduced in 1996 in the newly approved agricultural extension policy.

The Department of Agricultural Extension had a total staff strength of 20,566 in 1999-2000, consisting of 1,717 supervisory and directing officials, 15,955 field-level extension workers dealing directly with farmers at the village level, and 2,894 support staff. There was one field-level staff member for every 820 farmers. The department spent US$14.42 million in 1999-2000, of which $8.57 million were spent to implement special projects supported by foreign donors. Several NGOs with better connections with the small and marginal farmers are also engaged in disseminating improved varieties and crop management practices. Although notable progress has been made in recent years in reaching farmers with improved varieties and crop management practices, the linkage between research and extension remains weak, and rice yields could be increased further through better dissemination of knowledge-intensive technologies.

Sources of growth in rice production and productivity

The development of the rice economy

Agriculture now contributes nearly 26% to GDP and produces employment for nearly 55% of the labor force. The crop subsector overwhelmingly dominates agriculture, contributing 59% to the agricultural value added in 1999-2000. Rice is the single major crop, accounting for nearly three-fourths of the cropped area. It contributes 66% of the income from crops and 40% of the income from agriculture. Hence, rice is not only a major food staple but also the main source of livelihood for the rural population.

Table 2 shows the long-term growth rate in rice production over different subperiods. In estimating the long-term growth rate (fitting semilogarithmic trend lines on time-series data), we have excluded 1971 and 1972 because normal production activities were disrupted because of the war of liberation with Pakistan and the resettlement of 10 million refugees who fled to India during the war. Rice production has increased from 14.4 million t (in paddy equivalent) during 1961 to about 34.4 million t in 1999-2000. The long-term growth has been about 2.5% per year, almost on a par with the population growth rate. So, the per capita availability of rice from domestic production has yet to recover to the preindependence level of the late 1960s. Progress, however, is noteworthy considering that growth was achieved without much expansion of land in rice cultivation. Nearly 90% of the growth in the postindependence period was due to the increase in crop yield made possible through the diffusion of the seed-fertilizer-water technology. Rice yield has increased from 1.7 t ha^{-1} during the early 1960s to 3.2 t ha^{-1} in 1999-2000.

Some qualitative changes in sources of growth in rice production over different subperiods can be noted. The growth rate was nearly 3% per year during the 1960s, but the growth was due almost entirely to the expansion of cropped area, particularly from changes in single cropping to double cropping of rice in areas with favorable rainfall and well-drained land. Since the potential for extending cultivation to new land was almost exhausted by the end of the 1950s, farmers explored the possibility of increasing cropping intensity by shifting from direct seeding to the transplanting method of crop establishment for the wet-season (aman) rice crop. The delayed planting gave some lead time to grow a short-maturity drought-prone but low-yielding rice crop known as aus (early rice) with premonsoon rains during the April-July period. The area under aus rice increased from 3.4 to 4.0 million ha during the 1960s. Almost

Table 2. Long-term trends in growth (% per year) in rice production, 1961-2000.

Factor	1961-70	1973-85	1985-2000	1961-2000
Production	2.3	2.2	3.0	2.5
Area	1.9	0.3	0.2	0.7
Yield	0.4	1.8	2.8	1.8

Source: Estimated by fitting semilogarithmic trend lines on time-series data published by the Bangladesh Bureau of Statistics.

82% of the increase in rice production during this decade was due to the expansion of cropped land. The marginal increase in yield occurred because of changes in crop management practices, such as from direct seeding to transplanting and from random transplanting to line transplanting. Modern agricultural inputs, such as chemical fertilizers, irrigation water, and high-yielding seeds, were yet to play a significant role. The area covered by modern irrigation was less than 5% of cultivated land and fertilizer use was less than 10 kg NPK ha^{-1} by the end of the 1960s (Table 3). The high-yielding varieties of rice had just been introduced and did not contribute much to the growth of rice production during that decade.

The early 1970s were a period of stagnation because of disruptions in production and destruction of infrastructure caused by the war of independence (1971) and successive crop failures caused by droughts and floods. The decline in per capita availability in domestic production, the skyrocketing of rice prices in the international market following the oil price shock of 1973, and successive crop failures because of droughts and floods from 1972 to 1974 led to the humanitarian disaster in late 1974 and early 1975 in which thousands died because of starvation.

Production recovered to the preindependence peak during 1976. The adoption of modern varieties began to slowly pick up because of the limited expansion in irrigation facilities and constraints in the supply of chemical fertilizers, which were then controlled by government agencies, the BADC and the Bangladesh Water Development Board (BWDB). With the liberalization of the market for agricultural inputs, including small-scale irrigation equipment (power pumps and shallow tubewells), the irrigated area began to expand rapidly beginning in the early 1980s, and along with it the adoption of high-yielding modern rice varieties and the use of chemical fertilizers. Fertilizer consumption grew at more than 10% per year during the ’80s despite the large increase in fertilizer prices caused by privatization in fertilizer marketing and the gradual withdrawal of subsidies. From 1973 to 1985, the growth in rice-cropped area decelerated sharply to only 0.3% per year, but production growth was maintained at 2.2% because of technological progress, particularly in the dry-season (boro) rice cultivation. This period also coincided with a rapid expansion in the area and production of wheat from a very low base. Wheat production increased from less than 100,000 t in 1993 to 1.5 million t by 1985 but stagnated around that level till the

Table 3. Adoption of modern agricultural technology, 1970-2000.

Year	Irrigated area (% of cultivated land)	NPK fertilizer use (kg ha^{-1})	Area covered by modern varieties (%)
1970	2.6	10	2.1
1975	7.7	17	13.0
1980	12.8	30	19.7
1985	20.9	42	27.1
1990	30.7	67	40.7
1995	43.0	73	49.6
2000	51.4	99	65.0

Source: Bangladesh Bureau of Statistics.

mid-1990s. The production of cereal grains (rice and wheat) increased at 2.5% per year during this period, surpassing the population growth rate.

Further policy changes were introduced in the mid-1980s with reduced tariffs on the importation of agricultural machinery, the removal of the ban on imports by the private sector, and deregulation in the prices of agricultural inputs, which gave further impetus to the expansion of minor irrigation, particularly the extraction of groundwater with shallow tubewells. The area irrigated by tubewells increased from 0.3 million ha in 1985 to 2.9 million ha by 1999, of which nearly 80% was by shallow tubewells. Along with the expansion of minor irrigation, a market for transactions in irrigation water was developed, which provided small and marginal farmers access to irrigation. The terms and conditions for water transactions have also changed over time to improve efficiency in the use of irrigation equipment. Initially, the predominant practice in water pricing was to collect a fixed proportion of the harvest (25% of the gross produce) in exchange for irrigation water, in which the farmer did not have any incentive to save water. The current practice in many areas is to charge an hourly rate depending on the duration of renting the irrigation equipment. Since this practice provides incentives to save water, the capacity use of irrigation machines has increased.

The system of renting irrigation equipment on an hourly basis is convenient for supplementary irrigation during the wet season to cope with late-season droughts and has thereby reduced the risk of crop failure. This development has stimulated incentives to grow modern varieties during the aman season on flood-free and shallow flooded lands. Thus, the area under modern varieties has spread very rapidly and reached 65% of rice-cropped area by 1999-2000. Rice production grew at a respectable rate of 3.0% per year from 1985 to 2000 despite several disastrous floods (1987, 1988, 1998) and disincentives in production because of a drastic decline in rice prices from 1992 to 1996. The increase in yield from technological progress has accelerated to 2.8% per year during 1985-2000 compared with 0.4% during the 1960s and 1.8% from 1973 to 1985.

Many scholars argued earlier that the preponderance of small and marginal farmers and the widespread use of crop-sharing tenancy that characterize the Bangladesh agrarian structure would impede technological progress and constrain agricultural growth (Jannuzi and Peach 1979, Boyce 1988). These apprehensions have proved to be wrong. In-depth studies have shown that the adoption of modern varieties and the intensity in the use of chemical fertilizers are not affected by farm size and tenure status if farmers have access to water (Hossain et al 1994, Hossain 1996). In fact, the diffusion of new technology has led to institutional changes, crop-sharing tenancy has given way to fixed-rent tenancy in the cultivation of modern varieties, and the tightening of the labor market during the busy agricultural seasons has led to a change in the contractual arrangement in the labor market from daily-wage to piece-rate contracts. The areas that have not yet benefited from the new technology are those where irrigation development is uneconomical at current input-output prices or those with poor drainage and saline soils for which scientists have yet to develop appropriate high-yielding rice varieties. There is also some potential for increasing the yield of

Table 4. Annual growth rates[a] in total inputs, output, and total factor productivity for rice, Bangladesh, 1952-2000.

Period	Total inputs	Total output	Total factor productivity
1952-60	1.4	0.5	–0.4
1961-70	1.1	2.0	0.9
1973-80	0.7	2.2	1.4
1981-89	0.5	1.6	1.0
1989-2000	1.3	2.3	1.0

[a] Growth rates estimated by fitting semilogarithmic trend lines on three-year moving average of input and output indices.
Source: Dey and Evenson (1992) and Mustafi and Hossain (2001).

modern varieties in both the wet and dry seasons by using improved crop management practices. The exploitation of this potential, however, would require a more effective agricultural education and extension system and closer linkages with research and extension.

Growth in total factor productivity

The growth rate in total production can be disaggregated into two components: (1) growth attributable to the intensive use of inputs at constant levels of technical and economic efficiency and (2) growth attributable to technical and economic efficiency at constant levels of input use. The second component is known as total factor productivity (TFP) and can be taken as a measure of savings in unit production costs due to technological progress.

Table 4 shows the average annual growth rates of inputs, outputs, and TFP for rice. Input growth has slowed down substantially over time from about 1.4% per year during the 1950s to only 0.5% in the ’80s, but it increased again to 1.3% in the ’90s. During the 1950s, the growth in inputs was largely due to an increase in cultivated area. In the ’60s, the main source of growth was an increase in the effective supply of land by growing additional crops on the same land during the year and thereby also increasing labor use in crop production. Land cropped with rice has increased very little since independence, but some increase occurred in labor use as traditional rice varieties gradually gave way to modern varieties that required higher amounts of labor in weeding and the harvesting and threshing of the additional biomass. The main source of input growth during the period was the increasing use of chemical fertilizers and the capital invested in irrigation equipment. The creation of additional employment for agricultural workers in rice cultivation seems to have slowed down since the early 1980s because of a rapid rural-urban migration of population and the movement of the rural labor force from agriculture to nonfarm activities (Rahman et al 1996). Panel data produced through repeat surveys in 62 villages in Bangladesh conducted by the Bangladesh Institute of Development Studies in 1987 and 1995 show an absolute decline in the number of agricultural workers and in the variety-specific labor intensity in rice cultivation. The decline in the use of labor and draft animal power, however, was overcompensated for by the investment in irrigation and the use of mechanical power in the 1990s.

Total factor productivity growth almost doubled from 0.6% per year from 1958 to 1970 to 1.1% per year from 1973 to 1989, mainly because of the substantial slowdown in the use of agricultural inputs. During the 1990s, TFP growth slowed marginally, but still grew at a respectable rate of 1.0% per year.

Sources of productivity growth

Total productivity can be increased by investments in research, extension, human capital, and infrastructure. It is useful to understand the importance of different factors in determining productivity growth. To shed some light on this issue, Dey and Evenson (1992) estimated a multiple regression model relating TFP indices for seven major crops to crop-specific research stock (RESEARCH), kilometers of metal road per hectare (ROAD), number of literate adult males as a percent of total workers (LITERACY), and the area damaged by floods, droughts, and cyclones as a percent of total cropped area (WEATHER). The research stock variable was constructed from past research investment using a time lag with variable weights, with the following assumptions: (1) the reasearch will have an impact with a 2-year time lag, (2) the intensity of impact will increase with time, and (3) full impact will be achieved in the seventh year.

The estimated models for rice for the pre- and postindependence period are reported in Table 5. The value of the parameter is the elasticity of TFP on the change in the explanatory variables. The results show that the impact of investment in roads and agricultural research on TFP growth was stronger in the postindependence period than in the preindependence period. For example, a 10% increase in investment in roads led to a growth in productivity of 1.8% during the preindependence period, which increased to 4.0% during the postindependence period. Similarly, a 10% increase in expenditure on rice research led to a productivity growth of 1% from

Table 5. Estimated parameters of total factor productivity decomposition for rice, Bangladesh.

Explanatory variables	Preindependence period[a] (1952-70)	Postindependence period (1973-89)
Intercept	4.29	3.80
RESEARCH	0.041*	0.104*
	(4.52)	(9.49)
ROAD	0.178*	0.403*
	(2.06)	(6.14)
LITERACY	0.003*	0.003
	(2.74)	(0.35)
WEATHER	–0.237	–0.076
	(1.51)	(0.40)
Adjusted R^2	0.76	0.96

[a]Numbers within parentheses are asymptotic t values. * denotes that the regression coefficient is statistically significant at less than 5% probability error.
Source: Dey and Evenson (1992).

1973 to 1989, about 2.5 times higher than the contribution during the preindependence period. The investment in education, however, did not have any significant effect on productivity growth in the postindependence period.

Dey and Evenson (1992) estimated the marginal rates of return to investment in rice research from the above findings of the TFP decomposition analysis. The stream of marginal output produced from the investments was first computed from the estimated parameters and then internal rates of return were estimated as the discount rate at which the stream of output was equal to unity. The rate of return on research investment was found to be exceedingly high, at 149%. Bangladesh has benefited largely from rice research conducted at IRRI in the Philippines. Studies on the impact of IRRI's research on germplasm improvement in national agricultural research and extension systems (Hossain et al 2001) show that Bangladesh has used IRRI materials as parents for almost half of the improved rice varieties released to farmers. Assuming that 50% of the productivity gains in rice are attributed to the spillover effect from IRRI, the internal rate of return of public investment in rice research in Bangladesh was estimated at a robust 131%. This analysis provides strong empirical support to the high productivity of rice research investment in Bangladesh.

Factors affecting supply and demand trends

Determinants of supply

Several studies on the responsiveness of crop production to price changes are available for Bangladesh (Cummings 1974, Abedin 1985, Rahman 1986, Rahman and Yunus 1993, Alam 1992, Dorash et al 2001). The price response was very low with the exception of dry-season boro rice and jute, the major commercial crops. The most recent study by Dorash et al (2001) shows a short-run price elasticity of 0.16 for boro rice, 0.11 for aus, and only 0.05 for aman rice. The studies used the single-equation estimation of the Nerlovian supply response model, with the exception of Abedin, which used a translog profit function. Another limitation of the studies is that the area response functions excluded nonprice variables such as irrigation, which influences the production structure in Bangladesh most.

A modified version of the McGuirk and Mundlak (1971) model of dynamic supply response was used in this study to analyze the determinants of rice supply. The model uses a systems approach to estimate the effect of incentives and infrastructure variables on regulating supply. It distinguishes between irrigation techniques and between modern and traditional varieties, and decisions to allocate land to various cropping alternatives are assumed to be separable across seasons and within a season across rainfed and irrigated land. We were unable to estimate the input demand functions because of the lack of crop-specific data on input use.

Crop production in Bangladesh cycles over three distinct but overlapping seasons: aus (premonsoon, April to August), aman (monsoon, July to December), and boro (dry season, December to June). A two-season framework, however, appears more appropriate in analyzing crop and variety choices, given that (1) the average cropping intensity in Bangladesh has been about 174%, (2) only about 12% of the area is under triple cropping, and (3) different crops and varieties have specific agroecological requirements in land levels, soil type, and flooding depth. Since the aus and boro seasons largely overlap in the cultivation of different rice varieties (cultivation of boro rice precludes growing aus rice, but, for most of the land types, the cultivation of boro or aus rice does not preclude the cultivation of aman rice), we decided to group the boro and aus season crops as dry-season activities and the aman crops as wet-season activities.

The scope of the choice of technique (crops and varieties of rice) is much greater for the dry season than the wet season, when only rice and a special variety of jute can be grown because of flooding and high soil moisture. Modern rice varieties can be grown during the dry season if irrigation facilities are available, but they will replace many other crops that could also be grown with residual soil moisture and limited rainfall, such as jute, wheat, aus rice, and many different pulses, oilseeds, and vegetables. The long-duration deepwater aman rice is established as a direct dry-seeded crop during March-April and grows as an upland crop before the onset of floods in July and as a deepwater crop during the flood period (July to November). It is harvested after the floods recede. Since the deepwater rice competes for land with crops grown during the dry season, this aman rice variety is planted together with traditional aus rice and included in the set of crops for the dry season. For this study, the following crops are included in the choice set, depending on season and availability of irrigation:

- Dry-season irrigated: boro, wheat, pulses, mustard and rapeseed, potato
- Dry-season rainfed: rice (aus + deepwater aman), jute, wheat, pulses, and mustard
- Wet-season rainfed: modern transplanted aman, traditional transplanted aman

The McGuirk-Mundlak model treats irrigation as an important infrastructure variable that stimulates the supply response through incentive variables such as relative profitability among crops. For this study, the irrigated area has been classified into two types, private irrigation and public irrigation. The area under irrigation reported by the BBS includes traditional irrigation by swing baskets and hollow wooden lifters operated manually. It is hard to link this type of irrigation with policy variables. Canal irrigation has been under the control of the BWDB and is linked with flood control, irrigation, and drainage projects implemented by the government. Hence, it was treated in this study as public irrigation. The area irrigated by deep tubewells was also included under this category since the government subsidized this type of irrigation heavily and, until recently, BADC had rented deep tubewells to government-sponsored cooperatives. The area under low-lift power pumps and shallow tubewells is under private irrigation. The land under private irrigation has been treated as a quasi-fixed factor, whereas the land under public irrigation has been treated as an exogenous variable.

The main explanatory variables in the supply response model are the expected relative profitability of crops that compete with land and other resources during the growing season. Following McGuirk and Mundlak (1991), we measured expected profits by revenue of the crop (price × yield) for the previous season. After experimenting with alternative expectation variables, we used the average of the previous two seasons' crop yield and one season's price to produce the expected revenue variable. Information on prices at the district level, obtained from the Department of Agriculture Marketing, has been used for the study. For rice, the average price for coarse varieties of aus, aman, and boro has been constructed from the weekly price series in accordance with the seasons when these are marketed.

The system of supply equations has been estimated in two stages under a sequential decision-making framework. In the first stage, cropped land and private irrigation, which are considered quasi-fixed factors, are assumed to be determined by (1) the availability of total resources measured by per capita agricultural income and rural population per unit of land; (2) farm and nonfarm activities, measured by the expected revenue of the crop sector relative to the expected revenue of the noncrop sector; and (3) the lagged dependent variables that measure the flexibility of adjustment in the quasi-fixed factors over time. The amount of land and irrigation that farmers have decided to allocate during the season were then introduced as exogenous variables in the next stage of decision making when farmers decide how to allocate these resources among different crops depending on the set of incentive variables (expected relative profitability among crops, prices of variable inputs, etc.) and other exogenous factors. At this stage, we related the share of different competing crops of the total land-specific types to the set of incentives and infrastructure variables.

The model has been estimated with pooled time-series and cross-section data at the greater district level for 1983-84 to 1990-91. The iterative seemingly unrelated regression (SUR) method was used to estimate regression equations for each block. In estimating the area allocation equations, symmetry restrictions were imposed across coefficients of expected revenue variables. Cross-equation restrictions were also imposed to ensure that the net effect of the price change on the sum of shares of all crops is zero. Where necessary, corrections were also made for auto-correlations and heteroscedasticity. In all cases of the area share equations, we included district dummies to take into account structural differences (agroecological and climatic variations) among the districts. Dummy variables were also used to separate the effect of natural disasters and seasonal variations in rainfall.

The estimated parameters of the incentives and infrastructure variables of the area share equations are reported in Appendix Table 1. The parameters of the district dummy variables are not reported in this Table. The results show that an increase in the price and yield of competing crops—wheat and oilseeds—would reduce the allocation of land to boro rice, as shown by the negative value of the coefficients of the expected revenue variables, but the influence is not strong. The supply response of boro rice to its own price and yield is positive and statistically significant. The infrastructure variables, particularly private investment in shallow tubewells and low-lift pumps, have a much stronger positive effect on the supply of boro rice, as shown by the high statistical significance of the regression coefficient. The area increase under boro rice in response to the expansion of private irrigation, however, comes at the expense of wheat, as indicated by the negative and statistically significant coefficient of this variable in the area share equation for wheat. An increase in the price and yield of rice and oilseeds would also reduce the area under wheat.

The expansion of private irrigation has a large negative effect on traditional aus and deepwater aman, but not on jute and oilseeds. Results show that the private investment in irrigation results in an increase in the supply of boro rice at the expense of irrigated wheat, traditional aus, and deepwater aman.

In the absence of any important nonrice crops grown during the wet season (aman), we considered two rice varieties—traditional transplanted aman and modern transplanted aman for the wet season. A single rice price variable (aman rice) deflated by fertilizer price was included in the area share equations as an incentive variable. The result shows that the relative input-output price for rice did not have any significant effect on the area allocation decisions. This result is expected because farmers do not have any choice but to grow rice when the land remains flooded during the monsoon season, irrespective of the price situation. The availability of irrigation, however, gives them the option to grow higher-yielding modern varieties since they could protect the investment through supplementary irrigation if a late-season drought occurs. This is indicated by the positive coefficient of private irrigation in the area share equation of modern transplanted aman and the negative coefficient in the equation for traditional transplanted aman.

The elasticity of crop output on price and nonprice variables, as estimated from parameters of the area share equations, is shown in Table 6. The own-price elasticity is very low for rice (0.06) and wheat (0.15), but fairly high for jute (0.31) and mustard (0.22). The cross-price elasticity between jute and mustard is positive, which indicates that these two crops could coexist within the same cropping pattern, that is, jute could be grown on the same land after harvesting mustard. The findings suggested that farmers in Bangladesh are less responsive to price changes, at least in the short run.

In the long run, however, price changes could influence supply by inducing investments in irrigation. The provision of irrigation changes crop choices and the

Table 6. Estimates of short-run elasticity of crop output to prices and irrigation.

Variables	Rice	Wheat	Jute	Mustard
Prices				
Rice	0.06	–0.08	–0.11	–0.09
Wheat	–0.00	0.15	–0.11	–0.09
Jute	–0.01	–0.12	0.31	0.00
Mustard	–0.00	–0.04	0.02	0.22
Irrigation[a]				
Private sector	0.12	–0.21	–0.39	0.17
Public sector	0.06	0.10	–0.03	–0.15
Rice yield	1.02	–0.08	–0.11	–0.09

[a]Private-sector irrigation includes low-lift pumps, shallow tubewells, and hand tubewells. Public-sector irrigation includes area irrigated by canals and deep tubewells.
Source: Estimated from simulation of the estimated model.

relative profitability of various crops. Private investment in irrigation promotes rice supply by facilitating the adoption of modern rice varieties in both the dry and wet seasons. The public-sector investment in irrigation had a much smaller effect on rice production. One reason for the differential effect of the two types of irrigation may lie in the management problem associated with the large- and medium-scale irrigation projects implemented under the public sector. Farmers may not avail themselves of the full benefits of irrigation for the area covered by these projects and they may choose to grow crops requiring less irrigation water, such as wheat and modern aman varieties. The elasticities of output on rice yield were estimated indirectly from the parameter of the expected revenue (price × yield) variable for rice. The value of the elasticities is equal to unity, which shows the importance of technological progress in increasing rice supply. The increase in rice yield had negative incentives for growing other crops.

Determinants of demand

There have been more frequent attempts to estimate demand parameters for Bangladesh than comparable studies on supply response. These studies initially focused on rice and food grains (Alamgir and Berlage 1973, Mahmud 1979), but later studies attempted to capture a broader set of commodities (Chowdhury 1982, Pitt 1983, Rahman and Hossain 1988, Goletti and Boroumand 1992, Talukder 1993, Ahmed and Shams 1993). The studies have also evolved in terms of the underlying conceptual framework, which has been characterized by an increased use of sophisticated estimation techniques. For example, efforts have been made to estimate the almost ideal demand system (AIDS), which has a theoretical basis, and the econometric estimation technique permits imposing appropriate restrictions on parameters during estimation (Goletti and Boroumand 1992). The main problem, however, has been associated with incorporating price variables since most studies are based on cross-section data collected by the household expenditure survey (HES).

For this study, we developed an alternative framework that enables the use of published HES data for several years and can thereby capture the effects of price changes on consumer choices. We have used a multistage budgeting framework in which prices at different stages are linked to trace effects of changes in any one price. Since the link is provided by sample data, we have estimated elasticities through simulation rather than deriving them from estimated parameters.

At the first stage, it is assumed that the household will allocate total expenditure on major expenditure groups depending on its real disposable income and real prices for the expenditure groups. We consider three broad expenditure groups at this stage: food, clothing, and fuel and lighting. The expenditure share of each group is assumed to be a function of the logarithms of the price and income variables, and household size. A square term of the income variable is included to capture the nonlinear effect of income on the demand for specific commodity groups. At the second stage, the total expenditure on food estimated from the first stage is allocated to different groups of food items such as cereals, protein group (meat, fish, pulses, and meat), vegetables, edible oil and spices, fruits, and others. It is assumed that the allocation of food expenditure to these subgroups of food items would depend on the amount of real income available for the group, the relative prices for these subgroups of food items, as well as any scale effect due to variation in household size. At the final stage, the consumption of individual food items, such as rice, is expressed as a function of the per capita expenditure for the subgroup (cereal) and the prices of substitute commodities within that subgroup. At each block of the equation, a square term of the income (expenditure) variable was included to capture the nonlinear effect.

To estimate first-stage equations, we used the general price index and the price indices for the major expenditure groups from which the Bangladesh Bureau of Statistics constructs the cost of living index. At the level of food subgroups, the price indices were not available. We constructed the price indices using the harvest prices for major crops. For individual food items, we also used harvest prices.

At each stage, the relevant set of equations was estimated by the iterative SUR method. The only exception was in estimating third-stage equations for rice and wheat for urban areas where the application of three-stage least squares provided a better fit to the data. The change in higher-level price index (say, cereals) caused by the price change at a lower level (say, rice) was worked out during simulation.

The expenditure and price elasticities of demand for rice estimated from the model for rural and urban areas and for different income groups are reported in Table 7. The average expenditure elasticity for rice is estimated at 0.41 for rural areas and 0.27 for urban areas. The elasticity value declines sharply with the increase in income levels, more so for urban areas than for rural areas. For urban households, rice has reached the stage of being an inferior good only for the top 20% and will soon become so for the top 40–80% of the households in the income scale. But, in rural areas, the expenditure elasticity is still large, even for higher-income groups.

The own-price elasticity of rice is negative. Thus, the substitution of other food for rice in response to high rice prices is much stronger for urban consumers than for rural consumers. Rice-price increases raise the real incomes of rural households as producers of a major commodity, especially for those in the higher-income brackets. It is therefore quite expected that the own-price elasticity would be lower for the rural

Table 7. Estimates of expenditure and price elasticity of demand for rice, Bangladesh, urban and rural areas.

Income groups	Rural areas		Urban areas	
	Expenditure elasticity	Own-price elasticity	Expenditure elasticity	Own-price elasticity
Bottom 20%	0.96	–0.70	0.74	–1.08
20–40%	0.68	–0.43	0.28	–0.65
40–60%	0.53	–0.30	0.12	–0.50
60–80%	0.42	–0.21	0.04	–0.42
Top 20%	0.20	–0.03	–0.02	–0.41
All groups	0.41	–0.20	0.27	–0.65

Source: Authors' estimation using a multistage budgeting approach.

rich since the positive income effect will balance the negative substitution effect. The low price elasticity of demand, however, suggests that the price of rice will increase proportionately much more in response to any shortage in supply in relation to demand. Since a large proportion of the consumer expenditure is spent on rice, particularly at lower income levels, a rice shortage would have serious implications for the poverty situation in the country.

Perspective on demand-supply balances

Will Bangladesh be able to sustain the self-sufficiency in food-grain production achieved in 2000-01? In this section, we attempt to project the demand-supply balances for the 2000-20 period using a "common sense" approach based on the findings of the previous section on the determinants of demand and supply. The supply and demand exercises are carried out separately. No equilibrium price is determined; hence, the effect of the change in prices on demand and supply is ignored. This may not affect the results much as the price elasticity of supply is insignificant (except for boro rice). With the liberalization of external trade, we expect the rice price to follow the world market price (export parity), with some fluctuations in the short run depending on supply shortages caused by climatic factors.

The demand for food grains will be determined mostly by the increase in population, the composition of the rural and urban population, and, to a marginal extent, by the growth in per capita income and changes in the income elasticity of demand.

The preliminary report of the population census undertaken in January 2001 shows that the population has reached 129.2 million, with 23.4% living in urban areas. The rate of population growth declined sharply from 2.4% per year during the 1980s to 1.6% during the '90s. Following the population projection made by the United Nations, we assumed a growth rate of 1.3% from 2000 to 2010 and 1.1% from 2010 to 2020. The projected population is 160 million for 2020, about 12 million less than the number projected on the basis of the report of the 1991 population census. The urban population grew at 3.4% per year from 1991 to 2001, mostly because of the rural-urban migration and expansion of urban areas. We assumed that urbanization will proceed at the same rate from 2000 to 2020 as during the 1990s, and derived the rural population as the residual. According to this projection, nearly 36% of the population will be located in urban areas by 2020. The projected population is reported in Table 8.

Table 8. The projection of rural and urban population, 2000-20.

Year	Population (million persons)			Rate of growth (percent y^{-1})
	Rural	Urban	Total	
1991 (actual)	88.2	21.6	109.8	2.4
2001 (actual)	98.9	30.3	129.2	1.6
2010	104.2	40.9	145.1	1.3
2020	103.1	57.7	160.8	1.1

The analysis of consumer demand as reported in the previous section shows that the expenditure elasticity of demand is lower in urban areas than for rural areas and the value of elasticity declines with the growth in income. The income elasticity of demand is lower than the expenditure elasticity because of the high marginal rate of savings. The National Agriculture Commission estimated, by analyzing the HES report of 1996, that the income elasticity of demand for rice reached 0.18 in 1996 and will decline to negative 0.8 by 2020. The Commission projected that per capita rice consumption may continue to increase for rural areas till 2020, but for urban areas it will decline sharply. However, per capita wheat consumption will grow for both rural and urban areas, but at a higher rate for urban areas because of changes in food habits. The projections made under two alternative scenarios of income growth (5.0% and 7.0%) showed a marginal difference in the projected numbers for per capita consumption of rice. We used the Agriculture Commission's projection of per capita consumption of rice and wheat at 7.0% growth in national income for the projected rural and urban population to project the increase in demand for cereal grains for 2010 and 2020.

The estimates show that the demand for rice will grow at 1.5% per year from 2001 to 2010 and by only 0.7% per year from 2010 to 2020. The demand for wheat, however, will grow at 3.2% per year from 2001 to 2010 and by 2.8% from 2010 to 2020. It can be noted here that in Bangladesh the gap in the price of coarse and fine-quality rice has grown substantially in recent years. This indicates that the demand for fine-quality rice has been growing fast with urbanization and the increase in income, but the supply has not been able to catch up with the demand because most of the high-quality rice comes from traditional varieties. Although the average demand for rice will grow at a much slower rate over the next two decades, we expect a faster growth in the demand for high-quality rice while there might be an absolute decline in the demand for standard-quality rice. This change in the composition of the demand for rice has important implications for future rice breeding strategies.

As noted in the previous section, the major determinants of supply are (1) the distribution of land by agroecology, which constrains farmers' choice of alternative crop varieties; (2) the area under irrigation, which affects the choice between traditional and modern rice varieties; and (3) the agricultural research and extension effort that will determine the growth in total factor productivity in individual crop varieties and the reduction in unit costs of production.

We assume that for the 1.3 million ha of highland where aus rice is presently grown, farmers will gradually shift the land from traditional aus to grow high-value crops such as vegetables, fruits, and spices during the dry season. For the wet season, however, when there is too much moisture, they will continue to grow modern-variety aus under rainfed conditions in the highland. They will also continue to grow traditional boro (dry-season) rice on 200,000 ha of extreme low-lying land and deepwater aman on 700,000 ha that are flooded at a medium depth during the monsoon season. For this land type, modern varieties are not suitable because of high flooding depth and farmers have no other choice but to grow rice or to keep the land fallow. In the land with low flooding depth, the shift from traditional to modern transplanted aman varieties will continue depending on the availability of medium-height, shorter-duration aman varieties, the incorporation of submergence-tolerance traits in modern varieties, and the availability of supplementary irrigation.

The expansion of area under modern-variety boro depends almost entirely on the availability of reliable irrigation (Hossain et al 1994). The potential to expand groundwater irrigation has almost been exhausted. Further expansion may not be justified on environmental grounds—to prevent overexploitation of groundwater beyond the recharge potential of the aquifer and to mitigate concerns regarding the supply and quality of drinking water. Potential exists to harvest water during the monsoon season for use during the dry season, through surface-water development projects, but such investment has to be undertaken by the government. The investment may not be economical in view of the prevailing weakness in the management of surface-water irrigation projects and the potential to increase farmers' income through crop diversification during the dry season. We have assumed that there will be no further expansion of irrigation infrastructure, but there will be some increase in irrigated area through greater capacity use of existing facilities, particularly if the trend in rice prices provides adequate incentives to farmers to grow modern varieties. We assume an expansion of modern-variety boro area from 3.4 to 3.8 million ha from 2000 to 2020.

For the projection of the yield rates, we used the estimates of the TFP trend for modern varieties and the historical growth in rice yield for traditional varieties. This presupposes (1) a continuation of rice research and extension efforts at the same level, (2) a further increase in the use of chemical fertilizers in the traditional varieties but no increase in modern varieties, (3) some redirection of research efforts for pure-line selection for traditional varieties, (4) rapid expansion of the market for high-quality seeds for both modern and traditional varieties, and (5) the dissemination of more efficient crop management practices. We expect a further reduction in the use of labor in rice cultivation, but assume that mechanization will expand to substitute for labor and that there will be no yield effect because of this factor.

The outcome of these assumptions on the increase in the supply of cereal grains is shown in Appendix Table 2. The supply-demand balances for rice and wheat based on these estimates can be seen in Table 9. It appears from the numbers that from 2000 to 2010 Bangladesh may be able to maintain self-sufficiency in rice in normal years, but shortages might occur in the years of bad harvests. There will be some deficit in wheat from domestic production that could be met through imports. From 2010 to 2020, Bangladesh may produce a small surplus in rice that could compensate for the deficit in wheat production.

Conclusions and policy implications

Under a favorable scenario, we can expect Bangladesh to produce just enough rice to meet the domestic demand in normal years but to incur small deficits in years of natural calamities. Wheat importation at the present level will continue. In such a context, questions on policy intervention can be raised from several perspectives. For example, Are there feasible policies to manipulate the future scenario? What are the

Table 9. Projected balance in the supply and demand for rice and wheat, 2000-10 (million t).

Item	2000	2010	2020
Demand			
Rice (milled)	22.87	26.15	28.07
Wheat	2.13	2.82	3.75
Total	25.00	28.97	31.82
Supply			
Rice (milled)	22.38	26.02	29.13
Wheat	2.29	2.54	2.79
Total	24.67	28.56	31.92

Source: Authors' estimates.

implications of current policy practices for the projected scenario? Do they call for policy interventions? This concluding section analyzes these issues.

Since tastes take a longer time to change, policy interventions on the supply side in changing the future situation may be more realistically considered. Appropriate investments in the water sector may enable wider coverage of modern high-yielding varieties and thereby shift the production frontier for rice. Alternatively, subsidy on inputs and supporting rice prices at an artificially high level may induce more intensive cultivation of rice. However, implementation enforcement of all such policies would entail huge budgetary costs. Since the low-quality modern rice varieties cannot be marketed abroad, surpluses of these varieties are not socially desirable and will merely depress prices in the domestic market. A more desirable route may be to increase the allocation for research. If this bears fruit (increasing yield without involving excessive input costs), some land may be released to produce other remunerative crops. Research on high-yielding aromatic rice varieties in the Bangladesh environment would also widen the choice of farmers. Along with improved irrigation management and agro-processing, rice research to develop appropriate technologies is likely to enhance the potential of diversification in the crop sector.

Current policies in Bangladesh are evolving more toward the market economy, in which the private sector is expected to play the dominant role. Given this policy direction, the projected scenario is likely to have two important implications. First, because of a wide gap between import parity and export parity prices, the annual fluctuation in domestic rice prices will be more pronounced. This needs to be tackled through government intervention in the food-grain market. Second, with the opening up of market opportunities and provision of incentives for variety and crop diversification and promotion of high-profit crops for export (e.g., aromatic rice varieties and vegetables), the positive externality of the past growth in food grains on poverty alleviation through price declines will be greatly reduced. Policies need to examine both these issues for political stability that is so crucial to sustaining economic growth in the future.

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Notes

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Appendix

Table 1. Estimates of the crop-share equations for determining supply response to price and irrigation variables, Bangladesh.[a]

Explanatory variables	Irrigated land, dry season		Rainfed land, dry season				Wet season	
	Boro rice	Wheat	B. aman rice	Jute	Wheat	Mustard and rapeseed	Traditional transplanted aman rice	Modern transplanted aman rice
Intercept	0.477**	0.205**	0.57**	0.002	–0.013	0.018	0.62	0.108
	(10.85)	(5.19)	(20.4)	(0.19)	(1.55)	(0.27)	(5.30)	(0.80)
Expected revenue								
Rice	0.078*	–0.067	0.061	–0.072**	0.034**	–0.023		
	(1.66)	(1.61)	(1.60)	(4.23)	(2.12)	(1.21)		
Wheat	–0.067	0.075*	0.037**	–0.045**	–0.018	–0.013		
	(1.61)	(1.88)	(2.12)	(4.64)	(1.34)	(1.34)		
Jute			–0.072**	0.108**	–0.045**	0.009		
			(4.23)	(8.22)	(4.64)	(0.95)		
Mustard	–0.0066	–0.011*	–0.023	0.009	–0.013	0.043**		
	(0.62)	(1.61)	(1.21)	(0.95)	(1.34)	(2.21)		
Private irrigation	0.569**	–0.24**	–0.476**	0.030	–0.016	0.153*	–0.563**	0.573**
	(5.93)	(2.83)	(3.64)	(0.64)	(0.34)	(4.43)	(3.93)	(3.47)
Public irrigation	0.243**	0.170	–0.351	0.125**	–0.047	–0.030	0.019	0.156
	(1.66)	(1.27)	(1.78)	(2.15)	(0.77)	(0.71)	(0.61)	(0.70
Fertilizer/rice price ratio							0.021	0.020
							(0.29)	(0.24)
Interaction of deeply flooded area with public investment in flood control and drainage			0.0033**	–0.0004	–0.0008**	0.0002		
			(3.31)	(1.28)	(2.48)	(0.75)		
Adjusted R^2	0.94	0.93	0.87	0.89	0.69	0.90	0.94	0.84

[a]The expected revenue and public expenditure are measured in units of 000 Tk. The dependent variables are the share of the total land for the specific type, that is, irrigated dry, rainfed dry, and wet season. Significance levels of 1% are denoted by ** and those of 10% by *.
Source: Authors' own estimates using the McGuirk and Mundlak (1991) method.

Table 2. Projected changes in rice and wheat production, 2010-20.

Ecosystem/ varieties[a]	Cropped area (000 ha)			Rice yield (t ha^{-1})			Rice production (000 t)		
	2000	2010	2020	2000	2010	2020	2000	2010	2020
Wet-season rice	5,708	5,700	6,300	2.69	3.22	3.56	15,382	18,363	22,433
Deepwater aman	775	620	1,200	1.65	1.74	1.82	1,281	1,079	2,184
Transplanted TV aman	2,171	1,500	1,300	2.20	2.32	2.43	4,779	3,712	3,159
Transplanted MV aman	2,762	3,480	3,800	3.38	3.90	4.50	9,322	13,572	17,100
Dry-season rice	5,005	4,630	4,400	3.80	4.68	5.09	19,064	21,674	22,378
TV aus	913	230	0	1.53	1.61	–	1,397	370	–
MV aus	439	400	400	2.71	3.00	3.31	1,191	1,200	1,324
TV boro	227	200	200	2.42	2.54	2.67	549	534	534
MV boro	3,426	3,800	3,800	4.65	5.15	5.40	15,927	19,570	20,520
Total rice	10,713	10,330	10,700	3.22	3.88	4.19	34,446	40,037	44,811
Wheat	833	940	1,040	2.29	2.54	2.79	1,908	2,388	2,902

[a] TV = traditional variety and MV = modern variety.

Governance constraints to sustainable rice productivity in the Philippines

V.B.J. Tolentino

Since the early 1980s, growth in rice production in the Philippines has been quite slow. The rate of growth in rice productivity in particular, and in the country's agricultural sector in general, has also lagged behind much of Asia.

Political instability has contributed to the disappointing performance of the Philippines in food security and agricultural and rural development over the past 20 years. This paper outlines the effects of political and bureaucratic instability on the formulation and implementation of government policy and support programs for food security and agricultural productivity, particularly for rice.

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This paper aims to provide insights into aspects of the political economy and public administration regarding the effectiveness and efficiency of efforts to boost rice production, specifically in the case of the Philippines. It is clear that the significance of public goods and public policy is greater in rice productivity and growth than in most other commodities. Research and analysis that increase attention to public-sector governance as a crucial factor in the attainment of sustainable food security are thus appropriate.

The first section summarizes the performance of the Philippine rice sector over the past three decades, while the second section describes the country's institutional structure for governance of the agricultural sector. The third and fourth sections emphasize the frequency with which Philippine government officials have been changed since the 1980s and the negative effect of such changes on agricultural and food security programs. The fifth section takes a closer look at the effects of discontinuous leadership on the agricultural program's capacity for strategic sector planning and, finally, the sixth section concludes with some suggestions to strengthen the stability of the bureaucracy and in so doing help ensure improved governance for rice productivity.

The Philippines' overall performance in rice production,[1] productivity, and population growth

Growth in total rice production in the Philippines has averaged 2.44% per year from 1980 to 2000. This rate is considered quite low because, over the same period, the population of the Philippines was growing relatively rapidly at an average of more than 2.3% (Fig. 1).

Total rice usage in the Philippines began to regularly outstrip domestic rice production in the 1990s, and since then the country has shifted from a state of marginal self-sufficiency to that of a regular and growing importer of rice—the largest customer for the exports of Vietnam of low-quality rice and a regular customer for the better-quality rice exports of the United States, particularly those under soft loan terms provided by programs such as U.S. Public Law 480.

Relative to its major rice-producing neighbors in the ASEAN (Association of Southeast Asian Nations) region, the Philippines has been left behind in productivity growth (Tolentino et al 2001b). Over the 1990s, the rice productivity growth of Viet-

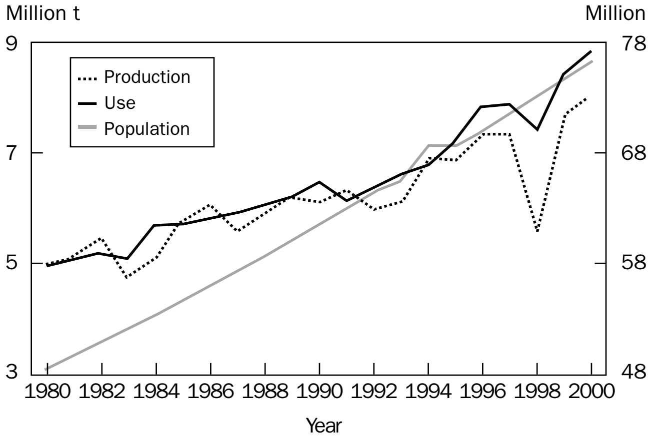

Fig. 1. Rice production and use and population, Philippines, 1980-2000.

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[1] For more details on the rice sector in the Philippines, see Tolentino et al (2001a).

nam spurted upward and that of Thailand rose steadily. In contrast, Philippine rice productivity stagnated (Fig. 2).

Equally worrisome are the trends in rice prices. In the 1990s, while world rice prices remained relatively low and stable, domestic consumer prices were two to three times those of Vietnam and Thailand and also more volatile (Fig. 3).

Unfinished reforms

Philippine governance has been unable to substantially implement the broad range of policy and institutional reforms necessary for long-term sustainable growth and

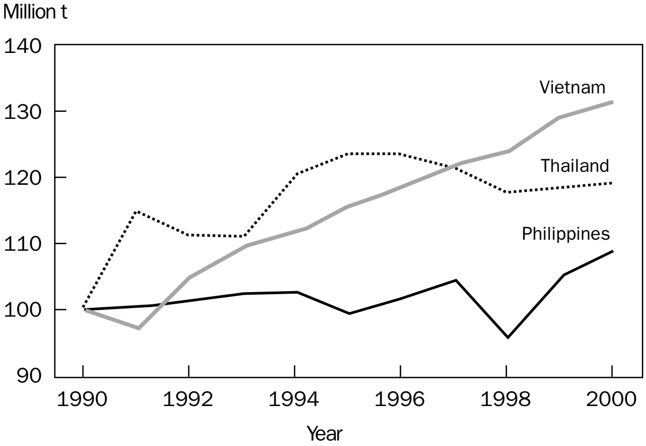

Fig. 2. Trends in paddy yields, Philippines, Thailand, and Vietnam, 1990 = 100.

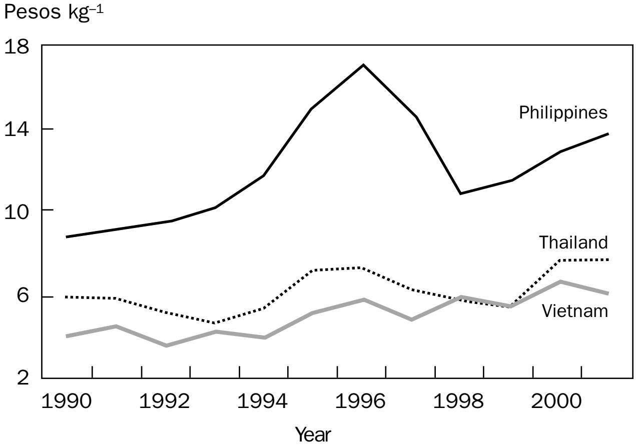

Fig. 3. Domestic consumer rice prices in Philippine peso terms, Philippines, Vietnam, and Thailand, 1990-2000.

development. From the early 1980s onward, a wide-ranging agenda of reforms has been set but left unfinished.[2]

The reforms left uncompleted include (1) the transfer of land ownership from large landowners to landless farmers under the comprehensive agrarian reform program; (2) the cost-effective delivery of support services, including infrastructure and technology, to farmers; (3) productivity- and competitiveness-enhancing policy reforms in grains, sugar, and coconut; (4) revitalization of the food parastatal, the National Food Authority (NFA); (5) quantum increases in public investments in irrigation, technology, and other public goods; and (6) the full financing and implementation of the Agriculture and Fisheries Modernization Law (DA 1998).

Several of the above reform areas have a direct bearing on rice productivity and food security: the provision of public goods determines the pace of productivity growth. Also crucial are irrigation and transport infrastructure and market interventions, particularly the reduction in constraints to international trade and domestic shipping.

The National Food Authority

The government food parastatal, the NFA, continues to exercise monopoly powers over the international trade of rice in the Philippines. Along with South Korea, the Philippines remains one of only two countries in the World Trade Organization (WTO) that maintain quantitative restrictions (QRs) on rice imports. These extended monopoly powers of the NFA and its tight implementation of these QRs have maintained high farm-gate and consumer prices in the country. This has contributed to an overreliance of policymakers on price intervention instruments rather than productivity increases to support farmers' income and ensure domestic food security.

As set by law—Presidential Decree 4 (1972)—the mission of the NFA is praiseworthy: buy high (from farmers), sell low (to consumers), and store long (to stabilize prices). However, its performance over the past three decades shows that its mission has been impossible to achieve successfully (see DA, DF, ADB, 2001).

The institutions of rice-sector governance in the Philippines

Over the past two decades, while there has not been much growth and change in Philippine agriculture, there have been many and frequent changes in the institutional structures of governance, as well as in the officials of government responsible for the sector's governance. To what extent can such frequent changes in the agricultural bureaucracy and bureaucrats explain the poor performance of the sector?

The basic institutions of government

The Philippine government is made up of co-equal and independent branches: the executive, legislative, and judiciary. The President is the chief executive. The President's cabinet is made up of secretaries who head key executive departments.

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[2] For a comprehensive enumeration of the unfinished reforms, see Tolentino (1999).

Directly supporting the President is the Office of the President, made up of the executive secretary and the presidential management staff (PMS). The executive secretary serves as the President's chief executive officer, and is thus termed the "little President" in everyday bureaucratic operations.

Key executive departments

By law, the three key agencies of the Philippine government that are responsible for rural and agricultural development are the departments of (1) Agriculture (DA), (2) Environment and Natural Resources (DENR), and (3) Agrarian Reform (DAR). Before the early 1980s, the DA was also responsible for matters related to agrarian reform and environment and natural resources as the large unified Department of Agriculture and Natural Resources (DANR).

The DA, DENR, and DAR are each headed by a department secretary, who is a member of the President's cabinet. Note that, before 1972, the roles and functions now split among the three departments were in only one: the DANR.

Of course, other departments also influence the agricultural and rural sector and the workings of the DA, DAR, and DENR. These are, in particular, the departments of (1) Public Works and Highways (DPWH), (2) Transportation and Communications (DOTC), (3) Trade and Industry (DTI), (4) Budget and Management (DBM), and the (5) National Economic and Development Authority (NEDA).

The Department of Finance (DOF) and the Bangko Sentral ng Pilipinas (BSP, Central Bank of the Philippines) exert major indirect influence on rural and agricultural development through fiscal and monetary policies.

Basic departmental structure

Within each major department, the Office of the Secretary includes the undersecretaries and assistant secretaries. These senior officials are alter egos of the secretary and serve to extend the secretary's authority into specific areas and assignments. In general, each department has three undersecretaries and three assistant secretaries.[3]

According to the commissioner of the Civil Service Commission (CSC), undersecretaries exercise line authority and assistant secretaries are responsible for staff functions.[4] However, in practice, these distinctions are either unknown to or ignored by the departments, since the undersecretaries and assistant secretaries indeed undertake a mixture of line and staff functions, depending on the assignments they receive from the secretary.

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[3] Before 1992, the number of undersecretaries and assistant secretaries in each department was not fixed. Beginning in 1992, Congress legislated limits of three undersecretaries and three assistant secretaries per department by legislating limits on the budget appropriations for these posts.

[4] Interview with Ms. Patricia Santo Tomas, former commissioner of the CSC, August 2000.

The rest of the departmental organization is made up of the bureaus, regional and other local offices, and attached agencies and corporations. The bureaus are core units of the departments and they generally undertake or provide specialist and technical functions and services.

The attached corporations (government-owned and operated) were chartered, or created, by law. Their charters specify their "attachment" to particular government departments or ministries. Attachment to a department is generally understood to be for the purpose of policy coordination, and thus the department to which a government corporation is attached is usually that which has responsibility for or authority over a particular sector. For example, the Fertilizer and Pesticide Authority (FPA) is attached to the DA and the agriculture secretary serves as the chairperson of the FPA board of directors.

Attached corporations are expected to raise revenues and even be self-financing by selling particular goods or services that normally would be sold by private enterprises. However, the corporations are created because, for the goods or services concerned, private production is either temporarily not feasible for competitive production or is being done by a private monopoly and thus the government corporation is expected to provide the competition. Thus, by and large, the corporations continue to require subsidies through occasional capital infusions or regular appropriations.

Frequent reorganizations

Over the past two decades, the DA has undergone several episodes of reorganization and devolution: 1983-84 under secretaries Tanco and Escudero, 1986-87 under secretaries Mitra and Dominguez, 1992-94 under secretaries Bacani and Sebastian, and 1998-2000 under secretaries Angara and Panganiban.

As of 2001, the DA has 53 offices, units, regional offices, bureaus, attached agencies, and corporations (Table 1).

Devolution since 1991

Since Republic Act 7160 (the Local Government Code, LGC, of 1991) was passed, the regional offices of key departments have been devolved to the local provincial and municipal governments. The regional offices have been maintained and are expected to serve as technical support units for the local government units (LGUs).

The LGC focused its devolution requirements on only three departments: the DA, Department of Health (DOH), and Department of Social Welfare and Development (DSWD). Note that, out of the three key departments responsible for agriculture and rural development, only the DA was devolved.

The strategy behind the partial implementation of devolution across agencies is that progress in devolution per the LGC was to be assessed after five years. The results of the assessment would then guide the expansion and modification of the LGC. Unfortunately, it seems that the five-year assessment was never fully implemented and thereby not translated into amendments of the LGC.

Also, unfortunately, the LGC as enacted in 1991 left many threads hanging and undefined. Therefore, in the absence of more specific instructions and authorization,

Table 1. Component units of the Department of Agriculture per executive orders 116 (1987) and 272 (1987), GAAs since 1990, RAs 8435 and 8550, DA AO6 (1998), and other AOs. GAAs = General Appropriations Acts, RAs = Republic Acts, AOs = Administrative Orders.

Group	Unit
Secretary of agriculture	(1) Secretary of Agriculture (2) Three undersecretaries (3) Three assistant secretaries (4) Head executive assistant
Office of the secretary of agriculture	(1) Administrative Service (AS) (2) Agribusiness and Marketing Assistance Service (AMAS)[a] (3) Agriculture and Fisheries Information Service (AFIS)[b] (4) Field Operations Service (FOS) (5) Financial and Management Service (FMS) (6) Information Technology Center for Agriculture and Fisheries (ITCAF) (7) Legal Service (LS) (8) Planning Service (PS)[c] (9) Policy Analysis Service (PAS)[c] (10) Project Development Service (PDS)[c]
Regional offices	One per region, regions 1 through 12, plus the Cordillera Administrative Region (CAR) and CARAGA, but not including the Autonomous Region of Muslim Mindanao (ARMM)
Bureaus	(1) Agricultural Research (BAR) (2) Agricultural Statistics (BAS) (3) Agricultural Training Institute (ATI) (4) Agriculture and Fisheries Product Standards (BAFPS)[d] (5) Animal Industry (BAI) (6) Fisheries and Aquatic Resources (BFAR) (7) Plant Industry (BPI) (8) Postharvest Research and Extension (BPHRE) (9) Soils and Water Management (BSWM)
Attached agencies	(1) Agricultural Credit Policy Council (ACPC) (2) Cotton Development Administration (CODA)[e] (3) Fertilizer and Pesticide Authority (FPA) (4) Fiber Industry Development Authority (FIDA) (5) Livestock Development Council (LDC) (6) National Agriculture and Fisheries Council (NAFC) (7) National Fisheries Research and Development Institute (NFRDI)[f] (8) National Meat Inspection Council (NMIC) (9) National Nutrition Council (NNC) (10) National Stud Farm (NSF) (11) Philippine Carabao Center (PCC) (12) Southeast Asia Fisheries Development Center–Aquaculture Department (SEAFDEC-AQD)[g] (13) Sugar Regulatory Administration (SRA)
Attached corporations	(1) Food Development Center (FDC)–a subsidiary of the National Food Authority (2) Food Terminal, Inc. (FTI)–a subsidiary of the National Food Authority

continued on next page

Table 1. continued

Group	Unit
Attached corporations	(3) Guarantee Fund for Small and Medium Enterprises (GFSME) (4) National Dairy Authority (NDA) (5) National Food Authority (NFA) (6) National Irrigation Administration (NIA) (7) National Tobacco Administration (NTA) (8) Philippine Coconut Authority (PCA) (9) Philippine Fisheries Development Authority (PFDA) (10) Philippine Genetics, Inc. (11) Philippine Rice Research Center (PhilRice) (12) Planters Foundation, Inc. (PFI)/Planters Products, Inc. (PPI) (13) Quedan Guarantee and Credit Corporation (QuedanCorp) (14) National Agribusiness Corporation (NABCOR), plus subsidiaries (15) Sacobia[h] Development Authority (SDA)

[a]Formed under AO 6 (1998) by merging the functions and personnel of the Marketing Assistance Service and the Agribusiness Investment Information Service, and renaming the AIIS the AMAS. [b]Formed under AO 6 (1998) by renaming the MAS and absorbing the Agricultural Information Division. [c]Created under AO 6 (1998). [d]Mandated under RA 8435. [e]Created under RA 8486. [f]Created under RA 8550. [g]Created under an ASEAN agreement. [h]Sacobia area in Central Luzon.

many subunits and functions of these agencies have generally continued to be centrally administered and undevolved.

For example, the DA has several key agencies and offices within it that continue to be centralized, such as the National Irrigation Administration (NIA), National Food Authority (NFA), Philippine Coconut Authority (PCA), National Tobacco Administration (NTA), and the Sugar Regulatory Administration (SRA). These agencies continue to exercise line functions and authority through independent offices at the regional, provincial, and in some cases municipal level. These offices also operate outside the purview of LGUs. Although these offices do some "consultation" with the LGUs, in essence their activities are under the full direction of their respective head offices, executives, and governing boards in Manila.

Frequent changes in bureaucrats responsible for rice-sector governance in the Philippines

Two key types of events have provided the contexts for frequent changes in officials responsible for rice-sector governance in the Philippines since the 1980s: elections and reorganizations.

Political appointments

Virtually all senior-level officials of the departments of the Philippine government, from the level of assistant director and upward to the secretary, are political appointees and are appointed directly by the President of the Philippines (assistant directors are at the 5th level of the Philippine bureaucracy, with cabinet secretaries occupying the first level below the President).

For example, at the Department of Agriculture, about 180 posts are to be filled by appointment of the President of the Philippines. Thus, when presidents change, the appointees to the top levels of government also change. Since there have been four changes of president since the departure of Ferdinand Marcos in 1986, at least four sets of changes of all political appointees have occurred.

Ongoing efforts exist to create a permanent civil service through the career executive service officer (CESO) system. However, the process of institutionalizing the CESO system has been slow because of its nature as a system of accreditation and qualification. To be recognized as a CESO and thereby protected from capricious removal from office, individual civil servants have to gain the qualifications required for appointment to a "permanent" or tenured post through examination and experience.

Despite the existence of the CESO system, however, appointing authorities have chosen to override the system or ignore its controls.

Five presidents in 35 years

Over the past 35 years, the Philippines has been led by a succession of five presidents. Mr. Ferdinand Marcos held on to the office for 20 of the 35 years. Presidents Corazon Aquino and Fidel Ramos served six years each. After President Marcos and under the Philippine constitution of 1987, Mr. Ramos has been the only President to serve out his full term of office—six years.[5]

President Joseph Estrada's service was shortened, while President Gloria Macapagal-Arroyo could serve for up to nine years. President Macapagal-Arroyo is currently serving the unexpired period of service of President Estrada, and she is eligible to stand for election and could win a full term of office from 2004 to 2010.

Nineteen executive secretaries in 36 years

In Philippine practice, the executive secretary of the cabinet serves as the so-called "little President," operationalizing the leadership of the President, as *primus inter pares* among the rest of the cabinet. Over the past 36 years, 19 men have served as executive secretaries.

On average, the executive secretaries of the past 35 years have served for 23 months. However, in more recent years, the executive secretaries have worked for much shorter periods. Six men were appointed to the post by President Marcos and served an average of 40 months. In contrast, President Aquino worked with four executive secretaries in six years, keeping them an average of only 19 months.

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[5] Mr. Ramos is generally regarded as a successful President, so much so that toward the close of his six-year term there was significant political support for a change in constitutional rules so that he could continue as President.

President Fidel Ramos had five executive secretaries during his six-year term. Over his presidency of only 31 months, Mr. Joseph Estrada worked principally with only one executive secretary.[6]

Finally, while the Presidency of Gloria Macapagal-Arroyo has yet to play itself out, so far she has already appointed two executive secretaries in only ten months.[7]

Eleven agriculture secretaries in 30 years

Eleven men have served as secretary of agriculture since 1971, averaging 33 months of service (Table 2). However, variability is great in the length of service among the agriculture secretaries. Secretary Arturo Tanco served for 162 months, while Secretary Domingo Panganiban served for barely a month.

With regard to the two men who served as agriculture secretary before 1986, Mr. Arturo Tanco was secretary from 1971 to 1984—a total of 162 months. Had the "EDSA Revolution" not taken place in February 1986, Mr. Tanco's successor, Dr. Escudero,[8] would have continued in office until at least 1990, adding another 48 months to the 20 that he had already served. Moreover, both Mr. Tanco and Dr. Escudero were no strangers to the Department of Agriculture. Mr. Tanco was assistant secretary for several years prior to being appointed secretary. Dr. Escudero had been director of the Bureau of Animal Industry (BAI) for several years before being promoted to the agriculture portfolio in 1984.

Table 2. Department of Agriculture leadership, 1971-2001 (as of December 2001).

Date	Secretary of agriculture	Months of service
January 1971-June 1984	Arturo Tanco[a]	162
July 1984-February 1986	Salvador H. Escudero	20
March 1986-February 1987	Ramon V. Mitra	12
March 1987-December 1989	Carlos G. Dominguez	34
January 1990-June 1992	Senen C. Bacani	30
July 1992-February 1996	Roberto S. Sebastian	44
March 1996-June 1998	Salvador H. Escudero	25
July 1998-April 1999	William D. Dar[b]	9
May 1999-December 2000	Edgardo J. Angara	19
6 January-15 February 2001	Domingo F. Panganiban	1
16 February-December 2001	Leonardo Q. Montemayor	10

[a]Including Environment, Natural Resources, and Agrarian Reform. [b]Acting secretary.

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[6] Mr. Estrada was elected in 1998 to a 6-year term as set by the Philippine Constitution. He was forced from the Presidency in January 2001. Mr. Zamora served as executive secretary until the month before Mr. Estrada was forced from office. Mr. Edgardo Angara then moved from the agriculture portfolio to Malacañang Palace, serving for barely a month before the administration of President Arroyo took over.

[7] Mr. Renato De Villa entered as executive secretary as President Arroyo began her administration in January 2001. He left in March 2001, citing health reasons. Mr. Alberto Romulo was asked by the President to leave the post of finance secretary to replace Mr. De Villa.

[8] Dr. Escudero, a veterinarian, was the dean of the College of Veterinary Medicine of the University of the Philippines when he was asked to serve as director of the Bureau of Animal Industry in the 1970s.

Thus, prior to 1986, the top leadership of the DA was quite stable, with the secretary and his team being in place for at least 5 years.

In contrast, the periods of service of the agriculture secretaries from the EDSA Revolution of February 1986 up to the present have been quite short. Since 1986, nine men have been appointed in quick succession to the post, each serving an average of only about 20 months. The longest period was 44 months—that of Secretary Sebastian in mid-1992 to early 1996. The shortest was that of Secretary Panganiban, barely a month in December 2000-January 2001 just before the "EDSA Revolution, Part 2."

It should be noted that since 1986 none of the agriculture secretaries have been able to serve their full terms as provided by law—six years. With the exception of the transition from Mr. Senen Bacani to Mr. Roberto Sebastian after the elections in 1992, all these secretaries came into office and left rather soon after, during a state of political turmoil.

Changing leaders, changing styles, changing programs

With each changing of the guard at the departments came changes in sectoral and departmental goals, objectives, strategies, timetables, programs, projects, and activities. Such changes were unavoidable, first because new people were in top positions in each of the departments, and new people at the very least meant changes in leadership styles and work arrangements.

The changes instituted immediately after the Marcos regime in 1986 were truly substantial. In the first place, there was a new openness and a return to democratic institutions, a clear differentiation between the very strong presidency (or, in some views, dictatorship) of President Marcos and that of Ms. Aquino, which was much more consultative and balanced by a reempowered legislature and judiciary.

The Aquino government came into power in 1986 with very broad, very ambitious ideas on reforms, initiatives, and programs. Most of these ideas still had to be translated into implementable form. Furthermore, many of President Aquino's appointees to the cabinet were also new to government service.

The combination of new initiatives and people new to government service meant that some time was necessary to "learn the job." This necessitated a very steep learning curve over a short period, and not a few birthing pains and mistakes. The task of learning the job is also complicated by the need for visibility and impact as soon as possible after taking office. This pressure results in two major initial preoccupations upon entry: (1) the need to erase the programs of the previous appointee and (2) the need to announce programs labeled as one's own, no matter if the difference is only the label.

Frequent changes in programs

A clear example of the need for immediate impact and visibility is the series of reinvented programs for rice production and food security announced and implemented by successive administrations since 1972 (Table 3).

Table 3. Chronology of rice production and food security programs, 1972-2001 (as of December 2001).

Date	Program name/title	Secretary of agriculture	Years of implementation
1972-86	Masagana 99 (M99)	Arturo R. Tanco/ Salvador H. Escudero III	15.0
1987-89	Rice Productivity Enhancement Program (RPEP)	Carlos G. Dominguez	2.5
1990-92	Rice Action Program (RAP)	Senen C. Bacani	2.5
1993-95	Key Production Areas (for rice and other priority commodities)	Roberto S. Sebastian	3.0
1996-98	Gintong Ani programs (for rice, maize, livestock, fisheries, high-value crops, and marginal areas)	Salvador H. Escudero III	2.5
1998-2000	President Estrada's MakaMASA programs (for rice, maize, livestock, fisheries, coconut, sugar, tobacco, and high-value crops)	William D. Dar/ Edgardo J. Angara/ Domingo F. Panganiban	2.5
May-December 2001	GMA CARES (for credit, "rolling stores," rice, maize, irrigation, livestock, fisheries, coconut, sugar, tobacco, and high-value crops)	Leonardo Q. Montemayor	0.5

The landmark program Masagana 99 (Productive 99) implemented during the tenure of President Marcos and Agriculture Secretaries Tanco and Escudero is credited for bringing the country from the brink of starvation in the early 1970s to self-sufficiency and some exports by 1979.

The M99 program ran for 15 years and had at least 14 phases, with refinements made with each phase. The initial phases were wracked with design errors and inefficiencies. Given that the country was under martial law, the implementers of M99 were allowed room to learn from their mistakes and improve the program with each succeeding cycle.

All the rice and food security programs since 1986 have been short-lived, at least in name. In 1986, the key features of the Masagana 99 program were abandoned in favor of a much more market-oriented approach based less on irrigation infrastructure and directed credit support and more on seed and fertilizer distribution and farm procurement. The program was named the Rice Productivity Enhancement Program (RPEP) and lasted for 2 years, through the administration of Secretary Carlos Dominguez.

Since 1989, the RPEP has been revived and relabeled at least five times through the administrations of at least five replacement secretaries of agriculture. The replacement of Secretary Roberto Sebastian in 1996 can be directly traced to the performance of the rice sector, where his "key production areas" approach was perceived to be not delivering the desired results, as manifested in a jump in rice prices during 1995—the so-called "1995 rice crisis."

An analysis of the blip in rice prices in 1995 suggested that it occurred fundamentally because of rice procurement, import, and inventory policies and not because of production support. The National Food Authority, attached to the DA and chaired by the secretary of agriculture, maintains the monopoly on rice imports. The policy to hold NFA inventories and imports down led to the rise in domestic rice prices in 1995.

Finally, it should be noted that, in terms of design, the rice production and food security programs in the post-1986 period differed only in labeling but not in substance. Each focused on priority production areas—usually irrigated areas. Each was highlighted by programs for access to and subsidies for seeds and fertilizer. Each was in the end dependent on the NFA for procurement support. Given the frequent changes in leadership, however, many changes occurred in timing, implementation calendars, and learning and relearning of the management and administration of the programs.

Frequent reorganization and restructuring

With each new secretary, a period of restructuring and reorganization usually followed. This was all explained as part of a process of "streamlining the bloated bureaucracy." Offices were moved around, abolished, created, or recreated in the process. However, because legislation is required to make any substantial changes permanent, many of these actions usually ended up as uncompleted.

Successive administrations, of course, had different ideas about how institutions should be structured. One of the actions that could be implemented under the President's executive authority was the attachment of agencies. An example of the changes in attachment is the case of the NFA, which since the 1970s has been shifted in attachment back and forth from the DA to the Office of the President (Table 4).

Fallout from frequent changes in sector leadership

By any measure, the management of the agricultural and rural sector for sustainable growth is complex and difficult. In the Philippines, the task of sector management has become even more difficult and complex because of the intensely political atmosphere that has come to envelop the bureaucracy.

Intensified politicization of senior bureaucrats

Therefore, it is no surprise that, particularly in more recent years, the men appointed as secretaries of the DA, DAR, and DENR are more politicians than sector experts. Politicians are rewarded for political support and cabinet seats and other top jobs in bureaucracy have become more rewards to be savored for tasks already accomplished rather than tasks that need to be performed for future benefit, not to oneself but for the sector and population at large.

The political nature of cabinet and other senior-level posts in government has emphasized the need for visibility and impact as soon as possible after taking office.

Table 4. Discontinuous structures: attachment of the National Food Authority (NFA).

Decree or order	Date	President/ secretary/ NFA administrator	Structural purpose
Presidential Decree (PD) 4 (as amended by PDs 699 and 1485)	26 September 1972	President Ferdinand Marcos/ Secretary Arturo Tanco/ Administrator Jesus Tanchanco	Abolishes Rice and Corn Administration (RCA), creates National Grains Authority (NGA), attached to the Department of Agriculture (DA)
PD 1770	14 January 1981	Prime Minister Marcos/ Secretary Imelda Marcos/ Administrator Tanchanco	Expands NGA to National Food Authority (NFA), establishes Minister of Human Settlements (MHS) as chair of NFA council
Executive Order (EO) 292	March 1987	President Corazon Aquino/ Minister Ramon Mitra/ Administrator Emil Ong	Attaches NFA to the DA, with DA secretary as chair
EO 2	July 1998	President Joseph Estrada/ Acting Secretary William Dar/ Administrator Edgardo Nonato Joson	Attaches NFA to the Office of the President (OP), with administrator as concurrent chair
EO 315	December 2000	President Estrada/ Secretary Domingo Panganiban/vacant	Attaches NFA to DA, with DA secretary as chair
EO 41	15 October 2001	President Gloria Macapagal Arroyo/ Secretary Leonardo Montemayor/Administrator R. Anthony R. Abad	Attaches NFA to the OP

This pressure results in two major initial preoccupations upon entry into office: (1) the demolition of previous programs and (2) the announcement, as soon as possible after taking office, of "new and better" programs carrying one's own identity and label, no matter if the difference is only the label.

Thus, cabinet members often find themselves rushed to announce half-baked goals, agendas, and programs of government even before they have had an opportunity to thoroughly review the challenges they need to face and the options available.

Each administration since 1986 has had so much to do, so little time, and not much experience in how to get the job done. This combination, in a context with a hungry political opposition anxious to capitalize on mistakes, has helped foster an atmosphere in which cabinet members are replaced at the first mistake, however unavoidable, whether in perception or in actuality. A culture of "cabinet revamps" and replacements of one official or another has emerged, in which one of the first reactions to a perceived inadequacy in leadership, capacity, or political skill is the replacement of the erring or inadequate cabinet member. In turn, such an atmosphere has emphasized political expediency and a focus on short-term gains, often at the expense of sustainable, long-term effectiveness.

Weakened planning, policy, and analytical capability

The brief tenures of the agriculture secretaries since the mid-1980s have contributed to the weakening of the agricultural sector bureaucracy as a whole. As the leadership focused on short-term gains, the tasks of long-term structural change and strengthening were neglected. These weaknesses are evident, as gleaned from several observations such as (1) noncompetitive compensation for mid- to upper-level technicians and managers, (2) declining overall quality of mid- to upper-level sector technicians and managers, (3) inadequate technical staff support for top managers, and (4) institutional and management structures not appropriate to the current challenges and realities.

Clearly, the compensation of mid- to upper-level employees in the bureaucracy has fallen behind that of their counterparts in the private sector. Analyses by the Personnel Management Association of the Philippines and the Department of Budget and Management report that the gross monthly salaries of government staff below the rank of division chief (grade 24) are competitive with the private sector. However, the salaries of all personnel of grade 24 and above are substantially below those of comparable jobs in the private sector.

It is interesting to note that the twin facts that the salaries of government employees below salary grade (SG) 24 are competitive with the private sector and the salaries of government staff and officials at SG 24 and above are not competitive are the result of the same program of “salary standardization” that has been implemented over the past 12 years. The salaries of lower-level staff have been successfully upgraded through the program. However, the program has been implemented in the context of a poor fiscal base, overall high unemployment and underemployment, and thus weak political support for substantial increases in the compensation structures of upper-level government officials and staff. This is made obvious in the salary of the President of the Philippines: P50,000 (less than US$1,000) per month.

Given that the President’s salary is the ceiling for all official compensation, the salaries of all cabinet officials, undersecretaries and assistant secretaries, directors and assistant directors, and division chiefs are all woefully low! The structure also invites the creation of mechanisms for hidden compensation, elaborate structures for allowances and other benefits, and graft and corruption. Unfortunately, it is at the mid- to upper-levels of government officialdom and bureaucracy where technical analysis, administration, decision-making, policy-making, resource allocation, and contracting take place. When compensation structures cannot attract and keep persons of sufficient training, experience, and capability in the bureaucracy, certainly the effectiveness of the government will deteriorate.

The preparation of these notes did not benefit from empirical analysis of personnel records. Thus, it is stated from the viewpoint of an experienced observer that the general quality of mid- to upper-level staff and officials in the agricultural and rural development bureaucracy has deteriorated rapidly in the last 20 years. Quality is understood to be determined by appropriate education and training (achieved prior to the assumption of office), direct experience, and other indicators of capability.

The same compensation conditions for upper-level sector officials also afflict mid- to upper-level analysts and technical staff. Accepting that the overall quality of upper-level sector officials has deteriorated, the analytical and technical staff support for these officials has also become weaker. The overall effect is a weaker bureaucracy, barely able to cope with the demands of sector leadership and management, and unfortunately more prone to corruption.

Inappropriate institutional structure

The technical assistance project TA 2733-PHI recently undertook an intensive diagnosis of the current capacities and capabilities of the DA.[9] This diagnosis was in the context of the DA's tasks in policy formulation, planning, and monitoring and evaluation in the context of the increasing globalization of agriculture and fisheries and the process of devolution. In summary, the diagnosis concluded that the agriculture and fishery policy, planning, and monitoring and evaluation structure of the Philippines is fragmented, uncoordinated, and weak. A "problem tree" of this conclusion is illustrated in Figure 4 (Tolentino 2001).

The diagnostic report produced under TA 2733 states that the DA's structure is fragmented:

- Institutionally, the structure is spread out over OSEC, 7 staff bureaus, and 25 attached agencies and corporations, ARMM, CAR, and 14 regional offices.
- Many sector policy and planning functions are handled by government units other than the DA, such as the PMS, cabinet clusters, the presidential advisers, and commissions (poverty, rural development, flagship programs, Mindanao, Visayas), NEDA, DAR, DENR, DTI, DFA, and DOF.
- There is perceived inconsistency between pronouncements and actions, particularly in the impact and implementation of the MTDP, MTADP, the GAA, and macroeconomic policies.

uncoordinated:

- The responsibilities, authority, and accountability for policy and planning are ill defined and not clearly assigned to particular units.
- There are no organized, continuing linkages among the policy and planning units of the various DA agencies.
- The relations, contacts, and coordination with LGUs, farming communities, farmers' groups, NGOs, and private-sector agribusiness groups is intermittent and generally of low intensity and weak follow-up.

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[9] SEA Consultants, "Diagnostic Report," TA 2733-PHI, "Institutional capacity building in policy formulation, planning, monitoring and evaluation for the agricultural sector," Department of Agriculture and the Asian Development Bank, October 1997.

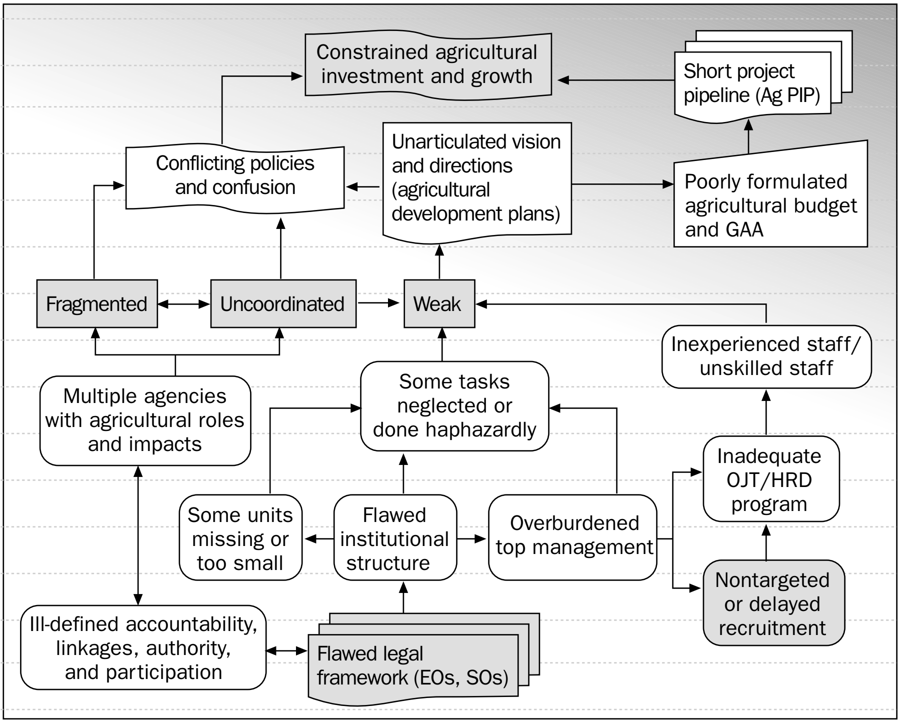

Fig. 4. Problem tree: fragmented, uncoordinated, and weak policy, planning, and M&E structure of the Department of Agriculture. GAA = General Appropriations Acts, OJT = on-the-job training, Ag PIP = Agricultural Public Investment Plan, HRD = human resources development, EOs = executive orders, SOs = special orders, M&E = monitoring and evaluation.

weak:

- There is no DA unit dedicated to agricultural trade policy (GATT/ WTO, APEC, ASEAN, PECC, Cairns, E.U., U.S., Japan, Australia, and other bilaterals).
- There is no DA unit responsible for maize (food and feed).
- Sector budgeting and appropriations preparation are split from planning.
- There is practically no economic and policy analysis unit at the DA. The existing OSEC PAD is very understaffed and ill trained.
- Most DA units have no staff dedicated to policy and economic analysis, particularly in support to legislation, the relationship between technological factors and productivity, the impact of macroeconomic factors on particular commodities and on agriculture as a whole, market competitiveness of particular commodities, and intersectoral linkages, both domestic and international.
- Most DA units are understaffed and have limited skills in agricultural investment project formulation, preparation, and appraisal, especially of public investments.

- The DA has a very weak influence on market infrastructure policy and programming, especially roads and shipping.
- The DA has a very weak influence on the size and allocation of technology research resources.
- The DA has been unable to fully tap and harness the considerable expertise in the research community outside of the DA (University of the Philippines system, etc.).
- There has been no continuing staff support and human resource development program that will promote staff skills and stability in service.

The bottom half of the problem tree in Figure 4 portrays the causes of the weak, fragmented, and uncoordinated nature of the DA. The DA is weak because some tasks are haphazardly done or not performed at all. This is because the required organizational units are missing, too small, or already overburdened. These structures find their basis in legislation or administrative decrees and some instruments were poorly structured to begin with or have already become obsolete in the light of current imperatives.

In sum, poor continuity in sector leadership is clearly a major factor in existing weakness in rural development governance. Such discontinuity results in an inadequate understanding of sector dynamics. As leadership focused on short-term gains, the tasks of long-term structural change and strengthening have been neglected. Short periods of service emphasize short-term gains.

Conclusions: the agricultural sector in flux and some recommendations

In can be said that the agricultural, rural development, and natural resource management sectors of the Philippine economy and government have been in transition since 1986. This is true particularly in reference to the very frequent changes in sector leadership and governance that have been made in the departments of Agriculture, Agrarian Reform, and Environment and Natural Resources since 1986.

Since 1986, all secretaries of the DA, DAR, and DENR have, with only a single exception, been unable to serve their full six-year terms as provided by law. Yet, before 1986, the ministers/secretaries of Agriculture and Agrarian Reform served for at least 13 and up to 20 years, in the process learning from both mistakes and victories.

At the very least, these frequent changes have caused the programs and projects in each department to be halted and then restarted with each episode of replacement of the secretary and other senior officials. At least six periods of transition between the outgoing and incoming secretary of Agriculture have occurred since 1986. These transition periods have each lasted, nominally, at least a few months.

Yet, the task of agricultural sector management must go with the seasons. Crops cannot be hurried through their growth cycles. But the sector grows more complex and long-term in nature with rapid population growth, increased food requirements, intensified domestic resource scarcity, and global openness.

In actuality, given that the DA is a very complex organization and the task of governance for agricultural growth is by itself a complex undertaking, the period of administrative transition is merely a subperiod of the overall learning period required to achieve a level of understanding and expertise sufficient for effective sector governance.

It is crucial that some stability and long-term vision be institutionalized into sector management. Quite clearly, the level of the President and perhaps even cabinet secretaries will remain political and thus subject to political tides.

At the very least, however, a professional, long-term technical core group of managers, administrators, and technical experts must be installed in each department. Even these key posts must not become spoils to be distributed as rewards in the aftermath of political contests.

A beginning point is to have a majority of undersecretaries, assistant secretaries, and agency heads not subject to political appointment. This can be achieved quickly by presidential order, confirmed by legislation.

Another easily accomplished step is to have all senior officials be subject to fixed terms of office, say, at least three or four years, with the possibility of renewal (perhaps limited) given some minimum acceptable level of performance.

The experience of the last two decades indicates that any period of service beyond two years is already a major achievement. A minimum of one year is required to thoroughly “learn the job.” The appointees can then focus the rest of their terms on accomplishing results for sustainable benefit.

Another measure to induce more stability in service is to accelerate the conferment of career executive service officer status on qualified officials. This is easily accomplished as part of the management powers of the President and the Civil Service Commission.

Poor growth in agriculture, weak rural development, fragile food security, and worsening poverty and hunger are results that are at least partly traceable to the discontinuous, disjointed attention to the management of the agricultural sector. Unless strong measures are taken immediately to stabilize sector leadership on a definitive sustainable growth path, the agricultural and rural sector will continue to be mired in stagnation.

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Rice supply and demand scenarios for Vietnam

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In Vietnam, it is necessary to have updated information on rice supply and demand balances for the government to effectively meet its twin objectives of further improving food security and maintaining its prominent position in the international export market. However, most existing rice supply and demand models are applied at the national level. Thus, they fail to provide more detailed characteristics of rice marketing at the regional level, where food security is in great disparity. In this connection, a rice balance model that describes supply and demand interactions at the subnational level would be most helpful for planning and programming by decision makers. Such a model is presented and described in this paper. The data used are gathered from the subnational level. The supply equation in the model is linked to a raster geographic information system to provide the geographic dimension for rice supply analysis. It is estimated taking into account the potential as well as attainable yields and applied to the cultivated area. Rice demand is also estimated on the regional level based on the population distribution and consumption patterns of urban and rural populations. Different scenarios affecting rice supply and demand are analyzed and net balances are estimated at both the regional and national level.

Rice is important in Vietnam not only because it is a major staple food but also because it is a significant source of foreign exchange earnings. Since the early 1990s, Vietnam shifted from being self-sufficient in rice to being a net exporter of the commodity. In 1995, 2 million t of rice were exported, which increased to 4.5 million t in 1999, making the country the second-largest rice exporter in the world market. As the government continues to achieve the twin objectives of further improving the country's food security situation while at the same time sustaining its position as a major rice exporter, it has to be able to successfully manage domestic trade flow so that rice will move around the regions effectively. Reliable and accurate analyses of rice supply and demand balances on the regional level are needed to help the government achieve these objectives.

Most existing rice supply and demand models are applied at the national level and are estimated using economic variables such as prices and the influence of markets and other policies. One example is the Vietnam Agriculture Spatial Equilibrium Model (VASEM), with its supply estimate that is based on the effect of prices, irrigation investment, policy, and other factors that influence the production of rice, maize, sweet potatoes, and cassava (IFPRI 1996). However, the supply and demand of food commodities such as rice are also determined by biophysical and socioeconomic factors that vary geographically within the country. Rice production in most countries is concentrated in specific regions that are biophysically suited for rice cultivation and where agro-hydrological conditions exclude other crops. In Vietnam, these are the Red River Delta (RRD) in the north[1] and the Mekong River Delta (MRD) in the south, where there are extensive low-lying areas with heavy soils and flooded regimes during the rainy season. The two deltas, described as "two baskets of rice connected by a stick," account for about 67% of rice land and 71.5% of rice production in the whole country.

This paper describes the application of geographic information systems (GIS) to model rice supply and demand at the subnational level in Vietnam. One major focus of the study is to strengthen the biophysical basis of supply estimation by taking into account geographic differences in the comparative advantage of rice cultivation and the yield potential of rice. The analysis of the rice supply in Vietnam, which is directly related to production, is therefore based on seven agroecological regions (Fig. 1) with different climate, soil, and water conditions (Phong 1995). Geographic subdivisions are also relevant in demand estimation as each of them is composed of provinces that are considered to be the basic subnational administrative units of the country. Provinces have the basic socioeconomic information to help estimate rice demand. Net deficit and net surplus areas are subsequently identified when provincial rice demand is aggregated to the agroecological level and compared with the respective rice production.

Study methodolody

The approach

This study employs the rice supply and demand analysis (RSDA) system. The general structure of the model consists of a supply block, a demand block, and a net balance block described as follows:

1. To estimate supply, a regional model is developed to estimate potential, water-limited, and nutrient-limited rice yields (based on input levels) as well as to

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[1] If only two regions, the north and the south, are referred to, the north consists of North Mountain and Midland (NMM), Red River Delta (RRD), and North Central Coast (NCC) and the south consists of the South Central Coast (SCC), Central Highlands (CH), Northeast South (NES), and Mekong River Delta (MRD). If three regions are mentioned, then the north consists of NMM and RRD, the central region consists of NCC, SCC, and CH, and the south consists of NES and MRD.

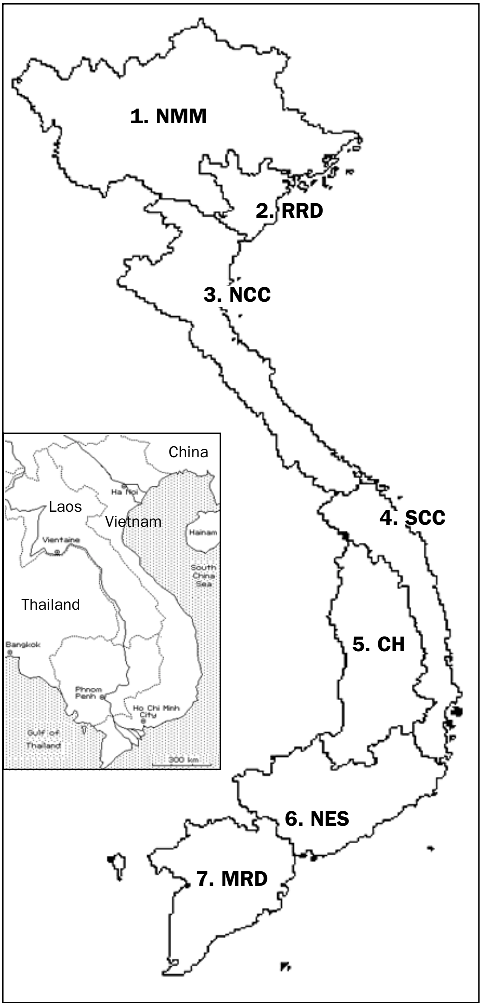


Fig. 1. Locations of seven agroecoregions in Vietnam. NMM = North Mountain and Midland, RRD = Red River Delta, NCC = North Central Coast, SCC = South Central Coast, CH = Central Highlands, NES = Northeast South, MRD = Mekong River Delta.

estimate existing rice area under different cropping intensities (influenced by irrigation and availability of a fresh water supply). From these estimates, attainable rice yield is determined by comparing the revenues from rice crops with the expected revenues.

2. Demand is estimated using population and consumption rates, with due consideration of the differences in income and price elasticities for per capita rice consumption regionally and between rural and urban sectors.
3. Balances between supply and demand are made at the grid-cell level, at which the supply and demand estimates are compared. The rice balance takes into account postharvest losses and other uses of rice apart from direct human consumption, then aggregates them to the regional level.

Figure 2 shows the schematic diagram and interrelationship of these blocks. Supply, demand, and balance estimates are made for existing conditions as well as for future scenarios. An RSDA is implemented within an integrated computer-based environment with a user-friendly interface. It serves as a decision support tool for policymakers and government planners.

GIS implementation of the RSDA system

We use GIS to explicitly provide the spatial dimension in modeling the balance between rice supply and demand within the country, and to facilitate the integration of biophysical and socioeconomic data and analysis. The raster data structure was chosen for the RSDA system for several reasons (Kam and Hoanh 1998), the most important of which is the need to integrate the biophysical and socioeconomic data over space and time (Fig. 3). For Vietnam, a grid-cell size of 4 km was selected. With a land area of 330,000 km^2, the whole country is thus subdivided into 20,944 cells.

A simple rice model for yield estimation. To estimate the rice supply under various agroecological conditions, we developed a model to simulate the potential and attainable yields, which when multiplied by cultivated area provide estimates of potential and attainable production. The Rice Yield Estimation for Potential and Attainable Production or RYSTPAP model (de Vries 2000), developed for the rice supply and demand analysis, is one such simplified process model that takes into account the most relevant physiological processes and uses the knowledge accumulated in the comprehensive, deterministic WOFOST (Boogaard et al 1998) and related models (Fig. 4). Three yields are estimated: potential yield, water-limited yield, and nutrient-limited yield.

For potential yield, we adopted the Monteith approach (Mitchell et al 1998) of estimating yields based on intercepted radiation and average temperature. For water-limited yield, we based the computation on the water balance in the Lintul2 model, which had been derived from more complex models documented by Stroosnijder and Penning de Vries et al (CT de Wit Graduate School for Production Ecology 1989). However, we adopted the formulae for the Penman calculation of potential evapotranspiration and critical soil moisture content for crop transpiration from WOFOST (Supit et al 1994) instead. The estimation of nutrient-limited yield is based on a version of the QUEFTS model (QUantitative Evaluation of the Fertility of Tropical Soils) (Janssen et al 1990) modified to estimate irrigated rice yield limited by N, P, and K (Witt et al 1999). This submodel computes the reduction in potential yield (calculated in the potential yield submodel of RYSTPAP) because of nutrient limitation by taking into consideration the potential indigenous N, P, and K supply in the soil and applied fertilizer rates, as well as interactions among these three macronutrients (Smaling and Janssen 1993).

GIS modeling for production estimation at the regional level. The RYSTPAP model is designed to be able to use minimum data sets that are relatively more readily available regionally. Data used in this model can be categorized into three groups:

1. A knowledge base on crop phenology of the various rice varieties (to provide the parameters for the crop yield model) and on soil suitability for rice.

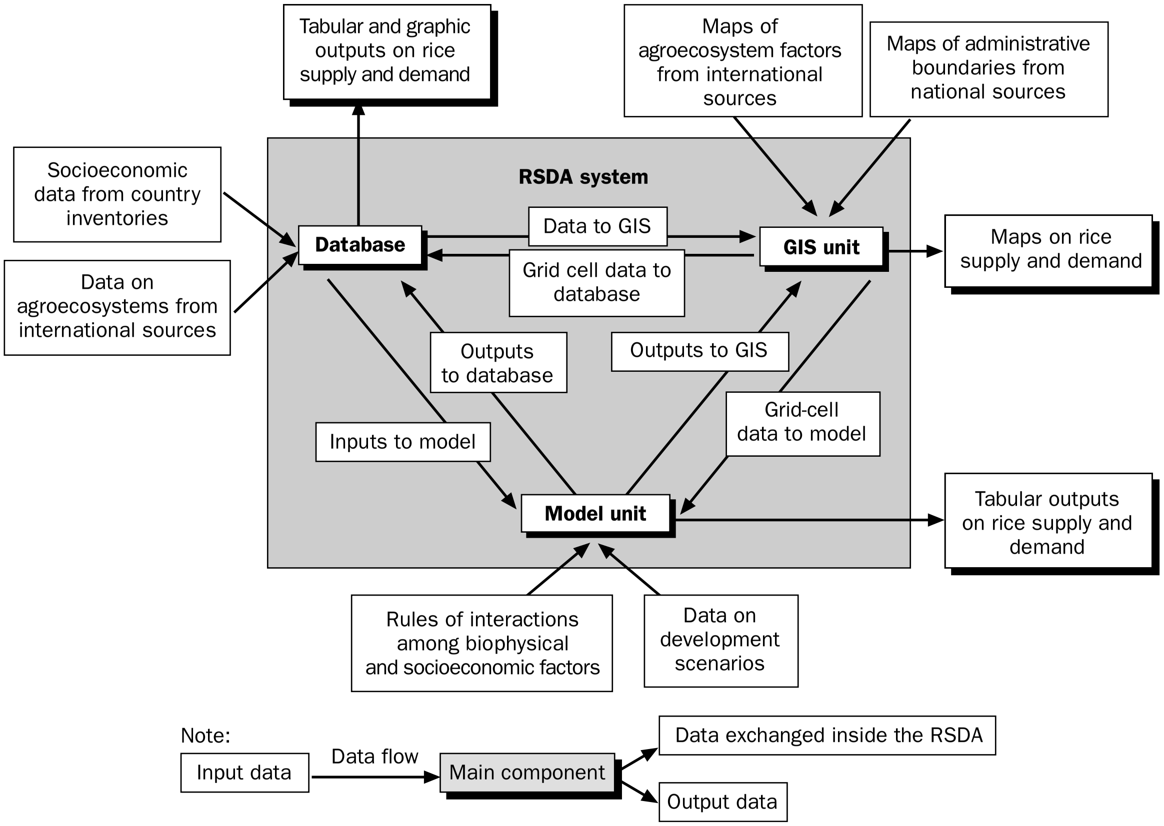
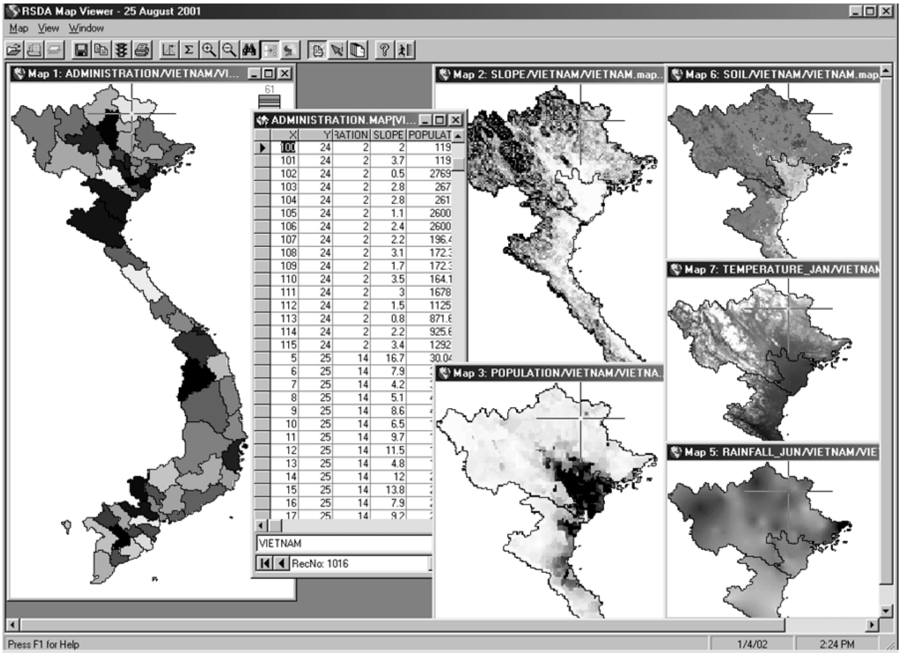


Fig. 2. Schematic diagram of the rice supply and demand analysis (RSDA) system.



X	Y	RATION	SLOPE	POPULAT
100	24	2	2	119
101	24	2	3.7	119
102	24	2	0.5	2769
103	24	2	2.8	267
104	24	2	2.8	261
105	24	2	1.1	2600
106	24	2	2.4	2600
107	24	2	2.2	196.4
108	24	2	3.1	172.3
109	24	2	1.7	172.3
110	24	2	3.5	164.1
111	24	2	3	1678
112	24	2	1.5	1125
113	24	2	0.8	871.6
114	24	2	2.2	925.6
115	24	2	3.4	1292
5	25	14	16.7	30.04
6	25	14	7.9	
7	25	14	4.2	
8	25	14	5.1	
9	25	14	8.6	
10	25	14	6.5	
11	25	14	9.7	
12	25	14	11.5	
13	25	14	4.8	
14	25	14	12	
15	25	14	13.8	
16	25	14	7.9	
17	25	14	9.2	

VIETNAM

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Fig. 3. Example of georeferenced value array in attribute table of raster maps.

2. Biophysical, socioeconomic, and rice area data as listed below:
   - Long-term monthly average climatic data: temperature (122 stations), radiation (6 radiation and 38 sunshine hour stations), rainfall (393 stations), number of rainy days (78 stations), wind speed (95 stations), and vapor pressure (calculated from temperature and humidity at 79 stations) collected from the country climate report (Toan and Dac 1993) and the FAO climate data (FAO 1995).
   - Soil data: the soil type of each grid cell is extracted from the Vietnamese soil map (Phong 1995) and associated properties are extracted from data on soil profiles.
   - Topographic data: slope is derived from a 1-km digital elevation model (National Geophysical Data Center/WDC-A for Solid Earth Geophysics Boulder 1997).
   - Water data: current flood, salinity, and irrigation (Phong 1995).
   - Administrative boundary: each grid cell belongs to one of the 61 provinces and to one of the 7 agroecological regions.
   - Population data: present and projected population (GSO 1999b).
   - Rice area: rice area in 1994 (Phong 1995), updated in 1996.
3. Data on cultural practices such as the amount of fertilizer applied, sowing dates, irrigation, etc., from various references.

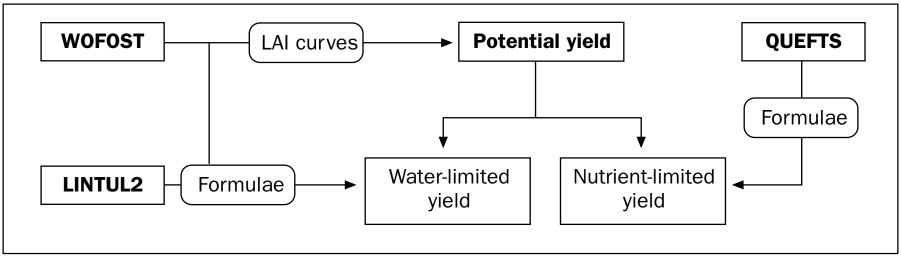

Fig. 4. Adoption of other models to the Rice Yield Estimation for Potential and Attainable Production (RYSTPAP) model. LAI = leaf area index.

Rice yield estimation is carried out in the following sequence:

1. By applying the yield model, outputs are gridded surfaces of potential, water-limited, and nutrient-limited yield estimated for 24 sowing dates (at half-month intervals) within a year. For the Vietnam case, five rice varieties are used for yield modeling: IR64 and IR8 (on saline soil) in the south, IR72 and a hybrid variety in the north, and a traditional variety for sloping lands with slopes of 3% to 8% in the whole country.
2. Simulated yield for each variety in each cell is calculated for two cases:

   in irrigated area: $Y_S = Y_N \times WCE$

   in rainfed area: $Y_S = Y_N \times Y_W / Y_P \times WCE$

   where Y_S is the simulated yield, Y_N is the nutrient-limited yield, WCE is water/crop management efficiency, Y_W is the water-limited yield, and Y_P is the potential yield. The water/crop management efficiency (such as properly supplying irrigation water or applying fertilizer) that varies from 0.6 to 1.0 is used as an adjustment coefficient for calibration to match the simulated yield with the reported yield in each province. The interactions between water and nutrients are not considered in the model because of the limitation of current knowledge.
3. A reduction caused by pests and diseases, about 5% on average, is applied to the simulated yield.
4. Selection of a single or double rice crop is based on the benefit-cost analysis by assuming that farmers select the double rice pattern only if the net revenue from these two crops is higher than that from the single rice crop. For both the single and double rice crop, it is assumed that farmers will select the optimal sowing date to achieve the highest revenue. Although in some regions farmers do grow triple rice in limited areas, this cropping pattern is not encouraged because of its adverse environmental effect. It was therefore not taken into consideration in this study.
5. To reflect the fact that rice is not cultivated if yield is low, only simulated yields with net revenue higher than the expected revenue are taken into account. The expected revenue is based on the minimum yield currently reported in each

province. For Vietnam, this revenue comparison is based on income per labor-day.

Rice production by grid cell is estimated by multiplying the simulated yield by the rice area in each cell (Fig. 5), which is derived from the land-use map (Phong 1995). To calculate this area, a provincial reduction factor identified as the ratio of provincial rice area from the inventory (GSO 1999a) to the total area of all rice cells in each province is applied.

GIS and rice demand estimation. Rice demand for human consumption in each grid cell is estimated based on population and per capita rice consumption. The estimated total population for each administrative unit is distributed in proportion to the accessibility index measures calculated for each grid cell based on the transportation network and urban centers (Deichmann 1996). Average per capita rice consumption in each agroecological region is extracted from the results of a household survey carried out in 1998 (see the section on "Rice demand in Vietnam").

GIS and rice supply and demand balances. The balance between rice supply and demand is calculated for each grid cell. For rice supply estimation, the following equations are applied:

$$P_P = P_S \times R_P$$

$$S_R = (P_P - S_E) \times MR$$

where P_P is the paddy production, P_S is the simulated production calculated from simulated yield and rice area, R_P is the reduction factor caused by postharvest losses, S_R is the milled rice supply, S_E is the seed requirement, and MR is the milling ratio.

For the demand estimation, the following equations are applied:

$$D_H = \mathrm{Popu} \times \mathrm{Cpercapita}$$

$$D_{OF} = D_H \times P_{OF}$$

$$D = D_H + D_{OF} + R_S$$

where D_H is the human demand, Popu is the population, Cpercapita is consumption per capita, D_{OF} is the demand for feed and other uses, P_{OF} is the percentage of feed and other uses compared with human demand, D is the total demand, and R_S is the amount for stock/reserve. The estimation for percentage of feed and other uses as well as stock/reserve for the Vietnam case is discussed in the section on "Rice demand in Vietnam."

Rice production and policy in Vietnam

Rice production in Vietnam: an overview

Vietnam is a country endowed with human and natural resources that are necessary

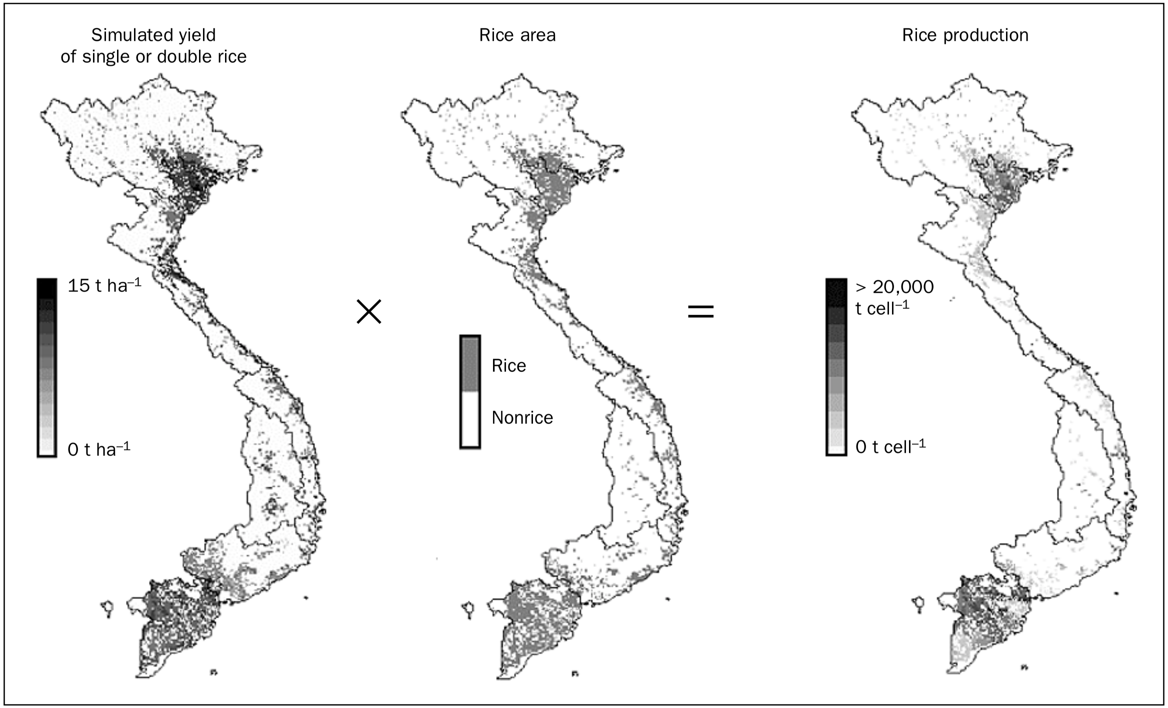

Fig. 5. Gridded surfaces for rice yield, area, and production.

for diversified agriculture. Under the centrally planned system, however, Vietnam was unable to feed its population. During the 1970s until the mid-1980s, annual rice imports averaged around 200,000 t, with a peak of 400,000 t in 1986.

As a result of macroeconomic and institutional reforms (*Doi Moi*, in Vietnamese) since the late 1980s, Vietnamese agriculture has undergone dramatic changes. Agriculture has shown a substantial response to the new policies and new structure of incentives. During 1990-99, the annual growth rate of agriculture averaged 4.2% (Fig. 6). In 1999, agriculture (including fishery and forestry) constituted 25.4% of the gross domestic product (Fig. 6) and it remains an important sector in the national economy. As in many Asian countries, rice is the most important crop in Vietnam. Rice is cultivated on more than 50% of the agricultural land and accounts for more than 60% of total crop sown area. Within less than two decades, after being a chronic rice importer, the country has reemerged in the world rice market as a sustainable rice supplier and it became one of the world's largest rice exporters, with exports averaging 3–4 million t in recent years. Rice production in Vietnam increased as a result of yield improvement and, in particular, the expansion of planted area induced by the improvement of the heavily subsidized irrigation system.

Rice production and consumption

Almost 80% of rural households in the RRD and the MRD are engaged in rice production. After the economic reform, paddy production increased significantly. During 1990-2000, the national rice output increased by more than 60%, corresponding to an average annual growth rate of about 5% (Table 1). This growth is mainly attributable to paddy yield increase, about 66% during 1985-90, 63% during 1991-95, and 50% during 1996-2000.

During 1990-2000, rice production growth was based mainly on improved yield and increased cropping intensity (Fig. 7). Rice land expansion was limited and its contribution to output growth was minor, around 3% during 1990-2000. The annual paddy yield growth rate is 2.9%, while cropping intensity increased from 1.45 to 1.78, with a growth rate of 1.85% annually. In contrast, at the end of the 1990s, several factors impeded land expansion, such as urban development and crop diversification. These factors even took land out of agriculture, resulting in a decrease in rice land in some regions. In the RRD, for example, rice land decelerated at the rate of –0.6% annually.

Table 1. Trend of paddy production in Vietnam, 1985-2000.

Period	Growth rate ($\% \, y^{-1}$)				Relative contribution (%)		
	Production	Rice land	Cropping intensity	Yield	Rice land	Cropping intensity	Yield
1985-90	5.4	–0.8	2.6	3.5	–15.6	49.2	66.4
1991-95	5.5	0.3	1.7	3.4	5.0	31.7	63.3
1996-2000	4.9	0.2	2.2	2.5	5.0	44.4	50.6

Source: Calculation based on data from GSO (1996, 1997, 1998, 2001).

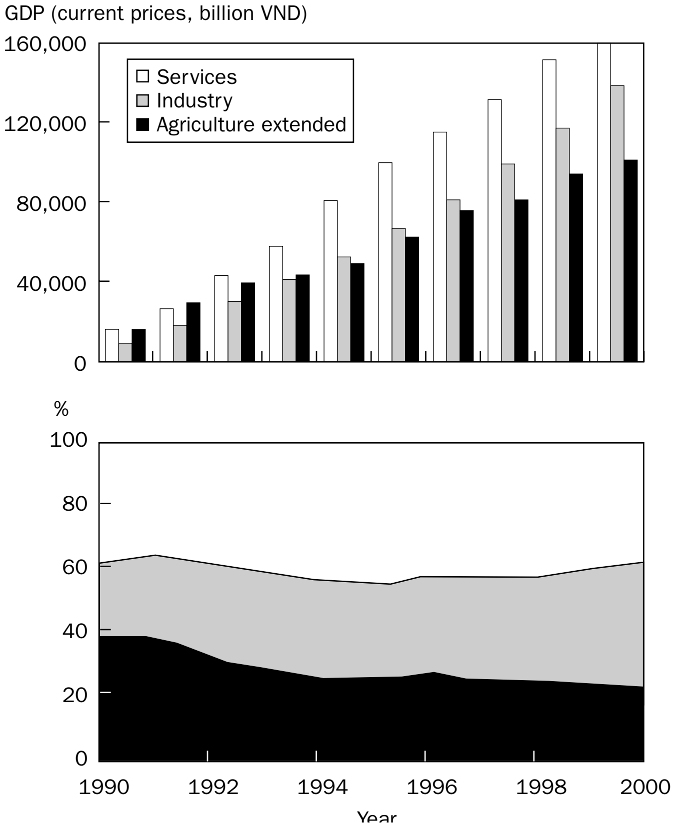

Fig. 6. Structural changes in the economy and agricultural sector of Vietnam. Agriculture extended includes forestry and fishery. GDP = gross domestic product. Data by GSO (2001).

The institutional reform encouraged farmers to produce more rice. Moreover, trade liberalization under the *Doi Moi* created favorable conditions for the rice industry. Rice production soared 3.2 times, from 10.3 million t in 1975 to 32.5 million t in 2000 (Table 2), which is equivalent to an annual per capita milled rice production of 275 kg. From 1975 to 2000, population increased 1.61 times, from 48.0 million inhabitants to 77.6 million inhabitants, while paddy for human consumption and feed increased 2.5 times, from 9.0 million t to 22.9 million t.

At present, the domestic uses of rice in terms of human consumption, seed, feed, and other purposes account for 70% of the total production. Over the last decade, great achievements in rice production have allowed rice exports to expand. From an initial amount of 1.4 million t in 1989, rice exports are now maintained at around 3.5–4.0 million t, which is indeed a significant improvement. As a result, Vietnam's share of the world rice market increased substantially and reached almost 20% in 1999.

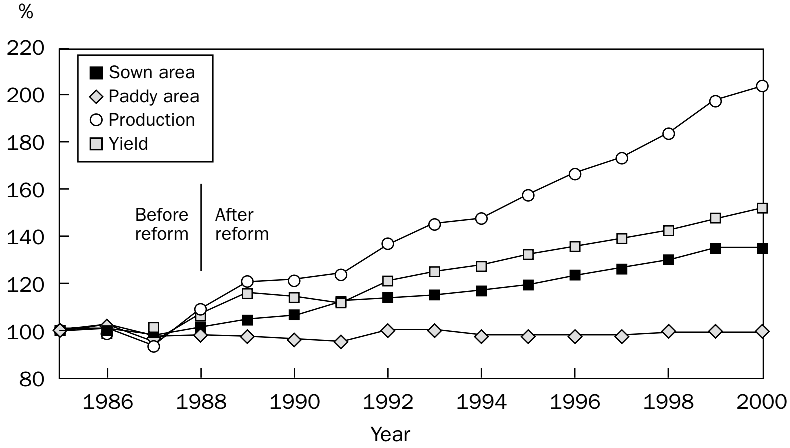

Fig. 7. Growth of paddy production (1985 = 100). Data from GSO (2001).

Table 2. Rice production and consumption in Vietnam, 1975-2000.

Item	1975	1980	1985	1990	1995	2000
Paddy production (million t)	10.3	11.6	15.9	19.2	25.0	32.5
Net export (million t of milled rice)	–0.3	–0.2	–0.3	1.6	2.0	3.5
Population (million inhabitants)	48.0	53.6	59.9	66.0	72.0	77.6
Consumption and feed (million t of paddy)	9.0	9.9	13.9	14.0	18.5	22.9

Source: GSO in various years.

Partial and total factor productivity in Vietnam

To understand the role of various factors in production, the most widely used indicator is partial factor productivity (PFP), which expresses a single output per unit input, such as land or labor. Plots of marginal productivities of land and labor for specific land-labor ratios are presented in Figure 8. It shows that from 1985 (the lower endpoint) to 2000 (the upper endpoint), both land and labor productivity rose, but the growth structures are markedly different among regions. In northern and central Vietnam, land productivity improved faster than labor productivity, while in the south both measures developed at nearly the same pace. The land-labor ratio decreased in all regions, but the situation was much less severe in the south.

A more comprehensive and meaningful measure of changes in productivity attributable to research and development (R & D)-induced changes in technology is the total factor productivity (TFP) index, which includes all relevant inputs used in production. In our analysis, TFP is computed based on the Divisia index procedure.

From 1985 to 1990, TFP in Vietnam's rice sector increased at an average annual rate of 3.3% (Table 3) but declined in the last decade to 1.1%. The high growth rate in 1985-90 was due to efficiency gains from institutional changes. This period experienced a transformation from the collective production system to household-based production with less administrative intervention in agricultural production, and the

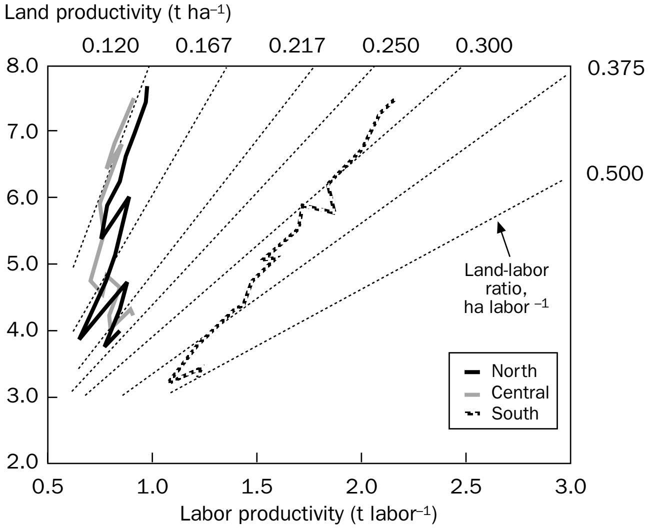

Fig. 8. Rice land and labor partial factor productivity in Vietnam, 1995-2000.

influence of the free market. This strong effect of radical policy changes on production efficiency under the *Doi Moi* suggests simply a one-time catching up. Once efficient production was established, further output growth required increased inputs.

The results of the relative contribution of TFP to growth in rice production indicate its importance in the late 1980s, accounting for around 62.7% of this growth (Table 3). The efficiency gains from institutional reforms can occur at any given level of technology. Therefore, the effect on growth lasted for only a limited time. A slowdown in TFP growth in recent years (1990-2000) indicates that, when Vietnam's rice production moved to its production frontier at the same level of technology, efficiency gains from further reform became smaller. Hence, additional growth in TFP would have to come from technological change.

Comparative advantage of rice production in Vietnam

During the last decade, exporting rice became a national economic target of the Vietnamese government and the amount of exported rice has been used as an indicator of the balance between rice supply and demand. Therefore, it is necessary to evaluate the comparative advantage of rice production in Vietnam. Price advantage is the main criterion for assessing the competitiveness of rice production in Vietnam. The price competitiveness index for rice is calculated as follows:

$$C_{R,t} = C_{R,t-1} \times (1 + \Delta P_{TL} - \Delta NER_{TL} - \Delta P_{VN} + \Delta NER_{VN})$$

where Δ denotes a proportionate change in the respective indicator from year t – 1 to year t. Thus, changes in price competitiveness depend on (1) changes in Vietnam's

Table 3. Total factor productivity (TFP) and its contribution to rice production growth in Vietnam, 1985-2000.

Period	Growth rate (%)			Relative contribution (%)	
	Output	Total inputs	TFP	Total inputs	TFP
1985-90	5.4	2.0	3.3	37.3	62.7
1991-95	5.5	3.9	1.6	70.8	29.2
1996-2000	4.9	3.8	1.1	77.2	22.8

wholesale price (P_{VN}), (2) changes in Vietnam's nominal exchange rate (NER_{VN}), (3) changes in the Thai wholesale price (P_{TL}), and (4) changes in the Thai nominal exchange rate (NER_{TL}). Thailand is chosen because it is the major competitor in the world rice market and because of its geographical and climatic similarity to Vietnam.

The results in Table 4 show that, on average, the competitiveness of Vietnamese rice in relation to Thai rice decreased by 8.4% per year. This trend is the result of the combined effect of changes in the following components: –13.6% in Vietnam's rice price because of inflation, 5.5% because of an increase in Vietnam's nominal exchange rate, 15.1% in the Thai rice price because of inflation, and –15.5% because of a decrease in the Thai nominal exchange rate. The depreciation of the Thai NER during the Asian financial crisis of 1997 provided an extra price advantage for Thai rice among importers, thereby resulting in the country's gaining an increase in rice exports by nearly 1 million t in 1998 vis-à-vis 1997 (i.e., from 5.6 million to 6.5 million). This increase enabled Thailand to account for a 25% share of the world rice market during that year. Despite the deterioration in its relative price competitiveness, however, Vietnam's rice still appears to be competitive in the international market as the volume of exports continues to grow.

Policies relating to the rice sector in Vietnam

Since *Doi Moi* began in 1986, the Vietnamese government has established new policies oriented toward a market economy. The main policies affecting the rice sector and farmer incentives to grow rice are those relating to land use, investment, marketing, and trade.

Land policy. In the transition from the planned to market economy, Vietnam has taken radical steps toward providing free land-use rights to farmers. The new land law in 1988 is considered to be one of the most important factors positively affecting farmers' incentives. Under this law, farmers are given the rights to private use of arable land for 10 to 15 years. This policy also allows farm households to determine the crops to be cultivated and how much surplus could be sold on the market. The revision of the land law in 1993 was a positive step that provided freedom in selecting land use to farmers. The tenure period has been increased to 20 years for annual crops and 50 years for perennial crops. The land policy also allowed the private transfer of land-use rights, including "exchange, transfer, lease, and mortgage." The positive response of farmers to this incentive is reflected in increased paddy production during the last decade.

Table 4. Changes in rice price competitiveness.[a]

Year	P_{VN} (VND kg^{-1})	P_{TL} (B t^{-1})	NER_{VN}	NER_{TL} (VND US\$$^{-1}$)	Change in C_R (B US\$$^{-1}$)		Contribution of changes (%) in			
					Index	(%)	P_{VN}	NER_{VN}	P_{TL}	NER_{TL}
1993	1,771	4,625	10,720	25.4	1.00					
1994	1,724	5,310	10,980	25.2	1.21	20.5	2.6	2.4	14.8	0.7
1995	2,231	6,959	11,050	25.0	1.24	3.3	–29.4	0.6	31.1	0.9
1996	2,487	7,174	11,040	25.4	1.12	–10.2	–11.5	–0.1	3.1	–1.7
1997	2,423	7,670	12,700	31.4	1.13	1.0	2.6	15.0	6.9	–23.5
1998	3,204	9,180	13,900	48.2	0.49	–56.8	–32.2	9.5	19.7	–53.7
Aver.						–8.4	–13.6	5.5	15.1	–15.5

[a] P_{VN} = Vietnam's wholesale price, P_{TL} = Thai wholesale price, NER_{VN} = Vietnam's nominal exchange rate, NER_{TL} = Thai nominal exchange rate, C_R = price competitiveness index.

Source: Calculated based on data of GSO and International Monetary Fund in various years.

Note on currency equivalents: US\$1 = VND 14,500 = B 44.7 (October 2001).

Investment and credit policy. Over the past few years, the Vietnamese government has made substantial efforts to upgrade the irrigation system. Investment in the agricultural sector focuses mainly on the infrastructure supporting production and rural development. During the 1990s, investment in irrigation accounted for about 70% of the total investment in agriculture.

Regarding rural credit, the formal rural financial support system currently includes the Vietnam Bank for Agricultural and Rural Development (VBARD), the Vietnam Bank for the Poor (VBP), and the People's Credit Fund (PCF). The objectives of the formal rural financial support system are to (1) ensure inputs for agricultural production, (2) strengthen postharvest technology and agricultural exports, (3) support agricultural diversification, (4) improve rural infrastructure, and (5) reduce poverty and natural calamities. The credit policy ensures direct lending to farmers and supports poor farmers in remote and mountainous areas. The lending rate for each rice farming household has increased from US$350 to $700 without collateral.

Input policy. Before the *Doi Moi*, agricultural inputs were distributed through the cooperatives. With the *Doi Moi* and the ensuing decline of the cooperative systems, the role of the private sector in distributing agricultural inputs became more important. Although the government still controls agricultural inputs by imposing quotas and maintaining monopoly import rights of state-owned enterprises (SOEs), the import tax on fertilizer is negligible. As an incentive for farmers to use improved seeds and to meet the government target of 70% usage of modern rice varieties, the import tax on seeds was rescinded.

Domestic marketing policy. The rice marketing system in Vietnam is extremely complicated, with complex linkages among marketing agents, farmers, assemblers, millers, wholesalers, retailers, and food SOEs. Since the 1980s, the *Doi Moi* policy has contributed significantly to the development of a liberalized rice distribution system in Vietnam. All restrictions on the domestic markets were removed, allowing for competition among marketing agents. The private sector has been playing an increasingly important role and now accounts for about a 95% share of the domestic markets. The role of SOEs in the domestic rice market has become minor.

International trade policy. In the early 1990s, the Vietnamese government, in its attempt to ensure national food security, strictly controlled the quantity of rice exports through licenses and quotas and allowed only the SOEs to export rice. From 1991 to 1993, there were only 40 rice export companies and these were mainly located in the south. The rice export system was inefficient and adversely affected farmers' income. The number of rice export companies decreased to 17 in 1997.

To improve the efficiency of rice exports, the government allowed the private sector to become involved in international trade activities from 1998 onward. In 1999, joint-venture companies were allowed to export rice if they found buyers in the international market. By 2000, the number of rice export companies had increased to 47 (Table 5). However, the share of private companies in total rice exports remains small. In 1998, private companies were estimated to export 185,000 t, or about 4% of total exports of 4.0 million t.

The Vietnamese government also imposes quantitative trade restrictions to control rice exports. Since 1997, total exports of rice are determined centrally by the government based on the estimated surplus of projected production and consumption. In practice, the export quotas are not strictly binding for individual enterprises as the transfer of quotas is permitted. Furthermore, the total export quota is periodically adjusted depending on actual production and world prices. The incentive is created for both central and provincial enterprises to increase exports.

Rice supply in Vietnam

Special features of the rice supply in Vietnam

One factor affecting rice production in Vietnam is the country's agroclimatic diversity. With its length extending from 8° to 23°N latitude, Vietnam is divided into seven different agroecological zones (Fig. 1). In these different regions of Vietnam, farming systems vary depending on the natural, economic, and social conditions in which farm households are located. Specifically, the factors affecting farming systems are natural conditions such as climate, topography, soil conditions, and others; market conditions for agricultural products; and socioeconomic conditions such as farm size and labor conditions of farms.

Table 5. Measures relating to rice exports.

Year	Quota (million t)	Number of export companies	Export tax (%)	Stock (million t of paddy)
1997	2.5	17	1–2–3	1
1998	4.0	19	0–1	1
1999	3.9	41	0	2.3
2000	4.3	47	0	

Source: Son (2000).

Biophysical characteristics and rice ecosystems in Vietnam

Climate is the main factor affecting rice farming systems and also rice yield. Three basic climatic regimes are found in Vietnam. In the interior areas of the north (covering primarily NMM, RRD, and NCC), the temperatures are subtropical. Shifting seasonal wind patterns result in dry winters and wet summers. The central and southeastern areas (covering SCC, CH, and eastern NES) typify the tropical monsoon climate, with high temperatures and abundant precipitation. In the southwest (i.e., MRD and western part of NES), distinct wet and dry periods are evident, but temperatures are higher than in the north. Thus, farmers in the south can grow three rice crops per year (winter-spring, summer-autumn, and main rainy season), while farmers in the north can grow only two rice crops per year (spring and main rainy season) because of low temperature in the winter.

The soils of the RRD and MRD are composed of rich alluvium except where polders for flood control, particularly in the RRD, prevent replenishment of alluvial deposits brought down by the rivers. Soils in the uplands are generally poor as a result of leaching of nutrients from the ground by the abundant rainfall.

The agroecological differences between northern and southern Vietnam, coupled with differences in history, farm-holding size, irrigation system, and cultural practices, give rise to different farming systems. Rice farming in the north is highly intensive, arising from the long history of rice cultivation, well-established irrigation systems, high population density, and small farm size. In contrast, the favorable agroclimatic conditions in the south, a younger civilization history (hence allowing for land expansion), larger farm size, and recently developed irrigation infrastructure system provide better opportunities for increasing rice production.

Rice supply and its determinants

In this study, the main factors affecting the rice supply are rice varieties, irrigation efficiency, fertilizer application, pest and postharvest losses, expected revenue from the rice crop, price, and policy.

Rice varieties. The widespread adoption of modern rice varieties has contributed substantially to the marked increase in rice production in Vietnam. From 1990 to 1995, the Ministry of Agriculture and Rural Development (MARD) officially approved and introduced 44 modern varieties[2] nationwide and 70 varieties at the regional level. In the north, the popular modern varieties, including hybrids, are VN10, NN20, NN75-2, NN8, Spring No. 2, C37, DT10, and C180. In the MRD, the popular modern varieties are IR1529-68, IR1561, IR28, and IR2103 as well as the insect-tolerant rice varieties such as IR64 and OM527 and adaptable short-maturing varieties such as NN2B, NN4B (IR42), OM89 (IR64), and OMCS7 (Kinh 1996). It was estimated that, until the late 1990s, modern rice variety adoption in Vietnam had reached 87% of the total rice land.

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[2] The modern or high-yielding varieties refer to those newly released by research centers that are different from traditional or local varieties.

Irrigation. In comparison with other countries in Southeast Asia, Vietnam has a relatively high proportion of irrigated area for rice production. In the 1980s, irrigated area expanded by 2.9% annually and in the '90s this growth increased to 4.6% annually. Investment in irrigation increased from US$140 million in 1996 to $179 million in 2000 (Fig. 9). At the end of the 1990s, the total irrigated area was 3.7 million ha (GSO 1999a), enabling about 6.7 million ha of planted rice under irrigation in 2000 (MARD 2001b). It was estimated that irrigated rice land increased from 68% in 1980 to 84% in 1990 (Xie 1995) and 88% in 2000. The RRD has the largest irrigation coverage, about 90%, followed by the MRD at around 70%. The lowest irrigation coverage occurs in the NMM and CH.

The main concern in irrigation development is the lack of funds for maintenance and repair. Of the irrigated area, only 28% is under direct water supply and the actual irrigated area is only 60% of the designed capacity. In the RRD, for instance, the shortfall between designed and actual irrigated area is about 30% (Hoat 1997). Consequently, although the proportion of irrigated area is relatively high, the system does not ensure the timely availability of water for rice production.

Fertilizer use. In the past, the sharp increase in fertilizer use per ha largely contributed to the favorable rice yield performance in Vietnam. Fertilizer use doubled from 1984 to 1991 (from a low rate of 56.9 kg ha^{-1} in 1984) and rose further to 174.5 kg ha^{-1} in 1994. This increment contributed to an increase in rice yield from 2.7 t ha^{-1} in 1984 to 3.4 t ha^{-1} in 1994. However, it is argued that there will be little room to further increase rice yields through additional fertilizer application. A study by Han and Eric (1995) in Hai Hung Province in the RRD proved that the improper application of fertilizer has caused a low rice yield. Based on experiments conducted in Can Tho Province in the MRD, Tan (1997) also indicated the low efficiency of urea appli-

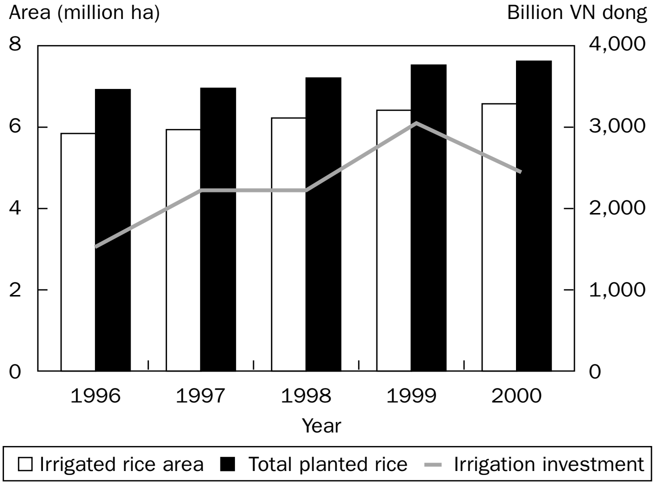

Fig. 9. Investment for irrigation, irrigated rice area, and total rice land. Data from GSO (2001).

cation by farmers. Therefore, the gap between current fertilizer application and the optimal point is negligible and an increase in rice yield will depend less upon additional fertilizer use but rather on a more careful balanced application of nutrient elements and improved efficiency of fertilizer application.

Expected revenue. A main factor affecting farmers' incentive to cultivate rice is the revenue from rice in comparison with other alternative activities. It is reasonable to assume that farmers would consider whether it is profitable to continue with rice cultivation or shift to other crops or to nonfarm activities. Therefore, in the RSDA model, we compare revenue from the rice crop (using income per labor-day for the Vietnam case) with what is considered as expected revenue (ER), which is estimated based on the lowest yield currently reported in each province. If the revenue from rice is greater than ER, farmers will continue to grow rice; otherwise, farmers will probably shift to seek income from alternative economic activities.

Table 6 shows that, based on price and rice yield in 2000, ER varies from about US$0.30 per labor-day in the north to $1.10 per labor-day in the south. This indicates that rice profits in the south are higher than in the north, which could be because of the more favorable conditions for rice cultivation in the region.

Postharvest losses. Although Vietnam has achieved great success in rice production, insufficient attention has been paid to reducing postharvest losses, that is, losses incurred during transport, drying, storage, and milling. Postharvest losses of rice in Vietnam range from 13% to 16% vis-à-vis 10% to 37% in Southeast Asian countries and 4% to 6% in Japan (IFPRI 1996).

Postharvest losses vary by season and region. Losses are lower in the major rice-producing regions such as the RRD and the MRD than in the mountainous regions. A recent survey carried out by the Postharvest Technology Institute (2001) shows that average losses are 15% in the SCC, 13% in the MRD, and 10% in the RRD, giving a national average of 12%.

Price and policy. As mentioned above, the new land law and recent new trade policies such as lifting the monopoly of SOEs in rice exports and rationalizing the export quota distribution have raised the rice price in the domestic market and encouraged farmers to invest more in rice production.

Table 6. Estimated expected revenue (VND/labor-day) for different rice crops in seven regions.

Region	Winter-spring	Summer-autumn	Rainy season
NMM	4,563	–	4,563
RRD	10,000	–	8,000
NCC	7,481	3,440	3,600
SCC	20,000	12,745	15,000
CH	10,000	–	10,000
NES	16,111	15,778	15,147
MRD	20,000	15,726	15,726

Future of the rice supply in Vietnam

Challenges in increasing the rice supply. The challenges in increasing the rice supply center around two issues: (1) filling the yield gaps, with attention on using well-adapted varieties, improving input and irrigation efficiency, and reducing postharvest losses in order to increase revenue; and (2) converting selected rice lands into other land uses that would earn higher revenue.

The second challenge is in line with the Vietnamese government's intention to enhance diversification and introduce structural changes in the rural area to increase farmers' income. In 2001, Vice Prime-Minister Nguyen Cong Tan said that Vietnam should allocate more land resources to uses that provide higher benefits rather than to focus them on rice cultivation. He argued that in the future rice land should be limited to 3.5 million ha (Tan 2001). This orientation will cause a substantial reduction in rice land. However, to ensure food security, the government targets are to maintain the total rice area at 4 million ha and increase cropping intensity for rice and maize. Consequently, future increases in the rice supply will have to come from yield improvement.

Recent rice supply projection. Several attempts have been made to estimate the future rice supply in Vietnam (Fig. 10). For instance, Goletti (IFPRI 1996) estimated future paddy production under different assumptions. The main variables in his model are (1) improvement in agricultural technology (higher yield or lower postharvest losses), (2) cultivated area expansion, (3) investment in irrigation systems, and (4) rice price changes. In his model, the price factor is considered as the main determinant. Seven options of policy views for 2005 were analyzed, as follows:

IFPRI 1: Rapid growth in agricultural technology with an export quota
IFPRI 2: Slow growth in agricultural technology with an export quota
IFPRI 3: Medium growth in agricultural technology without an export quota
IFPRI 4: Low international prices with an export quota
IFPRI 5: Low international prices without an export quota
IFPRI 6: Exchange rate appreciation with an export quota
IFPRI 7: Exchange rate appreciation without an export quota

These results showed that paddy production in 2005 varies from 25.9 to 33.8 million t (Fig. 10) depending on the scenario. On the other hand, Phong (1997), who focused more on physical conditions and ignored market factors, projected that Vietnam could produce 34 million t of paddy by 2010 if several interventions were made, such as expanding irrigated area, increasing cropping intensity, improving seed, and reducing postharvest losses.

Rice demand in Vietnam

Specific features of rice demand in Vietnam

Rice is the traditional staple food for the Vietnamese, accounting for about 75% of total calorie intake. The main factors affecting rice demand are population size and distribution, per capita human consumption, rice used for other purposes (e.g., as seed and feed), and distribution losses.

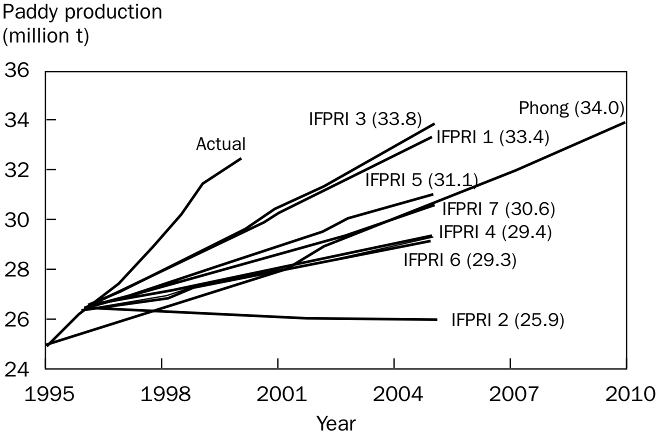

Fig. 10. Projections of paddy production in Vietnam.

As rice production increased substantially over the past two decades, a corresponding increase occurred in per capita rice consumption (Fig. 11). In the late 1970s, per capita annual rice consumption was around only 125 kg. In 1995, based on nutritional demand and the proportion of rice in the total food demand, a target rice intake for Vietnam was set at 147 kg per capita. However, since the mid-1990s, the balance between rice supply and demand at the country level has shown that per capita annual rice consumption has risen further to 155 kg. The current per capita rice consumption for Vietnam is higher than for other Asian countries (Fig. 11). Since the annual rice production per capita rose to 230 kg in 1997, the country still managed to have an ample surplus for exports, feed, and other uses. Minot and Goletti (2000) estimated human rice consumption as rice production minus net exports minus rice for other purposes (such as distribution losses, seed, and feed) that constitutes about 14.5% of the overall rice production.

The relatively stable per capita rice consumption during the last few years was attributable to the significant growth in income and increased rate of urbanization. In some urban areas, there was a very low or nearly zero response of rice demand to an increase in income.

Population, distribution, and projections

Over the past ten years, Vietnam has made substantial progress in reducing its population growth rate. In the early 1990s, the annual population growth rate was around 1.8%, but it decreased to 1.4% in 2000 (Fig. 12). The population in 2000 was about 77.6 million inhabitants, yielding a population density of about 240 persons km^{-2}. The majority live in small villages in the deltas or along the coast. The population of Vietnam is young, with 34% under 15 and only 5% over 60 years old.

Along with the industrialization and modernization process, especially since the *Doi Moi* policy began in the late 1980s, the urbanization process in Vietnam has been accelerated. There is an increasing trend of migration from rural to urban areas. From

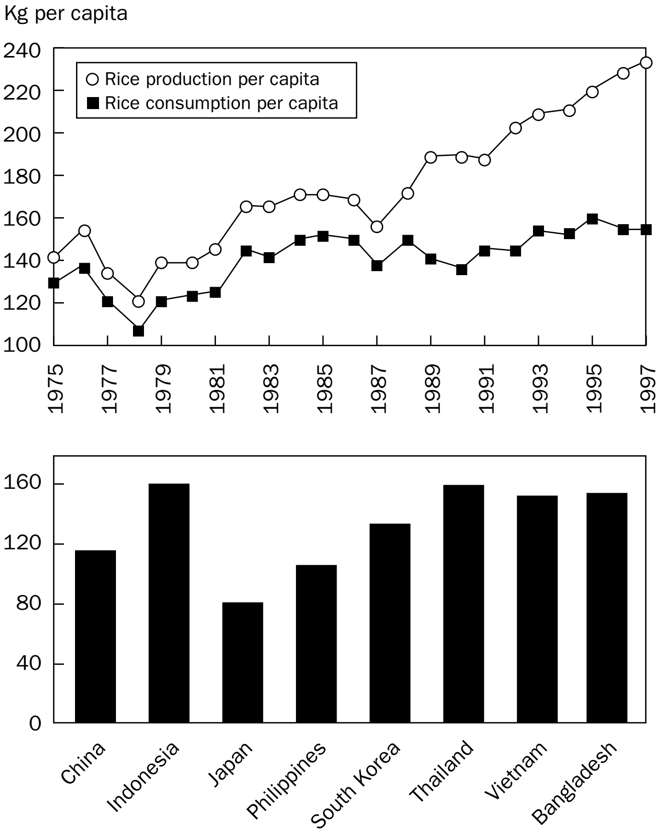

Fig. 11. Rice production and consumption in Vietnam and rice consumption in some Asian countries. In the second graph, data on rice consumption for Asian countries are for 1984-88; data for Vietnam are for 1997 (Minot and Goletti 2000, Huang and David 1991).

1990 to 2000, the population living in urban areas increased from 19.5% to 24%. The southern part of the country is more urbanized than the northern part. In recent years, several population projections have been made, with rather different results (Fig. 13). Phong (1997) projected that the population of Vietnam would reach 94 million by 2010. The World Bank (2000) estimate for 2010 is 88–89 million, of which 33% will live in urban areas. The GSO (2000) estimate for 2010 is 86 million, with an urbanization ratio of 27–29%. We selected the projected population of the GSO (86 million) and the World Bank urbanization rate (33%) for scenario analysis in this paper.

Consumption patterns

Figure 14 depicts the trend of rice consumption by income level as estimated by Minot and Goletti (2000), using data from the Vietnam Living Standard Survey 1992-93 (GSO 1994). It shows that household per capita rice consumption[3] increases as per capita income goes up to reach a peak of 164 kg at a certain income level (the 3rd

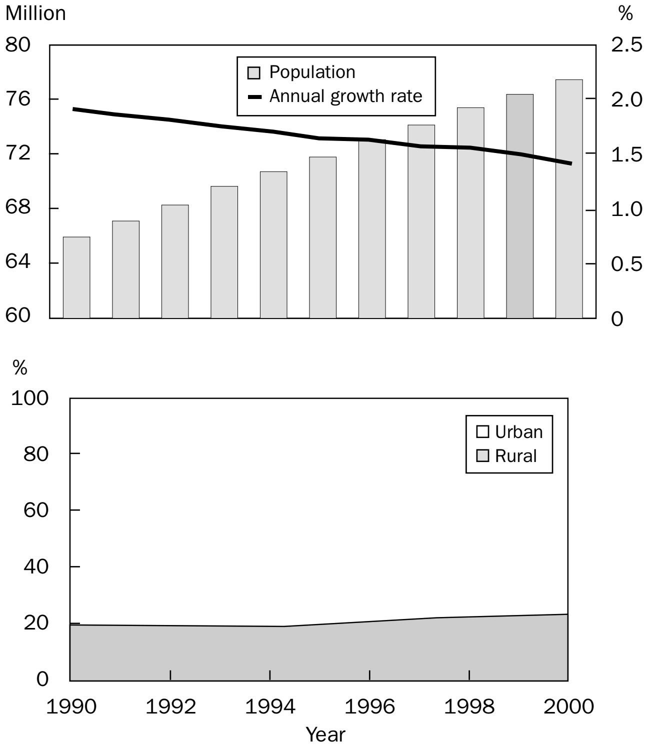

Fig. 12. Population growth and urbanization in Vietnam. GSO (2001).

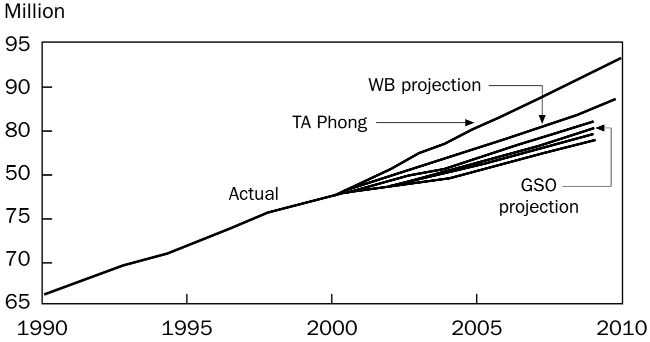

Fig. 13. Various population projections for Vietnam.

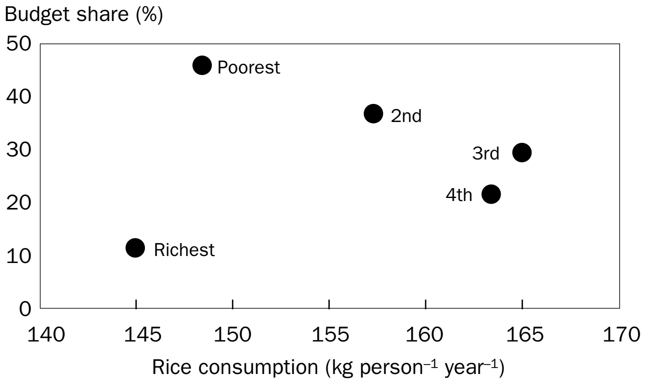

Fig. 14. Rice demand and budget share of rice consumption of different income quintiles. Source: Minot and Goletti (2000).

quintile), after which it declines to a low of 144 kg as people become richer. Figure 14 also shows that the budget share of rice in the household expenditure decreases from 47% for the poorest to 12% for the richest group.

Based on data from the Vietnam Living Standard Survey 1997-98 (GSO 1999b), we estimated that the urban person consumes about 112 kg compared with 152 kg per capita in rural areas. The lowest survey per capita rice consumption is in the urban area of NES (98 kg) and the highest is in the rural areas of the RRD (162 kg). Regionally, household per capita rice consumption ranges from 126 kg in NES (which includes Ho Chi Minh City) to 154 kg in the NMM (Fig. 15). These results corroborate the trend shown in Figure 14. It was also found that household per capita rice consumption in the south is lower than in the north; this is attributed to higher incomes and urbanization in the south (Fig. 16).

From the VLSS 97-98, we also estimated that the country average of household per capita rice consumption was 142 kg. This value is lower than the 155 kg from the balance estimation mentioned in the section on "Specific features of rice demand in Vietnam" because only the rice amounts purchased by households recorded in the survey are taken into account, while the Vietnamese are eating many products made with rice such as rice noodles (*pho, bun, mien, hu tieu*) and rice paper, considered as rice for other uses. During the last few years, these products were also exported to other countries, but the total amount is unknown.

There are only a few estimations of income and price elasticities for rice demand. Using the almost ideal demand system (AIDS) method, Minot and Goletti (2000)

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[3] Household per capita rice consumption is the per capita rice consumption estimated from the household survey that took into account only the amount of rice purchased by households. It is distinguished from per capita rice consumption from a balance calculation that assumes that human rice consumption = rice production – (losses + seed + feed + stock + exports). The total of household per capita rice consumption at the regional or country level is household rice consumption, i.e., human rice consumption = household rice consumption + rice for other uses.

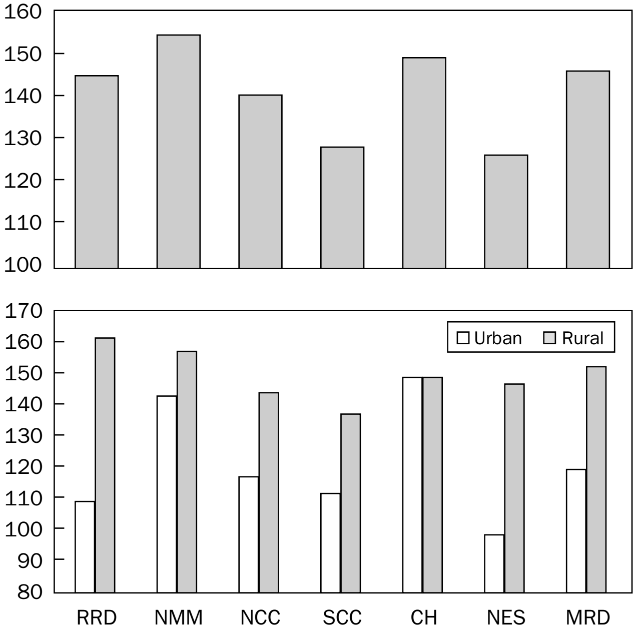

Fig. 15. Household rice consumption by region and by rural-urban area in each region (kg per capita). RRD = Red River Delta, NMM = North Mountain and Midland, NCC = North Central Coast, SCC = South Central Coast, CH = Central Highlands, NES = Northeast South, MRD = Mekong River Delta. Since data for rice consumption in the CH are only available for the rural area, we assume here that rural and urban rice consumption in CH are the same. Source: Calculated based on data from Vietnam Living Standard Survey 1997-98.

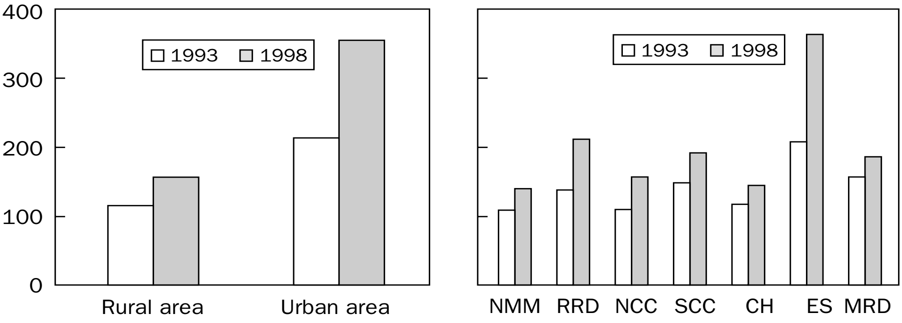

Fig. 16. Income by rural-urban area and by region (US$ per capita). NMM = North Mountain and Midland, RRD = Red River Delta, NCC = North Central Coast, SCC = South Central Coast, CH = Central Highlands, NES = Northeast South, MRD = Mekong River Delta. Source: World Bank (1999).

estimated that the income elasticity of demand for rice varies from –0.01 in the NES to 0.43 in the RRD, based on data from the VLSS 92-93. The income elasticity is higher in the north (0.48) than in the south (0.11) because of the generally higher incomes in the south that allow the population to reach rice consumption levels that surpass the malnutrition point.

Based on data from the VLSS 97-98, we also used the AIDS method to estimate income and price elasticities of rice demand by region (Table 7). The income elasticity of rice consumption ranges from 0.11 to 0.20 in urban areas and from 0.20 to 0.38 in rural areas. It is expected that, even with the same income growth rate, the increase in rice consumption of urban people would be lower than that of rural people. The price elasticity of rice demand ranges from around –0.5 in rural areas to –0.1 in urban areas.

Distribution losses and other uses

In the MRD and the NES, rice is used as feed for animals, mainly for pigs. The estimation of the use of rice as pig feed is based on the number of pigs per capita and feed demand per pig, assuming that people only use rice for pigs if rice bran (8% of paddy production minus seeds for planting in future crops) is insufficient. Such an estimation using data in 2000 resulted in about 300,000 t for animal feed. The balance between rice production and the total of seed + feed + household consumption + exports + a stock of 300,000 t showed a gap of about 15% in total household consumption. This amount is considered as rice for other uses mentioned earlier. As data on losses during distribution of rice to consumers are not available, we did not do a separate estimation of distribution losses but instead we assume that they are subsumed in the estimation of other uses of rice.

Previous estimations of future rice demand

Using the VASEM model, Goletti (IFPRI 1996) estimated rice demand under different assumptions concerning changes in rice price, quota lifting, exchange rate changes, and agricultural technology adoption. His estimates of rice demand by 2005 range

Table 7. Income and price elasticities of rice demand by region.

Region	Income elasticity		Price elasticity	
	Rural	Urban	Rural	Urban
North Mountain and Midland	0.201	0.107	–0.121	–0.259
Red River Delta	0.375	0.120	–0.480	–0.161
North Central Coast	0.320	0.202	–0.304	–0.087
South Central Coast	0.415	0.125	–0.442	–0.251
Central Highlands	0.258	–	–0.150	–
North East South	0.211	0.090	–0.258	–0.213
Mekong River Delta	0.213	0.111	–0.358	–0.430

Note: data for CH urban were not available in the survey.
Source: Calculated based on data of VLSS 97-98.

from 9 to 15 million t. Rice demand estimated by Phong (1997) based on the projected population is 13.6 million t by 2010.

Scenarios of balancing rice supply and demand in Vietnam

The RSDA system described earlier is used to estimate rice supply and demand under different scenarios reflecting changes in the key determinants or variables. As the Vietnamese economy is still under reform, with rapid changes in production and consumption, the analysis is focused on the medium term, that is, until 2010. Although the analysis is done for 20,944 grid cells in 61 provinces, emphasis is given to the aggregated results at the national level.

Production scenarios

For the production scenarios, the main variables considered are planted rice area, water/crop management efficiency, fertilizer use, postharvest losses, and prices of inputs and rice. Ten production scenarios are considered (Table 8). The first scenario, P1, is the current production situation (2000). In scenarios P2 to P8, a single factor is changed at a time to analyze the effect of this particular factor on the rice supply. The last two scenarios, P9 and P10, which are the most likely scenarios to occur because the interventions considered in these are the targets of the government, represent a combination of multiple factors, such as a reduction in rice land, improvement of water/crop management, as well as a reduction in postharvest losses, and an increasing (P9) or decreasing (P10) rice price. Table 8 summarizes the estimates of rice supply.

Table 8. Rice supply under different production scenarios (million t).

Scenarios	Major changes	Total paddy	Post-harvest losses	Seeds supply	Total rice
P1	Base scenario (production in 2000)	32.6	3.9	1.2	17.9
P2	P1 –250,000 ha of rice land	30.8	3.7	1.1	16.9
P3	P1 –450,000 ha of rice land	29.6	3.5	1.1	16.3
P4	P1 + increase irrigation/crop management efficiency to 95%	37.2	4.5	1.2	20.5
P5	P1 + reduce by 50% postharvest losses (from current 12% to 6%)	32.6	1.9	1.2	19.1
P6	P1 + increase fertilizer price by 20% and make corresponding changes in fertilizer input	30.7	3.7	1.2	16.8
P7	P1 + domestic rice price decline by 20% and corresponding changes in fertilizer input	31.5	3.8	1.2	17.3
P8	P1 + domestic rice price increase by 20% and corresponding changes in fertilizer input	33.4	4.0	1.2	18.4
P9	P2 + P4 + P5 + P7	34.1	2.0	1.1	20.1
P10	P2 + P4 + P5 + P8	36.2	2.2	1.1	21.4

Notes on production scenarios:

- *Scenario P2:* 26 of 61 provinces are selected for a reduction in rice land. The criteria of selection are a surplus of rice in 2000 and/or having opportunities to convert to nonrice crops. An average reduction of 6% is applied for these selected provinces. The reduction in each province is made by converting those cells with rice-upland crops, and then rice land with low yield, until the target of reduction is matched. The total rice area is 4 million ha and total sown area decreases from 7.6 to 7.3 million ha.
- *Scenario P3*: An additional reduction is taken from rice land in all provinces, 6% each. The reduction in each province is made in the same manner as in P2. The total rice area is 3.8 million ha and total sown area decreases to 6.9 million ha.
- *Scenario P6:* To calculate changes in fertilizer input, the own-price fertilizer demand elasticities (percentage changes in fertilizer demand when fertilizer price varies 1%) of –0.828 in the north and –0.364 in the south given by Khiem and Pingali (1995) are applied.
- *Scenarios P7 and P8:* To calculate changes in rice price and fertilizer input, the elasticities of fertilizer input to rice price, 0.421 in the north and 0.172 in the south given by Khiem and Pingali (1995), are applied.

Figure 17 shows that an improvement of water/crop management efficiency has the highest effect on paddy production (P4), while a reduction in postharvest losses is significant to improving the milled rice supply (comparing P5 and P1). An increase in fertilizer price of 20% (P6) has a more dampening effect on rice production than a decline in domestic rice price of 20% (P7). The worst-case scenario in production occurs when rice land decreases by 450,000 ha (P3) but no intervention is made to improve rice yield. A reduction in production because of the decline in domestic rice price and conversion of rice land into other land-use types can be compensated for, or

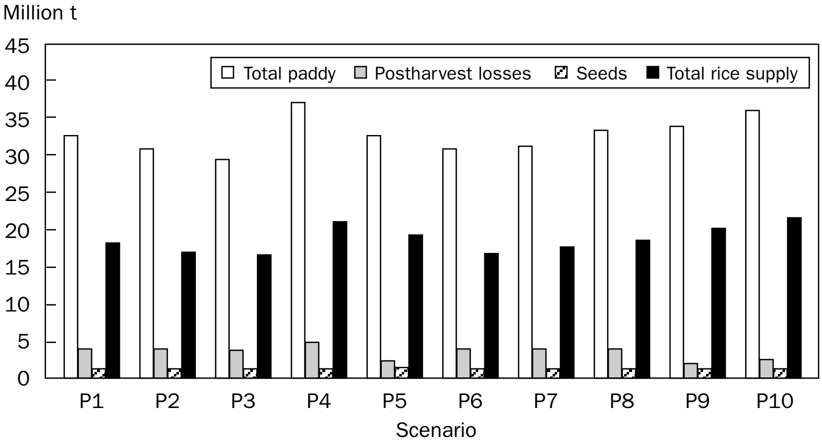

Fig. 17. Production scenarios.

even rice production can increase, by improvements in water/crop management efficiency and by reducing postharvest losses (P9). However, since it is difficult to predict the domestic rice price that is influenced by both the international market price and the price control policies in the country, a scenario with an increased domestic rice price (P10) is considered. In this scenario, total paddy production is about 1 million t lower than in the highest production (P4) as a result of converting 250,000 ha of rice land into other land-use types.

Consumption scenarios

Four scenarios (Table 9) are formulated for rice demand based on population and changes in per capita rice consumption in response to an increase in income and variation in rice price.

Scenario C1: Total current demand is estimated for a total population of 77.6 million in 2000 based on current consumption per capita (see the section on "Rice demand in Vietnam").

Scenario C2: The population in 2010 is 80.4 million, based on the GSO (2000) projection. Rural per capita consumption increases because of an increase in rural income of 48% (average of 4% per year for 2000-10), while urban per capita consumption remains unchanged. The income elasticities of rice demand mentioned earlier are applied. The urbanization rate increases to 33% as projected by the World Bank (2000).

Scenario C3 and C4: When rice price varies, urban consumption per capita is assumed to be unchanged. Rural consumption per capita varies by the price elasticities on rice demand mentioned earlier.

Figure 18 shows that rice demand for domestic consumption is highest for scenario C3, with a total of 16.8 million t. Compared with 2000, because of changes in population, urban/rural distribution, and income in that scenario, Vietnam will need

Table 9. Milled rice demand (million t) under different consumption scenarios.

Scenario	Description	Household consumption	Other use and feed	Reserve/ stock
C1	Base scenario (population in 2000 + current per capita consumption + current urbanization 24%)	11.1	2.0	0.3
C2	Population in 2010 (86.4 mil) + per capita consumption at projected income + urbanization 33%	13.1	2.8–3.2[a]	0.3
C3	Population in 2010 (86.4 mil) + per capita consumption at projected income + current urbanization 33% + rice price decline by 20%	13.6	2.9–3.2[a]	0.3
C4	Population in 2010 (86.4 mil) + per capita consumption at projected income + current urbanization 33% + rice price increase by 20%	12.5	2.7–2.9[a]	0.3

[a] As mentioned earlier, the amount of rice used as feed depends on total rice bran, which varies with production scenarios. Therefore, rice for other uses and feed varies within a range given in this column, depending on production scenarios.

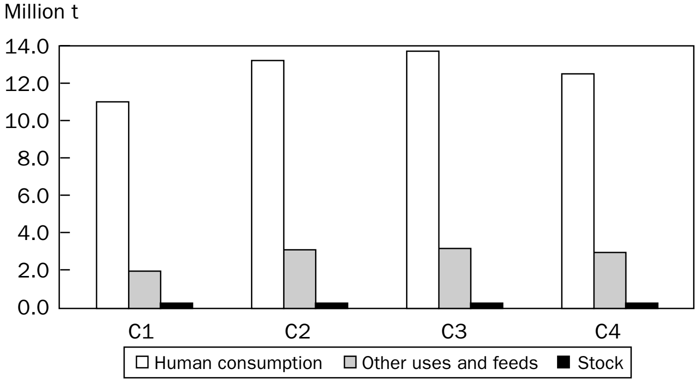

Fig. 18. Consumption scenarios.

an extra 2.5 million t of milled rice. A variation of 20% in the rice price causes about a 500,000–600,000 t variation in demand (C4 and C3 vs C2). Because of the progress in birth control in Vietnam in the last few years and the speed of urbanization, C2 is considered to be the scenario for 2010, with a demand of 2 million t for household consumption and about 1 million t for other uses, which is higher than in 2000. C3 and C4 reflect the effects of a variation in domestic rice price corresponding to scenarios P9 and P10 of rice supply. Total demand in these scenarios is about ±0.5 million t vis-à-vis scenario C2. The results from an additional model run showed that the effect of increasing the urbanization ratio from 24% to 33% is about –400,000 t.

Balancing supply and demand at the national level

Table 10 presents ten combinations of production and consumption scenarios. Scenario P1_C1 describes the balance in 2000 when Vietnam exported 3.5 million t of rice. By assuming that exported rice required further cleaning, an extra ratio of –0.15 is added to the current milling ratio of 0.65 for the conversion of paddy production to rice exports. This ratio would be lower if improvements in processing facilities were made.

The combinations of C2 (projected demand for 2010 at 33% urbanization and at current rice price) with five of the production scenarios show that, with the improvement in water/crop management efficiency (P4_C2), Vietnam is still able to export 3.1 million t of rice in 2010, while, in the cases of P2_C2 (converting 250,000 ha to other land-use types) and P6_C2 (increasing fertilizer price), only 300,000 to 500,000 t would be left for export (Table 10 and Fig. 19). The rice price has a strong influence on the remaining amount for export after domestic consumption. A variation from +20% to –20% in rice price (P7_C3 and P8_C4) causes a difference of 2 million t in rice exports. With an improvement in water/crop management efficiency and a reduction in postharvest losses, export capability in 2010 varies from 2.3 million t (if the price declines 20%) to 4.3 million t (if the price increases 20%), even with 250,000 ha less (P9_C3 and P10_C4). Obviously, the foreign currency earnings would be higher if products such as rice noodles, rice paper, etc., were exported rather than milled rice.

Table 10. Balance scenarios as combinations between production and consumption (million t).

Item	P1_C1	P1_C2	P2_C2	P4_C2	P5_C2	P6_C2	P7_C3	P8_C4	P9_C3	P10_C4
Total paddy	32.6	32.6	30.8	37.2	32.6	30.7	31.5	33.4	34.1	36.2
Total rice supply	17.9	17.9	16.9	20.5	19.1	16.8	17.3	18.4	20.1	21.4
Total rice demand	13.3	16.4	16.4	16.4	16.4	16.4	17.2	15.7	17.2	15.7
Exports[a]	3.5	1.1	0.4	3.4	2.2	0.3	0.1	2.1	2.5	4.6

[a]Assumes that milling ratio for export rice is 0.5 instead of 0.65.

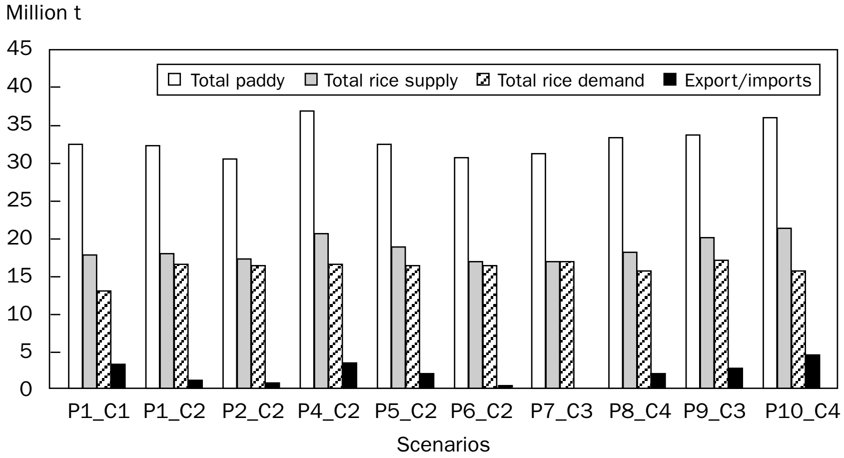

Fig. 19. Balance scenarios.

Balancing rice supply and demand at the subnational level

Table 11 shows the balance between rice supply and demand in seven regions aggregated from grid cells in three balance scenarios: P1_C1 as the current situation, P9_C3 in 2010, and P10_C4 (the most optimistic combination scenario) in 2010. Three regions that are not self-sufficient (NMM, CH, and NES) will continue to receive rice from the other regions in 2010. In scenario P9_C3, the SCC will also incur a deficit. The MRD continues to play the major role in rice supply in all scenarios while the role of the RRD becomes less important in the future; this is also evident in Figure 20.

Discussions on policy implications in the balance scenarios

In the vision for 2010 (World Bank 2000), the target is to achieve 38 to 40 million t of food, of which 34 million t are rough rice. To meet this target, the Vietnamese government is considering three types of interventions: (1) applying new advanced technologies rapidly, especially hybrid rice; (2) investing in drying, milling, and storage/ preservation systems for rice; and (3) developing policies to support and ensure reasonable income for rice growers.

Since Vietnam is shifting toward a free market system, there would be limited scope for and effectiveness in controlling the demand side. Therefore, most of the

Table 11. Balancing per capita rice supply and demand in seven regions.

Region	P1_C1			P9_C3			P10_C4		
	Supply	Household consumption	Balance	Supply	Household consumption	Balance	Supply	Household consumption	Balance
North Mountain and Midland	141	155	–14	143	172	–29	158	167	–9
Red River Delta	223	151	72	184	168	16	200	146	54
North Central Coast	160	142	18	172	165	7	188	151	37
South Central Coast	134	131	3	123	154	–31	129	138	–9
Central Highlands	78	141	–63	87	153	–66	90	147	–57
Northeast South	71	123	–52	69	126	–57	72	120	–48
Mekong River Delta	548	147	401	541	164	377	568	148	420
Country	230	142	88	217	158	59	231	145	86

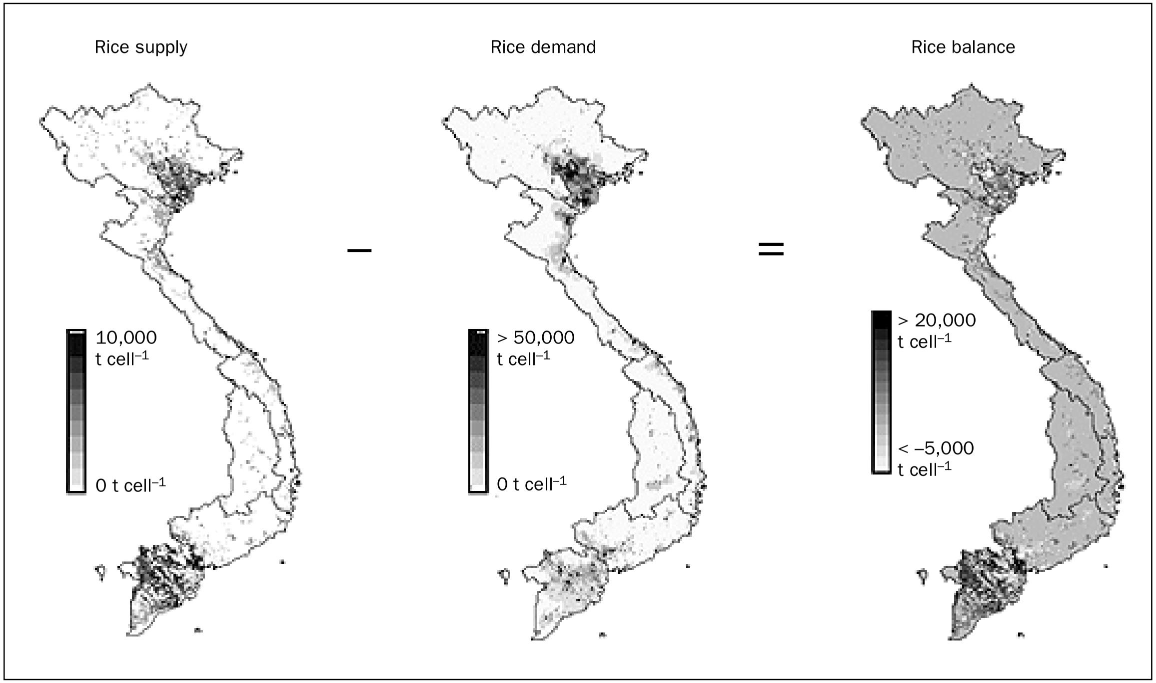

Fig. 20. Balancing rice supply and demand for combination scenario P10_C4.

interventions considered above relate to the supply side. For the first intervention, hybrid rice presently faces a quality problem and low price. It is more widely adopted in the north, while the main rice production is in the MRD. We also do not expect that new varieties with a significant improvement in yield potential could be spread over the country within the next 10 years. Our analysis shows that an improvement in water/crop management efficiency (as in scenario P4) can almost compensate for the increased demand because of a population increase and future urbanization in 2010 if rice area does not dwindle (balance scenario P4_C2). The second effective intervention, in fact, is not to increase paddy production but the milled rice supply by a reduction in postharvest losses. It is generally accepted that changes in rice price are very difficult to predict. Nonetheless, the result for scenario P8 indicates that an increase in supply with a hike in the rice price is not expected to be substantial; a mere additional 800,000 t of paddy are expected with a 20% increase in rice price and without improvement in irrigation.

As reflected in several documents of the MARD (2001a, b) and other government reports, the Vietnamese government intends to maintain about 4 million ha of rice land. However, the fluctuating rice price in recent years has been affecting farmers' income, prompting a rethinking and consideration of changing some rice land to other crops or activities with higher profit (Tan 2001). Because of the uncertainty over the market opportunity of agricultural products replacing rice, for the purposes of this study we limit rice land conversion to 250,000 ha, which would meet the target of 4 million ha of rice land in 2010.

Conclusions

This rice supply and demand analysis indicates that Vietnam will continue to be a major rice-producing country. The MRD will play an increasingly major role in rice production in the country. Although rice is still the most important crop in Vietnam, income from rice cultivation is lower than from other crops. Therefore, although the Vietnamese government still focuses on strengthening rice exports, it is also considering converting part of the rice land into other crops.

Our analysis of various production and consumption scenarios shows that paddy production would range from 30 to 36 million t depending on the interventions implemented by the government. Variations in the rice price may cause a variation of about 2 million t in paddy production. Improvement of water/crop management efficiency may lead to a significant increase in paddy production that can compensate for increased demand. In addition, a reduction in postharvest losses can further compensate for losses caused by the conversion of rice land to other uses. Rice demand for household consumption in 2010 under an urbanization rate of 33% is about 13.8 million t. Variations in rice price may cause about a 1 million t difference in demand.

By maintaining rice land at 4 million ha, Vietnam would be able to maintain rice exports ranging from 2 to 4 million t within rice price variations of 20% from the current price, provided that a combination of interventions, including improvement of water/crop management efficiency and a reduction in postharvest losses, is implemented. Besides the concern over rice exports, attention should also be given to efficient rice distribution in the country to ensure food security for people in the highlands and mountainous regions.

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Rice supply and demand in Thailand: recent trends and future outlook

S. Isvilanonda

This paper discusses the factors that contributed to the development of the rice sector in Thailand and analyzes their impact on the emerging trends in domestic rice supply and demand. Supply and demand parameters are estimated based on time-series data from 1971 to 1999 for use in assessing Thailand's rice exportable surplus in the next two decades. The study notes significant improvement in labor productivity despite slower growth in yield. Such improvement came from higher rural wage rates as labor shifted from rural to urban areas, thus inducing the adoption of machinery and other labor-saving techniques in rice production. The own-price elasticity of the rice supply is very inelastic. Among the nonprice factors, investment in rice research played a dominant role in raising the rice supply. Growth in the rice supply is projected to slow down at 0.54% per annum. Demand analysis similarly shows that the response to rice price is inelastic. The income effect on demand, however, is negative, which indicates that rice is an inferior good. With a projected lower growth rate in population, future growth in domestic rice demand will decline at 0.30% per annum. The projected trends in rice supply and demand will enable Thailand to maintain its exportable surplus. It is expected that surpluses will further increase from 7.4 million t (of milled rice) in 1999 to 9.9 million t in 2020.

Rice is a dominant subsector of Thailand's crop income and has long been an important source of export earnings. During the rapid economic progress in the nonagricultural sectors over the past few decades until the financial crisis in 1997, the importance of rice and the agricultural sector as a whole diminished. Once again, agriculture is regarded as a critical sector to cushion the adverse effect of the economic crisis. This is particularly true in the case of rice, which continues to be the dominant economic activity in rural Thailand. Recently, the rice crop has accounted for almost one-third of the total value of crop production. It continues to be a major export crop, with about 8 million t, close to a third of the total production of paddy, exported in 1999, which produced around US$1.65 billion in export earnings. Thailand thus remains the largest exporter in the world rice market.

The rice economy of Thailand appears to be in transition. A high growth rate in the nonagricultural sector and a small growth rate in the agricultural sector in the past few decades have essentially induced an adjustment in farm resource allocation within the sector and among the sectors. A remarkable increase in the demand for agricultural labor in the nonagricultural sector previously created a labor shortage in rural areas and the rise in the wage rate in turn inflated the cost of rice cultivation. These developments in the domestic economy along with the long-term declining trend in rice prices in the international market, and the increased competition from low-cost rice economies such as in Vietnam and Myanmar, have raised concern whether Thailand can maintain its exportable surplus of rice and future competitive strength in the world market.

While rice remains Thailand's staple food, both economic prosperity and rapid urbanization in the recent past led to some changes in people's consumption habits. In addition, rising income has inevitably stimulated consumers to diversify their diets away from rice in favor of meat and horticultural products. The practice of eating out associated with urbanization has also reduced per capita rice consumption. Continued development of these behaviors could further slacken the demand for rice in the domestic market.

This paper aims to analyze trends in both rice production and consumption and to project the exportable surplus in the next two decades. The paper has been organized into six sections. This introduction is followed by an examination of recent developments in the Thai rice economy in the second section. Changes in price policy regimes are discussed in the third section. The fourth section presents the methodology for estimating the rice supply response and the results of the functional estimation. The fifth section discusses rice use and the estimate of the rice demand function that projects domestic consumption. The sixth section projects the balance. The last section provides some conclusions and policy suggestions.

Recent developments in the Thai rice economy

Trends in rice production

From 1960 to 1980, Thailand invested significantly in agricultural development as prescribed in the economic and social development plans.[1] Developments in irrigation systems, road networks, marketing facilities, and agricultural research and extension in many parts of the country have induced changes in agricultural structure and farming systems. Crop diversification and intensification have largely been adopted in many regions that in turn increased the agricultural crop mix, particularly in irri-

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[1] The first Economic and Social Development Plan was inaugurated in 1954. Thailand is now in its 9th Economic and Social Development Plan.

gated areas. As a result, the share of rice crop area declined from 60.1% in 1971-75 to 51.8% in 1991-97 (Table 1). In the same period, the trends of upland and tree-crop areas increased significantly as change was induced by the relatively higher price of those crops. Despite the declining trend of rice cultivated area, rice production still accounted for a large amount of land and labor.

Rice is grown in Thailand mostly under rainfed conditions. The rainfed ecosystem accounts for nearly 80% of the total rice area. Water scarcity prevented the development of irrigation systems that would have allowed rice cultivation during the dry season. Thus, dry-season irrigated rice has accounted for only 10% of the total rice area in Thailand and about 19% of total rice production (Table 2).

The major rice-growing belt located in the northeast region accounted for almost half of the country's rice cultivated area (Appendix Table 1). A single rice crop grown with traditional high-quality rice varieties is the predominant cropping pattern in the region. Meanwhile, the average rice yield in this region is very low. It was around 1.7 t ha^{-1} and barely increased over time. Commercial rice production is mostly concentrated in the Central Plain and lower northern region, where a substantial area is irrigated. Modern rice varieties are commonly grown in this environment.

During the past few decades, rice area in Thailand rose at 1.0% per annum, from 8.15 million ha in 1971-75 to 10.26 million ha in 1996-2000 (Table 2). An exhaustion of agricultural land in the early 1980s and a problem of water resource scarcity in the early 1990s consequently reduced the cultivated area despite the rising share of dry-season crop area. Both the increase in rice cropping intensity and modern rice variety (MV) adoption since the early 1970s have regenerated growth in production, despite a diminishing growth in cultivated area. From 1971-75 to 1996-2000, rice production increased considerably from 14.23 million to 23.74 million t or 2.67% per annum, which is higher than the rate of cultivated area growth. The higher growth in production in the late 1990s stemmed from the increase in rice cropping intensity in flood-prone environments from growing one crop of floating rice varieties to two crops of MVs. By leaving the land idle during the wet season and waiting until the water drains out in December, double rice crops can be grown and cultivated area and yield can increase. Furthermore, the widespread adoption of new short-duration varieties in irrigated areas improves rice cropping intensity from two crops to three crops a year or five crops in two years.

Table 1. Average share of rice area in total crop production, 1971-97.

Period	Share (%) in total cultivated area				
	Rice	Upland crops	Tree crops	Vegetables	Total
1971-75	60.1	19.2	19.0	1.8	100.0
1976-80	57.5	21.7	19.2	1.6	100.0
1981-85	54.2	24.5	19.8	1.5	100.0
1986-90	53.1	24.8	21.0	1.0	100.0
1991-97	51.8	23.6	23.7	1.0	100.0

Source: Calculated from Agricultural Statistics of Thailand, various issues.

Table 2. Average and growth of production, area, and yield of rice classified by wet and dry seasons, 1971-2000.

Period	Wet season	Dry season	Annual average	Wet season	Dry season	Annual average
	Average area (million ha)			Growth (%)		
1971-75	7.83	0.32	8.15			
1976-80	8.85	0.50	9.35	2.61	11.25	2.94
1981-85	9.23	0.64	9.87	0.86	5.60	1.11
1986-90	9.26	0.71	9.97	0.07	2.19	0.20
1991-95	8.94	0.69	9.64	–0.69	–0.56	–0.68
1996-00	9.09	1.17	10.26	0.34	13.91	1.31
% share	88.60	11.40	100.00	–	–	–
Av growth per annum (1971-2000)				0.64	10.62	1.04
	Production (million t)			Growth (%)		
1971-75	13.20	1.03	14.23	–	–	–
1976-80	14.32	1.78	16.10	1.70	14.56	2.63
1981-85	16.54	2.34	18.88	3.10	6.29	3.45
1986-90	16.59	2.53	19.10	0.06	1.62	0.23
1991-95	17.44	2.94	20.38	1.02	3.24	1.34
1996-00	18.76	4.98	23.74	1.51	13.87	3.30
% share	79.02	20.98	100.00	–	–	–
Av growth per annum				1.68	15.33	2.67
(1971-2000)				1.68	15.33	2.67
	Average yield (t ha^{-1})			Growth (%)		
1971-75	1.67	3.21	1.75	–	–	–
1976-80	1.76	3.56	1.72	1.08	2.18	–0.34
1981-85	1.62	3.66	1.91	–2.80	0.56	2.21
1986-90	1.60	3.56	1.91	–0.25	–0.55	0
1991-95	1.94	4.26	2.11	4.25	3.93	2.09
1996-00	2.07	4.26	2.31	1.34	0	1.84
Av growth per annum (1971-2000)				0.96	1.30	1.28

Note: Calculated from Agricultural Statistics of Thailand, Office of Agricultural Economics, various issues.

Rice yield and chemical fertilizer use

Rice yield in Thailand is relatively low, with an average annual yield in 1996-2000 of 2.3 t ha^{-1}. The average yield in the wet season is 2.1 t ha^{-1}, which is half of that of the dry season. The lower yield of the wet-season crop stems from a significant share of rainfed and floating rice area where local varieties are grown. Despite the increase in the cultivated area of dry-season rice, the average share of dry-season cultivation in total rice area was very small, only 11.4% in 1996-2000. In this regard, dry-season production accounted for 23.8% of the annual rice production of 4.98 million tons.

During the 1970s and ’90s, the annual yield performance improved and the average growth in annual yield per annum was 1.28%. Investment in irrigation develop-

Table 3. Average application rate of chemical fertilizer for rice, 1971-2000.

Period	Wet season (kg ha^{-1})	Dry season (kg ha^{-1})	Annual rice (kg ha^{-1})
1971-75	23.3	169.4	27.2
1976-80	32.8	236.1	43.6
1981-85	44.2	295.2	60.1
1986-90	66.9	297.1	83.6
1991-95	113.3	340.6	129.7
1996-97	157.6	325.6	175.5

Source: Office of Agricultural Economics, Ministry of Agriculture.

ment, the adoption of modern rice varieties, and increased rice cropping intensity in irrigated areas have contributed to such improvements.

Since the introduction of modern rice varieties in 1969, the area cultivated to MVs has increased rapidly, particularly in the central region (Isvilanonda and Wattanutchariya 1994). Because the MVs respond well to chemical fertilizer, average fertilizer use rose dramatically from 27.7 kg ha^{-1} in 1971-75 to 175.5 kg ha^{-1} in 1996-2000. The average dry-season application rate per ha has been around two times higher than that of the wet season (Table 3). Most chemical fertilizers are imported. A high ratio of fertilizer price to rice price has therefore prevented farmers from following the recommended application rates that require a higher amount of fertilizer than the average farmers' practice.

Trends in infrastructure development

The government made massive investments in road construction during the 1960s and '70s that helped facilitate the reclamation of new farmland and improved marketing efficiency. Such investments later facilitated rural-urban and rural-rural migration to take advantage of the seasonal and spatial variation in employment opportunities. It was reported that, during 1966-70 and 1986-91, the average budget for road construction and improvement increased from US$256 to $1,721 ha^{-1} (Isvilanonda and Poapongsakorn 1995).

In Thailand, the government implemented most large- and medium-scale irrigation projects during the 1950s and '60s. High investment costs, the long gestation period, and low rates of return on investment led to a shift in investment priorities to small-scale projects during the 1970s and '80s (Isvilanonda and Poapongsakorn 1995). Irrigated area expanded slowly in the 1960s but, from 1971-75 to 1996-97, wet-season irrigated area rose from 1.91 million to 4.73 million ha (Table 4). However, the growth of irrigated area has declined over the past three decades. The irrigated area represents about 23.9% of the total cultivated area (Isvilanonda and Hossain 1998).

Even though irrigated rice yields more (4.0 t ha^{-1}) than rainfed rice (2 t ha^{-1}), the effect of irrigation on increasing the country's rice yield is small because of the larger area of rainfed environment. Dry-season irrigated rice also expanded from 300,000 ha in 1974 to 700,000 ha in 1997 (7% of the rice harvested area) and has fluctuated around that level since then, depending on paddy price.

A potential to further expand irrigated area is limited because of the rapid increase in the cost of irrigation development and growing concern regarding the adverse environmental conditions of irrigation projects. During the 7th and 8th National Economic and Social Development Plans (1992-96 and 1997-2001), the Royal Irrigation Department planned to concentrate on improving the water distribution system for both state-owned and private irrigation projects rather than constructing new projects. Improving the efficiency in water management and the collection of water charges were also mentioned as key objectives.

Rice research since the late 1960s has focused on improving yield per hectare in irrigated areas by using outputs from international research, particularly from the International Rice Research Institute (IRRI). However, the impact of this research was small because of a small proportion of irrigated area. Research on rainfed rice production is limited. Out of the Department of Agriculture's budget, rice research accounted for only 10.9% during 1996-98. The real budget value of rice research at constant 1988 prices rose from $1.71 million in 1971-75 to $5.12 million in 1996-98 (Table 5). Although it is difficult to separate the research budget from the institutional budget, around 50% was used for conducting research. The major focus of rice research has been on increasing yield for the irrigated ecosystem as well as developing resistance against major insects and diseases. The effects of rice research on productivity growth in irrigated areas are obvious. With a larger share of the rainfed ecosys-

Table 4. Average irrigated area, 1961-97.

Period	Wet-season irrigated project area (million ha)	Annual growth in irrigated area (%)
1971-75	1.91	
1976-80	2.65	7.74
1981-85	3.42	5.81
1986-90	4.08	3.86
1991-95	4.50	2.06
1996-97	4.73	0.73

Source: Calculated from Agricultural Statistics of Thailand, various issues.

Table 5. Budget allocation for rice research and institutions (at 1988 prices) from the Department of Agriculture (DOA), 1971-97.

Period	Average budget of DOA (million US$)	Average budget allocation for rice institutions (million US$)	Average annual growth (%)
1971-75	11.53	1.71 (14.83)	
1976-80	16.30	2.04 (12.51)	3.86
1981-85	20.35	2.59 (12.73)	5.39
1986-90	23.68	2.38 (10.05)	–1.62
1991-95	38.07	4.59 (12.06)	18.57
1996-97	46.94	5.12 (10.91)	5.77

Source: Agricultural Statistics of Thailand, various issues.
US$1 = 43 baht.

tem in rice production, rice research policy should also pay more attention to the welfare of rainfed farmers.

Labor scarcity and farm machine accumulation

The population in Thailand was estimated at 61.4 million in 2000 and it rose at 1% during the 1990s. During the early 1970s, nearly 72% of the Thai labor force was engaged in agriculture; the expansion of the land frontier for rice cultivation was therefore not constrained by the availability of labor. But the rapid growth of the nonagricultural sector since the late 1970s and the widening income disparity between urban and rural areas led to a rapid rural-urban migration of the population and an absolute decline in the agricultural labor force. The share of agricultural labor in the total labor force declined from 72.3% during 1971-75 to 45.5% during 1991-95 and the labor force engaged in rice cultivation dropped from 51.2% to 29.6% over the same period (Table 6).

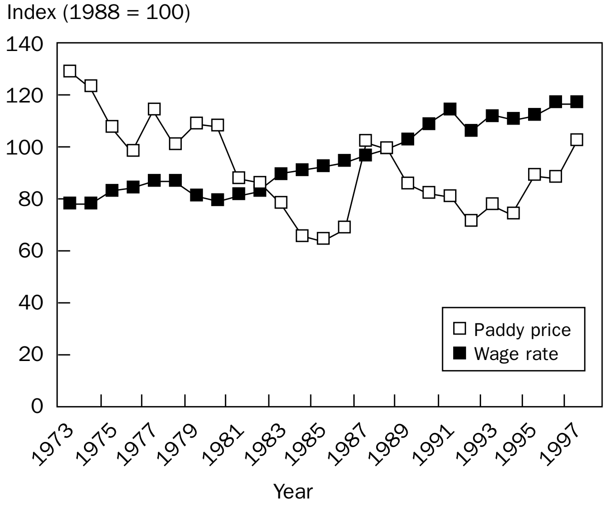
The absolute number of workers engaged in rice cultivation increased marginally from 10.44 million during 1971-75 to 11.83 million during 1981-85 and started declining in absolute terms since then (Table 6). The absolute decline in the labor force engaged in rice cultivation started in the early 1970s in the Central Plain as a result of the well-developed infrastructure and proximity to Bangkok. Other regions also experienced the same phenomenon during the early '80s (Isvilanonda and Hossain 1998). As a consequence, the rural wage rate increased much faster than the rice price (Fig. 1), thus inflating the cost of producing rice.

Rice farmers responded to the labor shortage by adopting machinery in farm operations. Mechanization began to spread in Thailand in the 1950s with the use of machines to reclaim new farmland (Siamwalla 1987, Rijk 1989). Tractor use in land preparation started in areas with large farms in the 1960s (Wattanutchariya 1983). In 1969, Thailand began to produce power tillers on a large scale. In 1971-75, 8,935 large tractors and 53,449 power tillers were in operation. Also, in 1996-98, the number of tractors increased fourteen times and power tillers thirty times (Table 7). Since 1990, custom service for the combine harvester has been spreading rapidly in the

Table 6. Total agricultural and rice labor forces and their shares, 1971-97.

Period	Total labor force (million) (1)	Agricultural labor force (million) (2)	Rice labor force (million) (3)	Share of agricultural labor in total labor (%) (2)/(1)	Share of rice labor in total labor (%) (3)/(1)	Share of rice labor in agricultural labor (%) (3)/(2)
1971-75	20.13	14.45	10.44	72.28	51.19	71.15
1976-80	25.27	16.44	11.34	65.06	44.88	68.98
1981-85	28.95	17.76	11.83	61.35	40.86	66.61
1986-90	31.43	17.06	10.89	54.28	34.65	63.83
1991-95	32.00	15.81	11.76	50.30	31.40	63.56
1996-97	32.34	14.73	10.05	45.54	29.06	63.81

Source: Agricultural Statistics of Thailand, various issues.



Item	1973	1980	1990	1995	1997
Real paddy price (US$ t^{-1})	117.79	98.23	74.47	81.37	93.63
Real wage rate (US$ d^{-1})	1.02	1.02	1.41	1.46	1.52

US$1 = 43 baht.

Fig. 1. Index trend (%) in real farm price of paddy and real wage rate from 1973 to 1997.

Table 7. Machinery and equipment used in agriculture, 1971-98.

Period	Large tractors (no. of units)	Power tillers (no. of units)
1971-75	8,935	53,449
1976-80	27,133	190,185
1981-85	34,164	347,143
1986-90	45,967	591,817
1991-95	102,518	1,787,171
1996-98	127,999	2,051,550

Source: Agricultural Statistics of Thailand, various issues.

Central Plain and the lower north region. The use of animals for land preparation has virtually ceased in most parts of the Central Plain and the northern region. In most regions, paddy is threshed by machines. Furthermore, to reduce labor use in transplanting, farmers have widely adopted the direct-seeding method for crop establishment, particularly in the Central Plain.

Table 8. Labor productivity (tons of paddy per labor) in rice production, 1971-97.

Period	Northeast	North	Central	South	Total
1971-75	0.90	1.92	3.05	0.88	1.69
1976-80	0.91	2.04	3.68	0.85	1.87
1981-85	1.27	2.48	4.50	0.85	2.27
1986-90	1.50	3.05	5.01	0.87	2.61
1991-95	1.92	2.93	5.20	1.05	2.78
1996-97	2.17	3.61	5.90	1.25	3.25

Source: Author's calculations.

Labor productivity in rice production

Infrastructure development and the rapid growth of the nonagricultural sector have caused a migration of the agricultural labor force out of rural areas. A decline in the rice labor force inevitably stimulated the adoption of labor-saving technologies, which in turn created an improvement in labor productivity. The average labor productivity in rice production rose substantially from 1.69 tons per labor during 1971-75 to 3.25 tons per labor in 1996-97 or about 92.3% (Table 8). Among regions, the Central Plain has the highest labor productivity, while the south has the lowest.

Labor productivity estimation

The labor productivity (PROLA; ton) function in this analysis is estimated using the following factors: (1) rice cultivated area per rice labor force (CUPA; rai), (2) irrigated area per rice labor force (IRGLA; rai), (3) rice research investment per rice labor force (RESLA; baht), (4) a dummy variable for rainfall conditions (UNRAIN), and (5) rice ecology (in terms of regional dummies; NORTH, CENTRAL, and SOUTH, where the northeastern region was chosen as a basic condition). Rice cultivated area is employed to capture the important effect of land resources on productivity since land is a basic resource of rice production. Intuitively, given the same amount of labor force, the larger the area, the higher the labor productivity. On the other hand, holding the same ratio of land to labor force, the lower the land quality, the lower the productivity. The capital variable is treated as the residual because of its unreliable data.

The data were disaggregated into the provincial level from 1971 to 1997, in which a total of 1,890 observations were used in the estimation. The Cobb-Douglas function is chosen and the equation is specified in the log-linear form. The weighted least squares (WLS) technique is employed instead of the ordinary least squares technique as a result of the unequal importance of rice production in different provinces. Table 9 shows the results. Except for the UNRAIN variable, which is insignificant, the other variables are significant at 1%. A positive relationship between rice area and labor productivity implies that labor productivity increases with area expansion. Furthermore, the results indicate that public investment in irrigation systems and rice research leads to productivity improvement.

Weather conditions, particularly drought, reduce productivity. The lowest productivity is found in the northeastern region.

The estimated coefficients represent the production elasticity arising from those inputs, excluding UNRAIN and regional dummies.

Sources of labor productivity growth

To determine its sources of growth, labor productivity is decomposed by factor uses. Productivity growth in labor from 1971-75 to 1981-85 was 2.86% per annum. Such growth was contributed primarily by the significant development of irrigated areas (1.85% per annum) as indicated by the estimation results in Table 10. The other factors have negligible contributions.

The impact of rice research investments, on the other hand, was greatest in the decade that followed, 1981 to 1990. Rice research investments primarily produced scientific information and technologies that led to the development of improved rice

Table 9. Estimated results of the production function, 1971-97.

Variables	ln PROLA[a]			
	OLS	t-value	WLS	t-value
Constant	–1.744	(–27.90)	–1.72	(–22.18)
ln CULA	0.926	(119.26)***	0.947	(84.67)***
ln RESLA	0.142	(8.91)***	0.123	(6.02)***
ln IRGLA	0.071	(9.85)***	0.042	(4.13)***
UNRAIN	0.016	(1.38)	–0.001	(–0.07)
NORTH	0.424	(21.89)***	0.455	(12.94)***
CENTER	0.322	(14.48)***	0.379	(10.11)***
SOUTH	0.078	(3.82)***	0.112	(3.04)**
Adjusted R-square	0.949	0.949		
F-ratio	5,081.52	5,081.52		
No. of observations	1,890	1,890	1,890	1,890
Chi-square			5,466.04	5,466.04
Log likelihood			–117.09	–117.09

[a] ** and *** = significant at 5% and 1%, respectively. OLS = ordinary least squares, WLS = weighted least squares.

Table 10. Sources of productivity growth in rice production in 1971-97.

Source	Rice output growth and sources of contribution (%)		
	1971-75 to 1986-90	1986-90 to 1991-95	1991-95 to 1996-97
Rice output growth per labor per annum[a] (PROLA)	2.86	3.76	3.74
Contribution from			
Cultivated area per labor (CULA)	0.10	0.30	0.84
Irrigated area per labor (IRGLA)	1.85	0.43	1.60
Rice research per labor (RESLA)	0.06	2.06	0.85
Unexplained residual	0.85	0.97	0.55

[a] By taking the five-year average of predicted value obtained from weighted least squares in Table 9. Then, the average growth was calculated according to the specified period in each column.
Source: Author's calculations.

varieties and crop management practices. In this regard, the wide dissemination and adoption of MVs improved productivity in the late 1980s. From 1981 to 1990, labor productivity growth was 3.76% per annum, a dominant portion of which stemmed from rice research investments (2.06% per annum). A machine accumulation variable did not appear in the model. Nonetheless, the effect of the machine variable is accounted for in the residual term.

From 1991 to 1997, productivity growth was 3.74%. Meanwhile, the sources of growth arising from irrigation area, research, and cultivated area are 1.60%, 0.85%, and 0.84% per annum, respectively.

In short, a capacity use of the existing irrigation projects and rice research contribute to rice production growth.

Previous price policies and their changes

Changes in rice price policies

In Thailand, rice has long been a politically strategic commodity as well as a vital food crop. Being concerned with the political effect of high rice prices in the domestic market, government policies were previously designed to restrict rice exports and ensure stable domestic prices. Price stabilization policies included an export tax program and rice reserve requirement program. However, these policies were abolished in the second half of the 1980s as a result of the increasing rice supply in the international market and a decline in the international real rice price.

Export tax program

The previous government policy aiming at intervention in the export market began after World War II when Thailand was forced to export rice as a war reparation. After its rice export trade was completely regained a few years later, the government retained a monopoly on rice exports. The Rice Office was set up and private exporters had to arrange to export rice under a license from the Rice Office. A quota rent, called by traders the "premium," emerged in such transactions in the form of a payment from rice traders to the Ministry of Commerce (Siamwalla 1975). In the 1950s and '60s, controls on rice exports were used to prevent a domestic rice shortage and to produce government revenue (Sanittanont 1967). In the 1960s and '70s, the premium rate was varied to stabilize domestic rice prices in response to fluctuations in world prices. Moreover, quotas were often set to control the export supply. As the crisis in the world rice market subsided in the early 1980s, the rate of the rice premium decreased. Nevertheless, the rice premium was abolished in 1986 and a provision of discounted credit rates or a packing credit was available for exporters to subsidize their export costs. In 1995, the available credit was about 41% of the rice export value. The packing credit is still available for rice exporters but will soon disappear under the free trade agreement.

Paddy price support program

This policy aimed at intervening to prevent seasonal decreases in the paddy planned price at the beginning of each rice harvest season. An important program was to buy paddy and keep it in storage until the market price became favorable. Some sort of rice support program has been in effect since 1965, but the declared support price was below the market price in the early years and the program thus played no significant role. The program was also less effective even when the market price dropped below the support price (Siamwalla and Setboonsang 1990) because the money available was never sufficient to buy a huge amount of marketed paddy after it was harvested. Until the Farmer's Aid Fund was set up in 1975, the main funding for this program had been allocated from this source. However, because of high transaction costs and a lack of continuity, the program later faced heavy losses.

Presently, the operation of the rice support program no longer exists. Instead, the paddy pledging scheme has been promoted since 1986. Under this program, farmers can acquire a short-term loan from the Bank for Agriculture and Agricultural Cooperatives (BAAC) by pledging their paddy with the Bank. The amount of loan obtained is about 80% of the market price. In an earlier program lasting until 1996, most farmers could redeem the paddy a few months after the end of the harvesting season because of a higher paddy price. However, in 1997, no farmers favored that program despite the available loan because the devaluation of the Thai baht stimulated a sharp rise in the amount of rice exports, which in turn induced increases in farm and domestic prices. Currently, this program is still available to farmers, but the wide adoption of the combine harvester in irrigated areas of the Central Plain and lower north in recent years caused many farmers to choose to sell their paddy right after harvest. In 2001, the government set the target for paddy pledging at around 8 million t.

Subsidy for input prices

The agricultural input markets in Thailand are mostly free from government intervention. Thailand is probably the only major exporter of agricultural products that imports all of its fertilizer requirements. Previously, the government has used the marketing organization of farmers (MOF) and agricultural cooperatives (AC) to distribute fertilizer with subsidized transportation costs. This is financed by the low-cost loan provided by the Farmers' Aid Fund. The most common fertilizers used are 16-20-0 and ammonium sulfate. The share of farmer institutions in the chemical fertilizer trade is around one-fifth. In recent years, a low-interest loan has still been provided for farmers through farmer organizations and agricultural cooperatives for purchasing chemical fertilizer. Farmers registered in this program could obtain this loan, and about 30% of the rice farmers received a loan from this program.

Before 1975, the agricultural credit market in Thailand was dominated by informal lenders, particularly middlemen, millers, and landowners (Thisayamondol et al 1965). Government intervention in the agricultural financial market began only during the Third National Economic Plan (1972-76). In 1975, the Bank of Thailand instructed all commercial banks to allocate 5% of all commercial loans for agriculture at an interest rate lower than the market rate. During 1979-86, the interest rate was pegged at 13% per year. As a result of such a policy, the supply of agricultural credit expanded from \$67.44 million in 1975 to \$127.91 million in 1984. At present, the BAAC is heavily involved in providing credit to farmers for different purposes, including marketing and rural business activities.

Under current government policies in the village revolving fund and for farmers applying for a maximum loan of \$2,326, a debt moratorium (no interest and principal payment needed for three years) exists. Only 55% of 1.1 million BAAC clients joined the scheme. With the lack of a proper rehabilitation program in farming practices and a sound financial management plan, few farmers can pay back their loan when it comes due.

In Thailand, insecticide and herbicide are mostly exempt from import taxes. This has promoted their excessive use, which could endanger the environment. In recent years, the integrated pest management (IPM) technique has been disseminated, but adoption is relatively low.

Estimation of rice supply response

A theoretical framework

Prices and nonprice factors play a crucial role in determining the quantity of rice produced. In Thailand, pioneer work in rice supply analysis was conducted by Behrman (1968). In that study, the Nerlovian-type approach is combined with a nonlinear estimation technique to estimate the structural parameters for both area and yield response function. However, a system of crop equations was ignored in his estimation. This study employs a joint estimation of the cropping system. It is postulated that farmers are rational. Their decision-making behavior is to maximize their profits and is represented by

$$\Pi = PQ - WV \tag{1}$$

subject to production function (Q):

$$Q = f(V, Z) \tag{2}$$

where Q is the vector of all crop outputs, V is a vector of all variable inputs, Z is a vector of other undefined variables that shift the crop supply, P is a vector of output price, and W is a vector of variable input prices. The maximizing process then yields the following supply equation system:

$$Q = g(P, W, Z) \tag{3}$$

In this framework, the crop supply system consists of four subgroups of crops: rice, an upland crop, a tree crop, and vegetables. Since the rice supply is nested in the crop supply system, the estimation of rice supply therefore involves a joint estimation of the share of the four subgroups. It is further assumed that the output supply in this analysis is evolved by two behavioral functions, area and yield response functions.

The area share function of each crop subgroup can be written as a function of its own price, the prices of the other three crop subgroups, and other exogenous variables. A yield per rai can be derived:

$$Y = Q/A = h(P, W, Z, A) \tag{4}$$

where Y is the yield of rice and A is the total cultivated rice area.

Econometric estimation

In estimating the crop supplies, the elasticity of crop supply with respect to prices can be derived from the estimated equation. The choice of dependent variable is between production and harvested area. In formulating the behavioral equation of area share, the partial adjustment model is employed. It is hypothesized that the planned area shares (s_j*) are dependent on the set of relative output prices (P_i) and relative input prices (W_k) and other supply shifters (Z_m), particularly public investment in research and irrigation systems, that is,

$$s_{jt}* = a_j + \Sigma_i b_{ij} \ln P_{it-1} + \Sigma_k c_{kj} \ln W_{kt} + \Sigma_m d_{mj} \ln Z_{mt} + u_{ijt} \tag{5}$$

where u_{ijt} is the error term in system equations and b_{ij}, c_{kj}, and d_{mj} are coefficients of independent variables.

It is further assumed that the process of area adjustment is

$$s_{jt} - s_{jt-1} = \Phi(s_{jt}* - s_{jt-1});\ 0 < \Phi < 1 \tag{6}$$

where j = 1, ..., 4 and t = year.

By solving equations 5 and 6, we obtained

$$s_{jt} = \alpha_j + \Sigma_i \beta_{ij} \ln P_{jt-1} + \Sigma_k \gamma_{kj} \ln W_{kt} + \Sigma_m \omega_{mj} \ln Z_{mt} + \chi_j s_{jt-1} + \eta_{2jt} \tag{7}$$

To get the estimated coefficient of the rice area share equation response, systems of area share equations are jointly estimated by using the seemingly unrelated regression technique. Restrictions on some coefficients are needed to maintain the property of output supply as follows:

$$\Sigma\alpha_j = 1 \tag{7.1}$$
$$\Sigma\beta_{ij} + \Sigma\gamma_{kj} = 0, \text{ for all i and k} \tag{7.2}$$
$$\Sigma\omega_{mj} = 0, \text{ for all m} \tag{7.3}$$
$$\beta_{ij} = \beta_{ji}, \text{ for all i and j} \tag{7.4}$$

The first three restrictions ensure that the shares (s_j) always sum up to one. The last restriction is a symmetry requirement.

The yield response function of the crop concerned (rice) is assumed to be a linear in logarithm and can be specified as

$$\ln Y_t = \Theta_0 + \Theta_1.\ln P_{t-1} + \sum_m \Theta_{2m} \ln Z_{mt} + v_{3t} \qquad (8)$$

To estimate the output elasticity of rice supply, the identity equation 9 is used to link the relationship between the area share and yield equations as follows:

$$Q_t = s_t A Y_t \qquad (9)$$

where Q_t represents the production of the crop concerned, A is the average cultivated area, and s_t and Y_t are area share and yield of the crop concerned.

This formulation of area supply and yield equation allows one to estimate the own-price elasticity of output (e_{QP}) from the following formula:

$$e_{QP} = e_{YP} + e_{AP} \qquad (10)$$

where e_{YP} and e_{AP} are the elasticity of rice yield and area with respect to crop price. They are derived simultaneously from equations 7, 8, and 9.

Estimation results

Rice area response equation. To estimate both area and yield equations, provincial pooled cross-sectional and time-series data of 22 crops from 1971 to 1997 were employed. The Divisia price index was used to construct a price index of rice, upland crops, tree crops, and vegetables at the provincial level. Each crop price index is weighted by a price index of nonagricultural goods (at 1988 prices) to reflect the relative importance of crop value.

In the model, the dependent variables comprise area shares of rice (SHRI), upland crops (SHUP), tree crops (SHTR), and vegetables (SHVG). The explanatory variables include one-year lag indices of four crop prices: rice price (PRRI-1), upland crop price (PRUP-1), tree crop price (PRTR-1), and vegetable price (PRVG-1); wage rate (WAGE, baht) and rice research institute's budget per unit area (RES, baht/rai) weighted by the nonagricultural price index; irrigated area (IRRG, rai); and average amount of rain (RAIN, mm). A lagged area share of rice is demonstrated by SHRI-1. Dummy variables that represent various regional ecologies are also included. Since the sum of the area share for all crops equals one, an area share of vegetables is treated as a residual and left out of the estimating system. Except for the dummy variables and the area share variables, all other exogenous variables are in the logarithmic form.

The estimated results of area rice supply are shown in Table 11. The rice price coefficient is positive and significant. This represents the percentage of increase in area for a 1% increase in the price of rice. The price of upland crops (PRUP-1) is insignificant but its sign indicates complementation to rice cultivation. The vegetable (PRVG-1) and tree crop prices (PRTR-1) are negative but insignificant. Their sign,

Table 11. Estimated result of area response equation.

Variables	Area (SHRI)	t-value[a]
Constant	0.014	(0.82)
ln PRRI-1	0.007	(1.60)*
ln PRUP-1	0.010	(1.08)
ln PRTR-1	–0.004	(–1.01)
ln PRVG-1	–0.003	(–0.92)
ln WAGE	–0.009	(–2.27)**
ln IRRG	0.002	(2.84)***
ln RES	0.011	(2.13)**
ln RAIN	0.001	(3.18)***
SHRI-1	0.974	(177.91)***
NORTH	–0.003	(–0.70)
CENTER	–0.003	(–0.71)
SOUTH	–0.005	(–0.99)
Chi-square	211.96	
Log likelihood	8,685.09	
No. of observations	1,890	

[a]*, **, *** = significant at 10%, 5%, and 1%, respectively.

however, indicates that they compete with rice. Research investment is positive and significant. But the wage rate is negatively related to rice area and this has a significant effect, that is, the higher the wage rate, the lower the area cultivated to the commodity. Weather conditions in terms of rainfall variables are positive and significant. The regional differentiation demonstrated by the regional dummy is significant as indicated by the negative coefficients (Table 11).

Yield response equation. Yield per rai is assumed to depend on rice price, irrigation, research, and regional dummies. Except for dummy variables, the other variables are in logarithm. All coefficients in the equation are significant and have a positive effect (Table 12), that is, a rise in price, irrigated area, and rice research improves rice yield. Among the regions, the northeast has the poorest yield in comparison with other regions.

Estimated rice supply elasticity. Table 13 shows the estimated parameter of rice price with respect to area ($\alpha 11$) and the estimated parameter of rice price with respect to yield. The mean value of the area share (SHRI) is 0.55. The value of $1 - \phi$ indicates the adjustment coefficient for longer run elasticity of the rice price supply.

Using the results of estimating equation 10, the short-run elasticity of output rice supply (e_{QP}) is 0.104, which is the sum of the elasticity of the area response (e_{AP}; 0.013) and the yield response (e_{YP}; 0.091). The long-run elasticity is equal to 0.141 (Table 14). The elasticity of output supply will be employed in projecting the future supply trend.

Rice use and demand estimation

Rice use

Thai rice exports have a long history. Before World War II, exports constituted around 40% of total production (Ingram 1954). After the war, a shortage of rice supply in the

Table 12. Estimated result of yield response equation.

Variables	ln Yield (YD)	t-value[a]
Constant	6.014	102.80
ln PRRI-1	0.091	2.86**
ln IRRG	0.0101	3.41***
ln RES	0.223	10.59***
NORTH	0.512	29.24***
CENTER	0.460	28.41***
SOUTH	0.203	10.82***
Adjusted R-square	0.429	
F-ratio	237.77	
No. of observations	1,890	

[a] ** and *** = significant at 5% and 1%, respectively.

Table 13. Estimated parameters, mean value, and price elasticities.

	ln PRRI-1 in area response equation	ln PPRI-1 in yield response equation	$1-\phi$	Mean value of SHRI
Parameter value	0.007	0.091	0.26	0.55

Source: Author's estimations.

Table 14. Estimated own-price elasticity and other-factor elasticity.

Elasticity	Short run	Long run
Rice price		
e_{QP}	+0.104	+0.141
e_{AP}	+0.013	+0.050
e_{YP}	+0.091	+0.091
Irrigation		
e_{QG}	+0.014	+0.025
e_{AG}	+0.004	+0.015
e_{YG}	+0.010	+0.010
Rice research		
e_{QR}	+0.243	+0.300
e_{AR}	+0.020	+0.079
e_{YR}	+0.223	+0.223
Wage		
e_{QW}	–0.016	–0.62
e_{AW}	–0.016	–0.62
e_{YW}	na[a]	na

[a] na = not applicable.
Source: From estimations.

world market led Thailand to exercise monopoly power during the 1950s and ’60s. As a consequence of the Green Revolution, which took place in the early ’70s, the export rice market was gradually transformed into a competitive market. Table 15 shows that the volume of rice exports in terms of paddy equivalent has a positive relationship with total production. During 1971-75, exports averaged 1.916 million t or 14.4% of total production. An increase in total production stimulated the volume of exports in subsequent periods. Exports reached 8.16 million t or about 40% of total production in 1996-98. Currently, Thailand is the largest exporter of rice in the world.

The domestic availability of rice each calendar year is estimated after deducting the volume of exports from total production, which inevitably includes annual changes in rice stock. On the other hand, domestic disappearance comprises industrial and domestic consumption but excludes seed use.

The total amount of seed use is associated with area and the seeding technique employed. The widespread adoption of pregerminated direct seeding and broadcast seeding in many areas in the past few decades has resulted in an increase in demand for seed. During 1971-75, seed use averaged around 0.56 million t (4.03% of total production) and increased to 0.80 million t (3.94%) during 1996-98.

The use of rice for agroindustry and feed mills is rather limited. However, it is difficult to quantify the volume for industrial use because of unavailable data.

In Thailand, reliable time-series data for rice stocks are not available. The per capita disappearance per annum in Table 15 is obtained by taking a three-year moving average (to reduce the effect of the annual change in rice stock on domestic availability) and dividing by population. Despite a rise in population, the trend of per capita consumption (paddy equivalent) declined continuously from 286.3 kg per capita (or 188.9 kg in terms of milled rice) in 1971-75 to 182.6 kg per capita (or 120.5 kg in terms of milled rice) in 1996-98. Given negligible growth for other uses, a declining trend of the disappearance per capita implies a reduction in domestic rice consumption per capita over the past few decades. Disappearance per capita will be used later in the estimation of domestic consumption demand.

Table 15. Average production, rice exports, and domestic use, 1971-98.[a]

Period	Total rice use (1)	Exports (2)	Seed use (3)	Domestic use available after seed use[b] (4)	Per capita domestic disappearance (5)
		(1,000 t of paddy equivalent)			(kg)
1971-75	13,862 (100)	1,995 (14)	559 (4)	11,308 (82)	286.25
1976-80	15,665 (100)	3,674 (23)	654 (4)	11,337 (72)	252.35
1981-85	18,704 (100)	5,749 (31)	692 (4)	11,863 (65)	236.51
1986-90	19,707 (100)	7,659 (39)	701 (4)	11,347 (58)	203.88
1991-95	19,415 (100)	7,766 (39)	742 (4)	10,908 (56)	193.27
1996-98	20,380 (100)	8,155 (40)	803 (4)	11,421 (56)	182.58

[a]Numbers in parentheses represent shares of total use. [b]Including changes in annual stock.
Sources: (1) and (3) from Office of Agricultural Economics, (2) Department of Customs, (4) and (5) from author’s calculations.

Household consumption of rice

In Thailand, the recent average per capita consumption per annum was estimated at 119 kg (or 180.3 kg of paddy equivalent). Per capita consumption in urban areas was only 57% of the level in rural areas and consumption in semiurban areas was about 14% lower than in rural areas. In rural areas, the consumption of the top 25% of the income group was 11% lower than that of the bottom 25%; for semiurban areas, the difference was 13% and for urban areas it was 20% (Isvilanonda and Poapongsakorn 1995). These figures suggest the tremendous effect of economic development on the demand for rice in Thailand (Table 16).

Rice is, however, a heterogeneous commodity in terms of quality. The quality of rice demand may also vary depending on the location of consumers, price variations, and income. In urban areas, Khao Dawk Mali 105 (KDML105) or jasmine rice with an aromatic smell is the most preferred rice, particularly among high-income groups. In Bangkok, the average retail price of 100% jasmine milled rice in 2000 was \$0.54, which is 1.4 times higher than that of nonaromatic milled rice.

Quantity demand analysis

The econometric model. The analytical framework is based on a model of consumer behavior in which households choose to maximize their consumption behavior subject to budget constraints. The maximization process simultaneously yields the demand function in which rice is one of the commodities demanded. The rice demand function can be demonstrated as

$$QD = QD(PR, PW, INC) \qquad (11)$$

where QD represents the quantity demanded, PR represents the price of rice, PW represents the price of wheat, and INC represents income.

Using the logarithmic form of the Cobb-Douglas function, the demand equation can be shown as

$$\ln QD_t = \ln \alpha + \beta_1 \ln PR_t + \beta_2 \ln PW_t + \beta_3 \ln INC_t + e_{it} \qquad (12)$$

Table 16. Per capita annual consumption of rice (kg of milled rice) by region and income group.

Income group	Av per capita consumption (kg)				Implicit price (baht kg^{-1})			
	Rural	Semirural	Urban	All av	Rural	Semirural	Urban	All av
Bottom 25%	151	133	97	142	6.78	7.12	8.41	7.03
Middle 50%	146	125	89	127	7.45	7.89	9.23	7.84
Top 25%	134	115	78	106	8.01	8.64	9.89	8.75
Total	146	125	83	119	7.29	7.87	9.52	7.98

Source: Adopted from Isvilanonda and Poapongsakorn (1995).

In this analysis, the dependent variable (QD) is per capita domestic paddy disappearance (kg). The independent variables comprise (1) the real price of 5% milled rice (PR; baht per kg), (2) the real price of wheat flour (PW; baht per kg), and (3) real per capita income (INC; baht). The ordinary least squares technique is employed for coefficient estimation. Time-series data of those variables from 1971 to 1999 were used in the econometric estimation.

Estimated results. Table 17 shows the estimated results: the income variable (INC) is significant and has a negative effect on the quantity demanded. This implies that rice is an inferior good. These results are consistent with the findings of Ito et al (1989). In that study, income elasticity varied annually and equaled –0.437 in 1985. The rice price variable was negative and inelastic but insignificant. Wheat price had a positive sign, reflecting a substitution of wheat for rice, but it was insignificant.

The income elasticity found in this study is –0.33, whereas the elasticity of rice price and wheat price are –0.011 and 0.014, respectively. These elasticity parameters will be employed later in the projection of domestic rice demand.

Projections of rice supply and demand balances

The previous sections examined the past trends of the major components of rice production and consumption in Thailand. These sections also presented the estimates of important parameters that determine rice supply and demand. This section examines possible future scenarios in the evolution of the rice supply and demand balances to 2020 by using the previous estimation of some important parameters. Also, the growth accounting technique is employed to project the future growth in supply and demand.

Future rice supply growth

The estimated elasticity parameters from the area and yield response functions are employed in the growth accounting equation. Considering the significant effect of parameters in the supply model, the growth model of the rice supply is

$$Q^{\wedge}/Q \;=\; e_{QP} \times PR^{\wedge}/PR + e_{QW} \times W^{\wedge}/W + e_{QIR} \times IR^{\wedge}/IR + e_{QRE} \times RE^{\wedge}/RE \qquad (13)$$

Table 17. Estimated results of rice consumption demand.

Variables	lnQD	t-value[a]
Constant	6.60	(3.82)**
ln INC	–0.33	(–2.75)**
ln PR	–0.011	(–0.18)
ln PW	+0.014	(0.24)
Adj R^2	0.93	
F-ratio	92.42	
D-W	1.928	
Observations	29	

[a] In parentheses are t-values. ** = significant at 1%.

where $Q^{\wedge}/Q$ represents growth in quantity supply, $PR^{\wedge}/PR$ represents growth in real paddy price index, $W^{\wedge}/W$ represents growth in real wage rate, $IR^{\wedge}/IR$ represents growth in irrigated area, $RE^{\wedge}/RE$ represents growth in real rice research budget, e_{QP} represents own-price elasticity of paddy supply, e_{QW} represents elasticity of wage rate, e_{QIR} represents elasticity of irrigated area, and e_{QRE} represents elasticity of real rice research budget.

Table 18 shows the resulting growth rates projected for rice production from 2000 to 2020 under various policy scenarios and employing the various price and wage elasticities as derived in earlier estimates. Three scenarios are considered with different growths of price and nonprice variables. The base case assumes that (1) the real rice price grows at 0.5% per annum; (2) the real wage rate rises at 1% per annum; (3) the irrigated area growth follows the previous 10-year trend, which is estimated at 1.5% per annum; and (4) the rice research budget growth follows the previous 5-year trend with the rate of 2% per annum. Under the base-case scenario, the result indicates that the rice supply will increase at 0.5% per annum.

The growths of price and nonprice variables for the pessimistic and optimistic cases are demonstrated in Table 18. Under the pessimistic case, the rice price is assumed to decline at 3% because of the advance in biotechnology, resulting in an oversupply of rice in the world market. At the same time, the wage rate variable is suggested to increase at 3% per annum, resulting from a recovery from the country's economic recession. It is further assumed that a high public debt made the government cut the rice research budget at 2% per annum and irrigated area is also assumed to have zero growth because of constraints to the government budget. The result indicates that the rice supply will decline at 0.86% per annum.

An optimistic case demonstrates a rise in real rice price at 2% per annum. The real wage rate is assumed to stay the same as in the base case but irrigated area and the real rice research budget are allowed to grow at 2.5% and 3%, respectively. The result indicates that the rice supply will grow at 1.1% per annum.

Table 18. Price and nonprice elasticity of quantity of rice supplied and growth assumption of some policy variables for projection.

Variables	Elasticity	Growth assumption		
		Base case	Pessimistic case	Optimistic case
Paddy price (PD)	+0.104	+0.5	–3.0	+3.0
Wage rate (WR)	–0.016	+1.0	+3.0	+1.0
Irrigated area (IR)	+0.014	+1.5	0	+2.5
Rice research budget (RB)	+0.243	+2.0	–2.0	+3.0
Growth of rice supply (%) per annum		+0.54	–0.86	+1.1

Source: From calculations.

Future rice demand growth

Growth in domestic rice demand is considered to be driven primarily by growth in population, real income, real rice price, and real wheat price as follows:

$$\begin{aligned} QD^{\wedge}/QD = {} & e_{QX}(INC^{\wedge}/INC - POP^{\wedge}/POP) + e_{QPR} \times PR^{\wedge}/PR \\ & + e_{QPW} \times PW^{\wedge}/PW + POP^{\wedge}/POP \end{aligned} \tag{14}$$

Despite the insignificant effect of rice and wheat prices in the model, we include these variables in the growth projection because of their importance. Three scenarios are simulated. The base case assumes that the real rice price stays the same as in the base year. But the real wheat price and real income are assumed to increase annually at 1.5% and 5%, respectively. At the same time, population growth follows the previous 10-year trend, which is at 1% per annum. In this scenario, the substantial growth in income and a small growth in population result in a negative growth of rice demand at –0.30% per annum (Table 19).

The optimistic case assumes a rise in the real rice price and real income at 3% and 7%, respectively, whereas the real wheat price declines at 1.5% as a result of free-trade liberalization. As a consequence, rice demand is expected to decline at 1.03% per annum.

The pessimistic case assumes a decline in the real price of rice at 1% per annum and that real income rises slowly at 3% per annum. On the other hand, the real wheat price goes up by 2% per annum. As a result, rice demand is expected to grow at 0.38% per annum.

Projections of rice demand, supply, and balance

The balance of domestic production and demand is indicated by the exportable surplus. The results show that, under the base-case scenario, the exportable surplus in terms of paddy equivalent rose considerably from 11.27 million t (or 7.44 million t of milled rice) in 1999 to 14.96 million t (or 9.87 million t of milled rice) in 2020. The increase in the exportable surplus is much larger under the optimistic case because of the rise in rice supply and a continuous decline in domestic consumption. As a conse-

Table 19. Income and price elasticity of rice demand and growth assumption of some policy variables for projection.

	Elasticity	Growth assumption (%) per annum		
		Base case	Pessimistic case	Optimistic case
Real income (INC)	–0.33	+5.0	+3.0	+7.0
Population (POP)	–	+1.0	+1.0	+1.0
Real rice price (PR)	–0.011	+0	–2.0	+3.0
Real wheat price (PW)	+0.014	+1.5	+2.0	–1.5
Growth of rice demand (%) per annum		–0.30	+0.38	–1.03

Source: From calculations.

quence, the exportable surplus will reach 20.04 million t of paddy (or 13.22 million t of milled rice) in 2020, or nearly double that of the base year. Nonetheless, the decline in rice price and a reduction in research budget associated with a small growth in population and real income resulted in a continuous drop in the balance for the pessimistic case. In this case, the balance declined to 6.20 million t of paddy (or 4.09 million t of milled rice) in 2020, or nearly half that of the base year (Table 20).

Conclusions and policy suggestions

Investments in rice research and irrigation development in Thailand were the key factors in promoting rice crop intensification and improving productivity. These helped boost the rice supply. The rapid growth in the nonagricultural sectors in the past few decades before a sharp decline in 1997 caused by the economic crisis and devaluation of the baht stimulated urban development and wage rate inflation. A disparity in wage rate between urban and rural areas caused a migration of labor to the cities that later created a shortage of farm labor and high production costs. The agricultural labor force, including the rice labor force, declined dramatically over the past few decades. At the same time, mechanization and other labor-saving technologies were widely adopted for cropping, with higher production costs. Thus, rice labor productivity seemed to improve gradually during the same period. Labor productivity growth mainly stemmed from irrigation development and investments in rice research.

Price and nonprice variables affected the rice supply. But price variables had less influence than nonprice variables, particularly irrigation development and investments in rice research. In this study, the price elasticity of the rice supply was low and hence very inelastic. The values are 0.1 and 0.14 for the short run and long run, respectively. For the demand side, the income variable was the important factor in determining the changes in rice demand. Since rice is an inferior good, the rise in income reduces per capita rice consumption. This study did not attempt to show that the demand for higher-quality rice increases with the rise in income. Isvilanonda and Poapongsakorn (1995) showed that the demand for higher-quality rice has a positive income elasticity.

The future rice supply and demand under the base-case scenario indicated that, while the rice supply tends to rise at a slow growth rate, rice demand declines at a higher rate. As a result, the exportable surplus of the Thai rice supply in the international market inevitably increases, which may in turn dampen the world price. If Thailand allows a growth in supply at 1% per annum within the next two decades, the exportable surplus will be double that of the 1999 level. In contrast, if the supply growth declines at 0.5% per annum, the future exportable surplus will be reduced by nearly half that of the current situation. In both scenarios, domestic demand is projected to slowly decline.

Rice farmers in Thailand are very poor. To prevent the worsening of their welfare and to maintain the future competitive strength of Thai rice in the international market, it is suggested that the government should pay more attention to crop restructuring and diversification programs for diverting areas not well suited to growing rice. It is necessary for Thailand to continue and prioritize its investments in rice research,

Table 20. Future rice supply and demand balances.

Year[a]	Domestic consumption			Domestic production			Exportable surplus		
	Base case	Pessimistic case	Optimistic case	Base case	Pessimistic case	Optimistic case	Base case	Pessimistic case	Optimistic case
				(000 t in paddy equivalent)					
1999	12,897	12,897	12,897	24,171	24,171	24,171	11,274	11,274	11,274
2001	12,820	12,995	12,633	24,433	23,758	24,706	11,614	10,762	12,073
2005	12,666	13,194	12,120	24,965	22,951	25,811	12,299	9,759	13,691
2010	12,478	13,447	11,509	25,647	21,981	27,262	13,169	8,534	15,754
2015	12,292	13,704	10,928	26,347	21,052	28,795	14,055	7,348	17,867
2020	12,108	13,966	10,377	27,066	20,162	30,414	14,957	6,196	20,035
				(000 t in milled rice equivalent)					
1999	8,512	8,512	8,512	15,953	15,953	15,953	7,441	7,441	7,441
2001	8,461	8,577	8,338	16,126	15,680	16,306	7,665	7,103	7,968
2005	8,360	8,708	7,999	16,471	15,148	17,036	8,112	6,440	9,036
2010	8,235	8,875	7,596	16,929	14,507	17,993	8,692	5,633	10,398
2015	8,113	9,045	7,213	17,389	13,894	19,005	9,276	4,850	11,792
2020	7,992	9,218	6,849	17,863	13,307	20,073	9,872	4,089	13,225

[a] 1999 is the base year. The conversion rate of paddy to milled rice is 0.66 per kg of paddy.

Source: Author's estimates.

particularly for productivity and quality improvements of irrigated and rainfed rice, in order to differentiate Thai rice from that of other competitors in the world market. In the rainfed environment, particularly in the northeastern region where high-quality rice is cultivated with a single crop a year, research on variety and cultivation improvements and water management, coupled with crop protection and mechanization development, still has much room for improving productivity. These developments would further improve the future competitive strength of Thai rice in the international market.

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Appendix

Table 1. Average rice area, production, and yield by region, 1971-2000.[a]

Years	Region									Annual growth (%)
	Northeast		North		Central Plain			South	Total	
	UPNE	LONE	UPN	LON	WT	MD	ET			
Cultivated area (million ha)										
1971-75	1.77	1.74	0.50	1.19	0.50	1.23	0.65	0.57	8.15	–
1976-80	2.12	2.20	0.62	1.34	0.49	1.30	0.64	0.64	9.35	2.94
1981-85	2.17	2.45	0.60	1.57	0.51	1.26	0.67	0.64	9.87	1.11
1986-90	2.26	2.48	0.57	1.70	0.52	1.21	0.65	0.58	9.97	0.20
1991-95	2.31	2.65	0.51	1.62	0.49	1.01	0.55	0.49	9.63	–0.68
1996-2000	2.40	2.79	0.53	1.88	0.55	1.09	0.56	0.46	10.26	1.31
% share	50.58		23.49			21.44		4.49	100.00	
Production (million t) %										
1971-75	2.37	2.35	1.44	2.29	1.04	2.68	1.12	0.94	14.23	–
1976-80	2.69	2.44	1.79	2.64	0.95	3.22	1.21	1.16	16.10	2.63
1981-85	3.10	3.41	1.80	3.45	1.33	3.41	1.31	1.07	18.88	3.45
1986-90	3.35	3.52	1.75	3.73	1.36	3.15	1.29	0.95	19.10	0.23
1991-95	3.72	4.29	1.40	3.86	1.61	3.24	1.30	0.96	20.38	1.34
1996-2000	4.13	4.59	1.54	5.24	2.00	3.94	1.32	0.98	23.74	3.30
% share	36.73		28.56			30.58		4.13	100.00	
Annual yield (t ha^{-1})										
1971-75	1.34	1.36	2.92	1.91	2.06	2.18	1.72	1.66	1.75	–
1976-80	1.27	1.11	2.88	1.96	1.92	2.48	1.89	1.80	1.72	–0.34
1981-85	1.43	1.38	3.00	2.20	2.62	2.69	1.95	1.66	1.91	2.21
1986-90	1.48	1.42	3.05	2.18	2.60	2.58	1.97	1.64	1.91	0
1991-95	1.61	1.62	2.74	2.37	3.26	3.18	2.36	1.96	2.11	2.09
1996-2000	1.72	1.66	2.90	2.78	3.65	3.63	2.35	2.13	2.31	1.84
Wet-season yield (t ha^{-1})										
1971-75	1.34	1.36	2.92	1.89	1.95	1.97	1.66	1.64	1.67	–
1976-80	1.25	1.10	2.87	1.93	1.66	2.15	1.76	1.78	1.76	1.08
1981-85	1.41	1.38	3.00	2.15	2.27	2.29	1.83	1.62	1.62	–2.80
1986-90	1.45	1.41	3.03	1.98	2.28	2.29	1.79	1.60	1.60	–0.25
1991-95	1.59	1.61	2.73	2.16	2.81	2.76	2.16	1.94	1.94	4.25
1996-2000	1.68	1.64	2.87	2.38	3.06	3.18	2.14	2.07	2.07	1.34

[a] Calculated from Agricultural Statistics of Thailand, Office of Agricultural Economics, various issues.

Table 2. Average quantities and growths of production, area, and yield of glutinous and nonglutinous rice, 1971-2000.[a]

Years	Glutinous	Nonglutinous	Share of glutinous (%)
Area (million ha)			
1971-75	2.93	5.22	35.95
1976-80	3.56	5.79	38.07
1981-85	3.33	6.54	33.74
1986-90	3.17	6.80	31.80
1991-95	2.97	6.66	30.84
1996-2000	2.93	7.33	28.56
Production (million t)			
1971-75	4.66	9.57	14.23
1976-80	5.10	11.00	16.10
1981-85	5.46	13.42	18.88
1986-90	5.35	13.75	19.10
1991-95	5.23	15.15	20.38
1996-2000	5.50	18.24	23.74
Yield (t ha^{-1})			
1971-75	1.59	1.83	–
1976-80	1.43	1.90	–
1981-85	1.64	2.05	–
1986-90	1.69	2.02	–
1991-95	1.76	2.27	–
1996-2000	1.88	2.49	–

[a] Obtained data from Office of Agricultural Economics.

Section THREE

The rice economy in Taiwan: demand and supply determinants and prospects

M. Gemma

The economy in Taiwan has exhibited remarkable growth for the past few decades and the rice economy in Taiwan has gone through drastic changes. Per capita rice consumption declined to 55 kg in 1999 from 130 kg in the 1970s. The continuous decline in the use of labor and land has also been observed on the production side of the rice economy. The objectives of this study were to identify the determining factors of the future demand and supply of rice and to project future demand-supply conditions of the rice economy in Taiwan.

This study found that future changes in rice consumption in Taiwan would mainly depend on changes in real income. It also discovered that rice area would be influenced by the level of urbanization while rice yield would be determined by rice prices and technical change. If we assume that the present pace of the changes in area and yield for rice continues in the future, Taiwan would become a net exporter of rice under the high-income growth scenario. Under the low-income growth scenario, Taiwan would be a net importer of rice. The impact of the liberalization of the rice market in Taiwan under the Minimum Access Agreement with the World Trade Organization would be relatively small for domestic producers in the short run as a large portion of the imported rice would be kept by the government for storage. In the long run, domestic producers face challenges to become more competitive in terms of production costs and product quality for their own survival.

Studies on rice demand and supply for the East Asian economies would provide important implications when the future conditions of the rice economies in other Asian economies are being considered. The economies in Korea, Taiwan, and Japan have achieved high economic growth and this has changed the shape of their rice economies. A decline in per capita rice consumption on the demand side and a decrease in the use of labor and land inputs on the supply side have been observed in the East Asian rice economies in recent decades. Rice policies have been supportive of domestic producers and the welfare of domestic consumers has been worsened by protective measures. As other Asian countries make progress in economic development, these countries will likely follow the East Asian path of changes in rice consumption and production. Therefore, an analysis of rice demand and supply in East Asia would help produce policy implications for what might happen in the future in rice consumption and production of other Asian countries.

Although Korea, Taiwan, and Japan in total annually produce and consume less than 5% of the rice produced in the world, changes in their trade practices would have a significant effect on the international rice market. This is attributed to the thin nature of the international rice market. For example, the Japanese emergency import of rice in the amount of 2.53 million metric tons in total, which took place from the latter part of 1993 till the middle of 1994, led to the doubling of rice prices in the international market. Therefore, changes in Japan's trade policies and practices for agricultural products, especially rice, are of great interest to the economies that are producing and consuming rice in Asia and other regions of the world. As Taiwan has undergone the most drastic changes in rice consumption and production for the past two decades among these three economies, this case study would produce important implications for the economies in Asia that would grow fast economically in the future. As similarities in traditions and culture for food consumption and production exist between Taiwan and mainland China, what has been observed in the rice economy in Taiwan would most likely take place in the rice-consuming and -producing regions of mainland China in the future.

The purposes of this paper are to review the changes in the rice economy in Taiwan, to identify the determinants of the changes in rice demand and supply, and to make predictions on future rice consumption and production up to 2020 for Taiwan as an effort to derive some policy implications for other countries in Asia and the international rice market. The rice economy in Taiwan is reviewed in relation to changes in agricultural policies first. Next, the characteristics of rice consumption and production are summarized. The following section deals with the projections of the future demand and supply for rice in Taiwan. The estimated price and income elasticities under the framework of an almost ideal demand system (AIDS) model using aggregated time-series data based on nonfarm and farm household expenditure surveys are used for the demand prediction. Population growth, income growth, movements in income elasticities, and price changes are considered as the factors accounting for future rice demand. The estimated area and yield equations are also employed for the supply predictions. Rice prices, the level of urbanization, and technical change are regarded as the sources of future supply changes. The last section discusses policy implications derived from this study.

The rice economy and agricultural policies in Taiwan

Taiwan has achieved economic success through industrialization and international trade. Its per capita gross national product rose to US$14,216 in 2000 (Council of Economic Planning and Development 2001). The agricultural sector played different roles over time as the economy grew. When the reorganization of the agricultural sector was completed in 1953 by finalizing the land reform introduced after World War II, agriculture's share in gross domestic product (GDP) was approximately 34.5%. Agriculture's employment share was about 56% and its export share was more than 90%. In 2000, agriculture's share in GDP was down to 2.1%. In the same year, agriculture's share in employment was about 7.8% and, for exports, its share was only 2.2%. Taiwan used to be a net exporter of agricultural products, but has been a net importer since 1970.

Agricultural production grew steadily throughout the 1950s and '60s. Its annual average growth rate was nearly 5%. With a limited supply of additional land in Taiwan, the source of growth for crop production, which occupied more than 60% of total production in this period, was the increase in yields through the introduction of new varieties and the employment of modern inputs such as chemical fertilizer and machinery. Rice's share in total value of production declined from around 40% in the mid-1950s to nearly 30% by the end of the '60s. The diversification of agricultural production was the reason for this decline. The absolute level of rice production was kept high by the rice-fertilizer barter policy in spite of the existence of the government-controlled low rice-purchasing prices. Rice had to be produced to obtain fertilizer, which is necessary for high yields in agricultural production. The cheap food policy was kept to promote the development of the industrial sector. The emergence of part-time farmers was observed in this period as industrial development took place. By the end of the 1960s, about 70% of farmers became part-time farmers. However, the movement of the labor force from rural to urban was not yet significant.

From the latter part of the 1960s to the mid-'70s, agricultural production faced a low growth. The average annual growth of this sector declined to about 2%. The only exception was animal production, which achieved annual growth of more than 8%. Rice production measured in the form of brown rice stayed almost constant at 2.2 to 2.5 million t per year in this period. One major reason for the low level of agricultural growth was the shortage of the labor force in this sector as a result of the migration of rural workers induced by the rapid industrialization in urban areas. The deterioration of the terms of trade in the agricultural sector accelerated this process.

A significant change in the government rice policy took place at the end of this period in response to the stagnation in crop production and the worsening of the welfare of farmers. The rice-fertilizer barter program was abolished in 1973 and the cheap food policy was abandoned by raising government rice-purchasing prices more than three times in 1975. These marked a change in the role of agriculture in the Taiwanese economy. Before these events, agriculture's role was to support industrialization through the transfer of workers and financial resources. The latter was achieved by imposing indirect taxes on the agricultural sector through intentionally low product prices. Thereafter, the agricultural sector became a protected and subsidized sector. A reverse flow of resources from the nonagricultural sectors to the agricultural sector has been observed since then. A combination of policy instruments such as the price support scheme through guaranteed prices, guided prices, buffer stock schemes and deficiency payments, and border control measures has been introduced for farm income support and food security purposes.

Compulsory rice-purchasing prices had been kept lower than market prices until 1974. All government prices began to be set higher than market prices starting in 1975. The guaranteed price was set to a level that was 20% higher than the production costs. In addition, the government set no limit on the amount of government purchases from 1974 to 1977. Rice production measured in the form of brown rice was 2.704 million t and reached its peak in 1976 in response to the favorable market conditions created by these government policies.

The government finally introduced a limit on its rice purchases to cope with the financial burden that suddenly emerged from the generous purchasing policy. Although the limit on purchasing quantity did not exist from the first crop in 1974 through the first crop in 1976, from the first quarter in 1976 through the second crop in 1988, the limit was imposed at 970 kg ha^{-1} crop^{-1}. Now, the limit is 1,920 kg ha^{-1} for the first crop and 1,440 kg ha^{-1} for the second crop with the planned purchase price scheme and 1,200 kg ha^{-1} for the first crop and 800 kg ha^{-1} for the second crop with the guided purchase price program. The rest of the rice that does not go through these channels is traded through private channels or is consumed by producers. The planned purchase program prices are generally higher than the guided purchase program prices and the latter program picks up what is left for sales to the government by the former program.

The planned price of paddy rice was US$10 per kg for the first crop in 1974. It became US$11.5 for the first crop in 1975 and remained the same until the second crop in 1978. Then, it was changed to US$12.5 at the time of the first crop in 1979, and had been switched to US$18.8 in the first crop in 1982. This lasted until the second crop of 1988. The planned rice price became US$19 kg^{-1} in the following year and remained at this level up to the first crop of 1993. Since then, it has been US$21 kg^{-1}. There has not been any difference in price for the first crop and second crop. Only the government purchasing limits per ha have been larger for the first crop than for the second crop. The purchasing quantities and prices have been set by the government in accordance with the government storage capacity and budget constraints with the efforts to indirectly support the farm sector.

Now, about 25% of the rice produced in Taiwan, which is approximately 400,000 t a year, goes through government channels. The government procurement rice was sold to the military and government officials for prices higher than market prices. Now, about 25% of this rice is consumed under the school lunch system. The rest goes for use by soldiers and prisoners and for processing purposes in addition to the rice allocated for exports.

The period from the mid-1970s to now is considered as a period of adjustment for the agricultural sector in Taiwan. Efforts have been made to enlarge the originally small operation size and to diversify initial rice-dominant agricultural production. Because of the existence of the price support policy and import restrictions for rice, domestic rice prices have been kept much higher than the international rice market prices. Despite the introduction of liberalization measures for other crops, the rice market has been protected to facilitate rural development and promote national food security.

As part of the adjustment measures, in 1984, the six-year rice-crop substitution plan began following experimental attempts at crop diversion for several years. This was to cope with the problem of surplus rice. The conversion of rice to other crops was attempted starting in the latter part of the 1970s on a voluntary basis. Farm extension workers encouraged farmers to grow other crops, but this was not much of a success. The new plan provided a direct subsidy of 1 t of rice per ha to the converted farmers when they shifted their production to maize, sorghum, and/or soybeans. Also, the guaranteed purchase prices were set for these crops for the converted farmers. Furthermore, the rice farmers who changed to produce crops other than maize, sorghum, and soybeans were able to obtain 1.5 t of rice per ha from the government for conversion. The number of participating farmers increased year by year. Rice production declined to 1.84 million t in 1988. This was a 32% reduction in total rice production in comparison with the peak year's rice production of 2.704 t. This program is still in effect.

A new system was introduced into this conversion plan in 1988. The cash payment system replaced the paid-in-kind method to reduce the government's program management costs and increase the direct benefits of the converting farmers. US\$16,500 ha^{-1} and \$24,750 ha^{-1} were granted for the farmers who used to receive 1 and 1.5 t ha^{-1} of rice, respectively. Furthermore, the ceiling on the government purchase with the planned price increased to 1,600 kg ha^{-1} for the first crop and to 1,200 kg ha^{-1} for the second crop from the 970 kg level for each crop. An additional procurement quantity of 1,000 kg ha^{-1} starting in 1989 allowed higher market prices. These were intended to provide more income to rice producers. Since these rice price support policies led farmers to continue producing rice, the effectiveness of the diversion programs was weakened (Huang 1992).

A conflict between two different government programs exists now. The planned price scheme encourages farmers to keep producing rice and the rice crop conversion program encourages farmers to grow other crops. The former is important to support farm income and the latter is critical to reduce the government financial burden and to cope with the condition of rice surplus.

The food stabilization fund, established in 1974, was abolished in 1989 with a total loss of US\$3.1 billion in the transaction of buying and selling rice for the purpose of rice price stabilization. There has been talk in the government concerning the abolition of the government price support scheme for the second crop of rice and also the disuse of price support means for growing nonrice crops in order to meet the aggregate measures of support (AMS) requirement that will have to be satisfied as a new member of the World Trade Organization (WTO). Taiwan's joining the WTO in January 2002 necessitated large adjustments in production structure in the rice sector. A large amount (144,720 t) of rice will be imported in 2002. This is 8% of the total rice consumed in Taiwan. In 2003, an annual increment of 14,472 t is planned until 2007 for this minimum access plan. The government is determined to abolish the price support for the second crop. The government has also made an announcement about introducing various income support programs as well as programs to restructure the agricultural production sector under the name of the adjustment programs in response to the liberalization of the rice market in Taiwan.

Rice consumption

Significant changes have been observed in food consumption in Taiwan. Per capita annual rice consumption has been declining for the past 25 years in Taiwan. Until the mid-1970s, it had stayed around 130 kg (food balance sheet data). It became 101 kg in 1980 and in 1990 it was 66 kg. Then, in 1999, it declined further to 55 kg. The reduction in per capita annual rice consumption was 58% for the past 25 years. Figure 1 shows this declining trend. A decline in annual rice consumption per capita is still observed in Taiwan. The same figure for Japan in 2000 was 66 kg. The estimate for Korea was about 100 kg in 1999. Taiwan has the lowest per capita consumption of rice among the East Asian countries. This decline in per capita rice consumption resulted in a declining share of rice in daily calorie intake. The substitution of other foods for cereals has also been noticed over time during the past two decades. The consumption of meat and fats has been increasing. Meat consumption more than doubled from 36.1 kg in 1976 to 78.1 kg in 1999.

The data on daily nutrient availability per capita in Taiwan for 1991 show that fat intake is more than what is needed whereas carbohydrate intake is lower than what is required. It is also reported that about 20% of schoolchildren are overweight. This is why the government is encouraging the use of rice in school lunches in Taiwan.

Rice production

Taiwan has been self-sufficient in rice for a long time. This was the case even before World War II. Excess rice has been exported. Since domestic rice prices have been substantially higher than international rice prices, the differences in these prices have been financed by the government in the form of export subsidies in recent years. Excess rice has also been used as animal feed since 1984. The government initially introduced a rice cultivation conversion policy in 1978 to reduce the amount of rice production. Rice area has been continuously declining since then (Fig. 2). This is the

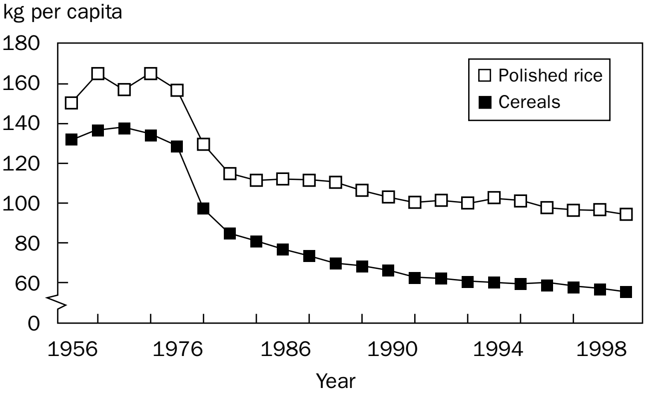

Fig. 1. Availability of cereals and rice for domestic consumption in Taiwan 1956-99. Source: Council of Agriculture.

period when per capita consumption of rice has been sharply descending. The continuous decline in rice area has been the result of urbanization as well as the conversion programs. Rice yields, on the other hand, have been increasing over time (Fig. 3).

In total, rice production has been shrinking because of the sharper decline in rice area (Fig. 4). As a result of a package of adjustment policies, rice production measured in brown rice weight decreased to 1.628 million t in 1992, but increased again in 1993 to 1.820 million t. The increase in the level of the quantity ceiling on the purchase of rice by the government had an additional effect on the increase in yield for that year besides favorable climatic conditions. The impact of the Asian economic crisis in 1997 was observed in rice area. The declining trend of rice area stopped temporarily. Rice yield has stayed almost the same for the past several years, with the exception of 1998, when climatic conditions were not favorable for rice cultivation. No significant effect was observed on rice yield.

Two major types of rice for table use are produced in Taiwan. One is a japonica type called Ponlai rice. This variety was originally introduced from Japan during its

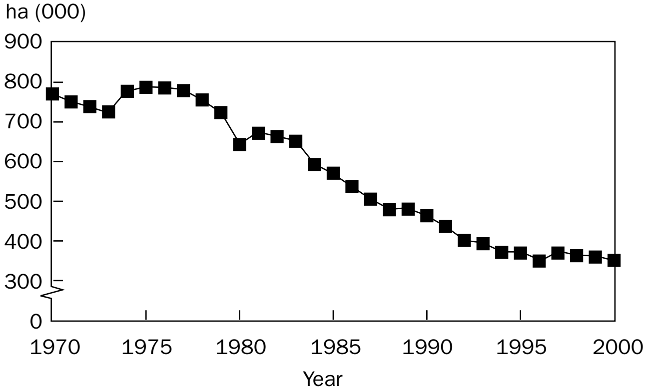

Fig. 2. Changes in rice area in Taiwan, 1970-2000. Source: Taiwan Provincial Government and Council of Agriculture.

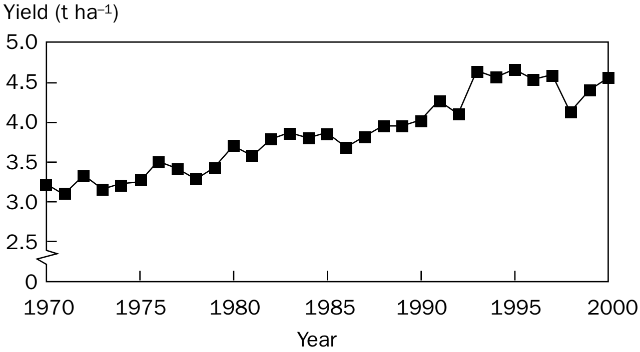

Fig. 3. Changes in rice yields in Taiwan, 1970-2000. Source: Taiwan Provincial Government and Council of Agriculture.

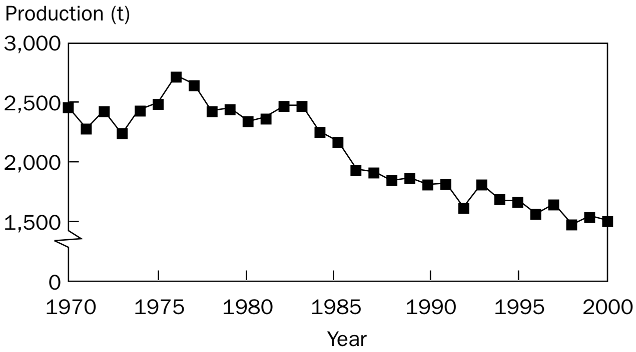

Fig. 4. Changes in rice production in Taiwan, 1970-2000. Source: Taiwan Provincial Government and Council of Agriculture.

occupation and has been widely produced in Taiwan. Continued research efforts and the improvement in irrigation facilities over time resulted in increased yield. Ponlai had a share of 87.8% of total paddy rice production in Taiwan in 2000 (Council of Agriculture 2001). It has earlier maturity and higher responsiveness to the application of fertilizer. The other type of rice is indica rice called Chailai and long indica. It had a share of 12.2% in total rice production in 2000. These figures include glutinous japonica (a share of 1.7% in 2000) and glutinous indica (a share of 2.6% in 2000), which are used mainly for processed food products.

Because of Taiwan's warm climatic conditions, rice has typically been produced twice a year. The first crop accounted for 54.9% of annual rice production in 2000. The second crop accounted for the remaining share. Fertilizer-responsive high-yielding types have been developed for all varieties. Historically, Ponlai has been producing higher yields than other varieties in most years. In recent years, however, small differences in yield have been observed among different varieties of rice. Long-grain indica has been yielding more than Ponlai for the past 20 years. A yield comparison between the first and the second crop shows that the first crop generally has higher yields than the second one. The yield for the first crop of Ponlai in 2000 was 6,266 kg ha^{-1} in the form of brown rice, whereas the second crop of the same variety yielded only 4,632 kg per ha.

Rice consumption analysis and demand projections

To understand the factors determining rice demand, a demand system is examined and price and income elasticities are estimated here. Then, future rice demand is projected using the parameters obtained through the estimation.

First, an analysis of demand elasticities is conducted here using expenditure survey data for nonfarm and farm households. The parameters of a share equation model (see Appendix 1 for details) derived from the linear approximate almost ideal demand system (LA/AIDS, Deaton and Muellbauer 1980) were estimated (see Tables 1 and 2).

All own-price elasticities are negative and all cross-price elasticities are positive. Rice consumption is very inelastic to price changes for both types of households in Taiwan. The own-price rice elasticity for the nonfarm households is –0.04, whereas the farm households' elasticity is –0.32. Depending on the extent of the decline in consumer prices for rice as a result of the future policy reforms by the government in price support programs and border control practices, per capita rice consumption can be restored to a certain extent. Nonetheless, it would not be so significant because of this inelastic nature of own-price elasticities.

The total rice expenditure elasticity is negative for the nonfarm households and is positive with the mean values and negative with the most recent values for the farm households. These total expenditure elasticities for rice can be considered as income elasticities showing movements in rice consumption in response to income changes. The mean total expenditure elasticities of rice over time for the nonfarm households are estimated to be –0.14. The estimate for the most recent year is –0.88. Farm household data, on the other hand, exhibited mean total rice expenditure elasticities of 0.01, and –0.73 for the most recent year. For both nonfarm and farm households, a declining trend in total expenditure elasticity is observed over time. The change of the sign

Table 1. Price and expenditure elasticities of food and rice demand for nonfarm households in Taiwan.

Price/expenditure	Marshallian elasticities
Food	
Own price	–0.68
Nonfood price	0.41
Expenditure (with mean values)	0.67
Expenditure (with recent values)	0.60
Rice	
Own price	–0.81
Nonrice price	0.08
Expenditure (with mean values)	0.72
Expenditure (with recent values)	0.67

Table 2. Price and expenditure elasticities of food and rice demand for farm households in Taiwan.

Price/expenditure	Marshallian elasticities
Food	
Own price	–0.81
Nonfood price	0.08
Expenditure (with mean values)	0.72
Expenditure (with recent values)	0.67
Rice	
Own price	–0.32
Nonrice price	0.29
Expenditure (with mean values)	0.02
Expenditure (with recent values)	–1.07

from positive to negative for the farm households happened in the early 1980s. The timing of this change is much later than in the case of Japan. Still, now the nonfarm households show a slightly larger total negative expenditure elasticity. The degree of rice becoming an inferior good is observed to be larger for nonfarm households in Taiwan.

The percentage change in rice demand $(\frac{\Delta D}{D})$ in the future can be approximated using the following formula:

$$(\frac{\Delta D}{D}) = (\frac{\Delta N}{N}) + (h_{ix})(\frac{\Delta(I/N)}{I/N}) + (h_{ii})(\frac{\Delta P}{P})$$

where D stands for the demand for rice, ΔD is the change in rice demand over the observed period, N is the population, h_{ix} means the expenditure elasticity, I/N shows the total expenditure per capita representing the level of per capita income allocated for consumption of goods and services, h_{ii} is the own-price elasticity for rice, the rice price is explained by P, and ΔP is the change in rice price during the observed period. Therefore, the percentage change in future rice consumption in Taiwan can be expressed as the sum of the percent change in population, the product of expenditure elasticity and the percent change in per capita expenditure, and the product of own-price elasticity and the percent change in rice price.

As a next step, the level of national rice consumption in the future can be estimated with the following equation using the derived rate of change in rice demand:

$$\text{Consumption}_t = (1 + \frac{\Delta D}{D})\ \text{table use}_{t-1} + \text{nontable use}_t$$

$\frac{\Delta D}{D}$ is different for each period, mainly reflecting changes in the expenditure elasticity. This expenditure elasticity is estimated to decline further and to stay almost constant at the level of –2.3 after reaching its bottom. As the sign for this elasticity is negative, rice consumption would decline as the total amount of expenditure increases in the future.

Table 3 shows the demand projection results for rice in Taiwan up to 2020. Three scenarios are presented here with three different assumptions on the levels of per capita income growth in the projected period. Case 1 is for a low economic growth scenario with per capita annual income growth of 1%. Case 3 is a high growth scenario with a growth rate of 3%. Case 2 is a medium growth scenario with a growth rate of 2%. Case 2 serves as the baseline projection for future changes in rice consumption in Taiwan. The population growth rates for the nonfarm sector and the farm sector are assumed to follow current trends. The own-price elasticities derived from the AIDS model analysis are used, which are –0.04 for the nonfarm sector and –0.32 for the farm sector.

The rice price is presumed to be declining at 2% annually as a result of liberalization of the domestic rice market. The price is not treated as an endogenous variable here because of the expectation that domestic rice prices would be maintained by the government at a certain level that is higher than international market prices for some time in the future. The government would probably keep intervening in the domestic

Table 3. Demand projections for rice in Taiwan scenarios based on differences in income growth.

Assumptions	Case 1 (low growth)	Case 2 (medium growth)	Case 3 (high growth)
Population growth ($\Delta N/N$)	0.8% (nonfarm) –0.06% (farm) (the current trend)	0.8% (nonfarm) –0.06% (farm) (the current trend)	0.8% (nonfarm) –0.06 % (farm) (the current trend)
Income elasticity	Baseline scenario (estimated from the AIDS model)	Baseline scenario (estimated from the AIDS model)	Baseline scenario (estimated from the AIDS model)
Per capita income growth [$\Delta (I/N)/(I/N)$]	1% (low growth)	2% (medium growth) (baseline)	3% (high growth)
Own-price elasticity (η_{ii})	0.04 (nonfarm) –0.32% (farm)	0.04 (nonfarm) –0.32% (farm)	–0.04 (nonfarm) –0.32% (farm)
Price changes [$\Delta (P)/(P)$]	–2%	–2%	–2%

Projections (× 1,000 t—brown rice)

Year	Case 1	Case 2	Case 3
2002	1,500.3	1,439.2	1,397.3
2005	1,478.5	1,378.7	1,279.1
2010	1,441.9	1,282.0	1,103.8
2015	1,416.5	1,210.2	976.2
2020	1,423.4	1,194.7	923.3

Projection equation

$$\left(\frac{(\Delta D)}{D}\right) = \left(\frac{(\Delta N)}{N}\right) + (\eta_{ix}) + \left(\frac{\Delta (I/N)}{I/N}\right) + (\eta_{ii}) \left(\frac{(\Delta P)}{P}\right)$$

rice market to support farm household income. Pulling out completely from any intervention operation would be the last action to be taken by the government. Therefore, rice prices are anticipated not to be systematically determined by the demand and supply relationship for rice even in the projected period. Changes in rice prices would instead be guided by the government as we observe now.

The levels of projected rice consumption vary for the different scenarios (Fig. 5). With the high economic growth, rice consumption is predicted to be as low as 923,300 t in 2020. On the other hand, with the low economic growth, the decline in rice consumption would be much smaller. Only a 24.5% reduction from the current level would be observed in 25 years and the level then would become 1.19 million t.

Table 6 shows the projection results under the different assumptions on future changes in rice prices. Insignificant differences are observed in the numbers derived here. This insignificance in the price factor for the determination of future rice de-

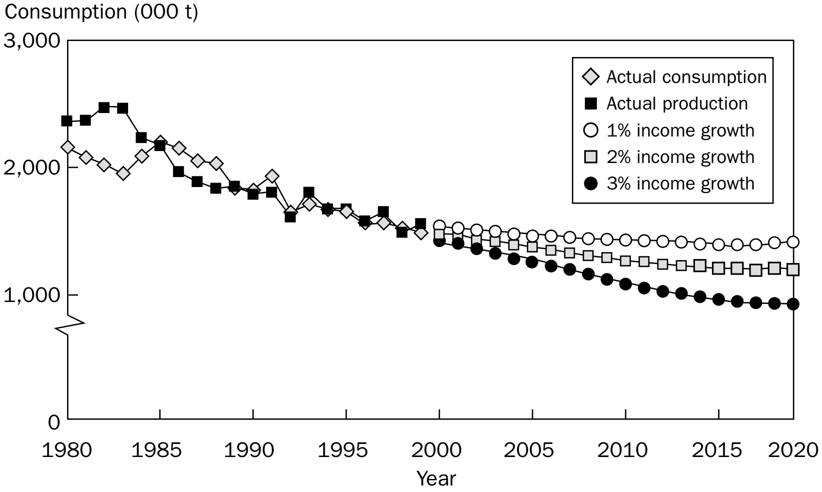

Fig. 5. Consumption projections for rice in Taiwan.

mand can be explained by the inelastic nature of the own-price elasticities. The income factor has more effect on the determination of future rice demand in Taiwan.

The future level of rice consumption would also be confined by the change in dietary habits and in life style. Dietary habits are changing and consumers are choosing less rice for a variety of food items available in the marketplace. The decline in the size of households and the increase in the number of women in the workplace have an effect on rice consumption at home and away from the home. These effects are not explicitly captured in the above framework, though.

Rice production analysis and supply projections

A pair of yield and area response equations were employed to examine the factors determining the levels of rice yields and area for rice production. The aggregated national-level time-series data from 1970 through 2000 (Department of Agriculture and Forestry 1999, Council of Agriculture 2001) were used to estimate parameters. The estimation results are as follows:

Area response function

$$\ln[\text{area}_t] = \underset{(1.99)}{1.3940} + \underset{(2.15)}{0.1466} \ln[\text{agricultural population}_t/\text{total population}_t] + \underset{(10.17)}{0.8386} \ln[\text{area}_{t-1}]$$

$$\text{Adjusted } R_2 = 0.98 \quad \text{D.W.}^1 = 1.86$$

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[1] D.W. = Durbin Watson coefficient for autocorrelation.

Yield response function

$$\ln[\text{yield}_t] = \underset{(3.27)}{4.9763} + \underset{(2.10)}{0.3433} \ln[\text{market price}_t/\text{price paid by farmers}_t]$$

$$+ \underset{(2.45)}{0.4698} \ln[\text{yield}_{t-1}] + \underset{(2.57)}{0.0073} [\text{trend}]$$

$$\text{Adjusted } R_2 = 0.87 \qquad \text{D.W.} = 2.18$$

The numbers in parentheses show t-values. The second term in the area equation gives the ratio of the agricultural population to the total population. This variable represents the structural changes taking place in the national economy. Effects of the move of the population from rural areas to urban areas as a result of income disparities can be captured by this term. The second variable in the yield response equation is the term for the market price for rice deflated by the price index for the input items paid for by farmers. This shows the output prices in real terms, but also demonstrates the relative changes in the profitability of rice production in comparison with the changes in the cost of production and the opportunity cost for continuing to be a rice farmer. Government programs play indirect roles in determining market prices in Taiwan. A trend term is included in the yield equation to explain the effects of technical change over time.

Based on the estimated area and yield equations, the future levels of rice production can be projected. Here, a baseline projection of rice supply in Taiwan for the period from 2001 to 2020 is presented. First, a set of trend equations is estimated to capture the current trends in changes in the explanatory variables in the area and yield equations. Second, the current trend is extended to future years for each independent variable. Third, the projected values for the future are calculated by multiplying the future values of the explanatory variables and the parameters from the area and yield equations. Fourth, production projections are made by calculating the product of the area and yield estimates. This baseline projection produces the estimate to go below one million t of rice production in the form of brown rice around 2020 (Fig. 6).

The decline in area is the major source of this decrease in rice production in the projected period (Fig. 7). Rice yields are estimated to continuously increase (Fig. 8). Rapid urbanization and further economic development would accelerate the retirement of paddy fields from rice production. The extent of the government's involvement in keeping paddy fields for rice production purposes for reasons such as environmental conservation would determine the rate of decline in rice area. This current study does not explicitly take into account these changes as not enough information is available to make any assumptions about future changes. The numbers presented here show a possible outcome to the case without any major changes in government land policies for rice production.

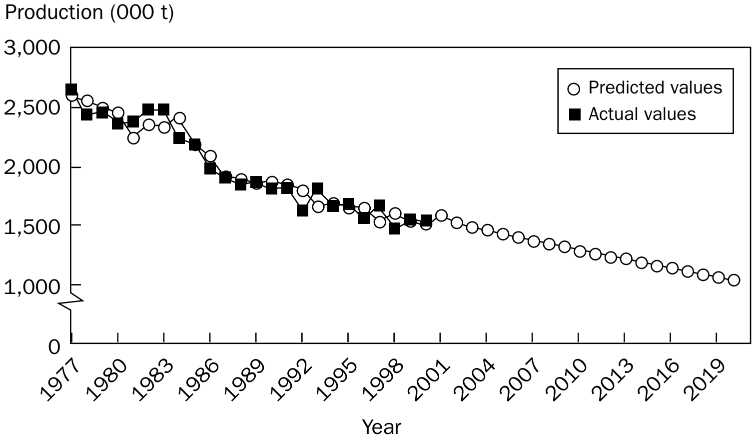

Fig. 6. Production projections for rice in Taiwan up to 2020.

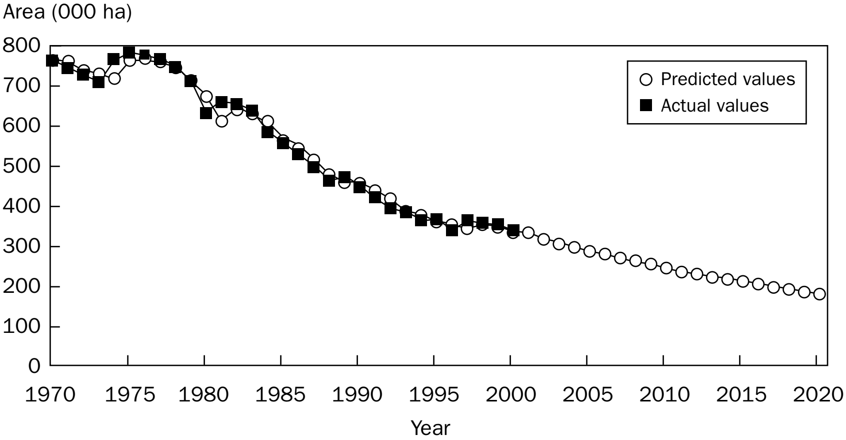

Fig. 7. Area projection for rice in Taiwan up to 2020.

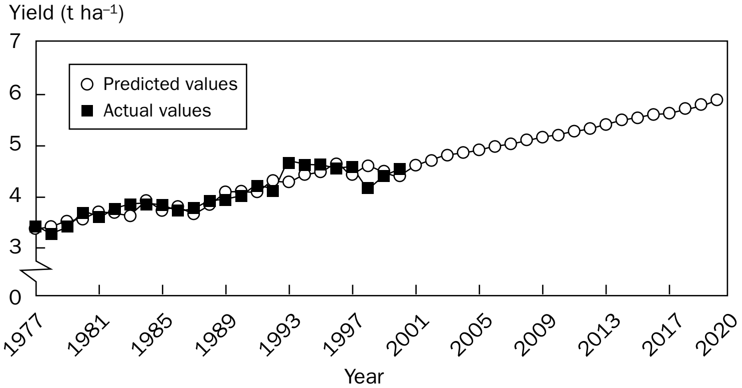

Fig. 8. Yield projection for rice in Taiwan up to 2020 (× 1,000).

Policy implications and conclusions

Through this study, we found that changes in income are an important determinant for the future levels of rice demand in Taiwan. Income changes were identified as more critical than rice price changes for the projections. This was because the derived income elasticities were larger than the derived own-price elasticities in absolute terms.

For the supply-side determinants, the reduction in rice area is the major cause of the decline in domestic rice production. In addition to relative rice prices, a noneconomic factor such as the share of the agricultural population in the total population was found to be an explanatory variable in the area equation. This variable was considered to represent the structural changes in the whole economy in Taiwan. If the government wishes to maintain certain areas of the paddy fields for ecological purposes or other reasons beneficial to the country, some incentive programs have to be introduced to keep this land from being converted to nonagricultural uses. An analysis showed that urbanization would reduce the total area of paddy fields at a rather rapid pace. If paddy fields are converted to nonagricultural purposes, the cost for conversion back to agricultural purposes would be very high.

The decrease in the rate of the agricultural population in the total population is also a reflection of the change in the labor force structure in the agricultural sector. As observed in other East Asian countries, aging of farmers is a problem in Taiwan. Fewer and fewer young people are entering farming activities. The percentage of part-time farmers is very high already. These all contribute to the decline in rice-producing areas.

Figure 9 depicts demand and supply situations under different scenarios. The demand projections are combined with the baseline supply estimation here. With the assumption that domestic production would follow the baseline projection, the country would become a net importer of rice under the low-income-growth scenario. On the other hand, high income growth would lead to a position of a net exporter producing more than it consumes in the domestic market. Similarly, the matching of domes-

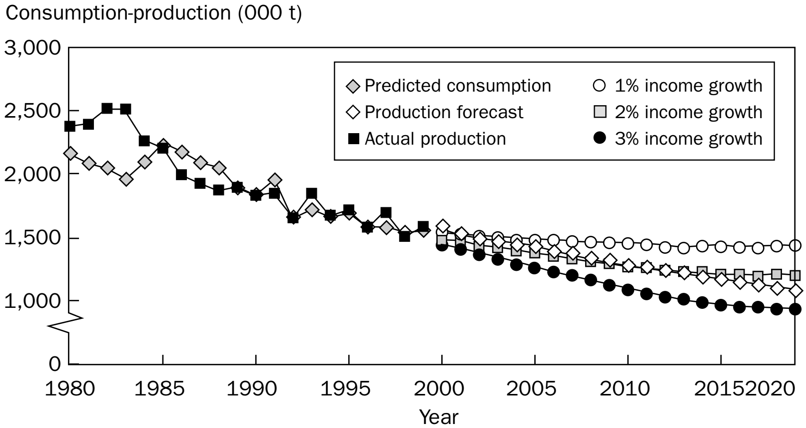

Fig. 9. Consumption and production projections for rice in Taiwan (× 1,000 t).

tic supply and demand would be achieved with a medium level of economic growth of 2%.

So far in our argument, the effect of the liberalization of the domestic rice market in Taiwan on international trade has not been directly analyzed. This is mainly because it is unlikely that the rice market in Taiwan would be completely liberalized in the projection period. A compromised liberalization measure to be effective in 2002 as a result of WTO membership talks includes a minimum access import of 144,720 t of rice. Within this imported rice, 65% will be imported by the government. The rest will be imported by private firms. The rice imported by the government will be kept away from the domestic retail market as storage for emergency measures. To minimize the cost of importation, the government is expected to import inexpensive rice. Thailand and Vietnam would be the sources of the government-imported rice. For the private-sector portion, high-quality rice is expected to be imported. Even the premium-brand rice of Koshihikari from Niigata, Japan, might be imported to satisfy particular consumers' needs for high-quality rice. The current market price of variety Koshihikari in Taiwan is about US$6 kg^{-1} in the retail market. It might make sense to import from Japan and sell to relatively high-income households.

The government will probably maintain its control over the export and import of rice in the medium- to long-term period to avoid drastic changes in agricultural production in Taiwan. The political voice of the farmers is still strong and regulatory measures would remain in effect in the domestic rice market. However, despite the government efforts to protect the domestic rice market, domestic rice prices would continuously fall in real terms as has been observed for the past two decades.

The effects of Taiwan's start in rice imports on the international rice market might be small as the amount of imported rice would be less than 1% of the average annual international rice trade. Renegotiation would take place before the completion of the first round of liberalization in 2007. Further developments in liberalization would presumably be undertaken even after the first phase. For Taiwan, tariffication of rice imports may be an option for adoption to stop the increase in the amount of rice imports as Japan did in 2000 before the start of discussions for the second phase of liberalization under the minimum access program.

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Notes

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Appendix 1. Rice demand analysis using an almost ideal demand system (AIDS) model

An analysis of demand elasticities is conducted here using expenditure survey data for nonfarm and farm households in Taiwan.

Basic model

The general form of the share equations derived from the linear approximate almost ideal demand system (LA/AIDS, Deaton and Muellbauer) is specified as

$$W_i = a_i + \sum_{J=1}^{n} dij \ \ln P_j + b_i \ln \left(\frac{X}{P*} \right) \qquad (1)$$

where W_i stands for the share of expenditure on food item I, P_j is the price of food item j, and $\left(\frac{(X)}{P*} \right)$ represents the real expenditure on the food items in question. P* shows the level of prices that can be derived using an approximation method called Stone's geometric price index. The employment of this index makes the empirical estimation of (1) simpler because of its linearity.

$$\ln P* = \sum_{i=1}^{n} W_i \ln P_i \qquad (2)$$

Based on the estimated parameters, the price (h_{ij}) and expenditure (h_{ix}) elasticities are estimated using the estimated parameters. The formulae of the Marshallian price and expenditure elasticities (Chalfant) for the LA/AIDS model are

$$h_{ii} = -1 + \frac{d_{ii}}{W_i} - b_i \qquad (3)$$

$$h_{ij} = \frac{d_{ij}}{W_i} - b_i \frac{W_j}{W_i} \qquad (4)$$

$$h_{ix} = 1 + \frac{b_i}{W_i} \qquad (5)$$

Estimation and results

For the empirical estimation, equation 1 was estimated using time-series data. The data were obtained from the published sources. The data on prices were obtained from various issues of *Commodity-Price Statistics Monthly* (Directorate-General of Budget, Accounting, and Statistics). For nonfarm and farm household expenditure survey data, the Report on the Survey of Family Income and Expenditure (Department of Budget, Accounting, and Statistics) was the major source of the necessary information. Data from 1974 through 1992 were used. Since changes took place in the format of the household survey in the 1990s, more recent data were not available for use in this study. No rice consumption data accounting for differences among different qualities of rice were available.

A rice demand system was estimated in two stages for the nonfarm and farm survey data. In the first stage, consumption items were grouped into two groups: food and nonfood. Then, the second stage covered rice and nonrice food items.

Imposing symmetry and homogeneity conditions, the estimation share equation was set to have the following form to have more degree of freedom:

$$W_i = a_i + d_{ii} \ln \frac{P_i}{P_j} + b_i \ln \frac{X}{\left(P^* \right)} \qquad (6)$$

Although a set of two equations was to be estimated in each stage, only a single equation was estimated for singularity reasons. Because of the existence of autocorrelation, the error term was assumed to have the first-order autoregressive form.

Rice supply and demand scenarios for Malaysia

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This paper analyzes the trends and future status of rice supply and demand in Malaysia, taking into consideration the new and emerging challenges the country faces. The assessment is done by using the rice supply and demand analyses (RSDA) model, an integrative model that considers both biophysical and socioeconomic factors in determining the supply-demand balance under different development scenarios. The supply scenario takes into consideration possible changes in land-use pattern, irrigation efficiency, technology, farm inputs, and farm prices. On the demand side, consideration is given to future changes in population and per capita consumption. The analyses indicate that the pursuance of a 65% self-sufficiency level, which is one policy thrust in the rice industry, will be jeopardized if rice production is concentrated only in the eight granary areas of Peninsular Malaysia, unless farm productivity improves significantly. Although the effect brought about by the decline in the farm-gate price caused by liberalization is marginal, the complete removal of the rice price subsidy would result in a significant decline in the supply-demand ratio. These represent some of the challenges faced by policymakers and planners in achieving an acceptable ratio between rice production and consumption in Malaysia.

Rice production contributes a mere 0.25% of Malaysia's gross domestic product (GDP) and 2.9% value added in agriculture. Nevertheless, rice is considered to be a strategic crop, given its importance as a food staple in the diet of Malaysians. In the face of rapid economic development favoring industrialization and urbanization, rice production has gone through major transformations over the past three decades as rice farming became less competitive for land, water, and labor resources. The government's strategy to maintain a minimum self-sufficiency level has been through substantial direct support to producers by providing fertilizer and price subsidies and to consumers by price controls. Now, in having to comply with international trade agreements of the World Trade Organization (WTO) and ASEAN Free Trade Area (AFTA), these direct support mechanisms have to be dismantled, and the country faces new challenges of sustaining a viable rice industry to meet national self-sufficiency targets.

This paper analyzes the trends and status of rice supply and demand in Malaysia, examines issues related to these new challenges that the country faces, and assesses the possible strategies that can be used. Most studies and models on rice supply and demand are based on economic considerations. In this study, we used an integrative model that takes into consideration the biophysical and socioeconomic factors that influence rice production and supply, while incorporating the economics approach for demand estimation and balance. The model outputs are interpreted in the light of emerging and possible trends of rice supply and demand as they are affected by the new trade regime and other related policy changes, with the intention of using the results to support policy decision making in relation to future rice production in Malaysia.

Rice production and consumption in Malaysia

Growth in rice production and productivity

Malaysia produces about 2 million tons of paddy, 86% of which is produced in Peninsular Malaysia. Rice area and production have not changed much; from 1991 to 1999, the country recorded net increases of 0.15% in annual planted area, 0.69% in total production, and 0.53% in average yield (Table 1). This modest increase in production is due more to an increase in productivity than an increase in area.

The national average yield has remained at about 3.0 t ha^{-1}, with minor fluctuations from 1991 to 1999 (Table 2). Average yields for Peninsular Malaysia are higher than those for the two states of East Malaysia.

Despite its minor role in the national economy, rice production is, and will continue to be, one of the most important agricultural activities in Malaysia. Hence, the rice sector has been accorded special treatment by the Malaysian government. Rice

Table 1. Trends in planted area, paddy production, and average yield for Malaysia, 1991-99.

Year	Area planted (000 ha)	Production (000 t)	Average yield (t ha^{-1})
1991	683.6	1,926.4	2.82
1992	672.8	2,012.7	2.99
1993	693.4	2,104.4	3.04
1994	698.6	2,138.2	3.06
1995	672.8	2,128.0	3.16
1996	685.4	2,228.4	3.25
1997	691.0	2,120.0	3.07
1998	674.4	1,947.2	2.88
1999	689.2	2,036.6	2.96
% growth per annum	0.15	0.69	0.53

Sources: Paddy Statistics 1999, Department of Agriculture, Malaysia; Paddy Production Survey Report, Off-Season 1999 and Main Season 1999/2000, Department of Agriculture, Malaysia.

Table 2. Average paddy yield (t ha^{-1}) by region, 1991-99.

Year	National	Peninsular Malaysia	Sarawak	Sabah	Major granaries
1991	2.82	3.39	1.22	1.87	3.70
1992	2.99	3.56	1.21	2.36	3.72
1993	3.04	3.60	1.16	2.49	3.83
1994	3.06	3.60	1.27	2.67	3.85
1995	3.16	3.70	1.19	2.70	3.99
1996	3.25	3.86	1.12	2.88	4.04
1997	3.07	3.57	1.15	2.90	3.81
1998	2.88	3.47	0.93	2.19	3.75
1999	2.96	3.49	1.04	3.01	3.70
Average	3.03	3.58	1.14	2.57	3.82
% change per annum	0.53	0.13	–1.96	6.30	0.003

Source: Paddy Statistics 1999, Department of Agriculture, Malaysia.

land is legally gazetted; conversion to other uses is not encouraged and has to be approved by the respective state governments.

Of the total rice land area of 441,000 ha in Malaysia, about 250,000 ha receive irrigation and can be double-cropped. Of these, about 80% are located within eight designated rice granary areas or "granaries," all of which are located in Peninsular Malaysia (Fig. 1 and Table 3). These granaries are governed by their own semiautonomous authorities. Examples are the Muda Agricultural Development Authority (MADA) and the Kelantan Agricultural Development Authority (KADA), which have jurisdiction over the two biggest rice granaries in the northwestern and northeastern plains of Peninsular Malaysia, respectively. These agencies are primarily responsible for irrigation engineering and water management, but they also provide agricultural extension, social services, and other aspects of farmers' development as well. The remaining 44,700 ha of irrigated rice land belong to 74 small irrigation schemes serviced by the Department of Drainage and Irrigation in various parts of the country. Because of better infrastructure and management, paddy yields in the granaries are higher than in other areas (Table 2). Even so, there is potential for productivity improvement in these granaries.

There are no major intensive rice-growing areas in East Malaysia except for a handful of small government irrigated schemes and a few private sector-led rice "estates." The two East Malaysian states produce 22% of the total main-season rice and only 3.3% of the off-season rice in the country. Most of the lowland rice areas in Sabah and Sarawak are rainfed and yields are generally lower than in Peninsular Malaysia, particularly in Sarawak. The extensive upland rice areas in the two East Malaysian states, especially in Sarawak (Table 3), are mainly upland rice grown under shifting cultivation. Although these upland areas account for 19% of the total rice planted area in the country, yields are low, averaging 770 kg ha^{-1} (Department of Agriculture Malaysia Paddy Production Report for Main Season 1999/2000); hence, upland rice production accounts for a mere 3% of the national production.

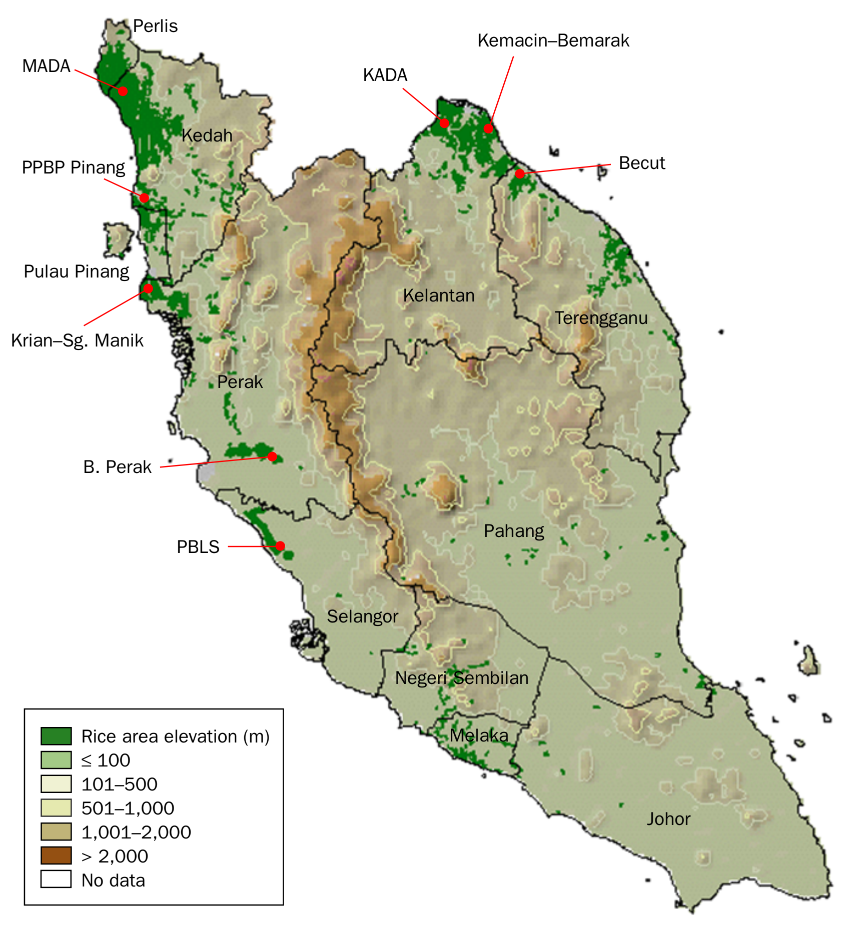

Fig. 1. Rice production and granary areas in Peninsular Malaysia.

From 1991 to 1999, the eight granaries consistently contributed 69–72% of national rice production, except for 1998, when the contribution reached 76% because of low production from the nongranary areas (Fig. 2). Of the eight granaries, the MADA scheme on average contributed about 55% of total granary production, followed by KADA, Kerian-Sungai Manik, and PBLS (Selangor) each at about 10%, PPBP Pulau Pinang and S. Perak each at about 5%, and Besut and Kemasin each at about 1%. These levels of contribution from the various granaries have been fairly consistent over the years.

Table 3. Distribution of paddy land (main season 1999-2000).

State	Irrigated					Nonirri-gated area (ha)	Overall total area (ha)
	Granary			Nongranary area (ha)	Irrigated total area (ha)		
	Name	Cropping intensity	Area (ha)				
Perlis	MADA	2	18,684	3,675	22,359	4,240	26,599
Kedah	MADA		77,475	12,945	90,420	15,604	106,024
Pulau Pinang	PPBP Pinang	2	9,852	4,341	14,193	168	14,361
Perak	Kerian/Sg. Manik	1.8	28,962	4,401	41,273	145	41,418
	Seberang Perak	2	7,910				
Selangor	PBLS	2	18,637	65	18,702	332	19,034
Negeri Sembilan				856	856	0	856
Melaka				580	580	619	1,199
Johor				1,142	1,142	80	1,222
Pahang				489	489	3,790	4,279
Terengganu	KETARA	1.9	5,074	4,553	9,627	2,992	12,619
Kelantan	KADA	1.7	23,669	3,832	34,274	8,928	43,202
	Kemasin/Semerak	0.7	6,773		6,773		
Peninsular Malaysia			197,036	36,879	240,688	36,949	270,864
Lowland			197,036	36,879	240,688	36,898	270,813
Upland	PBLS					51	51
Sabah			–	7,569	7,569	32,144	39,713
Lowland				7,569	7,569	20,812	28,381
Upland						11,332	11,332
Sarawak			–	257	257	130,270	130,527
Lowland				257	257	57,753	58,010
Upland						72,517	72,517
Total			197,036	44,705	248,514	199,363	441,104
Lowland			197,036	44,705	248,514	115,463	357,204
Upland			–	–	–	83,900	83,900

Sources: Paddy Production Report, Main Season 1999/2000; Paddy Statistics, 1999.

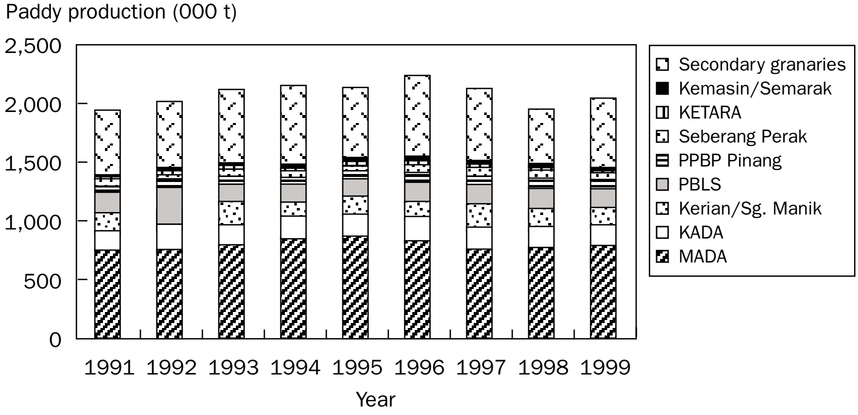

Fig. 2. Total paddy production by main and secondary granaries, 1991-99. Source: Paddy Statistics 1999, Department of Agriculture, Malaysia.

The rice areas outside the eight granaries, which include the secondary irrigation schemes, rainfed as well as upland rice, contribute from 27% to 31% of total rice production, except in 1998, when the contribution was lowest at 24%.

One major factor that has contributed to increased production from the granaries is the increase in cropping intensity. Currently, MADA, PPBP Pinang, and Seberang Perak have achieved 200% cropping intensity, while the other granaries range from 170% to 190%. The exception is the Kemasin/Semarak scheme; this ongoing massive irrigation infrastructure development has temporarily put many areas out of rice production. With completion of the irrigation infrastructure, the scheme is expected to achieve cropping intensity levels comparable with those of other granaries.

Consumption patterns and trends

Rice produced within the country has met a gross self-sufficiency level of 66–80% over the past 10 years. Imports of rice into Malaysia ranged from a low of 389,000 t in 1993 to a high of 656,000 t in 1998 (Table 4). In 1999, Malaysia imported 612,000 t of rice, valued at US$189 million.

The apparent per capita consumption of rice averaged 90 kg ha^{-1}; the year-to-year fluctuation does not show a clear trend. This could be due to the basis of estimation, that is, national production plus net imports divided by the population. Uncertainties occur in estimating actual production because of stock changes and illegal imports (transnational smuggling) of rice, as well as in estimating population because of illegal immigrants.

Policies and changes in policy regime

The Malaysian rice policy has been guided in the past to fulfill three main objectives:

1. *Ensuring food security.* As Malaysia faces a production deficit, rice is considered as a security commodity. Hence, the national policy is to maintain a prudent level of self-sufficiency, at a minimum of 65%.
2. *Raising farm incomes and productivity.* To sustain a strategic industry, government support is provided to make rice cultivation financially viable. Two forms of government support have been instituted: boosting farm income by keeping farm product prices high and reducing production costs by subsidizing the cost of inputs, particularly fertilizer.
3. *Ensuring the food supply to consumers at fair and stable prices.* Currently, market forces are allowed to determine rice price and quality, with only one price-controlled grade to protect the interests of low-income consumers.

Despite the generous support given to the rice sector by the government in the past, either directly through the rice price and fertilizer subsidy, and indirectly through public-funded investments in infrastructure, research, and extension services, rice production has shown only relatively modest gains in output while poverty incidence among rice farmers purportedly continues to be high.

The greatest challenge facing the rice industry in Malaysia stems from the country's commitment to liberalization in rice trade in compliance with WTO and AFTA agreements.

Table 4. Rice consumption estimates for Malaysia, 1991-99.

Variable	Unit	1991	1992	1993	1994	1995	1996	1997	1998	1999	Av
Domestic production	000 t	1,242	1,298	1,357	1,379	1,373	1,439	1,368	1,257	1,314	1,336
Net imports	000 t	339.2	443.8	389.1	334.6	425.1	577.3	645.6	655.8	611.9	498
Total apparent consumption	000 t	1,641	1,742	1,746	1,714	1,798	2,016	2,014	1,913	1,926	1,834
Proportion of production to total apparent consumption	%	76	75	78	80	76.0	71	68	66	68	73.1
Apparent per capita consumption	kg	90.3	93.6	90.9	87.2	86.9	95.2	92.9	86.2	84.8	89.8

Source: Paddy Statistics 1999, Department of Agriculture, Malaysia.

A study by Tengku Mohd Ariff and Ariffin Tawang (1999) indicates that, as a consequence of liberalization, rice production would decline because of a decline in rice price. It is expected that farm-gate and retail prices would decrease by 10.3% and 9.2%, respectively, because of increasing competition from cheaper rice within the region. Furthermore, under a situation in which all forms of farm subsidies are withdrawn, farm profitability would decrease by about 60%. This constitutes a substantial and significant reduction in farm income.

Scope for further improvement in policies to increase production

In view of these challenges, the Third National Agricultural Policy (1998–2010) has outlined six major strategic thrusts that are geared toward ensuring the continued relevance and competitiveness of the rice industry in the globalized economy. These strategies, which would have direct implications for the future rice supply-demand situation, are outlined below.

1. *Rationalize resource use.* The eight granary areas will be designated as permanent rice-producing areas to realize a minimum self-sufficiency level of 70% in the coming decade. Unproductive areas outside the granaries, including areas under secondary irrigation, would be phased out for other uses. New areas for commercial large-scale rice production by the private sector will be promoted, especially in Sabah and Sarawak.
2. *Increase efficiency and productivity by increasing farm yield and cropping intensity*. The national yield target is 5.5 t ha^{-1} in 2010, with at least 185% cropping intensity for all granaries. The yield target has since been revised to 7.0 t ha^{-1} and 5.5 t ha^{-1} for the major granary and outside granary areas, respectively (Government of Malaysia 2001). Yield losses are targeted to be reduced below 5%. To ensure a remunerative return to rice farming, the operation of larger production units through farm enlargement, group farming, and estates will be enhanced and encouraged. In this respect, the government, together with the private sector, will jointly undertake to develop new rice areas for large-scale commercial production.
3. *Strengthen competitiveness under a liberalized market.* The rice trade industry will be deregulated to allow market forces and preferences to determine rice price and quality. In the long term, more traders will be allowed to import rice to encourage healthy competition. The fertilizer support program will be reviewed to improve its efficiency, while rice price support would undergo structural adjustment to conform to international obligations.
4. *Strengthen the economic foundation.* The areas of research and development (R&D), extension and advisory services, irrigation and drainage facilities, credit, marketing, and farmers' institutions will be strengthened. Particularly for R&D, the application of high technology to ensure the exploitation of potential yield is to be encouraged.
5. *Strategic sourcing of rice from offshore investments, especially in low-cost rice-producing countries.* This is to ensure a constant supply of rice to meet future domestic demand and to exploit international market opportunities.

6. *Promote sustainable development of the rice industry.* Strategies are to adopt environment-friendly farm practices such as precision farming, integrated pest management, and water conservation measures.

Challenges and the future outlook for increasing rice production

The challenge brought about by pressure from international trade arrangements has not only raised serious doubts about the ability to continue with some existing policies and practices but also triggered a basic rethinking within the country about the desirability and viability of the rice industry in its current form. Presently, Malaysia is not an efficient and cost-effective producer of rice. Despite the attractive price, fertilizer subsidy, and proven mechanization technology to offset labor, paddy yields have not increased noticeably because of some inherent problems associated with rice cultivation in Malaysia. For most farmers, rice farming is not their main occupation. Since their farm size is small and production costs are rising, returns to rice farming are very low. Consequently, these part-time farmers do not spend much time in the rice field. Farm labor use is as low as 8 to 25 labor-days per season. This and other challenges faced by the rice industry in Malaysia as listed below account for the slow growth in production in the past decade.

1. *Competition for land and labor.* Most of the more productive and well-managed irrigated rice areas are located along the west coast of Peninsular Malaysia, which is experiencing rapid urbanization and strong industrial growth. There has been a substantial conversion of land use from rice to industrial and urban development and this is expected to accelerate in the near future. In the MADA area, about 3,030 ha of rice lands were converted to other purposes from 1987 to 1993. The continued shrinkage of rice area may undermine any advantage that might be expected from higher yields. Labor outflow from rice farming to other attractive sectors is also likely to continue. This is presently manageable, and in fact encouraged, because of the heavy mechanization inputs in rice cultivation.
2. *Water availability and distribution.* The decline in rice cropped area in the rainfed single crop areas is due mainly to the problem of inadequate or excess moisture at different times of the year, so that rice cultivation is often risky and unprofitable. Outside of the granaries, irrigation water resources are insufficient and not assured to support double cropping of rice. Consequently, farmers in these areas prefer to plant other more lucrative field or permanent crops or simply leave the land uncultivated.
3. *Water-use and technological efficiency.* Despite efforts to improve irrigation infrastructure as well as land leveling, water-use efficiency in rice fields is still generally low because of poor in-field water management. In-field losses, especially at the postharvest stage, are still substantial. This may be attributed to the low efficiency of combine harvesters, most of which are imported reconditioned machines operated by contractors. These inefficiencies result in reduced yields.

Under the current situation, Malaysia will face increasing difficulty in sustaining a viable domestic rice industry once international rice trade becomes fully liberalized. The rice market will be open to the cost-effective producers from countries within the region, to the benefit of consumers, who would pay less to buy rice. However, this would depress the price of Malaysian rice, making it even less attractive for farmers to continue production.

The greatest threat to reducing the profitability of farming is the dismantling of the price support program, which constitutes noncompliance with the international trade agreements. Presently, there is a guaranteed minimum price of paddy, \$145 t^{-1}. In addition, farmers receive a price subsidy amounting to \$66 t^{-1}. Even though rice production without subsidies can still be profitable, typical net returns of \$50–185 ha^{-1} would not be sufficient to provide a decent level of income to rice farmers with smallholdings.

Table 5 summarizes the government's perspectives on the future outlook of the rice industry in Malaysia.

Analyzing rice supply and demand

In the face of the changing climate of trade liberalization, Malaysia needs to reformulate its national policy to maintain the minimum level of self-sufficiency in rice that it is committed to. Such policy intervention needs to be accompanied by technological interventions to increase productivity as well as careful geographical targeting of rice production. Already, irrigation infrastructure development confines intensive rice cultivation to specific geographical areas. Rice production has high opportunity costs in terms of land and water use, especially in Peninsular Malaysia, where rice areas face increasing competition from urbanization and from the domestic and industrial use of water resources.

Therefore, from the national perspective of balancing rice demand against supply, the question remains if the production targets as articulated in the National Agricultural Policy can be met, given both the socioeconomic factors governing rice con-

Table 5. Future outlook for the rice industry: Malaysian government's perspective.

Variable	Year			Average annual growth rate (%)	
	2000	2005	2010	2000-05	2005-10
Production (000 t)	1,457	1,513	1,609	0.8	1.2
Value added (\$)	185	195	207	1.1	1.2
Domestic demand (000 t)	1,995	2,139	2,284	1.4	1.3
Deficit (000 t)	538	626	675	3.0	1.5
% deficit	26.9	29.3	29.6	1.7	0.2
Per capita consumption (kg y^{-1})	85.7	82.8	80.4	–0.7	–0.6
Self-sufficiency level (%)	73.0	70.7	70.4	–0.6	–0.1

Source: Compiled from the Third National Agricultural Policy (Government of Malaysia 1999).

sumption and production and the biophysical and technological factors that would optimize the efficiency of rice production within limited, and possibly diminishing, geographical areas where rice can be grown.

To this end, we employed a rice supply and demand analysis (RSDA) model, developed at the International Rice Research Institute (IRRI) (Hoanh et al 2000), for this case study for Malaysia. Several features of the RSDA model make it particularly suited to examining the specific concerns of rice supply and demand within the Malaysian context, in ways that are not handled by more conventional, economics-driven rice supply and demand models. These features constitute the objectives of this study:

1. Strengthen the estimation of rice supply by taking into account biophysical factors affecting rice production, besides socioeconomic and policy factors.
2. Explore scenarios of rice supply and demand within the country as implications for policy and technological interventions targeting and influencing rice production and consumption in different geographical areas.

In this respect, the RSDA model constitutes another option to the conventional economics-based models, providing a refinement in the supply estimation, and offers itself as a decision support tool that could be used by planners, at both the national and regional level.

Approach and methodology for analyzing rice supply and demand at the subnational level

The approach taken in developing the RSDA methodology emphasizes the integration of biophysical and socioeconomic analysis, and consideration of policy factors as well. The RSDA model is briefly described below; details on the theoretical basis and the computations are described in Hoanh et al (2000, this volume). The model has three components:

1. *Estimating rice supply.* To estimate supply, we adapted a crop growth model so that it could be used to estimate potential, water-limited, and nutrient-limited rice yields (based on fertilizer input levels) at the regional scale. The model has been validated for a limited number of rice varieties (IR64 and IR72) at selected locations (New Delhi, India, and Can Tho, Vietnam); the model results also corresponded closely with outputs from ORYZA-W and WOFOST crop growth models (de Vries 2000). We mapped rice areas, taking note of the availability of irrigation for intensive cropping. From these estimates, we computed potential and attainable rice production, taking into account cropping intensities. This method constitutes the major difference of the RSDA from the conventional approach of estimating rice supply, which is based entirely on economic parameters.
2. *Estimating rice demand.* We employed the conventional approach for estimating demand, that is, multiplying population by per capita consumption, taking into account differences in consumption rates between rural and urban populations.
3. *Balancing rice supply and demand.* The balance between supply and demand is obtained by comparing supply and demand estimates, after taking into account

postharvest losses and other uses of rice apart from direct human consumption, such as use as seeds for planting.

Figure 3 shows the components of the RSDA model schematically. The model was applied only to Peninsular Malaysia. Rice production and consumption were estimated as gross values for East Malaysia, without geographical disaggregation, for two reasons:

- Lack of comprehensive geographical information on rice areas, soil properties, and irrigation status.
- Rice is mainly cultivated as part of extensive shifting cultivation systems that do not lend themselves easily to crop yield modeling; only limited areas are under irrigation (6%).

In Peninsular Malaysia, the rice supply modeling was carried out only on rice areas, within and outside the granary areas, as mapped by the Malaysian Department of Agriculture (1998 base year). The total mapped physical rice area (Fig. 1) taken into account in the rice supply modeling is 390,000 ha. This is about 30,000 ha more than the total registered rice parcel area reported for Peninsular Malaysia, which is 362,000 ha (Department of Agriculture, Malaysia, Paddy Production Report for Main Season 1999/2000). Presently, 271,000 ha (or 75%) of the registered rice land are actually planted, as estimated from the main season 1999-2000 rice area (Table 3). This is done on the assumption that, even if new areas would be put into rice production in future scenarios, the total physical area would not exceed what has been mapped.

Rice demand estimation was done at the district level for Peninsular Malaysia, for both the base year (2000) and with projected population and per capita consumption for exploring future scenarios. Hence, the balance between rice supply and demand was computed at the district level; these estimates can then be aggregated to the state level and for Peninsular Malaysia. The latter can be added to the aggregate estimates for the two states of East Malaysia, Sabah and Sarawak, to obtain national figures.

Rice supply determinants and estimation

Rice supply is estimated by production levels, which are determined by biophysical as well as socioeconomic and policy factors.

Biophysical characteristics of rice areas in Peninsular Malaysia. The natural conditions for lowland rice are mainly found in three physiographic regions: (1) coastal alluvial plains, (2) river terraces of major rivers, and (3) floodplains and valleys of small rivers. Historically, the human population and economic activities concentrated along the west coast of the peninsula; hence, more lowland areas in the west coast were put into rice cultivation than in the east coast. The coastal alluvial plains are mainly concentrated along the west coast of the peninsula. The most extensive coastal alluvial plain put into rice cultivation is the Kedah-Perlis plain, where the largest of the eight granaries, the MADA irrigation scheme, is located (Fig. 1). The typical feature of coastal alluvial plains is the zoning of the marine and riverine soil sediments, more or less parallel to the coast. In some instances, inland soils tend to overlay deep peaty soils as in the PBLS irrigation scheme in Selangor. There are very low-lying areas along the west coast, with poorly drained soils that have high accu-

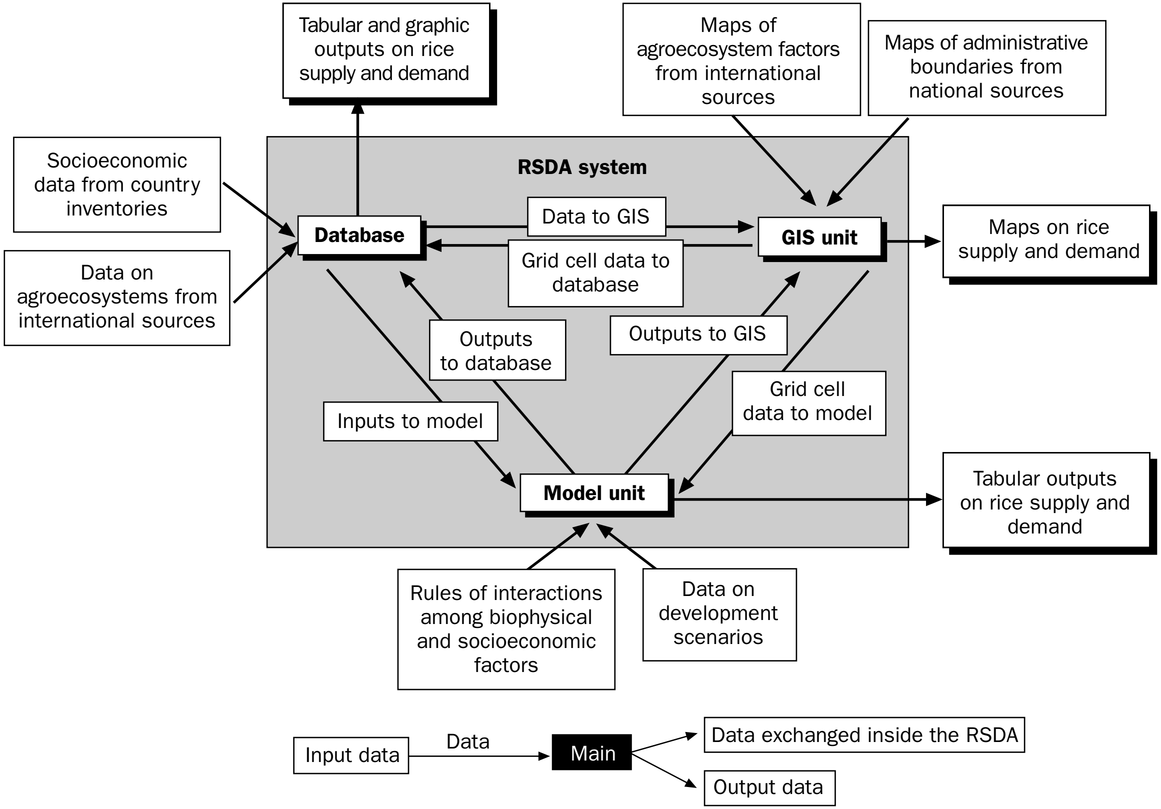

Fig. 3. Schematic diagram of the rice supply and demand analysis (RSDA) model and system.

mulations of organic matter, such as the Krian/Sg. Manik and Seberang Perak schemes in southern Pulau Pinang and Perak states. Along the east coast, the rice soils are typically riverine and are developed on terraces associated with the major rivers. The main rice area is the KADA irrigation scheme in the Kelantan River plain. Smaller and more recent schemes are being developed along the east coast states of Kelantan (Kemasin/Semarak scheme) and Terengganu (KETARA scheme). Being confined to alluvial and fluvial plains, rice grows on soils that are generally heavy-textured and relatively fertile—the west coast soils more so than the east coast soils. A few local areas have specific soil problems, such as peaty and acidic soils, but limitations are not difficult to overcome.

Climatically, there are no temperature constraints to rice growth. The rainfall pattern of the peninsula is influenced by the two monsoon systems. The southwest monsoon dominates the weather patterns in the west coast, while the east coast is subject to the northeast monsoon. There is a distinct difference in the quantum and seasonality of rainfall in the west and east coasts. Being located in the northern parts of the peninsula, both the major rice bowls are subject to distinct dry seasons. The main-season rice is partially irrigated, whereas the off-season rice is fully irrigated.

Production characteristics. Rice cultivation in Peninsular Malaysia is not so much limited by biophysical constraints but by socioeconomics, opportunity costs, and labor availability under the predominantly smallholding nature of rice farms. The average farm size is about 1.5 ha per farm holding. The average yield for the granaries is 3.8 t ha^{-1}, which is 27% higher than the national average. There is considerable yield variation among granaries—the highest average yields are attained in PBLS, followed by MADA—not because of inherent environmental characteristics but because of management practices. For example, farmers in the PBLS scheme, particularly in the Sawah Sempadan area, take advantage of the best irrigation and drainage infrastructure in the country to attain the highest yields (6.5–8.0 t ha^{-1}) by applying very high inputs—inorganic fertilizer, chemicals, and farm labor. However, the cost of production in PBLS is the highest in the country, at about $790 ha^{-1} per season, which is double that of the lowest-cost producer, KADA.

Yield estimation using the RSDA model shows that an average yield of 6.6 t ha^{-1} is attainable in the granary areas (assuming that the national target of 7.0 t ha^{-1} in the granaries will only be achievable beyond 2010) with high fertilizer inputs (up to 400 kg N ha^{-1}, 200 kg P_2O_5 ha^{-1}, 200 kg K_2O ha^{-1}) if irrigation efficiency is also improved to at least 95% in those granaries that are currently operating below this level. However, sustainable production at such high input levels is questionable. In addition, it brings into question the capacity of farmers to adopt such practices.

Socioeconomic characteristics. The main socioeconomic factor that normally influences production and supply is commodity price. In the case of rice production in Malaysia, price elasticity on supply is low, ranging from 0.11 to 0.17 (with some studies quoting elasticity values from 0.2 to 0.6). The main reasons for this low impact of changes in price structure on domestic production are the various forms of government subsidies, the very limited scope for expanding area for rice cultivation, and the significant increment in planted area brought about by double cropping of rice.

Rice supply estimation. Taking into account the government policy direction and the need to address some of the emerging issues highlighted above, ten production scenarios (P1 to P10) were selected for the purpose of supply model runs for Peninsular Malaysia (Table 6).

In the case of scenarios P8, P9, and P10, instead of using price elasticity as a factor influencing production, it is assumed that farmers will move out of rice production if the net revenue drops below the minimum current revenue (1998 base) obtained in the granary/area concerned, when the farm-gate price drops from the prevailing level of \$225 t^{-1} by \$66 t^{-1}.

In all scenarios, it is assumed that rice production in East Malaysia remains constant at the base year (1998) level; this amount is added to the Peninsular Malaysia estimate to obtain production estimates for the country. The rice supply estimates, derived from rice production estimates (which have accounted for 5% losses because of pests and diseases), take into account the amounts saved for use as seed (estimated from planted area and seeding rates by state) as well as postharvest and distribution losses (set at 5% and 0.5%, respectively).

The results of the model runs for rice supply are shown in Figure 4. The estimated rice supply under the base scenario for 2000 is 1.22 million t compared with the government estimate of 1.46 million t (Table 5). The model estimate already deducts out the amount used as seed (estimated at 38,000 t rice equivalent) and also takes into account postharvest and distribution losses. These deductions account for about 3% of the gross rice production. Even so, the model has underestimated the supply; this is mainly because the model was calibrated against the production figures for 1998 as the base year, which was the latest year for which detailed production data were avail-

Table 6. Description of rice production scenarios.

Code	Description
P1	Base production scenario for 2000—maintain all granary areas, i.e., the 240,000 ha within the main and secondary granaries
P2	Rice production restricted to the eight major granaries
P3	Maintain all granary areas (as in P1), with improvement in irrigation efficiency to 100% and reduction in yield losses to 5%
P4	Rice production within main granaries (as in P2), with improvement in irrigation efficiency to 100% and reduction in yield losses to 5%
P5	Maintain all granary areas (as in P1), with improved technology to attain an average yield of 6.6 t ha^{-1} in main granaries and 5.3 t ha^{-1} in secondary granaries
P6	Rice production within main granaries (as in P2), with high fertilizer inputs to attain an average yield of 6.6 t ha^{-1}
P7	Maintain all granary areas (as in P1), with high inputs to attain highest possible yields without improvement to current irrigation efficiency in main granaries, and 5.3 t ha^{-1} in secondary granaries
P8	Maintain all granary areas with improved efficiencies (as in P3), but with a farm-gate price reduction of 10.3% because of market liberalization
P9	Maintain all granary areas (as in P1), but with removal of price subsidy whereby farm-gate price drops by \$66 t^{-1}
P10	Maintain all granary areas to attain target yields (as in P5), but with removal of price subsidy whereby farm-gate price drops by \$66 t^{-1}

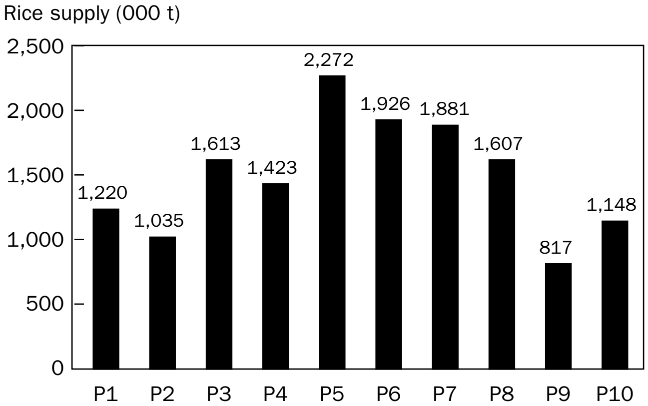

Fig. 4. Rice supply under production scenarios P1–P10 (refer to Table 6).

able. Rice production in 1998 happened to be the lowest over the 1992-99 period (Table 1). This means that the supply estimates for the various scenarios are conservative.

As would be expected, improving irrigation efficiency and reducing pest losses would increase the rice supply by 32% (comparing scenarios P3 and P1). Limiting rice production to the eight granaries would have the effect of reducing the rice supply by 15% (P2 versus P1) and 12% (P4 versus P3)—reductions that are still substantial.

A larger increase in supply over the base scenario (by 86%) occurs if average yields of 6.6 and 5.3 t ha^{-1} are attained in the granary and nongranary areas, respectively (scenario P5). The 6.6 t ha^{-1} average yield for the granaries can be attained if irrigation efficiency is improved. Otherwise, the average attainable yield in the granaries would be 5.5 t ha^{-1} (scenario P7) and the rice supply would be 54% higher than in the base scenario.

The effect of a lowered farm-gate price (by 10.3%) because of a liberalized market has a minor effect on the rice supply, depressing it as shown by the comparison between scenarios P8 and P3. A more drastic reduction in rice supply would occur with the removal of the rice price subsidy in compliance with the WTO agreement. A 26% drop in the farm-gate price would reduce the rice supply by 33% from the base scenario if no improvements were made in productivity (comparing scenarios P9 and P1). Even with attainment of the target yields for the granary and nongranary areas, this price subsidy removal will result in a supply level that is lower than the base scenario (comparing scenarios P10, P5, and P1). This marked reduction occurs because, with the depressed farm-gate price, the net revenue would still be lower than the minimum acceptable level to make rice farming viable. Table 7 shows the reduction in or complete removal of rice cultivation areas in the granary and nongranary areas under scenarios P9 and P10 (i.e., the base scenario and high target yield scenario, respectively, if subject to a withdrawal of the price subsidy). Areas particularly affected are those where production costs are high. Four of the eight granaries would go out of production in the main season (PPBP Pinang, Seberang Perak, PBLS, and KETARA), with the addition of Kemasin/Semarak in the off-season. This shows the very serious implications that price subsidy removal would have for the rice industry unless other support mechanisms were instituted to ensure the viability of rice farming in the likely affected areas.

The estimation of supply is likely to suffer from uncertainties of under- and overestimation for two main reasons:

1. Rampant smuggling of cheaper rice into the country occurs across porous international borders. The quantities of rice smuggled in may be substantial in proportion to the total rice production and consumption amounts for a small country such as Malaysia, but these cannot be accounted for in official statistics. For example, official records from permits issued indicate that about 117,000 t of rice were "exported" out of Kelantan State (which borders with Thailand) from January to September 2001. Over the same period, the total rice production in the state was only 64,000 t, while the total consumption/demand was 72,000 t. This means that about 109,000 t of rice are not accounted for, which is equivalent to the amount of rice smuggled in. This alone accounts for more than 5% of the national domestic production (averaging 2 million t).
2. It is difficult to assess losses from pests, diseases, and postharvest operations. These losses are often estimated in isolation from other losses. If these separate losses were cumulated, the total losses would be staggering. An alternative estimate is the quoted % losses based on standard estimation by the industry.

Rice demand determinants and estimation

Rice demand is driven mainly by population and socioeconomic factors that influence per capita consumption.

Population growth. The one single factor that boosts rice demand in Malaysia is population growth. With growth above 2% per annum and the existing government policy to increase the population to 75 million by 2050, rice demand is expected to increase significantly in spite of the declining per capita consumption caused by higher incomes.

The latest census carried out in 2000 put the population for Malaysia at 23.3 million, of which 18.5 million (80%) live in Peninsular Malaysia. About 14.4 million, or 62% of the national population, live in urban areas. Malaysia's population is projected to increase at 2.28% per annum to reach 26.0 million in 2005, and thereafter to increase by 1.85% per annum to reach 28.5 million in 2010. Using the 2000 population census preliminary count data by district, the state-wise 2000 estimates adjusted for underenumeration, the state-wise urbanization ratio, and the estimated population of major towns (Department of Statistics 2001, World Gazetteer 2001), as well as the state-wise projected population for 2005 and 2010 (Department of Statistics, unpublished data), we estimated the district-wise urban and rural population for 2000, 2005, and 2010 in order to estimate rice demand by district. Figure 5 maps the district-wise population for 2000 for Peninsular Malaysia, while the embedded bar charts show the urban-rural populations for 2000, 2005, and 2010 by state.

Table 7. Rice production areas likely to be affected by price subsidy removal.

Area	Off-season					Main season				
	Total area (ha)	Base scenario		High target yields		Total area (ha)	Base scenario		High target yields	
		Area (ha)	%	Area (ha)	%		Area (ha)	%	Area (ha)	%
MADA	96,307	–	–	–	–	96,320	–	–	–	–
PPBP Pinang	9,747	9,747	100	9,747	100	9,881	9,881	100	9,881	100
Kerian/Sg. Manik	28,676	–	–	21,404	75	27,672	–	–	–	–
Seberang Perak	8,355	8,355	100	8,355	100	8,352	8,352	100	8,352	100
PBLS	18,670	18,670	100	18,670	100	18,669	18,669	100	18,669	100
KADA	28,955	3,648	13	22,414	77	27,231	2,612	10	2,612	10
Kemasin/Semarak	416	416	100	416	100	7,118	145	2	145	2
KETARA	4,863	4,863	100	4,863	100	5,007	5,007	100	5,007	100
Secondary granaries	38,155	6,529	17	6,335	17	72,667	3,725	5	3,725	5
Overall	234,144	52,228	22	92,204	39	272,917	48,391	18	48,391	18

Per capita consumption. The series of household expenditure surveys conducted once every 10 years indicate an overall declining trend in per capita consumption of rice, resulting mainly from an overall increase in per capita income. As income increases, people change their food habits, eat out more frequently, and consume less rice in favor of other high-value quality foods such as bread, vegetables, fish, and

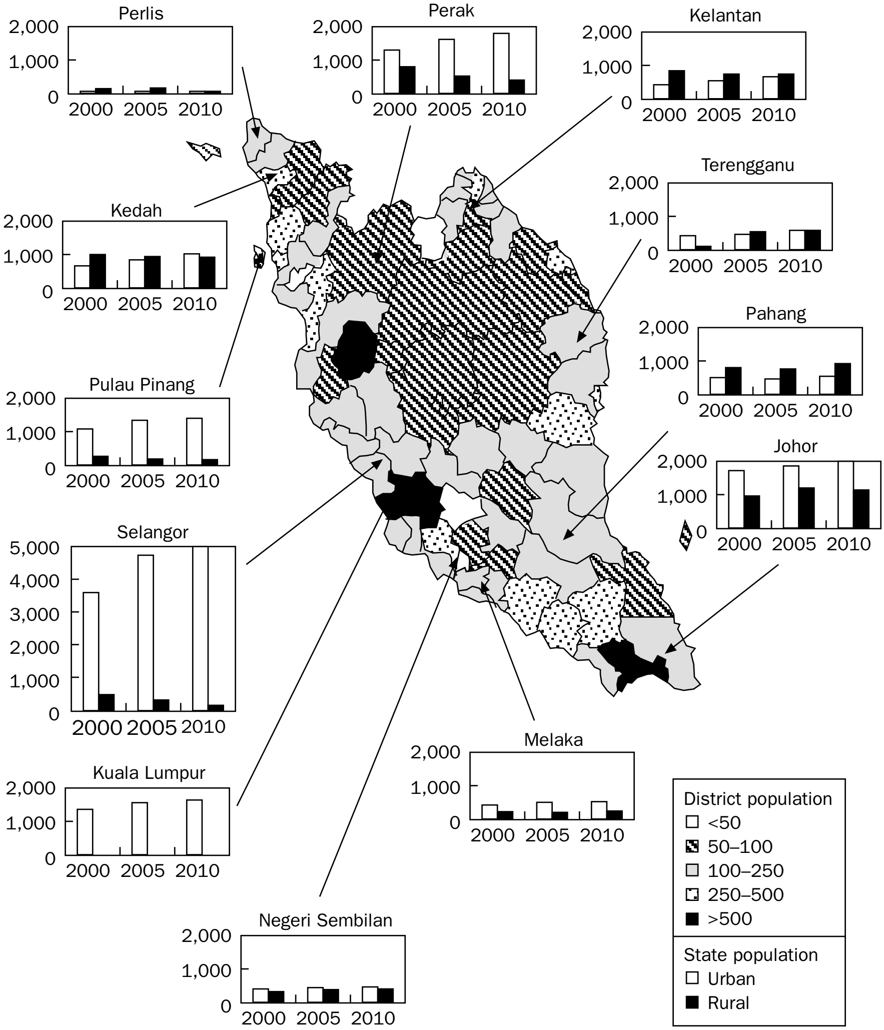

Fig. 5. Population of Malaysia by district for 2000 and projected urban and rural population by state for 2005 and 2010. For columns, numbers underneath are years and numbers to left are population (000).

meat. The latest household expenditure survey (1993-94) carried out on 8,000 urban and 7,500 rural households showed that rice accounted for 8.2% and 13.6% of the urban and rural household expenditure on food, respectively, and that national per capita consumption was 85.5 kg year^{-1}. The per capita rice consumption was also lower for Peninsular Malaysia than for the East Malaysian states of Sabah and Sarawak. A trend analysis done for the Third National Agricultural Policy (Government of Malaysia 1999) indicates a general decline in national per capita rice consumption (in kg y^{-1}) as follows: 102.2 (1985), 89.8 (1990), 86.9 (1995), 85.7 (2000), 82.8 (2005), and 80.4 (2010).

Income and price elasticity on consumption. Demand elasticity is also low, with price elasticity ranging from –0.2 to –0.5 and income elasticity from 0.31 to –0.1. The reason for this inelastic demand in both price and income is the relative affluence of the Malaysian society; this phenomenon has already occurred in Japan, Republic of Korea, and Taiwan (China).

In this study, rather than applying demand elasticity of income, we used the present (2000) and projected figures for national per capita consumption for 2005 and 2010 (Government of Malaysia 1999), in conjunction with the regional and urban-rural differences obtained from the 1993-94 household expenditure survey (HES), to estimate the per capita consumption for rural and urban households for 2000, 2005, and 2010. The derived values, plotted for East and Peninsular Malaysia in Figure 6, were computed such that they are consistent with the national estimates of per capita consumption for the years of interest, and also with the rural and urban differences based on the 1993-94 HES.

Rice consumption estimation. Table 9 lists the consumption scenarios (C1 to C5) that were selected for the demand model runs. For scenarios C3 and C5, we nominally applied the price elasticity on consumption of –0.3 for rural households only, assuming that urban per capita rice consumption is inelastic with respect to price. All consumption scenarios were run at the district level for both East and Peninsular Malaysia.

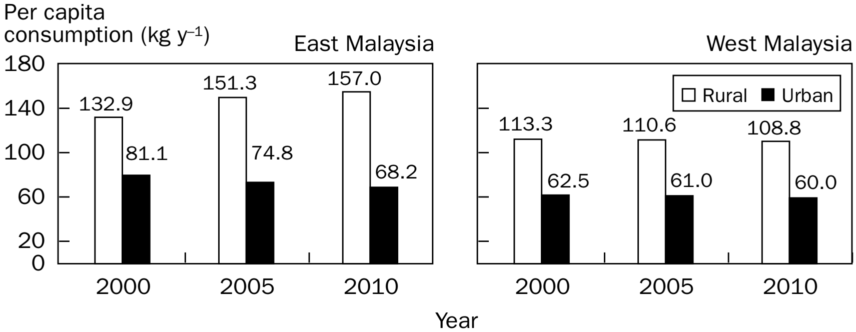

Fig. 6. Per capita consumption for East and Peninsular Malaysia by rural and urban sector for 2000, 2005, and 2010.

Figure 7 shows the results of the model runs. Rice demand for 2000 and projected demand for 2005 and 2010 (scenarios C1, C2, and C4) agree very closely with the official figures (Table 5). A reduction in the retail rice price by 10.3% (because of market liberalization) would increase demand by only 1.3% for both 2005 (comparing C3 and C2) and 2010 (comparing C5 and C4).

As is the case for rice supply estimation, estimation of demand, especially projected over time, is likely to suffer from underestimation because of the large population of immigrant labor, both legal and illegal, which is not adequately accounted for in official population statistics. Current guesstimates are from 1 to 1.5 million (i.e, 4–6% of the official 2000 population), but there can never be certainty over the figures because a substantial proportion of the immigrant labor is illegal.

Balancing rice supply and demand

The various supply estimates under production scenarios P1–P10 can be combined with the demand estimates under consumption scenarios C1–C5 to examine the balance between supply and demand. The balance is computed at the district level by the RSDA model, so it is possible to map and display the outputs by district for Peninsu-

Table 9. Description of rice consumption scenarios.

Code	Description
C1	Base consumption scenario for 2000, based on 2000 population and per capita consumption figures
C2	Consumption scenario for 2005, based on projected 2005 population and per capita consumption figures
C3	Consumption scenario for 2005, based on projected 2005 population and assuming retail rice price drops by 10.3% because of trade liberalization
C4	Consumption scenario for 2010, based on projected 2010 population and per capita consumption figures
C5	Consumption scenario for 2010, based on projected 2010 population and assuming retail rice price drops by 10.3% because of trade liberalization

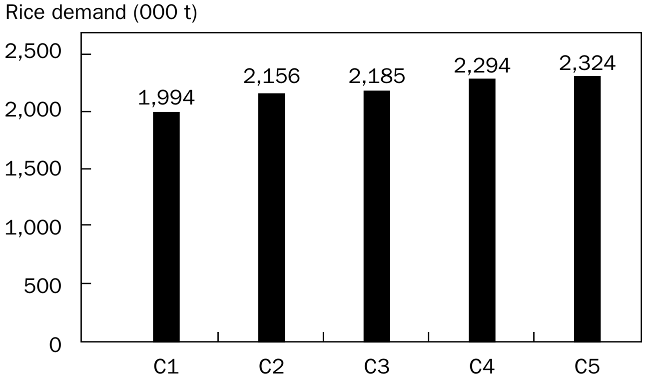

Fig. 7. Rice demand under consumption scenarios C1–C5 (refer to Table 9).

lar Malaysia. However, it may not be so meaningful to examine surpluses and deficits at the district or even state level because of the good transportation and distribution system and because considerable bidirectional movement of rice occurs between the granary and nongranary areas as rice may be brought into the granary areas for milling and redistributed again.

Instead, the district-level results were aggregated to provide state and national estimates of the balance between rice supply and demand. However, the discrepancy between demand and supply may not directly reflect the volume of rice imports because imports fluctuate from year to year depending on the amounts released from or added to the national stockpile.

Figure 8 shows an example of combining the 10 production scenarios with the consumption scenario C5, that is, demand in 2010 assuming that retail prices drop by 9.2% from current levels. The balance ratios, plotted as points against the bar chart of supply and demand, can be compared with the government's target self-sufficiency level (SSL), with some adjustment. The official SSL is computed based on gross domestic supply estimates that do not take into account use as seed and postharvest and distribution losses. To be comparable to the balance ratios computed from the model, the SSL values in Table 5 ought to be adjusted downward by 3 percentage points. The SSL for 2010 is shown in Figure 8 as the broken horizontal line.

Three scenarios occur where the balance ratios are distinctly higher than the target SSL. These three scenarios are associated with productivity levels that are much higher than current levels; the most optimistic of which is the combination P5C5 in which average yields of 6.6 and 5.3 t ha^{-1} are attained in the granary and nongranary areas, respectively. Two scenarios, P3C5 and P8C5, would just exceed the target SSL. These scenarios are associated with achieving 100% irrigation efficiency, thus allowing 200% cropping intensity in the granaries, as well as retaining the nongranary areas; if the latter areas go out of production, the SSL would barely be met. Figure 8

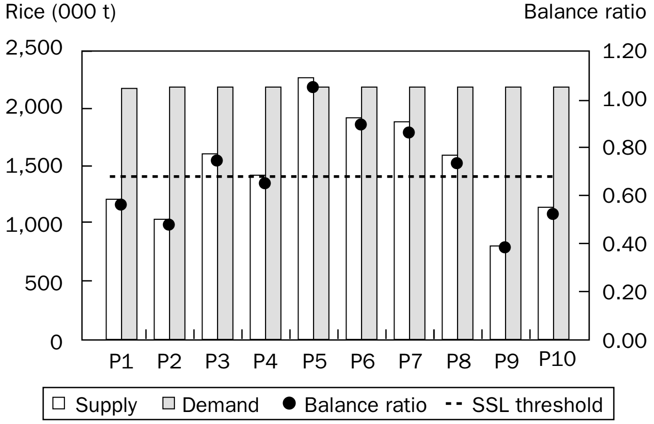

Fig. 8. Balancing rice supply and demand: case scenarios P1–P10 for consumption scenario C5 (year 2010 with retail price reduction of 9.2%). SSL = self-sufficiency level.

also shows that the balance would fall far short of the target SSL in 2010 if current production conditions continue (P1C5) or worsen if the nongranary areas stop production (P2C5) and with removal of the price subsidy (P9C5). Even with the attainment of high yield targets, the effect of the price subsidy would depress supply to a level that would fall far short of the target SSL (P10C5).

Table 10 summarizes the combined results of the 10 production and 5 consumption scenarios. The balance ratios that exceed the targeted self-sufficiency levels are highlighted in bold. The balance between rice supply and demand as indicated by the selected combination of production and consumption scenarios can be interpreted in the light of the various policy issues raised in the earlier part of this paper.

1. *Limiting rice production to the granaries only.* Nongranary areas contribute about 180,000 t under the base scenario (comparing P1 and P2) and 350,000 t under the most optimistic (high yield) scenario (comparing P5 and P6). This accounts for about 15% of the total production, which is a fairly substantial proportion. It would therefore take rather strong political willpower to completely phase out rice production outside of the eight granaries.
2. *Removing the price subsidy.* The effect of removing the price subsidy will be very significant since many areas, including the high-productivity granaries such as PBLS, will no longer be profitable for rice production. The most serious implication is when the price subsidy is terminated and rice cultivation is limited to the granaries only (scenario P9). The balance ratio falls below 0.4 and worsens over the years as demand increases. Even with the high yield scenario, removal of the price subsidy would depress the supply to a level such that the balance ratio would fall far short of the target SSL (scenario P10). This underscores the importance of putting in place other farm income support mechanisms that do not contravene international trade agreements to ensure that rice production remains viable for thousands of farmers who would otherwise go out of business.
3. *Reduction in farm price because of market liberalization*. The effect of a 10.3% decline in the farm-gate rice price is less severe. Comparing scenarios P8 and P3, it is still possible to maintain supply marginally above the SSL if all the granary areas are maintained, but the situation will worsen over the years.
4. *Improving infrastructure support.* Improving irrigation efficiency and postharvest losses would increase production by 390,000 t for both scenarios P3 and P4, also by maintaining all granary areas and limiting production to the granaries only. Further government investments in upgrading and improving irrigation infrastructure would pay high dividends, as this would lift the supply above the SSL, particularly if production in the nongranary areas were curtailed. There is scope for transferring the existing "subsidy allocation components" of government expenditure, by intervention in the rice industry, to infrastructure improvement.
5. *Increasing productivity.* The most promising measure to boost the domestic supply to ensure that SSL targets are more than adequately met would be through qualitative improvements in productivity. P5 is the most optimistic scenario.

Table 10. Balancing rice supply and demand for combinations of production scenarios P1–P10 for consumption scenarios C1–C5.

	Production scenario	Consumption scenario	C1 Population 2000	C2 Population 2005	C3 Population 2005, retail price –9.2%	C4 Population 2010	C5 Population 2010 retail price –9.2%
P1	Base scenario 2000: maintain current permanent paddy area	Supply	1,219,538	1,219,538	1,219,538	1,219,538	1,219,538
		Demand	1,993,905	2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio	0.612	0.566	0.558	0.532	0.525
P2	Maintain main granaries: P2 minus secondary granary areas	Supply	1,035,166	1,035,166	1,035,166	1,035,166	1,035,166
		Demand	1,993,905	2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio	0.519	0.480	0.474	0.451	0.445
P3	Maintain current permanent paddy area (P1); 100% irrigation efficiency and 200% crop intensity in granaries; 5% decrease in losses	Supply		1,612,562	1,612,562	1,612,562	1,612,562
		Demand		2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio		**0.748**	**0.738**	**0.703**	**0.694**
P4	Maintain main granaries (P2); 100% irrigation efficiency and 200% crop intensity; 5% decrease in losses	Supply		1,423,170	1,423,170	1,423,170	1,423,170
		Demand		2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio		0.660	0.651	0.620	0.612
P5	Maintain current permanent paddy area (P3); attain yields of 6.6 and 5.3 t ha^{-1} for main and secondary granaries	Supply		2,272,480	2,272,480	2,272,480	2,272,480
		Demand		2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio		**1.054**	**1.040**	**0.990**	**0.978**
P6	Maintain main granaries (P4); attain average yield of 6.6 t ha^{-1}	Supply		1,926,123	1,926,123	1,926,123	1,926,123
		Demand		2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio		**0.893**	**0.882**	**0.840**	**0.829**
P7	Maintain current permanent paddy area (P1); attain yields of 5.5 and 5.3 t ha^{-1} for main and secondary granaries	Supply		1,880,669	1,880,669	1,880,669	1,880,669
		Demand		2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio		**0.872**	**0.861**	**0.820**	**0.809**

continued

Table 10. continued

P8	Maintain current permanent paddy area (P3); liberalized market (farm price down by 10.3%)	Supply	1,606,637	1,606,637	1,606,637	1,606,637
		Demand	2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio	**0.745**	**0.735**	**0.700**	**0.691**
P9	Maintain current permanent paddy area (P1); price subsidy removed (price drops by $66 t^{-1})	Supply	816,618	816,618	816,618	816,618
		Demand	2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio	0.379	0.374	0.356	0.351
P10	Maintain current permanent paddy area (P5); price subsidy removed (price drops by $66 t^{-1})	Supply	1,148,157	1,148,157	1,148,157	1,148,157
		Demand	2,155,797	2,184,773	2,294,331	2,323,874
		Balance ratio	0.533	0.526	0.500	0.494

> By maintaining all granary and nongranary areas, and supported by technology management (high fertilizer inputs and improved irrigation efficiency), it is possible to achieve production beyond the national requirement. An almost 100% SSL is achievable up to 2010, but at excessively high fertilizer inputs. Even if rice production is concentrated within the granaries, the SSL is still above 80% up to 2010 (scenario P6). However, since this is achievable under the current price subsidy structure (and its removal will affect production significantly), it is not likely that this scenario can be fully realized.

Nonetheless, this is one area to which the government can give more focus, since it would permit the most substantial increases in rice supply. Strong government intervention is required, especially in improving irrigation facilities (possibly also including extensive land-leveling programs), introducing high-yielding varieties, and encouraging an increment in fertilizer inputs (although removal of the fertilizer subsidy could dampen this effort). The targeted yield is 6.6 t ha^{-1}, which is already achievable in some parts of the country. For example, farmers in PBLS, MADA, and Seberang Perak manage to achieve consistently high yields with good management.

Implications for the future rice industry in Malaysia

To meet the targeted level of self-sufficiency while ensuring that rice farming remains remunerative in the face of new international trade arrangements, changes need to be made to the structure of production units by fostering the emergence of a new generation of farmers operating on a purely commercial basis with a profit orientation. Profits can be realized, even without the existing input and price subsidies, through economies of scale in rice production. The targeted size is 10 ha and above for each farmer. This is to be realized by providing support to encourage and facilitate farm-size enlargement by renting rice land from a large number of individual landowners. A farm enlargement fund for this purpose is one option that could be considered. This transformation would have the effect of reducing the number of rice farmers; adequate alternative employment or other direct income support programs for these displaced farmers must be made available.

Another future outlook is to promote the production of high-quality or specialized rice to meet the growing demand from consumers who are willing to pay premium prices for quality. With the possibility that small farmers will not be able to compete with the more cost-effective advanced farmers as well as neighboring rice producers within the region, the production of higher-value rice in low-input production systems could be one option worth considering. Increasing the domestic production of high-quality rice is one of the objectives stipulated in the Third National Agricultural Policy for Malaysia.

Conclusions

The above review of the rice industry of Malaysia and analysis of rice supply and demand in the face of recent changes in international trade arrangements show that the national target to maintain a prudent level of self-sufficiency in this strategic food staple has to be accompanied by policy instruments that move away from direct financial support to interventions that promote greater efficiencies of production in the limited areas designated for rice in the country. The analysis also underscores the need for structural changes as well as production orientation toward a greater degree of commercialization of rice farming that would gradually displace small part-time farmers. If these changes are instituted over the coming decade, the target of meeting a self-sufficiency level not exceeding 70% could be reasonably met.

This study has attempted to use a more integrative approach in balancing rice supply and demand through the use of the RSDA model. The intention is not to replace the conventional purely economic-based estimation; rather, the inclusion of biophysical factors in the estimation (hence limiting production potential) strengthens the supply estimation, which would otherwise be dictated solely by cropping area, price (of both inputs and outputs), and technology.

As illustrated in this paper, the RSDA allows for exploring different sets of new scenarios, based on possible changes in policy, crop management, production orientation, etc. The outputs from these explorative scenarios are very useful for decision-making, at either the national or regional (granary) levels. Basically, it provides a tool with which planners and managers can explore different possibilities and assess the effects of the different policy and production environments on rice supply and demand. The study team members intend to extend the methodology/model for immediate application at the national level by the relevant government institutions, as well as expose regional managers in the granaries to the use of such a tool for their area-specific planning purposes.

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Section **FOUR**

A long-term outlook for rice supply and demand balances in South, Southeast, and East Asia

M.A. Sombilla, M.W. Rosegrant, and S. Meijer

Alarms are once more being sounded about the beginning of a long-term trend in which staple grain harvests, particularly of rice, are slackening and are failing to outpace demand in several countries in Asia. This spells trouble for the region, which is the home of about 800 million poor people that depend on rice for food energy.

This paper tries to assess the world rice market in the years ahead by analyzing projection results to 2025 produced by the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) on supply, demand, trade, and prices under various scenarios. The baseline scenario indicates that rice production in the Asian region as a whole will still be able to increase at a rate to meet demand for the commodity while prices will further decline. This rosy picture is contingent on the continuation of trends of a large number of underlying drivers of world food markets as these are influenced by complex interactions among technology, policy, investment, environment, and human behavior.

The alternative scenarios indicate that policy or technology failures that change the course of any one of these drivers could have a significant impact on future rice balances. The low population growth rate scenario, for example, can be beneficial for welfare improvement with the attainment of much lower prices that lead to higher per capita demand for rice, less pressure on fragile land to be brought into cultivation, and significant expansion of trade. The low yield scenario, on the one hand, can translate into market difficulties—high world prices, high domestic prices, and social protests—especially in the low-income countries that depend the most on rice for their staple food. In contrast, the high yield growth scenario could bring significant benefits but should be achieved with great care so that gains would accrue to both producers and consumers, especially in the high-poverty countries and less-favored regions within those countries.

In all of the scenarios, including the baseline, the poor countries—mostly in South Asia and some in Southeast Asia—are greatly affected by variations in the factors that influence production and demand. This is because these countries have the most fragile environments for rice production. The future challenge is clear: to adopt appropriate and well-balanced policy reforms that promote growth and equity in Asia, especially in the more difficult agroecological and low-potential systems.

There are great risks in looking as far as 25 to 30 years ahead. This vision, however, is needed to avoid facing unacceptably higher risks that the right answers will not be found in time to avert potential disaster. In most of these looks ahead, the importance of minimizing the risk of shortages in staple food is highly recognized. Alarms are once more being sounded about the beginning of a long-term trend in which staple grain harvests, particularly of rice, are slackening and are failing to outpace demand in several countries (Hossain 1999). To many people, particularly in Asia, this spells trouble for several reasons:

- Dependence on rice for food energy continues to be high in Asia compared with other regions in the world (Fig. 1). On average, each person in the region eats from 87 to 214 kg of milled rice annually, which provides 30% to 76% of total calories consumed.
- Eight hundred million poor people live on less than one dollar a day in Asia. They subsist on rice. And so will many of the 50 million new people that will be added annually to the region's population, most of them from the low-income countries of South and Southeast Asia. Migration to urban areas in search of a livelihood additionally leads to various forms of poverty. As Dr. Muhammad Yunus said, "Poor people in Asia can live without many things in life but they cannot live without rice" (IRRI 2000).
- The days are long gone when resources were plentiful and accessible for increasing production. In Asia, the land frontier is shrinking, water is scarce, labor costs are high, and the response to extra doses of fertilizer is lower.
- The most intensively cultivated irrigated areas have reached their maximum production potential considering the genetics of current rice varieties and technologies. Stresses on natural resources and other environmental problems have made rice production systems more and more vulnerable.
- Unlike wheat and maize trade, rice trade remains a very small portion of total production. Rice is mostly consumed in the country where it is grown, and in much of Asia the production of sufficient income to alleviate poverty will require a heavy reliance on expanding domestic rice production.

Increasing the rice supply in the future faces problems for which the solutions are now more difficult to find. Considering the growth in population alone, there does not seem to be time to pause and relax. We need to look far enough ahead for good information to help us identify the knowledge and technology that will be required to achieve the noble mission of ensuring a food-secure world.

This paper aims to provide the information that will enable us to assess the world rice market in the years ahead. It presents the projection results produced by the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)

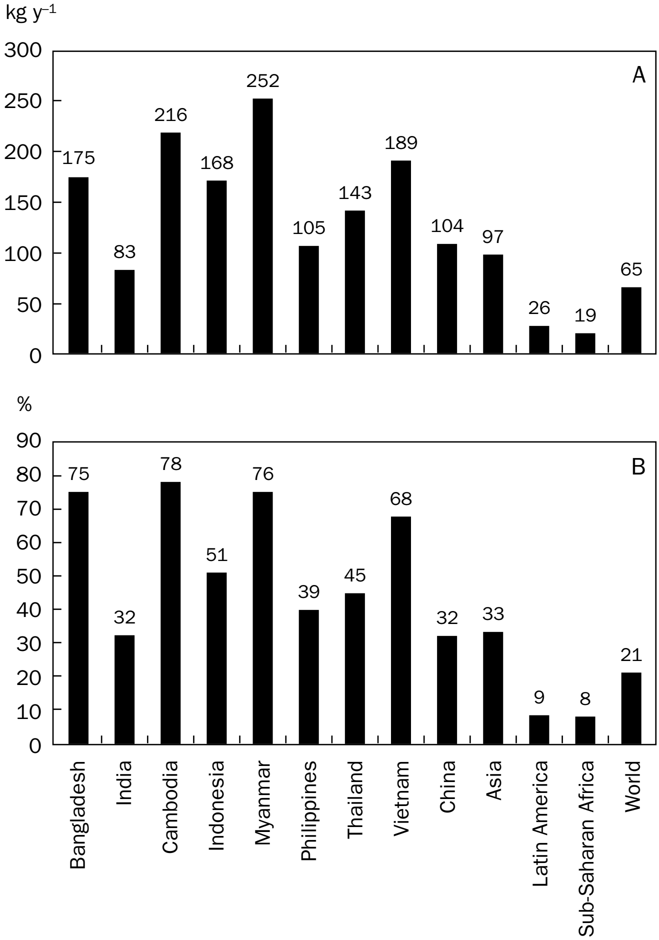

Fig. 1. Average per capita consumption (A) of rice and percent of rice in total calorie intake (B), 1991-99. Source: FAO Agrostat database.

on supply, demand, trade, and prices, primarily for rice, under various scenarios (Rosegrant et al 1995, 2001, Sombilla and Hossain 2001). It analyzes these results and determines their implications for the future strategy for research and investment. The paper starts with a brief description of the performance of the rice market in the past and then proceeds to discuss the development of the rice market in the future. It concludes with a section on policy choices and the challenge of ensuring further growth of the rice sector.

Rice supply and demand balances in Asia

Despite rapid population growth and widespread poverty, Asia has been able to increase the production of its staple food to alleviate what was once thought of as an impending food crisis. Over the last four decades, rice production in Asia as a whole increased rapidly to meet the growing demand for the commodity. The situation on the subregional level, however, differed.

Rice production

Asia's remarkable production performance in rice is indicated in Figure 2. Growth in production managed to keep pace with the growth in population. This was primarily the case in Southeast Asia, where countries such as Vietnam, Myanmar, and Indonesia exhibited rice production growth that significantly surpassed their growth in population. India and China showed a similar achievement. But, for the rest of Asia, the increasing deficits in rice were met with imports from neighboring countries.

A closer scrutiny of Figure 2, however, shows the leveling off of the production lines in the region as well as in the different subregions, especially in the last 10 to 15 years. The trend indicates a general slowdown in the growth of production that comes primarily from the significant decline in yield growth rates. As can be noted from Figure 2, area growth has remained almost constant over the period, implying that its contribution to production growth has been nil. In fact, in countries such as Japan and South Korea, rice area contracted as its use shifted for commercial and industrial purposes. A similar trend was exhibited in Lao PDR and Cambodia, not for the same reason, but because area development has been greatly affected by political instability and internal conflicts. Only in Indonesia and Vietnam did rice area expand at more than 1% per annum over the last 40 years. Yield, on the other hand, which grew at an average rate of about 2.1% per year over the same period, has accounted for almost 80% of production growth. The rise in yield was rapid at 2.25% per year from 1967 to 1984, which marked the peak of the Green Revolution technology (Table 1). The rates were substantially higher among the early adopters of the technology, particularly China, the Philippines, South Korea, Indonesia, and Myanmar. Yield growth deteriorated to 1.3% per year in the years that followed despite the strong yield performance exhibited by the late adopters of the technology, such as India, Bangladesh, Vietnam, and Lao PDR.

Many factors account for the slow growth of rice production since the 1980s. A key one has been the decline in the world rice price (Fig. 3). From 1970 to 2000, real world prices of rice declined by about 60% from US\$550 t^{-1} to \$201 t^{-1} (World Bank 2001). The decline in prices has caused a direct shift of land out of rice production into more profitable cropping alternatives (Hossain and Sombilla 1999, Moya et al 1994). Declining world prices have likewise reduced the use of inputs that helped improve yields. This pertains to fertilizer and to both labor and water, which face more intense competition from the nonagriculture sectors. Many young people are continuously drawn to the big cities where earnings are better. The rate of investment in irrigation infrastructure, as well as in crop research, has been drastically cut, which consequently affected yield growth (Rosegrant and Pingali 1994, Rosegrant and Svendsen 1993). Other factors are related to the exhaustion of the current technology and the increasing intensification of rice production. The yield potential of modern rice varieties has not increased significantly after the introduction of IR8 in 1966. The modern varieties developed later incorporated new traits such as resistance to insects and diseases, improved grain

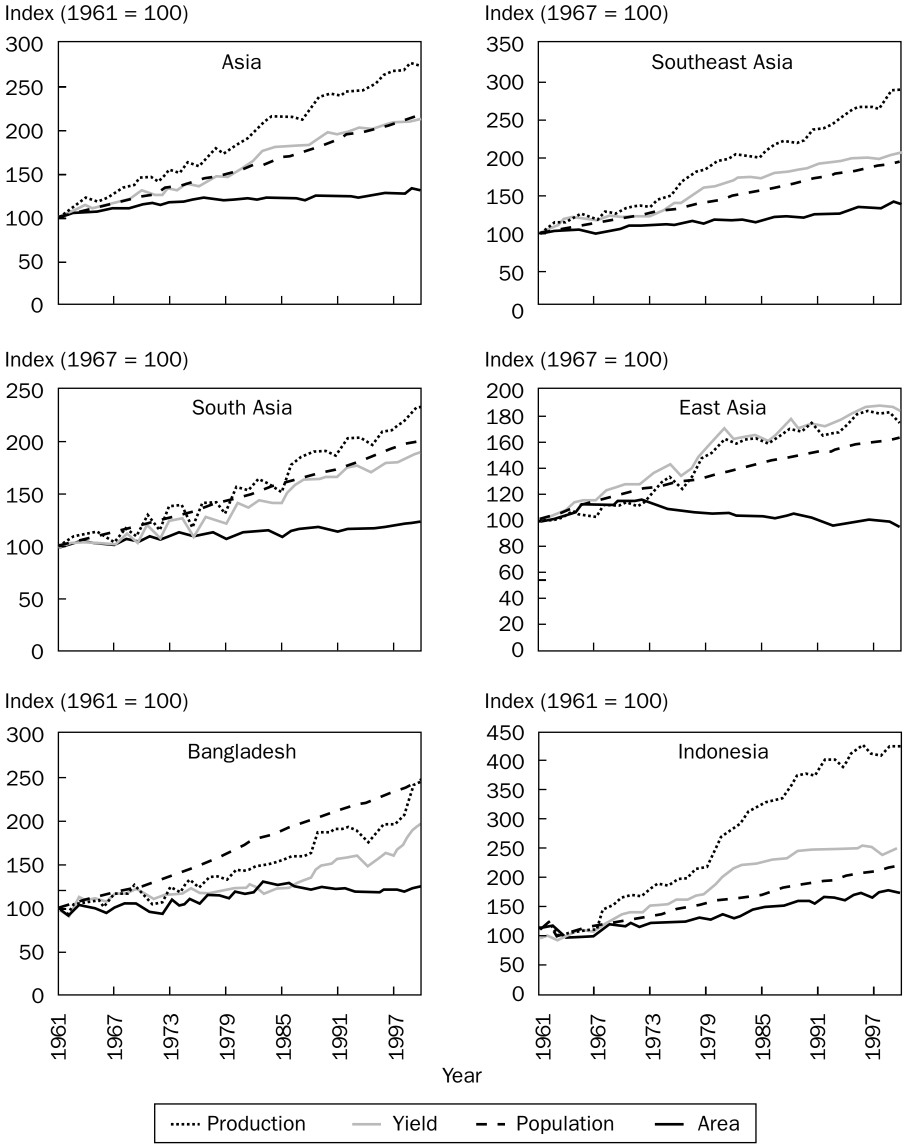

Fig. 2. Production vs population growth in Asia, 1961-2000. Source: FAO (online) 2001.

quality, and shorter crop maturity period, but did not shift the yield frontier (Khush 1995). With intensive monoculture of rice in irrigated land in Asia and with the heavy use of chemical fertilizers and pesticides, soil and water quality have deteriorated. Farmers now find it difficult to sustain high yields because the quick fixes derived from increasing input use are not very effective (Cassman and Pingali 1995).

Table 1. Past growth rates (%) in rice area, yield, and production, 1964-84 and 1984-2000.

Country/region	1964-84			1984-2000			1967-2000		
	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production
Cambodia	–3.7	–0.9	–4.6	2.5	3.0	5.5	–0.2	1.2	1.0
Indonesia	1.3	4.1	5.3	1.2	0.7	1.9	1.4	2.8	4.3
Lao PDR	–1.3	3.2	1.9	0.3	2.4	2.6	–0.6	3.5	2.9
Malaysia	0.6	1.5	2.2	0.5	1.3	1.8	0.4	1.0	1.3
Myanmar	–0.1	3.6	3.5	2.0	0.4	2.4	0.5	2.3	2.8
Philippines	0.3	3.5	3.8	1.1	0.9	2.0	0.4	2.7	3.0
Thailand	2.2	0.4	2.6	0.2	1.1	1.3	1.2	0.8	2.0
Vietnam	1.0	1.4	2.4	2.1	2.9	5.0	1.2	2.2	3.4
Southeast Asia	0.8	2.6	3.4	1.2	1.3	2.5	0.9	2.2	3.2
Bangladesh	0.5	1.4	1.8	0.0	2.5	2.4	0.3	1.8	2.1
India	0.7	1.9	2.6	0.6	2.0	2.6	0.6	2.1	2.7
Nepal	1.0	–0.3	0.7	0.7	1.6	2.2	0.9	0.7	1.6
Pakistan	2.2	2.6	4.9	1.4	1.6	3.0	1.6	1.6	3.3
Sri Lanka	2.7	1.8	4.5	0.0	0.6	0.6	1.3	1.6	3.0
South Asia	0.7	1.8	2.5	0.5	2.0	2.6	0.6	2.0	2.6
China	0.6	2.8	3.4	–0.5	1.3	0.8	0.1	2.6	2.7
Japan	–2.0	0.6	–1.4	–1.5	0.3	–1.2	–1.6	0.6	–1.1
Korea (South)	0.1	2.4	2.5	–1.4	0.3	–1.0	0.7	0.0	0.7
Korea (North)	2.0	0.8	2.8	–1.5	–3.6	–5.1	–0.2	1.4	1.2
East Asia	0.4	2.4	2.8	–0.6	1.1	0.6	0.0	2.3	2.2
Asia	0.7	2.2	2.9	0.4	1.2	1.7	0.5	2.1	2.6
World	0.8	2.1	2.9	0.5	1.3	1.7	0.6	2.0	2.6

Source: FAO (online) 2001.

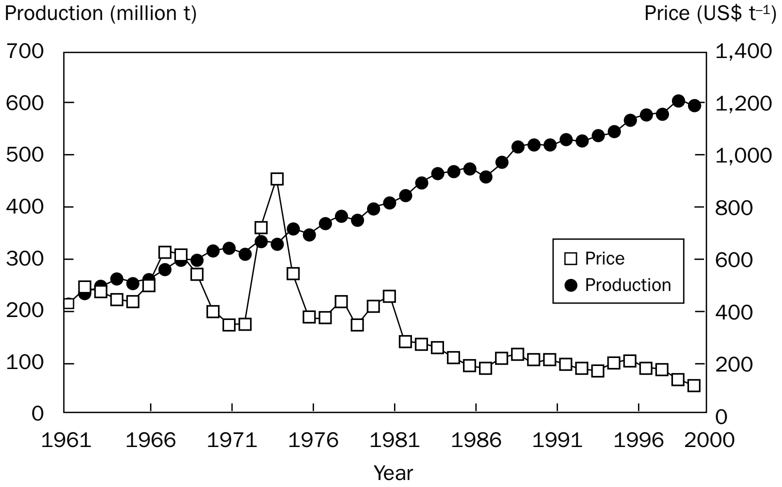

Fig. 3. Trends in world rice production and price, 1961-2000. Source: Production—FAOSTAT electronic database, 31 May 2001; rice price—relates to Thai rice 5%-broken deflated by G-5 MUV index deflator (World Bank Quarterly Review of Commodity Markets).

Asia continues to dominate rice production, accounting for 90% of total world production. China and India remain the largest rice producers with a combined average production of 220 million t in 1997-99 (Table 2). The combined rice production of Southeast Asian countries averaged 91.6 million t (or 138.8 million t in paddy equivalent), with Indonesia accounting for about 36% of the subregional production, Vietnam 21%, and Thailand 17%. Myanmar's production averaged about 11.3 million t and the Philippines 7.0 million t. The rest of South Asia contributed about 29.4 million t (or 44.2 million t in paddy equivalent) to total production, about 70% of which came from Bangladesh. Japan's average production during the period was 7.8 million t, whereas North and South Korea exhibited a combined production that averaged 6.1 million t.

Rice demand

Past trends in rice demand followed almost the same pattern as that in production, for which demand growth was relatively strong in the first subperiod but was followed by a slowing down in the second subperiod. The average rate of growth of rice demand dropped from 2.8% in 1967-84 to 1.7% in the years that followed. The reasons

Table 2. Rice production, demand, and net balances (in 000 tons), 1967-69 and 1997-99.

Country/region	1967-69			1997-99		
	Production	Demand	Net balances	Production	Demand	Net balances
Cambodia	1,826	1,358	468	2,439	2,401	38
Indonesia	10,762	11,293	–531	33,226	35,280	–2,054
Lao PDR	551	591	-40	1,209	1,100	109
Malaysia	940	1,296	–356	1,356	2,008	—652
Myanmar	5,286	4,322	964	11,278	11,228	50
Philippines	3,217	3,177	40	7,028	7,979	–951
Thailand	8,230	6,356	1,874	15,492	8,624	6,868
Vietnam	5,863	7,055	–1,192	19,579	15,271	4,308
Southeast Asia	36,675	35,448	1,227	91,607	83,891	7,716
Bangladesh	11,512	10,858	654	20,518	22,833	–2,315
India	39,287	37,048	2,239	85,990	80,024	5,966
Nepal	1,454	1,153	301	2,457	2,454	3
Pakistan	1,978	1,671	307	4,723	2,890	1,833
Sri Lanka	866	1,140	–274	1,732	1,905	–173
South Asia	55,097	444	54,653	115,420	110,126	5,294
China	65,021	63,704	1,317	134,233	132,403	1,830
Japan	12,398	10,596	1,802	7,826	8,652	–826
Korea (North)	1,386	1,406	–20	1,373	1,694	–321
Korea (South)	3,366	3,661	–295	4,749	4,662	87
East Asia	82,171	79,367	2,804	148,181	147,411	770
Asia	175,242	168,297	6,945	357,991	347,442	10,549
World	191,570	183,509	8,061	391,802	385,877	5,925

Source: FAO (online) 2001.

are apparent: a decline in growth in per capita demand (and an actual decline in per capita demand for some countries) for rice combined with a slowing down in population growth in many countries (Table 3). In the more affluent developing countries, the decline in per capita demand was mainly caused by greater diversification of diets as consumers shifted to high-quality and high-value food products such as meat, milk, vegetables, and fruits. For rice, the shift has been from the "ordinary" to the high-quality type. In the low-income economies, on the other hand, growth in per capita demand has been slow because of the inadequate growth in per capita income and the lack of foreign exchange earnings to purchase rice from other countries. But, with economic growth and reduced poverty, demand for rice is expected to escalate in the poorer countries of South, Southeast, and East Asia as the poor satisfy their so-far unmet needs for food.

Asia's rapid move toward urbanization has likewise put greater pressure on the growing rice supply and demand imbalances. Today, the continent is home to nine of the world's 14 megacities of more than 10 million people. In 1965, Asia had a rural population of 1.5 billion and an urban population of 430 million. Today, about one-third (or 1.2 billion) of the population is urban. One of the effects of urbanization is that rice demand per person should go down. It has been documented that, at the same

Table 3. Past trends in per capita demand and population growth.

Country/region	Average per capita demand (in kg per year)			Population growth (in %)	
	1967-69	1987-89	1997-99	1961-70	1990-2000
Cambodia	162.9	157.7	163.7	2.6	2.6
Indonesia	89.5	143.3	151.0	2.3	1.5
Lao PDR	187.5	171.2	171.5	2.2	2.7
Malaysia	118.5	81.0	89.5	2.9	2.2
Myanmar	148.4	204.1	210.9	2.2	1.2
Philippines	82.1	95.2	97.6	3.2	2.3
Thailand	145.5	124.2	104.1	3.1	1.0
Vietnam	153.3	150.1	169.6	2.1	1.8
Southeast Asia	131.3	160.2	168.1	2.5	1.6
Bangladesh	154.3	146.9	161.1	2.6	1.7
India	63.0	73.6	75.8	2.3	1.8
Nepal	82.1	106.4	95.7	2.0	2.5
Pakistan	25.7	18.1	15.7	2.8	2.8
Sri Lanka	90.4	97.1	93.2	2.4	1.0
South Asia	76.2	81.8	84.8	2.4	1.9
China	71.3	92.7	91.3	2.5	1.0
Japan	95.1	65.5	60.4	1.0	0.3
Korea (North)	92.1	83.6	71.0	3.1	1.6
Korea (South)	111.3	112.9	94.5	2.4	0.9
East Asia	84.6	101.4	101.1	2.2	0.9
Asia	75.3	87.8	86.4	2.4	1.5
World	46.0	56.7	57.8	2.1	1.4

Source: FAO (online) 2001.

income level, city people in Bangladesh and Thailand eat less rice than their rural relatives, primarily because city workers have less physically taxing work (IRRI 2000). These extra mouths, however, do not grow their own food. Feeding them becomes an additional burden to the farmers that remain to till the lands for the staple food.

The total domestic use of rice in Asia averaged 347.4 million t (519 million t in paddy equivalent) in 1997-99 (Table 2). This is about twice the 1967-69 total use of about 168.3 million t. The domestic use of rice is virtually all for direct food consumption. Only about 4% is saved by farmers for seed use and minimal percentages go for processed products and animal feed.

Rice balances and trade

Table 2 also shows rice production and demand balances for the various countries in Asia; as can be noted, Asia gradually increased its net rice surplus over the years. Table 4 shows Asia drastically reducing its share of rice imports from 63% in the late 1960s to only about 24% in the late 1980s. This is primarily because several countries, especially in East and Southeast Asia, transformed themselves from import dependence to self-sufficiency, in significant part because of the Green Revolution technology that boosted rice production. Asia's share in world imports rose slightly again to 35% in the latter part of the 1990s because of the increased demand from Bangladesh, Indonesia, and the Philippines, where production became sluggish because of the combined effect of bad weather, financial difficulties, and slowing technology-led growth. Whether import demand in the region further strengthens or not will largely depend on the movement of world rice prices and the capacity of various governments to adopt appropriate policies to revitalize domestic production along the principles of comparative advantage and liberalized markets.

Thailand has maintained its reputation as a consistent and reliable net export market for rice (Table 4). Thailand's rice exports have more than quadrupled over the last four decades. It regained its position as the largest rice exporter in the mid-1970s as U.S. rice exports rose only slightly because of uncompetitive prices. Pakistan has likewise managed to maintain its rice exports, which expanded most rapidly from the mid-1970s to reach their current average of 1.8 million t. Myanmar's exports, on the other hand, declined, especially from the mid-1980s, as the hope for reforms to strengthen its market dimmed. Average exports in 1997-99 dropped to less than 100,000 t.

Vietnam and India recently became significant players in the export market by taking advantage of the recent strong international demand for the commodity by their neighboring countries. Vietnam's exports rose from about 50,000 t in the early 1980s to an average of about 4.0 million t in 1997-99. It overtook the U.S. as the world's second largest rice exporter in 1996. Low production costs and improvements in rice milling and handling enabled Vietnam to capture a growing share of the export market. India's exports similarly shot up to an average of about 3.3 million t in 1997-99 after being a net importer a decade earlier. This is due to the combined effect of favorable weather, government efforts to liberalize the market, and private investment in the milling industry. India reached a record high export of about 4.2 million t and then dropped to 3.3 million t in 1997-99.

Table 4. Average imports and exports (000 tons) of rice in Asia, 1967-69 to 1997-99.

Country/region	1967-69	1977-79	1987-89	1997-99
Rice imports				
Bangladesh	329	153	333	1,169
India	788	50	442	41
Nepal	0	0	20	18
Sri Lanka	320	306	173	222
South Asia	1,440	518	977	1,469
Indonesia	492	1,962	144	2,670
Malaysia	344	321	299	680
Philippines	104	11	108	1,360
Vietnam	1,201	172	189	2
Southeast Asia	2,222	2,683	844	4,810
China	399	465	1,117	669
Japan	261	40	18	529
Korea (North)	0	13	29	358
Korea (South)	302	86	1	67
East Asia	962	604	1,165	1,623
Asia	4,624	3,805	2,986	7,902
% share in world	63	37	24	35
World	7,331	10,324	12,283	22,852
Rice exports				
Thailand	1,208	2,505	5,464	6,445
Pakistan	308	913	1,107	1,836
USA	1,699	2,147	2,434	2,824
India	8	164	388	3,315
Vietnam	9	48	533	4,000
Myanmar	485	539	175	70
China	1,658	1,438	849	2,551
Cambodia	174	0	0	2
Asia	4,369	6,355	8,973	18,535
World	7,587	10,501	13,487	25,862

Source: FAO (online) 2001.

The Asian rice economy to 2025

What is the long-term market outlook for rice in Asia? The past remarkable growth in rice production and decline in prices contributed to improving malnutrition status by empowering the rural landless and urban laboring class to acquire more food from the market. However, food insecurity and poverty are still widespread in many low-income economies. In the more recent years, we witnessed a deceleration in the growth of production and demand. Will these trends continue? Will Asia be able to fill its rice bowl as it has done in the past? To answer these questions, different scenarios are simulated using IMPACT and the results are presented and analyzed in this section.

The baseline scenario

The baseline scenario described here gives the best estimates of the most likely world food situation in 2025 if governments make no major changes in their agricultural and economic policies and investments and if population grows at the rate given in the United Nations' medium projections. The focus here is rice. Figure 4 shows that, under the baseline scenario, Asia's rice production will still be able to increase at a rate to meet demand for the commodity and world prices will continue to go down, but at a slower rate. As in the past, countries that experienced production shortfalls will continue to do so.

Rice production. Rice production in Asia is projected to grow at 1% per year from 1997 to 2025 to reach about 450.5 million t in milled rice equivalent (Table 5). This is about 0.6% less than the rate achieved in 1991-2000 and not even half the rate achieved from 1967 to 2000 (Table 6). It can also be noted from Table 6 that South Asia is projected to grow slightly faster than Southeast Asia.

South Asia overtakes East Asia in the projected contribution to the total regional rice production. This is from the combined effect of area expansion and a smaller reduction in yield growth as will be discussed later. China's contribution to the projected regional total will be down to 33% from 39% in the base year. Southeast Asia's share will also be up slightly because of the rapid production expansion in Vietnam, Myanmar, and other Southeast Asian countries, primarily Cambodia, which more than offsets the smaller contribution of Indonesia and Thailand. For the rest of East Asia, production declines will be witnessed in both Japan and South Korea.

The contribution of area will be low or even negative in some countries. This is expected as nearly 80% of potentially arable land in Asia is already under cultivation. Land for cultivation is scarce in many parts of the region, including China. South Asian countries are projected to cultivate about 2 million hectares more to rice. Most of this will be contributed by India (1.6 million ha). Southeast Asia will increase its area by about 1.5 million ha, about 50% of which will come from Myanmar. The projected area expansion in South and Southeast Asia, however, will be offset by East Asia, where area is projected to decrease by about 3 million ha. This will take place

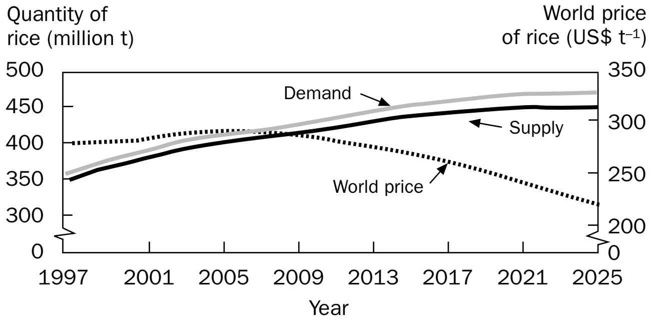

Fig. 4. Projected rice production and demand in Asia under the baseline scenarios. Source: IMPACT projections.

Table 5. Projected net balances in rice (in 000 tons) under the baseline scenario.

Country/region	1997			2025		
	Production	Demand	Net trade	Production	Demand	Net trade
India	83,498	82,509	2,552	124,666	124,112	554
Pakistan	4,439	2,669	1,627	6,836	5,164	1,672
Bangladesh	18,816	18,559	–843	27,213	27,581	–368
Other South Asia	4,249	4,649	–404	7,094	8,584	–1,490
South Asia (excluding India)	27,504	25,877	379	41,143	41,329	–186
South Asia	111,003	108,386	2,931	165,809	165,441	368
Indonesia	33,287	34,891	–1,604	44,840	47,834	–2,994
Thailand	15,273	8,682	5,478	17,971	9,260	8,711
Malaysia	1,397	1,989	–710	1,737	2,854	–1,117
Philippines	7,290	7,831	–1,394	10,699	11,171	–471
Vietnam	18,468	14,778	3,333	29,497	21,701	7,796
Myanmar	11,597	11,209	90	19,444	16,492	2,952
Other Southeast Asia	3,349	3,068	–82	6,530	5,363	1,167
Southeast Asia	90,660	82,448	5,111	130,718	114,674	16,044
China	133,484	132,638	821	148,598	148,784	–186
Japan	8,151	8,788	–376	6,410	7,810	–1,399
South Korea	4,716	4,604	–62	4,005	3,856	149
Other East Asia	1,169	1,482	–353	1,347	1,305	42
East Asia (excluding Japan)	139,370	138,724	406	153,950	153,945	5
Asia	341,033	329,558	8,449	450,477	434,060	16,417
World	384,078	380,827	0	516,312	516,312	0

Source: IMPACT projections.

mostly in China. Part of the area lost will be devoted to cultivating crops that will be more profitable than rice. The rest will most likely be converted for commercial and industrial uses.

Although growth in yield will account for most of the production growth, this will be much lower than the yield growth achieved in the past. The same forces, namely, increased intensity of land use, high input use, poorly functioning markets, and reduced rate of public investment in irrigation and research, push yield growth rates further down. Yield growth in East Asia will be around only 0.76% per annum. Most of the countries here, such as Japan and South Korea, have experienced yield stagnation since the mid-1980s. China has also leveled off, starting in the 1990s. Its projected rate of yield growth is only 0.38%. The projected yield growth in South and Southeast Asia is almost half the respective average growth rates in the past. As the impact of the current technology becomes exhausted, yield increases in these countries will be smaller.

China and South Korea are each projected to attain an average yield of about 5.1 t ha^{-1}, which will surpass that projected for Japan. The rest of the countries will have yields that will range from 1.9 t ha^{-1} in Thailand to 3.9 t ha^{-1} in Indonesia. All the projected yields will still be much lower than the maximum theoretical yields calculated by Linneman et al (1979).

Rice demand. Rice demand in the region is projected to increase at 1% per year, which is the same rate as that projected for production (Table 7). This rate is slower than the historic rate because population growth rates are slowing and income elasticities of demand for rice are gradually declining in many countries. The amount of additional rice needed to meet effective demand by 2025 is about a third smaller than the increase during the previous 32 years (1967-99). Rice demand in the region is projected to increase by 32% (104.5 million t), with most of it channeled for food use (Table 5). Rice for feed use will remain an insignificant 3% of total demand.

South Asia is projected to have the strongest demand growth, resulting in a total demand increase of about 54%. India will still account for most of the increase because of its huge population, although its rate of growth will be the slowest among the South Asian countries. South Asia's projected share in total Asian demand will rise by 5% from 33% in 1997 to 38% in 2025. In Southeast Asia, total demand will increase by 39% at a projected average growth rate of 1.19% per year. Indonesia will account for 40% of the increase, followed by Vietnam (22%), Myanmar (15%), the Philip-

Table 6. Past and projected rice area, yield, and production growth rates (%) in Asia under the baseline scenario.

Country/region	1967-2000			1997-2025		
	Area	Yield	Production	Area	Yield	Production
India	0.60	2.11	2.70	0.13	1.31	1.44
Pakistan	1.63	1.61	3.25	0.11	1.44	1.55
Bangladesh	0.34	1.77	2.11	0.06	1.26	1.33
Other South Asia	1.03	1.06	2.09	0.18	1.67	1.85
South Asia (excluding India)	0.61	1.63	2.24	0.09	1.36	1.45
South Asia	0.60	1.98	2.58	0.12	1.32	1.44
Indonesia	1.39	2.81	4.19	0.12	0.95	1.07
Thailand	1.22	0.81	2.02	–0.08	0.66	0.58
Malaysia	0.36	0.98	1.34	–0.32	1.10	0.78
Philippines	0.36	2.63	2.99	0.19	1.19	1.38
Vietnam	1.21	2.17	3.37	0.18	1.50	1.69
Myanmar	0.48	2.28	2.75	0.43	1.43	1.86
Other Southeast Asia	–0.33	1.83	1.50	0.20	2.21	2.41
Southeast Asia	0.93	2.19	3.12	0.13	1.18	1.32
China	0.08	2.61	2.68	–0.39	0.78	0.38
Japan	–1.62	0.56	–1.06	–0.99	0.14	–0.85
Korea (South)	–0.21	1.40	1.19	–1.04	0.46	–0.58
Other East Asia	0.70	0.03	0.73	–0.14	0.64	0.51
East Asia (excluding Japan)	0.08	2.51	2.59	–0.40	0.76	0.36
Asia	0.51	2.03	2.54	0.00	1.00	1.00
World	0.59	1.96	2.55	0.06	1.00	1.06

Sources: FAO (online) 2001 and IMPACT projections.

Table 7. Past and projected growth (%) in demand for rice under the baseline scenario.

Country/region	Past growth rate 1967-2000		Projected growth rate 1997-2025	
	Per capita	Total	Per capita	Total
India	0.64	2.71	0.31	1.47
Pakistan	–1.67	1.29	0.21	2.39
Bangladesh	0.30	2.59	0.07	1.43
Other South Asia	0.17	2.17	0.21	2.21
South Asia (excluding India)	–0.16	2.39	–0.16	1.69
South Asia	0.45	2.63	0.17	1.52
Indonesia	1.80	3.76	0.07	1.13
Thailand	–1.22	0.72	–0.47	0.23
Malaysia	–1.45	1.02	–0.11	1.30
Philippines	0.51	2.89	–0.22	1.28
Vietnam	0.46	2.62	0.12	1.38
Myanmar	1.49	3.32	0.38	1.39
Other Southeast Asia	0.32	2.09	0.33	2.02
Southeast Asia	0.78	2.83	0.03	1.19
China	0.82	2.33	–0.21	0.41
Japan	–1.55	–0.85	–0.28	–0.42
Korea (South)	–0.95	0.39	–1.13	–0.63
Other East Asia	–0.36	1.38	–1.37	–0.45
East Asia (excluding Japan)	0.72	2.24	–0.25	0.37
Asia	0.46	2.39	–0.03	0.99
World	0.76	2.46	0.03	1.09

Source: FAO (online) 2001 and IMPACT projections.

pines (10%), and the other Southeast Asian countries (8%). The projected demand share of East Asia in total regional demand will be only 36% compared with 42% in the base year. Demand will actually contract in Japan and South Korea and slow down in China at the rate of 0.41%.

Per capita food demand for rice in Asia will stay relatively constant, decreasing slightly to 105.2 kg per capita in 2025 from 106.3 kg per capita in 1997 (Table 8). As mentioned in earlier sections, much of this decline comes from shifts in consumption to other staple foods such as wheat (e.g., bread) and other processed products (e.g., French fries, etc.) because of growing incomes and rapid urbanization. The baseline scenario assumes income growth rates across countries in Asia ranging from 3.5% to 6.0%. At these rates of growth, a large portion of the population will indeed reach threshold income levels during the projection years at which staple grains are replaced by other high-value food. Moreover, in most of Asia, the urban population's share of total population is expected to double by 2025. As depicted in Table 8, countries in South Asia are shown to increase per capita demand for rice from 84 to 88 kg per capita per year or at an average of 0.2% per year from 1997 to 2025. In Southeast

Table 8. Projected per capita demand (kg per year) for rice under various scenarios.

		2025					
Country/region	1997	Base-line	Low population growth	Low income growth	Low yield growth	High yield growth	Trade liberal-ization
India	85.9	93.7	96.4	90.9	87.8	101.0	92.7
Pakistan	18.5	19.6	20.3	19.2	18.1	21.6	19.5
Bangladesh	151.6	154.6	157.7	154.0	146.3	165.0	156.3
Other South Asia	75.1	79.6	84.4	79.3	67.5	95.7	80.4
South Asia (excluding India)	78.8	75.3	76.9	74.7	69.4	82.7	75.9
South Asia	84.1	88.3	90.6	86.2	82.4	95.7	87.8
Indonesia	171.7	174.9	178.1	173.2	166.8	185.1	173.1
Thailand	146.4	128.2	129.6	134.7	121.9	136.0	125.4
Malaysia	95.1	92.2	94.8	94.0	84.4	101.7	97.5
Philippines	110.7	104.0	107.0	108.2	94.0	116.5	104.9
Vietnam	194.1	201.0	203.5	198.1	196.4	207.4	202.6
Myanmar	242.5	270.0	277.4	259.5	255.9	286.7	270.3
Other Southeast Asia	193.3	211.7	221.4	204.8	189.5	239.1	213.8
Southeast Asia	167.4	169.0	172.2	168.1	160.3	179.9	168.8
China	106.2	100.1	102.3	102.1	94.4	107.6	99.6
Japan	70.0	64.7	66.2	64.1	59.5	71.2	67.7
Korea (South)	100.9	73.4	73.8	82.0	69.6	78.3	79.0
Other East Asia	57.4	39.0	35.1	44.9	48.0	31.3	38.5
East Asia (excluding Japan)	105.1	97.9	99.9	100.3	92.6	105.0	97.6
Asia	106.3	105.2	107.4	105.0	99.1	113.1	104.9
World	65.8	66.4	68.0	66.2	61.9	72.3	66.3

Source: IMPACT projections.

Asia, the rise in per capita demand in Myanmar and Vietnam will be offset by the decline in Malaysia, Thailand, and even the Philippines. All countries in East Asia except North Korea are expected to exhibit declining per capita demand for rice.

Rice balances. The projected trends in rice production and demand allow Asia to increase its exportable supplies further from 8.4 million t in 1997 to 16.4 million t in 2025 (Table 5). Much of this increase will still come from Southeast Asia. Thailand will still be able to raise its exports by about 3 million t. But this will not come from increased production but from a more rapid decline in demand because of the combined effect of slower population growth and a gradual shift by consumers from rice to other staple foods. Thailand will most likely continue to cater to the demand of countries such as Iran, Nigeria, and even the U.S. and thus strengthen its niche in the high-quality market.

Exportable surpluses in Vietnam will reach 7.8 million t in 2025 unless the government strictly imposes a policy to shift land use out of rice to improve farmers' incomes (Hoanh et al, this volume). Vietnam's production for exports under the baseline scenario, however, will extend far beyond its Asian neighbors to cater to the import demand of countries in other regions. A significant contribution to the projected increase in Asia's exportable surplus comes from Myanmar and Cambodia. The continued achievement of political stability in these countries will be accompanied by reforms that will provide a great boost to domestic production that will more than outstrip the growth in demand. Rice exports will increase from the current trickle to a significant tonnage.

South Asia's exports will drop drastically from 2.9 million t in 1997 to less than 400,000 t in 2025. Exports from Pakistan will be maintained as efforts to further increase production will be hampered by problems in salinity and waterlogging in the main cereal production areas, including those for rice, thereby greatly limiting crop yield growth. India will return to being a marginal net exporter or importer mainly because of slowing rice productivity growth and continued growth in per capita demand. Domestic production will have to fully meet domestic demand as the Indian government strengthens its drive to improve the food security status of its population. The domestic supply and demand gap in the other South Asian countries are expected to widen and their demand for imports to increase.

China will continue to be a small player in the international world rice market as it grapples to balance the impact of its price and market reforms associated with its entry in the World Trade Organization (WTO) (Huang et al, this volume). Japan's imports will more than triple as it continues to open its market in compliance with the prescription of the General Agreement on Tariffs and Trade (GATT) for trade liberalization. The other East Asian countries will also just be marginal net importers or exporters and their position will largely depend on their market policies and on the performance of their domestic production.

The alternative scenarios

Five alternative scenarios are examined here: a low Asian population growth scenario, a low Asian income growth scenario, a trade liberalization scenario, and low and high yield growth scenarios resulting from the development of new technology options. The following sections explore how changes in the fundamental assumptions affect rice supply and demand prospects.

Low population growth scenario. The low population growth scenario uses the low population growth variant projected by the United Nations (UN 1999). Under this scenario, population in Asia will increase at 0.7% annually, which is 0.3% lower than the baseline assumption. Asian population in 2025 will be 3.8 billion, which is 3.0 million people less than projected under the baseline. This scenario will result in much lower price levels because of a general reduction in the demand for rice (Fig. 5). Rice demand will be as much as 5% lower than the baseline result and production will be 4% lower (Table 9, Fig. 6). Reduction in total demand comes from two sources—the smaller number of people and shifts in per capita consumption to high-value products such as wheat in the form of bread and other processed products, especially in the richer countries of the region. The latter is caused by the increasing effective per capita income that improves purchasing power. Per capita demand for

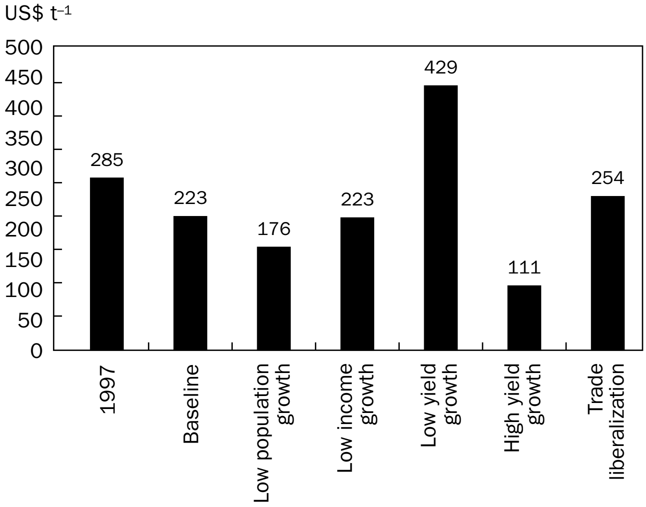

Fig. 5. Projected world prices of rice under various scenarios. Source: IMPACT projections.

rice will be slightly higher in all countries compared to the baseline. But these changes are modest to offset the effect of slow population growth rates.

Production declines compared to the baseline in East Asia will be around 8 million t, in South Asia around 7 million t, and in Southeast Asia around 5 million t. The declines are primarily because of the relatively low projected world prices.[1] The production declines will be small in Myanmar, Vietnam, and India, however. The additional excess supply that these countries will provide will be channeled mostly to sub-Saharan Africa, Latin America, and West Asia. Rice trade, the bigger portion of which would probably be the lower quality rice, will increase to 19.5 million t, which are about 3.1 million t more than that projected in the baseline scenario (Table 9, Fig. 7). Thailand and Pakistan, which cater primarily to the high-quality and higher-priced rice market, will have lower production and hence lower rice exports compared to the baseline. All East Asian countries are projected to increase their dependence on rice imports.

Low income growth scenario. The baseline projected steady expansion in rice production, although at a much slower pace, which depends on several assumptions, one of which is the stable growth in the economy that ensures the sustained support to the agricultural sector through further development of infrastructure and maintenance

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[1] The impact of population changes on production growth and crop yields is not as straightforward as in demand. Several studies indicate that the impact is mixed (Brown and Kane 1994, Ehrlich et al 1993, Ruttan 1994, Simon 1981, Pritchett 1996). The low population growth scenario here assumes no second-order effects on aggregate income and crop yield other than those through the movement of international prices.

Table 9. 2025 production, demand, and trade (in 000 tons): comparing the baseline and the alternative scenarios.

Country/region	Baseline			Low population growth			Low income growth	
	Production	Demand	Net trade	Production	Demand	Net trade	Production	Demand
India	124,709	124,084	625	119,531	116,859	2,672	123,579	120,325
Pakistan	6,839	5,162	1,676	6,533	5,003	1,530	6,756	5,048
Bangladesh	27,224	27,575	–352	26,007	25,755	252	26,765	27,451
Other South Asia	7,097	8,579	–1,482	6,754	8,513	–1,759	7,026	8,542
South Asia (excluding India)	41,159	41,317	–158	39,294	39,272	23	40,546	41,041
South Asia	165,868	165,401	467	158,825	156,131	2,694	164,125	161,366
Indonesia	44,854	47,8252	–2,970	43,111	44,115	–1,004	44,745	47,369
Thailand	17,976	9,261	8,715	17,305	8,768	8,537	18,079	9,731
Malaysia	1,737	2,853	–1,115	1,675	2,697	–1,022	1,735	2,909
Philippines	10,703	11,167	–464	10,283	10,645	–363	10,688	11,622
Vietnam	29,508	21,733	7,775	28,141	19,766	8,374	29,187	21,416
Myanmar	19,450	16,477	2,974	18,640	15,470	3,170	18,946	15,839
Other Southeast Asia	6,532	5,359	1,174	6,249	5,236	1,013	6,369	5,183
Southeast Asia	130,762	114,674	16,087	125,404	106,698	18,706	129,749	114,070
China	148,663	149,058	–395	141,039	143,309	–2,270	149,344	152,167
Japan	6,415	7,807	–1,392	5,915	7,683	–1,768	6,423	7,740
Korea (South)	4,007	3,854	153	3,807	3,670	138	4,006	4,300
Other East Asia	1,348	1,304	44	1,291	1,109	182	1,348	1,502
East Asia (excluding Japan)	154,018	154,215	–197	146,137	148,087	–1,950	154,698	157,970
Asia	450,648	434,290	16,358	430,366	410,915	19,450	448,572	433,406
World	516,514	516,514	0	492,451	492,451	0	515,035	515,035

Source: IMPACT projections.

of other productivity-enhancing activities. Many observers, however, believe that this assumption is not tenable in a long-run scenario. In this section, GDP growth is assumed to slow down at rates that are a third smaller than the income growth figures used for the baseline. This slowdown affects agricultural performance as the necessary amenities to induce or sustain productivity growth are curtailed. Contrary to speculation, however, the scenario does not create havoc in the global rice market as prices will continue a downward trend to levels similar to those projected in the baseline (Fig. 5). This indicates the considerable flexibility in the global supply response of rice as occurred in the 1997-98 Asian financial crisis. The projected price movement, however, results from a different kind of link among the factors influencing both consumption and production of the commodity. Demand is expected to be lower by about 884,000 t (compared with that projected in the baseline) because of reduced per capita income. The biggest demand reduction will take place in South Asia (Tables 8 and 9). On the other hand, East Asian countries are projected to expand their demand, especially China.

Production will decrease by about 2.1 million t compared to the baseline, mostly because of slower growth in yield (Table 9). This reduction would probably have been larger if not for the additional cultivation of 923,000 ha of land that helped to

	Low yield growth			High yield growth			Trade liberalization		
Net trade	Production	Demand	Net trade	Production	Demand	Net trade	Production	Demand	Net trade
3,254	98,962	116,209	–17,247	155,192	133,768	21,424	124,175	122,765	1,411
1,708	6,523	4,754	1,769	7,062	5,669	1,394	6,912	5,131	1,781
-686	26,082	26,088	–6	29,774	29,427	346	26,971	27,885	–914
–1,516	6,738	7,277	–538	7,751	10,318	–2,567	7,178	8,670	–1,493
–495	39,344	38,118	1,225	44,588	45,414	–827	41,061	41,686	–625
2,759	138,305	154,327	–16,022	199,780	179,182	20,597	165,236	164,450	786
–2,624	43,187	45,611	–2,424	50,041	50,621	–580	45,561	47,356	–1,796
8,348	18,303	8,803	9,500	17,971	9,819	8,151	18,124	9,057	9,067
–1,174	1,865	2,613	–749	1,904	3,148	–1,244	1,662	3,017	–1,355
-934	10,219	10,098	122	12,081	12,517	–436	10,580	11,269	–689
7,771	27,609	21,209	6,400	32,864	22,390	10,473	28,880	21,874	7,006
3,107	18,614	15,632	2,983	20,444	17,513	2,932	19,265	16,514	2,751
1,186	5,754	4,801	953	7,308	6,058	1,250	6,460	5,417	1,043
15,679	125,552	108,767	16,785	142,613	122,066	20,546	130,531	114,504	16,026
–2,823	148,837	140,325	8,512	147,715	160,030	–12,315	150,449	148,092	2,357
–1,317	7,798	7,181	616	5,092	8,594	–3,501	5,382	8,173	–2,791
–295	4,421	3,653	769	3,631	4,113	–482	3,559	4,146	–587
–154	1,404	1,606	–202	1,424	1,047	378	1,334	1,289	44
–3,272	154,662	145,584	9,078	152,771	165,189	–12,419	155,342	153,528	1,814
15,166	418,519	408,679	9,841	495,163	466,438	28,725	451,109	432,483	18,626
0	481,003	481,003	0	561,902	561,902	0	515,300	515,300	0

boost production. Seventy-eight percent of this additional land will come from China and India and hence their projected huge increases in production. Area expansion in Southeast Asia will be only 143,000 ha. In this subregion, almost all the suitable land is already under cultivation and cities are encroaching on prime agricultural lands. Area expansion will not take place in Myanmar either, even though it has the most abundant land resources among all Southeast Asian countries because of financial setbacks. Rice trade will decrease by about 1.2 million t as Asian countries will have to first meet the demand of their domestic consumers (Fig. 7).

The low and high yield scenarios. As already described, rice yields have been growing ever more slowly around the world. Yield gains in rice in the past have come mainly from the gradual adoption of modern varieties as both the public and private sector made investments to expand irrigated areas. It has been observed that the current technology is approaching its physical limitations. Work is in progress to develop new plant types that possess multiple characteristics including more grain load per panicle, resistance to insects and diseases, a shorter maturity period, and improved grain quality (Khush 1995). It may take some time for these varieties to reach farmers, though. Another technology that is within the reach of farmers is hybrid rice for

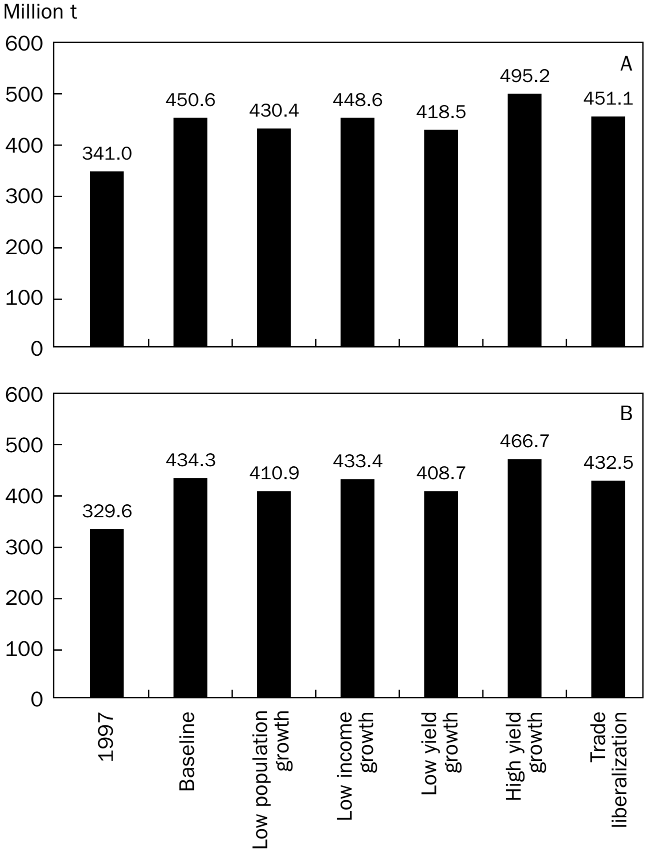

Fig. 6. Projected rice production (A) and demand (B) in Asia under different scenarios.

the tropics (Virmani 1994). The rapid expansion of hybrid rice among small farmers is constrained by the development of the infrastructure for seed production and distribution as farmers need to change seeds every planting season, which is an unconventional practice. The potential for raising yields in the rainfed ecosystem is still vast as the current yield is only 2.0 t ha^{-1}. In nearly 45% of the land in Asia, rice is grown under rainfed conditions. This ecosystem is the dominant one in the low-income countries of the region, where demand for rice is projected to remain strong. If rice science succeeds in developing appropriate technologies, this ecosystem could be the major contributor to the future growth in rice production. But what if work in all these new areas declines dramatically because the attention of governments, international organizations, and private firms is focused somewhere else?

The low-yield scenario assumes that new technologies will not be produced and that irrigation does not grow. The combined effect is that yield growth rates of all commodities decrease by 50% in developed countries including Japan and by 40% in

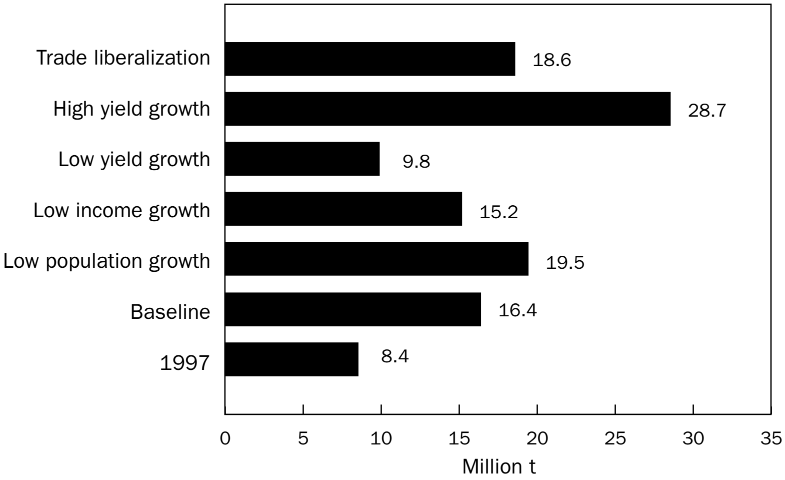

Fig. 7. Projected net trade in rice under various scenarios.

developing countries including most of Asia.[2] With slower growth in yield, the rice price in 2025 will rise to a level that is almost double that projected under the baseline (this is a huge increase compared with the projected price increases in maize and wheat, which are about 54%). Rice prices are particularly sensitive to slower yield growth because of the high proportion of rice produced in the developing regions that are particularly affected in this scenario. The rice production decrease in Asia will be as much as 32.1 million t, most of which will be in South Asia. Area expansion is not expected as irrigation development is halted. In fact, cultivated rice area will shrink slightly. A major reduction in area will take place in India, most likely in the technologically progressive states of Andhra Pradesh and Punjab, where profitability of rice production is prone to price fluctuation because of the excessive use of tradable material inputs (Bagchi and Hossain, this volume). Area expansion in eastern India, where the comparative advantage in rice production is relatively high, is not expected to take place either because of the curtailed investments in both area and technology development. Area will expand significantly in China, from which a huge excess supply will come. Southeast Asian countries are also expected to increase rice area, primarily in Vietnam and Myanmar, which will cushion the adverse effect of the projected yield decline.

Demand reduction under this scenario will be smaller than that of production and will be 25.6 million t. But this decline will again take place in the countries that are most vulnerable to food insecurity as they will be forced to reduce per capita demand

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[2] Changes in investment policy have been applied to the agricultural sector as a whole and thus affect the yield growth assumption of all commodities. Discussion here focuses only on rice.

because of price increases induced by slowing production. Regional rice exports will be only about 9.8 million t, about 7 million t less than the baseline as production will almost all be consumed locally.

The high-yield growth scenario, however, presents an entirely opposite picture. In this scenario, more initiatives for developing new and appropriate technologies and management practices as well as investments in facilities and services to further enhance productivity will be pursued. Crop yield growth is therefore assumed to increase by 20% in the developed countries and by 40% in the developing world compared with its respective rates assumed in the baseline. The projection results show the world price declining to a level that is lower than that achieved in the baseline as exports rise to about 28.7 million t. Production and demand will both increase, resulting in the achievement of a relatively higher per capita demand in all countries. Production will expand despite the projected lower prices since farmers will increase their profits from larger yield gains.

Trade liberalization scenario. Most governments have been unwilling to turn food production over to the forces of the free market. This resistance is particularly strong for rice. Market intervention has come in different forms—import quotas, price supports, input subsidies, etc. Total elimination of these intervention measures has been a major thrust of recent trade negotiations. In this scenario, the wedges between international and domestic prices in the form of producer and consumer subsidy equivalents are removed, with the elimination of these wedges phased in from 2005 to 2006. Special caution is warranted in interpreting the results for this scenario because IMPACT is a partial equilibrium model that does not account for the cross-sectoral linkages that would undoubtedly accompany widespread trade liberalization. A general equilibrium model best assesses such linkages (see, for example, Diao et al 2001). Nevertheless, the direction and relative magnitude of the changes that result from implementation of the full trade liberalization scenario are instructive in assessing the importance that should be given to the agricultural trade liberalization agenda.

As this scenario shows, full trade liberalization would cause the rice price to increase relative to the price projected in the baseline. This happens because production falls slightly in the countries that have high protection levels under the baseline. In the case of rice, the price rise is 14% above the baseline level. Import demand in Japan will increase further as the country opens up its market completely to world trade. Under this scenario, South Korea is also projected to import about 587,000 t of rice in 2025 versus exporting 153,000 t under the baseline. China, however, will increase its net rice surplus to more than offset the combined imports of the other East Asian countries. The rise in price provides the incentive for the slight increase in production in Asia while per capita demand and hence total demand decline modestly. Asian rice exports will therefore rise to 18.6 million t, which is more than 2 million t more than the rice trade under the baseline.

Policy choices and challenges for the long-term sustainable development of rice

Will Asia continue to fill its rice bowl? Under the baseline scenario, the answer is yes. Rice exports will expand and the rice price will decline. Buying rice from the world market will not be difficult for those that will have the budget resources to do so. Moreover, the commodity will be more affordable, particularly to the poorer countries, including those in sub-Saharan Africa, where rice demand will more than double. This rosy picture, however, is contingent on the continuation of trends of a large number of underlying drivers of world food markets as these are influenced by complex interactions among technology, policy, investment, environment, and human behavior. The alternative scenarios indicate that policy or technology failures that change the course of any one of these drivers could have a significant effect on future rice balances.

Rapid population growth has been one of the pressing problems in the region, particularly in South Asia. The low population growth scenario would indeed have a beneficial effect by attaining much lower prices, which lead to a higher per capita demand for rice, less pressure on fragile land to be brought into cultivation, and a significant expansion of trade. However, family planning programs to curtail population growth will only be partially helpful as they cannot fix the deeply rooted structural and technological challenges that confront the poor—particularly the rural poor.

The wide price swings associated with the alternative yield scenarios indicate that yield growth will be the key determinant in ensuring sufficient and affordable rice over the next several decades. The low-yield scenario translates into market difficulties. High world prices that would mean high domestic prices could result in significant social protest, especially in the low-income countries that depend most on rice for their staple food. Many of the poor will be priced out and their welfare endangered.

The high-yield growth scenario, on the other hand, could bring significant benefits. But this growth strategy has to be followed with great care so that gains would accrue to both producers and consumers, especially in the high-poverty countries and less-favored regions within those countries. Rising productivity should not leave behind the rice producers who make up the rural population in these poor countries and who could experience a gradual decline in their incomes. Greater attention to the needs of this segment of the population, especially those in difficult agroecological and low-potential systems, is critical.

Sustained economic growth will be an essential component in ensuring that the high-yield scenario can be attained rather than its opposite. With economic growth, investment will be more ensured for infrastructure support and research and extension services to enhance productivity. Equally important are investments in social services, such as education and health. Globally, projection results under the low economic growth scenario do not pose a threat to market stability as long as the Asian countries rebound immediately to again pursue their food production programs and other developmental activities. For the low-income countries in South Asia and some in Southeast Asia, however, slower income growth would further reduce per capita demand for their staple that could impinge on their move toward more food security.

Full trade liberalization shows a moderate increase in rice price compared to the baseline. Changes in supply and demand will be small in developing Asia but will be substantial in Japan and South Korea. Rice exports will expand, which can boost foreign exchange earnings of the region. Poor countries and poor people, however, risk losing out on the economic benefit embodied in trade liberalization (Diaz-Bonilla and Robinson 1998). Without appropriate economic and agricultural policies, the developing countries will not be able to capture fully the potential benefit from more liberalized markets. They should continue to remove distortions adverse to small farmers, who are the majority of the rice farmers. They should promote new export strategies to tap industrial markets for their produce. This would involve adding value to the product and competing in the high-quality rice market. The low-quality indica rice market, to which many countries cater (including India and Vietnam), is becoming saturated (Table 10, Fig. 8). Great potential exists in the high-quality market, for both volume and price. Marketing processed rice products could also be a lucrative direction. But the improvement of rice quality and the manufacture of rice products greatly depend on an efficient market and improved postharvest facilities. In many countries, these facilities remain antiquated.

The future challenge is clear: to adopt appropriate and well-balanced policy reforms that promote growth and equity in Asia, where countries are diversified in their natural resources, economic status, and cultural milieu. In all of the scenarios, the poor countries—mostly in South Asia and some in Southeast Asia—are greatly affected by variations in the factors that influence production and demand. This is

Table 10. Preferred rice grains by type, based on grain length and amylose content.

Type	Glutinous (waxy)	Low	Intermediate	High
Short	Lao PDR, northern Thailand	China, Japan, South Korea, United States, Taiwan (China), Australia, northeast Thailand	China, Italy	
Medium		U.S., Argentina, Cuba, Madagascar, Russia, Spain	Cambodia, Cuba, Indonesia, Vietnam, Malaysia, Nigeria, Philippines, central Thailand, Madagascar	Bangladesh, China, India, Philippines, Thailand (central, north, south), Colombia, Guinea, Mexico, Peru
Long		Nepal, Argentina	India, Malaysia, Myanmar, Pakistan, Brazil (upland), Côte d'Ivoire, U.S.	Bangladesh, India, Pakistan, Sri Lanka, Brazil (irrigated)

Source: Juliano and Villareal (1993).

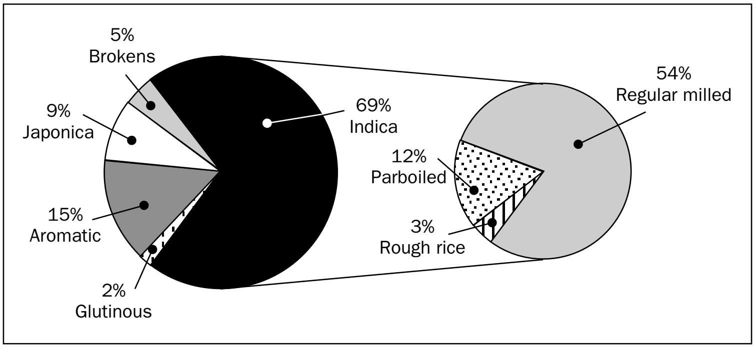

Fig. 8. Rice trade, type, and quality, 1996. Source: Slayton (1997).

because these countries have the most fragile environments for rice production. More effort should focus on solving the difficult and complex problems in these areas than has occurred in the past.

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Section **FIVE**

The comparative advantage in rice production in India, 1975-97

B. Bagchi and M. Hossain

This study aims to evaluate the comparative advantage in rice production for India, using the detailed data on costs and returns available from the reports of the costs of cultivation of principal crops. It also identifies the factors that caused changes in the comparative advantage from 1975 to 1995 when India experienced respectable growth in rice production through technological progress. The comparative advantage is assessed through an estimation of social profitability and domestic resource cost ratio by imputing the value of rice and the resources involved in its cultivation at their opportunity costs.

Because rice is a dominant staple food and the principal source of employment and income for rural households in the Asian tropics, the achievement of self-sufficiency through domestic production of rice remains a major political objective in the region. Whether this objective is consistent with the efficient allocation of resources is an issue debated by economists in their analysis for policy advice to governments (Bruno 1972, Krueger 1972, Srinivasan and Bhagwati 1978, Scandizzo and Bruce 1980, Monke and Pearson 1989, Gulati and Sharma 1991, Masters and Winter-Nelson 1995). The answer would depend on the comparative advantage in the domestic production of a commodity vis-à-vis other economic activities in which the available resources could be used.

The humid and subhumid regions of eastern India are traditionally the main rice-producing and -consuming belt. But because of the high density and rapid growth of the population, and the predominance of the rainfed ecosystem subject to the vagaries of the monsoon, not long ago India had to import a huge amount of food grains to meet the deficits of the rice-consuming eastern states. With the availability of high-yielding rice varieties since the early 1970s, a rapid growth in rice production in the irrigated ecosystem, particularly in Punjab, Andhra Pradesh, and Haryana, has changed the situation over the last three decades. The government now faces the problem of disposal of grains procured from the domestic market, although food insecurity still persists because of a lack of purchasing capacity of low-income households. While pursuing the policy of generating productive employment for poor households, India must explore the possibility of participating in the export market for low-quality rice (India is a major exporter of high-quality Basmati rice) to sustain farmers' incentives to grow rice in the states where it has become a commercial crop. To assess the potential for exports, a study of India's competitive strength in the international market is needed.

India launched its economic liberalization program in 1991 and signed the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) in April 1994 (Chand 1998, 1999, Gulati and Kelly 1999). As a founding member of the World Trade Organization (WTO), India is committed to adjusting its domestic and international trade policies to meet WTO obligations. Under these circumstances, an assessment of the comparative advantage in rice production for different rice-growing regions of India vis-à-vis the world market might be useful. The findings may shed light on the desirability of maintaining policies to protect input and product markets in the face of the ongoing WTO trade negotiations, promoting technological progress to improve competitiveness, and the probable effect of trade liberalization on the distribution of gains between rice producers and consumers (Bhalla 1995, Chand 1998).

Several studies on the comparative advantage of rice have been conducted for neighboring Asian countries (Unnevehr 1986, Ali 1987, Estudillo et al 1999, Kikuchi et al 2000, Morris et al 1997, Shahabuddin 2000) and on other crops in India (Gulati 1990, Gulati et al 1994, 1996, Gulati and Kelly 1999), but studies on rice in India are particularly lacking. Gulati and Kelly (1999) provide an average picture for rice along with other crops for the 1980-81 to 1993-94 period, but mostly for the semiarid states of India where rice is not the principal crop.

This study aims to evaluate the comparative advantage in rice production in selected states of India representing different stages of technological development, for which detailed data on costs and returns are available. It will also identify the factors that contribute to changes in comparative advantage from 1975 to 1997 when India experienced respectable growth in rice production through technological progress. The first section explains the methodology and specifies the definition and measurement of the variables. As a background to the study, the second section gives an overview of the development of the rice sector of the economy and the regional disparity in technological progress. The third section presents the findings on regional variations in input use, the cost structure, and the financial profitability for the selected states. The fourth section reports the estimates of the social profitability and comparative advantage, and identifies the factors that contribute to changes in comparative advantage. Major findings are recapitulated in the fifth section.

Conceptual framework

Measurement of comparative advantage

A country has a comparative advantage in producing a commodity if the social opportunity cost of producing a unit of the commodity is lower than its international price

(Chenery 1961). The social benefit of producing rice domestically is the amount of foreign exchange that can be earned when the country exports a unit of rice. The social opportunity cost of producing rice, on the other hand, is the value of domestic resources used per unit of rice production when the inputs are evaluated by their opportunity cost or shadow price.

The inputs can be classified into two groups: tradable ones in the international market and the nontradable ones that have a market only within the country. For the tradable inputs, the opportunity cost is the border price, that is, the c.i.f. price plus the domestic trade margin for the importable inputs and the f.o.b. price minus the domestic trade margin for the exportable inputs. For the nontradable inputs, the opportunity cost is the price prevailing in the domestic market adjusted for a margin required to ensure full employment of the resources.

The exchange rate is required to convert prices of the output and the tradable inputs into domestic currency units. To calculate social benefits and costs, a shadow exchange rate (SER) is used. It is the rate that would equate the demand for foreign exchange with its supply, that is, a zero balance in the external account. The net social profitability (NSP) is the difference between the social benefit of exporting a unit of rice and the social opportunity cost of producing it. The country has a comparative advantage in rice production if the NSP is positive.

A well-established method of assessing comparative advantage is to measure the domestic resource cost (DRC) ratio. The DRC compares the opportunity costs or shadow prices of domestic resources in production with the value added that they generate, that is,

$$\text{DRC} = \frac{\begin{array}{l}\text{Nontraded inputs used to produce one unit}\\ \text{of the good imputed at shadow prices}\end{array}}{\begin{array}{l}\text{Net foreign exchange earned (for export)}\\ \text{or saved (import substitution) by producing one unit}\\ \text{of the good domestically}\end{array}}$$

The DRC is derived as follows using the concept of NSP:

$$= P_r^{SER} - \Big(\sum_i^k a_i P_i^{SER} + \sum_j^m b_j P_j\Big)$$

$$\text{NSP} = \text{B} - \text{C} \qquad (1)$$

where B = social benefit of producing a unit of rice, C = social opportunity cost required to produce a unit of rice, P_r = international (border) price of rice in foreign currency, SER = the shadow exchange rate, a_i = input coefficient of the ith tradable input, b_j = input coefficient of the jth nontradable input, P_i = shadow price of the ith tradable input, and P_j = shadow price of the jth nontradable input.

Let us define DRC as that SER (SER*) that equates social benefits with social costs, that is, the NSP is equal to zero. Then,

$$\text{DRC} = \frac{\sum\limits_{j=i} b_j P_j}{(P_r - \sum\limits_{i=1}^{k} a_i P_i)} \qquad (2)$$

Domestic rice production has a comparative advantage if the DRC is less than unity and a comparative disadvantage if the DRC is greater than unity.

Sources of data

The data needed to estimate changes in the input coefficients in rice production over time are obtained from the official publication, "Cost of cultivation of principal crops in India," released by the Government of India (1996, 2000a) as a statistical publication. These reports provide detailed information on costs and returns, including physical units as well as prices for major inputs. The sampling procedure for the series of studies for a different period followed a three-stage stratified random sampling with *Tehsil* (Tehsil consists of a number of villages), villages, and households as units in successive stages. Each state is demarcated into homogeneous agroecological zones and primary sampling units are allocated to different zones in proportion to the total area of all crops covered in the study. For the selected villages, all operational holdings are enumerated and classified into five farm-size classes and two farm households are randomly selected for each class. Since there would be a larger proportion of households in the lower size classes, and more so in states with a lower average size of holding, the estimates obtained from the survey may be biased in favor of larger farm-size groups.

The data for rice are not available for all states, and years for which the data are available are not uniform across the states. Considering the availability of data, we decided to conduct the analysis for four states at different stages of technology development—Orissa, West Bengal, Andhra Pradesh, and Punjab. The first two are states from eastern India, where rice is the principal subsistence crop grown mostly under rainfed conditions (although dry-season irrigated rice cultivation, known locally as boro rice, has spread in West Bengal over the last two decades). Rice is grown under irrigated conditions in the last two states, where it has become a commercial crop. In 1997-98 conditions in the last two states, it has become a commercial crop. Andhra Pradesh and Punjab contributed 9.9 million out of the 15.6 million t of milled rice procured by the government, while the procurement was only 0.9 million t from Orissa and West Bengal (GOI 2000, a and c). Judging the trend in yield rates and prices for rice, we decided to select 1975-76, 1984-85, and 1996-97, in order to avoid abnormal years, to assess changes in relevant variables over time.

Definitions and measurement of variables

Exchange rate. The exchange rate policy can have a strong influence on the incentives afforded to individual production activities. Overvaluation of a country's exchange rate imposes a tax on the production of tradable goods and gives a subsidy to consumers. Exchange rate distortions may have dissimilar effects on production activities that differ in their use of tradable inputs. Consequently, in calculating economic prices for the tradable inputs, it is necessary to recognize and correct exchange rate distortions. Following Gulati and Kelly (1999), we assume that the Indian exchange rate was overvalued by 20% till 1991, when the government introduced a floating exchange rate system, which allowed market forces to determine the exchange rate.

Rice prices. Rice is treated as a tradable commodity. The shadow price of rice is calculated at a three-year moving average (to smooth out fluctuations in the price in the world market) of the f.o.b. price offered by the major rice exporter, Thailand, for low-quality rice (A1 super, which has the lowest price in the international market). To estimate the rice price that farmers would receive if the world market price had prevailed, we assume a milling ratio of 67% and a 25% margin for processing, transportation, and traders' profits. These assumptions would imply a ratio between the farm-gate paddy price and the retail consumer price of 1:1.87. The actual ratio for Bangladesh and Sri Lanka, where no significant market distortions occur, is 1:2 (IRRI 2001). For India, the ratio between the farm harvest price and the wholesale price of rice in the domestic market for the 1994-97 period was 1:1.86 (Chand 1999). The assumptions are therefore not out of line. The price thus arrived at is called the export parity border price.

The shadow price of rice would be different for consumers if the rice were imported. To estimate the import parity border price, we add 8% to the f.o.b. price (Kikuchi et al 2000) to estimate the c.i.f. price for India (if the rice were exported from Thailand, the major rice exporter in the world market) and an additional 25% on account of transportation and traders' margin for the product to reach the retail outlet. The paddy equivalent price is calculated by assuming a milling recovery of 67%.

Tradable inputs. Seeds, fertilizers, pesticides, and agricultural machinery (including irrigation equipment) are considered as tradable inputs. The price of seeds is assumed to be double the border price of paddy on the basis of the ratio observed between the seed and rice price for Andhra Pradesh, the major commercial seed-producing state in India. Chemical fertilizers are considered as importable inputs. We used the five-year average c.i.f. price of urea (to smooth out large fluctuations in yearly prices in the world market) evaluated at the shadow exchange rate, and added 25% for the trade and transport margin to get the import parity price for fertilizers that farmers would pay in the absence of any market distortions. Pesticides account for a small fraction of the cost (see below). We assumed that there is no subsidy on pesticides and adjusted the cost, using the shadow exchange rate for the 1975-76 and 1984-85 periods.

Calculating the opportunity cost of services of farm machinery is problematic because of the nonavailability of detailed data. Experience has shown that the calculation of economic prices is not warranted for all purchased inputs that account for a small portion of the total cost (Morris 1989). However, there is a huge difference in the use of agricultural machinery across states (see below) and considerable subsidy exists in the use of intermediate inputs such as electricity and diesel fuel and formal credit from institutional sources (Chand 1999), which could be a major source of finance for the acquisition of farm machinery. The cost of cultivation survey imputes the cost of the services of owned machinery on the basis of the depreciation of the machines plus the cost of operation and maintenance, which includes diesel fuel, electricity, lubricants, and repairs. Chand (1999) estimates the subsidy on account of electricity and irrigation at $4.21 billion for 1994-95 for Indian agriculture, which is 50% of the actual cost ($8.19) paid by farmers for irrigation and machinery rent in the production of rice and wheat, which are major users of irrigation and farm machinery. We have adjusted the nominal cost figures using this ratio.

Interest charges on working capital employed in farm operations are estimated on the assumption of a 10% per annum social discount rate and a 6-month cropping cycle for which the working capital is used in rice cultivation.

Nontradable inputs. Human labor, animal draft power, land rental charges, and farmyard manure are treated as nontradable inputs. The opportunity cost of the animal draft power is estimated on the basis of the cost of maintenance, which includes livestock feed, labor charges, and the depreciation of animals and cattle sheds. Farm-produced manure is imputed at prices prevailing in the village market.

The cost of labor (both family and hired) is computed by the survey at the market wage rate or the statutory minimum wage, whichever is higher. For states with substantial underemployment of labor, the opportunity cost of labor should be lower than the market wage rate because the creation of employment would bring additional social benefits. However, we made no adjustment in the labor cost because of a lack of reliable information on the shadow wage rate for different states. Since labor is a major component of the cost of the nontradable inputs, its social cost would be biased upward, particularly for the low-income states of Orissa and West Bengal.

The land market is imperfect and estimating the opportunity cost of land is problematic. There is a vibrant tenancy market with several tenancy arrangements under operation with different terms and conditions. The sharecropping system is the dominant tenancy arrangement under which a payment of one-third of the gross produce to the landowner as land rental is a common practice. The survey on the cost of cultivation estimates the rental charge of owned land on the basis of prevailing rents in the village, subject to the ceiling of fair rents provided in the land legislation of the state. Land rental charges were found to vary from 20% to 30% of the gross value of produce. We have adjusted the cost of land rent according to the difference between the farm-gate price and the export parity border price of rice.

Rice yield. The output per unit of cropped land (the yield rate) is used as the denominator to estimate the input coefficients. It was noted that for most rice-growing states (except for Punjab) the value of the by-product (rice straw) is a significant component of the output, besides paddy. So, we estimated the paddy equivalent of the value of by-products by imputing it with the farm-gate price of paddy, and included it in the estimates of the yield rate.

Development in the rice sector

Growth in production

India has made notable progress in the rice sector of its economy over the last three decades. Rice production has grown from 61 million t in 1971 to 134 million t in 1999-2000, an increase of 120% over 30 years, much faster than the increase in population (87%) during the period. Nearly 80% of the increase in production came from the growth in the yield rate, an outcome of the adoption of the "seed-fertilizer-water" technology. The rice yield (paddy equivalent) increased from 1.61 t ha^{-1} in 1969-70 to 3.01 t ha^{-1} in 1999-2000, an increase of 85%. The semilogarithmic trend lines fitted with the time-series data for the 1970-2000 period show a trend rate of growth of 2.9% per year for production, 2.3% for yield, and only 0.6% for the expansion of rice area (Table 1).

The yield achieved in India, however, is still substantially lower than that of China (6.35 t ha^{-1}), where almost 95% of the rice area is irrigated, and of Indonesia (4.43 t ha^{-1}) and Vietnam (4.25 t ha^{-1}), the other major rice-growing countries in Asia. The yield is not even higher than that of the neighboring South Asian countries, except Nepal (2.61 t ha^{-1}). However, in Punjab and Tamil Nadu, where rice is grown under irrigated conditions, yield has approached 5.5 t ha^{-1}, considered very high for tropical conditions. The all-India average yield is low because, in the predominantly rainfed ecosystem in eastern Indian states (except in West Bengal), yield is lower than 2.5 t ha^{-1}.

There is an indication that the growth in rice yield slackened during the 1990s. The increase in yield was 19% in the 1970s, 30% in the 1980s, but only 15% in the 1990s. To see whether the growth rate decelerated in the 1990s, as technological

Table 1. Estimated trend lines for area, yield, and production of rice in India, 1970-2000.

Variable	Unit	Constant (value for 1970)	Regression coefficients[a] for			Value of R^2
			Dummy for 1990s (D)	Time (T)	D × T	
Area	1 Million hectares	37.5		0.0057		0.85
				(12.62)		
	2 Million hectares	37.6	–0.021	0.0054	0.011	0.85
				(–0.34)		
Yield	1 t ha^{-1}	1.57		0.0232		0.91
				(17.19)		
	2 t ha^{-1}	1.56	0.244	0.0230	–0.0094	0.92
			(1.39)	(9.26)	(–1.26)	
Production	1 Million tons	58.8		0.0289		0.92
				(17.97)		
		58.9	0.223	0.0284	–0.0083	0.92
			(1.05)	(9.46)	(–0.93)	

[a] Numbers within parentheses are estimated t values of the regression coefficient.
Source: Own estimates with the Indian official time-series data.

progress was losing steam in the irrigated ecosystem, the following trend equation has been fitted on the data for 1970-2000:

$$\mathrm{Ln}Y = a + bD + cT + d\,(D \times T) \tag{3}$$

where Ln is the natural logarithm of the variable, Y is the variable for which the rate of growth is estimated, D is the dummy variable taking a value of one for 1990-2000 and zero otherwise, and T is the time trend starting with the value of one for 1970. The rate of growth for 1970-90 is given by the value of the estimated parameter c and that for 1990-2000 is given by (c + d). The value of d is expected to be negative if the growth rate decelerated during the 1990s. Table 1 reports the estimated equations. Table 2 shows the growth rates derived from the estimated equations. The results indicate that the growth in production decelerated from 2.8% per year for 1970-90 to 2.0% for 1990-2000. The decline in the growth of production was mainly on account of the yield rate, which declined from 2.3% per year in 1970-90 to 1.4% in the 1990s. However, the growth in rice cropped area has increased marginally from 0.5% to 0.6% per year. The changes in growth rates, however, are not statistically significant.

Which states have contributed to the decline in the growth of production in the 1990s? To answer this question, we estimated the above trend equation for the major rice-growing states in India and estimated the sources of growth of rice production for 1970-90 and 1990-2000. These results are also shown in Table 2. It can be noted that there has been an absolute decline in yield for Haryana, Orissa, Madhya Pradesh

Table 2. Sources of growth (% y^{-1}) in rice production in India, 1970 to 2000.

States	Production		Area		Yield	
	1970-99	1990-2000	1970-90	1990-2000	1970-90	1990-2000
Eastern India	1.91	1.68	0.26	0.38	1.66	1.31
Assam	1.65	1.05	0.93	0.02	0.72	1.03
Bihar	1.35	5.07	–0.01	0.41	1.36	4.66
Madhya Pradesh	1.99	–0.05	0.68	0.68	1.31	–0.73
Orissa	1.39	–1.33	0.44	0.16	1.83	–1.49
West Bengal	2.60	2.54	0.36	0.57	2.25	1.98
Rest of India	3.64	2.25	0.92	0.98	2.72	1.27
Andhra Pradesh	3.58	1.48	0.75	0.34	2.83	1.14
Gujarat	2.93	3.65	0.88	1.87	2.05	1.76
Haryana	7.19	4.30	4.79	5.94	2.40	–1.64
Jammu & Kashmir	2.25	–2.07	1.05	–0.43	1.20	–1.64
Karnataka	0.88	3.42	0.23	1.69	0.64	1.73
Kerala	–1.23	–4.89	–2.25	–5.70	1.00	0.81
Maharashtra	2.74	1.37	0.74	–0.72	2.00	2.09
Punjab	11.80	2.47	8.95	2.44	2.85	0.03
Tamil Nadu	0.44	1.95	–1.81	1.29	2.24	0.66
Uttar Pradesh	5.29	3.02	1.11	0.82	4.18	2.20
India	2.84	2.01	0.54	0.65	2.30	1.36

Source: Estimated from the trend line $\mathrm{Ln}\,Y = a + bD + cT + d\,(D \times T)$ fitted with the time-series data from 1970-71 to 1999-2000 where Y is the variable for which the growth is estimated, D is the dummy variable with a value of 1 for the 1990s, and T is the time trend.

(Chattisgarh), and Jammu and Kashmir. The decline in yield for Orissa and Madhya Pradesh might be due to frequent droughts, floods, and cyclones in the 1990s. The decline in yield in Haryana is presumably caused by an increase in the proportion of area under the relatively low-yielding but high-value Basmati rice. There has been a substantial deceleration in yield growth in Punjab, Tamil Nadu, Andhra Pradesh, and Uttar Pradesh, the states where the irrigation infrastructure is highly developed and yield has reached a high level.

There is a perception that eastern India has done better in the 1990s than in earlier decades. But this was not the case. Yield growth in eastern India also declined from 1.65% per year in 1970-90 to 1.31% in the 1990s. A substantial increase in yield occurred in the 1990s only for Bihar and Assam, and for Maharashtra and Karnataka in southwestern India. The acceleration of yield in Bihar and Assam in the 1990s presumably occurred because of an expansion in area under dry-season high-yielding boro rice.

The change in the yield trend was statistically significant for Bihar and Karnataka (positive) and Punjab, Haryana, Andhra Pradesh, and Orissa (negative).

Regional disparity in technological progress

According to the latest information obtained from the state-level agricultural extension offices, the coverage of modern high-yielding rice varieties had reached nearly 80% of the rice cropped area by 1999-2000 (personal communication). The rate of adoption varies from 67% in Assam to more than 90% in Tamil Nadu, Kerala, and Andhra Pradesh. The coverage of modern rice varieties is almost complete in the irrigated ecosystem in Punjab and Haryana, but, since a large area under these states is allocated for the production of high-quality Basmati rice, traditional varieties still account for a significant proportion of land.

However, the statistical relationship is weak between the adoption of modern varieties and the interstate variations in rice yield (Fig. 1A). An explanation could be that, in the absence of good water control, the full yield potential of the modern rice varieties is not realized in the rainfed ecosystem. The association between the coverage of irrigation and the variation in rice yield across the states is quite strong (Fig. 1B). In the dominant rainfed ecosystem of eastern India such as in Bihar, Orissa, Chattisgarh, and Assam, yield is less than 2.5 t ha^{-1} in spite of the more than 60% adoption of modern varieties. A further increase in yield in these states would depend on the development of reliable irrigation (with pumps and tubewells instead of canals) and/or the development of drought- and submergence-tolerant high-yielding modern varieties.

State-level data on the use of chemical fertilizer in rice cultivation, an important element in the improved seed-fertilizer-water technology, are not available. However, data on fertilizer sales (NPK) per hectare of land for all crops taken together (The Fertilizer Association of India 2000) show a large regional variation in the use of nutrients. This varies from less than 50 kg ha^{-1} in Assam, Orissa, and Madhya Pradesh to more than 140 kg ha^{-1} in Haryana (149), Andhra Pradesh (158), and Punjab (185).

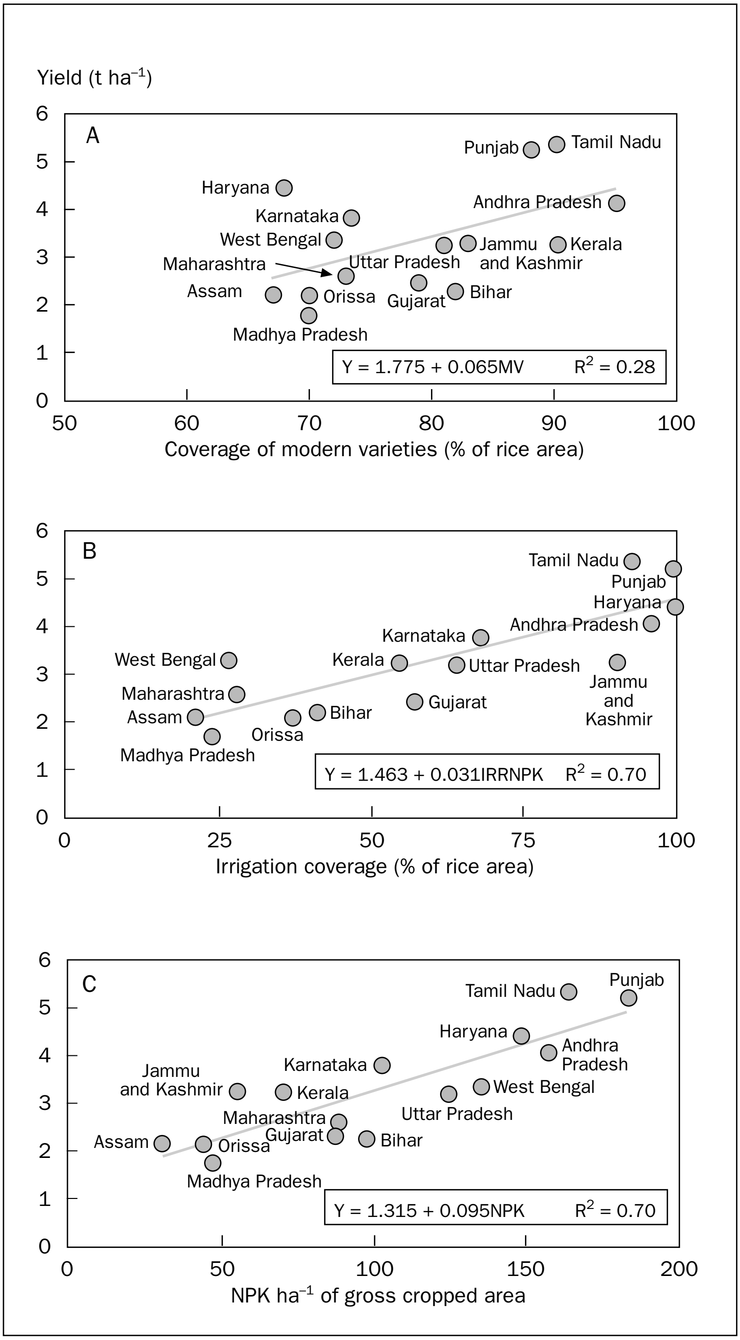

Fig. 1. Relationship between rice yield and (A) coverage of modern varieties, (B) irrigation coverage, and (C) fertilizer consumption.

The association between the variation in NPK use and yield for rice across states is very strong (Fig. 1C).

To conclude, a large interstate variation occurs in rice yield that is associated with the coverage of modern irrigation infrastructure and the use of chemical fertilizers. Rice production will continue to increase if the yield gap can be reduced by developing and diffusing appropriate modern varieties for the rainfed environment and/or investing in the development of irrigation infrastructure, provided the market sustains farmers' incentives to continue rice cultivation.

Technological change, cost structure, and financial profitability

This section analyzes the data on the cost of rice cultivation at prices faced by farmers in the domestic market for four selected states: Assam, West Bengal, Orissa, and Punjab.

Figure 2A shows the level and changes in rice yield (paddy equivalent) from 1975-76 to 1996-97. The figure shows that the states are at different stages of development with respect to rice production. Orissa represents a state at a low level of development of the technology, where rice yield is low and yield growth over the last three decades has remained slow, presumably because of the predominance of the rainfed ecosystem and risks involved in the cultivation of input-intensive modern varieties. Orissa may represent the situation prevailing in Chattisgarh (eastern Madhya Pradesh), Bihar, and Assam. West Bengal and Andhra Pradesh are at the mid-level in technological progress. These states have made impressive progress in rice cultivation by developing modern irrigation infrastructure, including private investments in pumps and tubewells for the extraction of groundwater. Uttar Pradesh and Karnataka are at similar stages of development. In Punjab, where irrigation infrastructure was already developed, farmers took advantage of the availability of the improved rice varieties and crop management practices early, and paddy yield surpassed 5 t ha^{-1} by the early 1980s. But, as farmers approached the potential of the new technology, yield growth slackened. Yield in Punjab, which represents the highly developed rice-growing states such as Haryana and Tamil Nadu, has increased only slightly since the mid-1980s.

As mentioned earlier, rice straw is an important by-product in rice cultivation and it has commercial value in states where cattle are an important component of farm holdings and livestock feed is scarce. The straw is used as a livestock feed and for thatching the roofs of poor-quality houses of low-income households. As shown in Figure 2A, the straw accounts for 15% to 20% of the gross value of output in Orissa, West Bengal, and Andhra Pradesh. In Punjab, where agriculture is mechanized and cattle are no longer a significant source of draft power, rice straw has little value in the market.

The difference in the use of major inputs—human labor, chemical fertilizers, and agricultural machinery—as well as changes in the use of inputs over time can be reviewed in Figures 2B,C, and D. Labor use per hectare has increased very little over time. The intensity of labor use is higher in states with lower yields. As rice yield and the level of household income increase, the opportunity cost of labor becomes higher

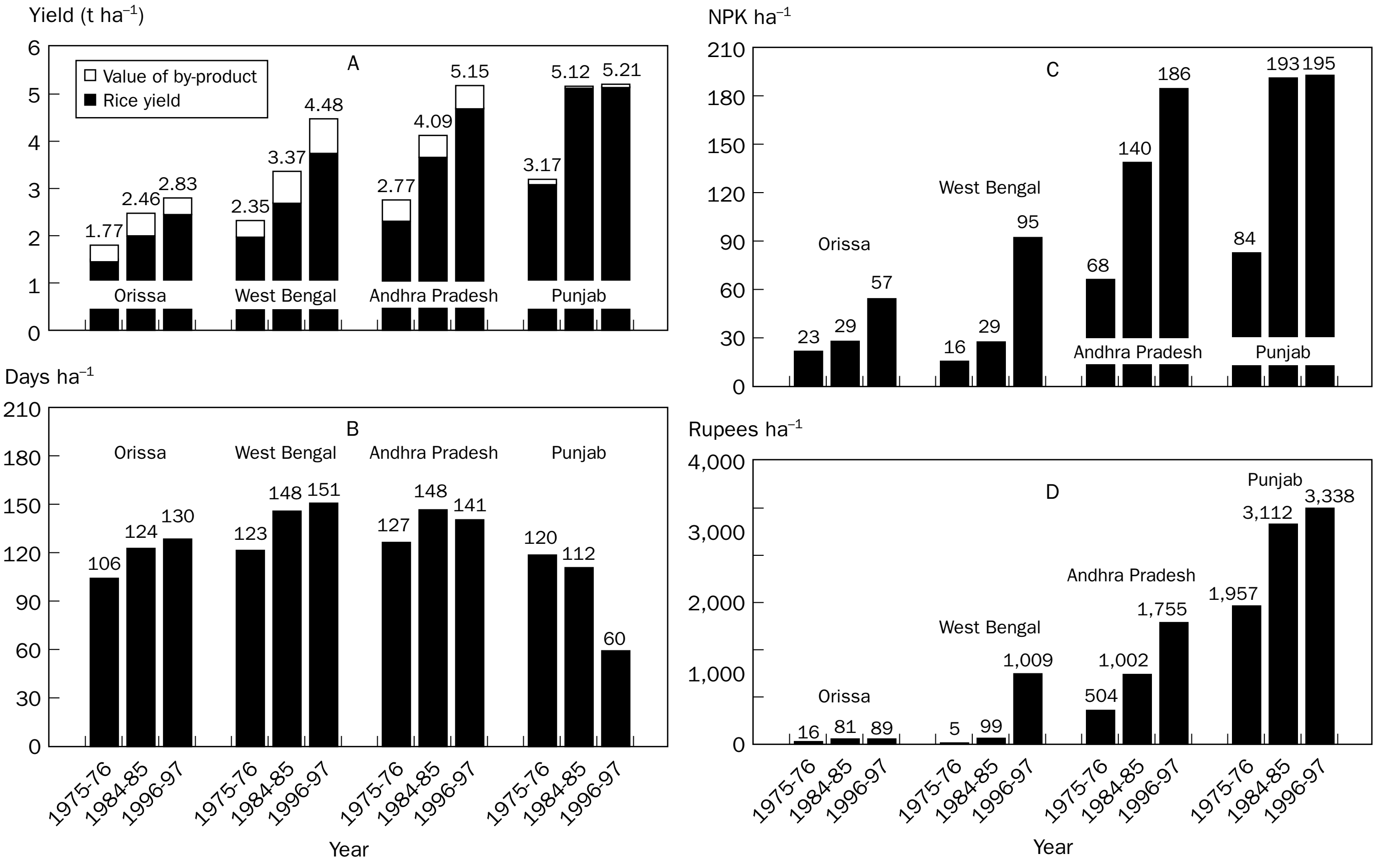

Fig. 2. (A) Changes in rice yield (t ha⁻¹) in Indian states, (B) changes in labor use (d ha⁻¹) in rice cultivation, (C) changes in fertilizer use (NPK ha⁻¹) in rice cultivation, and (D) changes in the use of farm machinery in rice cultivation.

and farmers are induced to reduce labor use by introducing mechanization of farm operations. In 1996-97, the wage rate per day was $1.58 in Punjab versus $0.85 in Orissa. These figures show a large reduction in the use of labor and a substantial increase in the use of agricultural machinery in Punjab since the mid-1980s. The use of agricultural machinery to replace human and animal labor has started in Andhra Pradesh and West Bengal, although at a low level. The use of agricultural machinery is almost absent in Orissa.

There is also a huge difference in the use of chemical fertilizers, and the difference is positively associated with yield. It is obvious that the intensity of fertilizer use is an important contributory factor to the increase in rice yield. Fertilizer use in 1996-97 varied from 57 kg NPK ha^{-1} of rice land for Orissa to about 195 kg ha^{-1} for Punjab. The level of use has increased rapidly in the low-yielding states, and has remained at that level since the mid-1980s in the high-yielding state of Punjab, in line with the stagnation of rice yield.

The change in input coefficients reveals that material inputs (intermediate consumption) increase more than proportionately with the increase in rice yield. So, with the progress of the new technology, the value added and farm income increase at a slower rate than the growth in rice yield.

The interstate difference in the cost structure and the unit cost of production for 1996-97 can be reviewed in Table 3. The most important component of the cost is human labor, which accounts for one-third of the gross value of output for Orissa, West Bengal, and Andhra Pradesh. For Punjab, human labor accounts for only 16% of the value of output because of the progress made in farm mechanization, which helped substitute capital for human and animal labor. The other major cost component is the rental charge for land (most of it is imputed value of land owned by the farm). The rental charge is lower for Orissa and West Bengal and higher for Andhra Pradesh and Punjab. It appears from the data that a larger share of the increase in productivity from technological progress accrues to landowners, as the opportunity cost of land increases with economic progress. Andhra Pradesh, which has made rapid economic progress in the last decade, has the highest opportunity cost of land, where the rental charge accounts for one-third of the gross value of production. In Punjab, the opportunity cost of land is lower than in Andhra Pradesh, presumably because of the larger size of landholdings (less pressure of population on this scarce natural resource).

Among material inputs, chemical fertilizer is the most important one, accounting for 8–9% of the gross value of production for the technologically progressive states of Punjab and Andhra Pradesh. For Orissa and West Bengal, fertilizer accounts for only 5% of the gross value of production. With technological progress, the consumption of chemical fertilizers increases more than proportionately compared with the yield rate. So is the case with pesticides and irrigation. The cost of irrigation varies from 0.3% of the value of output for Orissa to 7.3% for Punjab. Pesticides account for a very small fraction of the gross value of output: about 4% of the value of output for Punjab, the highest user of pesticides. Pesticides are not used at all at low yield levels. With technological progress and the increase in yield, farmers save on seed costs. In Punjab, seeds account for only 1.7% of the gross value of output. The unit cost on

Table 3. Importance of different inputs in rice cultivation, 1996-97 (numbers in percent of gross value of output).

Inputs	Orissa		West Bengal		Andhra Pradesh		Punjab	
	Dollars t^{-1}	Percent of Gross value	Dollars t^{-1}	Percent of gross value	Dollars t^{-1}	Percent of gross value	Dollars t^{-1}	Percent of gross value
Seed	4.29	3.8	2.77	2.3	3.30	2.7	1.92	1.7
Fertilizer	6.12	5.4	6.75	5.6	11.40	9.4	9.34	8.2
Pesticides	0.17	0.1	2.91	2.4	2.37	2.0	4.46	3.9
Irrigation charges	0.28	0.2	4.71	3.9	3.78	3.1	8.38	7.3
Manure	4.54	4.0	2.91	2.4	2.46	2.0	1.27	1.1
Animal power	9.57	8.4	8.04	6.7	3.84	3.2	0.20	0.2
Machine rental	0.62	0.5	1.64	1.4	5.84	4.8	9.68	8.5
Human labor	38.84	34.2	39.37	32.7	39.09	32.2	18.46	16.1
Interest charges	1.41	1.2	1.50	1.2	1.83	1.5	1.50	1.3
Land rental	26.19	23.0	28.87	24.0	40.67	33.5	32.23	28.2
Operational surplus	21.62	19.0	20.83	17.3	6.55	5.5	27.18	23.7
Output value	113.58	100.0	120.29	100.0	121.14	100.0	114.62	100.0
Unit cost of production	91.96	81.0	99.46	82.7	114.59	94.5	87.44	76.3

Source: Government of India (2000a).

account of modern inputs (seed, fertilizer, pesticides, and irrigation) varies directly with yield. It varies from 10% of the gross value of output in Orissa to 21% of output for Punjab. So, higher yield is achieved at the expense of a substantially larger use of material inputs.

An important point to note from the numbers in Table 3 is that the substitution of agricultural machinery for human labor and animal draft power contributes to a reduction in the unit cost of production. For Orissa and West Bengal, where the extent of mechanization is very low, the total costs of human labor, machine rental, and animal power constitute about 42% of the value of output. For Punjab, the state with the highest level of agricultural mechanization, the number is 25%. Mechanization helped Punjab to reduce its unit cost of production compared with the other states from 1985-86 to 1996-97.

Table 4 presents findings on changes in the unit costs (per ton of output) and financial profitability from 1975-76 to 1996-97. Andhra Pradesh had the highest unit cost and the lowest rate of financial profits mainly because of the higher land rental rates and wage rates as well as relatively high labor intensity in rice cultivation. For Punjab, where the cost of production was relatively high in the mid-1970s, substantial progress has been made in reducing the cost since the mid-1980s, through increased farm mechanization and the judicial use of chemical fertilizers and pesticides. Punjab had the lowest unit cost and the highest rate of financial profits in 1996-97. Orissa and West Bengal had the lowest unit cost and the highest rate of profits till the mid-1980s despite having lower yields, but has lost the advantage to Punjab since then.

Table 4. Changes in unit costs (dollars t^{-1}) and financial profits in rice cultivation, 1975-76 to 1996-97.

State	1975-76	1984-85	1996-97
Orissa			
Unit cost (dollars t^{-1})	76.01	92.96	91.96
Price (dollars t^{-1})	92.00	123.24	113.58
Operating surplus (% of cost)	21	33	24
West Bengal			
Unit cost (dollars t^{-1})	84.84	104.05	99.46
Price (dollars t^{-1})	106.56	123.24	120.29
Operating surplus (% of cost)	26	35	21
Andhra Pradesh			
Unit cost (dollars t^{-1})	84.84	116.19	114.59
Price (dollars t^{-1})	95.82	124.56	121.11
Operating surplus (% of cost)	13	7	6
Punjab			
Unit cost (dollars t^{-1})	100.84	105.19	87.44
Price (dollars t^{-1})	92.60	129.40	114.68
Operating surplus (% of cost)	–8	23	31

Source: Estimated from Government of India (2000a).

Social profitability and comparative advantage

Social profitability is estimated by adjusting the prices of inputs and output to reflect their true opportunity cost to the society, as explained in the methodology section. The estimates of the unit costs (per ton of output), after adjusting for the market distortions for the tradable and nontradable inputs, for the four states are given in the Appendix Tables.

The states differ substantially in the use of tradable inputs. In 1975-76, tradable inputs accounted for only 13% of the total cost for West Bengal, 24% for Orissa, 32% for Andhra Pradesh, and 50% for Punjab. The share of tradable inputs did not change much over time except in West Bengal. In 1996-97, the share was 21% for Orissa, 29% for West Bengal, 33% for Andhra Pradesh, and 51% for Punjab, a direct relationship with the level of technological progress and yield rates. Thus, the opening of the economy to the world market would have a more substantial effect on incentives (positive or negative) for rice production for the technologically progressive states with higher yields, such as Punjab and Andhra Pradesh, than for the technologically backward states with lower yields, such as in eastern India.

In 1996-97, Orissa and West Bengal had a higher social profitability in rice cultivation than Punjab, and Andhra Pradesh had a negative social profitability, a completely different ranking among the states than that based on private profitability (see the section above). Social profits declined from 1975-76 to 1984-85 but increased marginally from 1985-86 to 1996-97. In spite of higher absolute yields, Punjab had a negative social profitability for both 1975-76 and 1984-85 but achieved a breakeven position in 1996-97.

The estimates of the domestic resource cost (DRC) ratios are shown in Table 5. As mentioned in the first section, a comparative advantage in producing rice is gained if the DRC ratio is less than unity. The lower the value of the DRC, the higher the potential gains from the domestic production of rice. The estimates of DRC ratios at the export parity price of rice show that farmers from Andhra Pradesh would not gain

Table 5. Domestic resource cost ratio in rice cultivation, 1975-76 to 1996-97.

States	1975-76	1984-85	1996-97
Export parity price for rice			
Orissa	0.69	0.85	0.80
West Bengal	0.78	0.92	0.88
Andhra Pradesh	0.74	1.16	1.07
Punjab	1.32	1.57	0.91
Import parity price for rice			
Orissa	0.38	0.46	0.44
West Bengal	0.44	0.52	0.45
Andhra Pradesh	0.39	0.56	0.52
Punjab	0.51	0.51	0.39

Source: Own estimates from the numbers in the Appendix Tables.

by exporting rice in the world market, and farmers in Punjab would gain only marginally, as the DRC ratio for the state is close to unity. The lower DRC ratios for Orissa and West Bengal suggest that these states have a higher comparative advantage in rice cultivation than Andhra Pradesh and Punjab. But, with the present state of technological developments, these states do not produce enough rice to meet their own domestic demand.

If we consider the import parity price, all the states have highly favorable DRC ratios. The substantial difference in the value of DRC for rice under the export parity and the import parity price is because of the difference in the treatment for freight charges and marketing margins, which adds value to the economy if the rice is traded within the country. In 1996-97, the import parity price of paddy ($209.57) was 1.68 times the export parity price ($124.19). The numbers suggest that Indian rice consumers gain substantially more from the domestic production of rice than from importing it from abroad. Also, the opening up of the Indian rice market would *not* lead to flooding of the domestic market with imports, as many fear. Exporters would not be able to compete with domestic producers, at least for low-quality rice (at the 1996-97 world market prices).

It may be worthwhile to compare the DRC ratios of rice for other countries. For Bangladesh for 1994-95 to 1996-97, Shahabuddin (2000) estimates the DRC ratio at the export parity price at 0.80 for aman (wet-season, rainfed) and 0.99 for boro (dry-season, irrigated) rice. At the import parity price, the estimates are 0.48 and 0.75 for the aman and boro seasons, respectively. Kikuchi et al (2000) estimate the DRC ratio for Sri Lanka for 1996 at the import parity price at 0.96 for the rainfed system and 0.96 for the irrigated system. Estudillo et al (1999) estimate the DRC ratio for the Philippines for 1995 at 1.59 at the import parity price. The studies for the Philippines and Sri Lanka show a deterioration in comparative advantage since the mid-1980s with the slowing down of technological progress and a large increase in the opportunity cost of labor. But India and Bangladesh experienced an improvement in comparative advantage during this period. The numbers also show that India had a better DRC ratio than Sri Lanka and the Philippines, but almost the same level as Bangladesh.

What has been the effect of the changes in government policies on the shift in comparative advantage? An important factor behind the difference between private profitability and social profitability is the distortion in the market for rice and tradable inputs, which can be measured by the nominal protection coefficient (NPC). A change in government policy would affect the NPC and in turn the DRC ratios. The nominal protection rate is computed as the difference of the ratio between the domestic prices and the border prices (world prices converted at an appropriate exchange rate, adjusted for quality differences of output, and transportation, handling, and storage cost) from unity. The changes in the nominal protection rate for rice (paddy equivalent) and fertilizer (the major tradable input) can be seen in Table 6. The numbers show that from 1975-76 to 1984-85 there was a substantial movement from taxing farmers to giving subsidies while there was a marginal reduction in fertilizer subsidies. The real price (adjusted for inflation) of rice in the world market moved drastically downward

Table 6. Changes in the nominal protection rate for paddy and fertilizer, 1975-76 to 1996-97.

Variable	Farm-gate price[a] (dollars t^{-1})	Border price[b] (dollars t^{-1})	Nominal protection coefficient (%)
Paddy			
1975-76	97.01	118.30	–18
1984-85	129.49	106.07	22
1996-97	117.41	124.19	–5
Fertilizer (NPK)			
1975-76	508.35	550.00	–8
1984-85	434.23	449.74	1
1996-97	307.65	518.18	–41

[a]The farm-gate price is the average price received/paid by farmers in the four states under study. [b]The border price for paddy is the export parity price and for fertilizer it is the import parity price.

during this period because of a rapid growth in rice production, particularly in China, Indonesia, and the Philippines (Hossain and Pingali 1998). The decline in price was not transmitted to the Indian market. The rice price in the Indian market remained lower than in the world market till the late 1970s, but became higher by the mid-1980s. The removal of these distortions would have a negative effect on the comparative advantage in rice cultivation. From 1984-85 to 1996-97, the price trend in the rice market led to almost an equalization of prices between the domestic and world market. However, a substantial increase in fertilizer subsidy occurred. The net effect of the price movement was unfavorable to rice farmers.

The effect of the discrepancies in the prices of tradable inputs and output on farmers' incentives can be measured more precisely by the effective protection coefficient (EPC). It is defined as the difference of the ratio of value added in domestic prices to the value added at border prices from unity. The change in the estimated EPC for different states is reported in Table 7. The numbers show a movement from taxation of farmers toward substantial protection from 1975-76 to 1984-85, and a reverse movement from 1984-85 to 1996-97. In 1996-97, the value added in domestic prices was almost similar to the value added in the world market prices, indicating little net combined effect of the market distortions for tradable inputs and output.

A substantial change in the prices of nontradable inputs had effects on changes in comparative advantage. The change in the composite price index for tradable and nontradable inputs can be seen in Table 8. From 1975-76 to 1984-85, the prices of tradable inputs increased at a slower rate than the prices of nontradable inputs. So, the cost of production increased at a slower rate for states that had a larger share of tradable inputs (Punjab and Andhra Pradesh). From 1984-85 to 1996-97, the prices of the inputs increased at a much faster rate, mostly because of the rapid depreciation of the Indian currency. The difference in the increase in price for tradable and nontradable inputs was negligible for Orissa and West Bengal, but quite substantial for Punjab and Andhra Pradesh. In the latter states, the price of nontradable inputs continued to increase at a faster rate than the prices of the tradable inputs. Faster economic progress in

Table 7. Changes in effective protection values for different states.

State	1975-76	1984-85	1996-97
Orissa	–22	29	–1
West Bengal	–7	42	10
Andhra Pradesh	–9	147	3
Punjab	–21	38	6

Table 8. Increase in prices for tradable and nontradable inputs (% per year).

State	1975-76 to 1984-85			1984-85 to 1996-97		
	Tradable[a]	Nontradable	All inputs	Tradable[a]	Nontradable	All inputs
Orissa	2.7	6.3	5.5	10.7	11.5	11.2
West Bengal	2.3	5.8	5.5	11.5	11.5	11.5
Andhra Pradesh	3.9	7.4	6.5	10.0	12.5	11.8
Punjab	4.7	6.3	5.9	9.2	12.1	10.6

[a] The prices for tradable inputs are the border prices evaluated at the shadow exchange rate.

these states put upward pressure on the wage rate and land prices. As the cost of these inputs continued to increase, these states have been losing their comparative advantage in rice cultivation.

What has been the effect of the technological progress in rice cultivation on comparative advantage? To answer this question, we estimated the cost structure at the constant prices of inputs and outputs prevailing in 1996-97 and estimated the cost per unit of output. The numbers are presented in Table 9. It can be noted that with technological progress the unit cost of tradable inputs continued to increase, and at a faster rate for West Bengal and Andhra Pradesh, which experienced a faster growth in yield rates. Punjab was able to keep down the unit cost of tradable inputs because of economy in the use of chemical fertilizers and pesticides. The unit cost of nontradable inputs has declined over time for all states. The unit cost of all inputs declined by 33% for Punjab and by 15–16% for Andhra Pradesh, West Bengal, and Orissa. With technological progress, the rental share of land (imputed cost rather than real cost) also increased, and for Andhra Pradesh it increased substantially. If we exclude the cost of land, the reduction in unit cost is substantially higher for all states and the magnitude of the reduction is positively associated with the increase in yield. So, technological progress and growth in yield did make a positive contribution to reducing the domestic resource cost and improving the comparative advantage in rice cultivation in India.

Conclusions

An important finding of the study is that the technologically progressive states that have achieved higher rice yields do not necessarily have a better comparative advantage in rice cultivation. The increase in yield comes at the expense of a substantially higher use of material inputs such as fertilizer, water, and pesticides. So, the effect on

Table 9. Unit cost of rice production on account of tradable and nontradable inputs.

State/input type	Cost t^{-1} at 1996-97 prices (dollars)			The change in cost from 1975-76 to 1996-97 (%)
	1975-76	1984-85	1996-97	
Orissa				
Tradable	22.41	19.61	22.52	1
Nontradable	101.50	88.54	81.57	–20
All inputs	123.91	108.72	104.09	–16
Inputs excluding land	95.51	78.61	75.47	–21
West Bengal				
Tradable	12.98	15.52	33.22	156
Nontradable	119.93	101.44	80.13	–33
All inputs	132.91	116.99	113.35	–15
Inputs excluding land rental	104.90	86.88	83.55	–20
Andhra Pradesh				
Tradable	31.89	39.04	42.70	34
Nontradable	120.10	103.84	87.10	–27
All inputs	151.99	142.87	129.81	–15
Inputs excluding land	119.19	107.00	88.09	–26
Punjab				
Tradable	69.94	65.54	60.71	–13
Nontradable	104.46	66.33	57.72	–45
All inputs	174.40	131.87	118.43	–32
Inputs excluding land rental	146.06	105.45	80.64	–45

value added is substantially lower. Many of these inputs are tradable in the world market; therefore, the technologically progressive states are prone to risks from large price fluctuations in the world market. Also, with the economic prosperity that goes hand in hand with the increase in yield of the basic food staple, the opportunity cost of the nontradable inputs such as land and labor increases more than proportionately, which contributes to an erosion of the comparative advantage. For a labor-intensive crop such as rice, the comparative advantage shifts to low-income states that have a low opportunity cost of land and labor and a lower coefficient of tradable inputs.

The study finds that the domestic resource cost ratio at the export parity price is close to unity for Andhra Pradesh and Punjab, the major surplus rice-growing states. So, farmers in these states would not be able to compete in the world market for rice. The domestic resource cost at the import parity price, however, is substantially lower than unity for all states, implying that Indian rice consumers benefit substantially more from the domestic production of rice than from importing it from the world market. The states in eastern India have a higher comparative advantage in rice cultivation than the technologically progressive states because of the substantially lower cost of the dominant nontradable inputs, land and labor.

The comparative advantage in rice cultivation deteriorated during 1975-85 because of the removal of distortions in the rice market, but improved again during 1985-97 because of faster technological progress in West Bengal and Andhra Pradesh, the diffusion of farm mechanization, and economies in the use of fertilizer, pesticides, and seeds, particularly in Punjab. The technological progress has contributed to improving the comparative advantage by reducing the unit cost of production over time.

The unit cost has been reduced by about one-third in Punjab and by about 15% in Orissa, West Bengal, and Andhra Pradesh.

As India will need to produce more staple grains to meet the increase in demand emanating from the growth in population in the low-income states with a higher incidence of poverty, the priority for raising yields and increasing production should be given to states that still have low yields and a large technology gap. These are the states that have a higher comparative advantage in domestic production. Additional social benefits can be gained by generating productive employment in those states that have a low opportunity cost of labor, and empowering small and marginal farmers to meet the deficit in domestic food needs through self-cultivation of higher yielding varieties, rather than the option of obtaining the food from the market when they lack effective demand.

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Notes

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Appendix Table 1. Economic profitability in rice cultivation, Orissa (dollars per ton of output at current price).

	1975-76	1984-85	1996-97
Tradable inputs	21.60	17.70	22.57
Seeds	11.46	7.66	8.20
Fertilizers	7.04	5.37	10.41
Pesticides	0.95	0.44	0.17
Capital services	0.48	2.29	1.78
Interest charges	1.67	1.94	2.00
Nontradable inputs	66.94	74.74	81.73
Manure	5.97	5.02	4.52
Animal power	10.38	11.53	9.58
Human labor	23.63	33.01	38.91
Land rental	26.97	25.18	28.68
Total cost	88.54	92.43	104.30
Output price	118.02	106.08	124.43
Operational surplus	29.47	13.64	20.14
Surplus as percent of total cost	33	15	19

Appendix Table 2. Economic profitability in rice cultivation, West Bengal (dollars per ton of output at current price).

	1975-76	1984-85	1996-97
Tradable inputs	12.17	13.12	33.22
Seeds	7.16	5.09	4.09
Fertilizers	3.70	3.79	10.95
Pesticides	0	0.53	2.91
Capital services	0.12	2.02	12.73
Interest charges	1.19	1.76	2.54
Nontradable inputs	82.22	85.92	80.13
Manure	4.18	4.31	2.91
Animal power	21.84	15.32	8.04
Human labor	29.59	40.40	39.37
Land rental	26.61	25.88	29.81
Total cost	94.39	99.03	113.35
Output price	118.02	106.07	124.19
Operational surplus	23.63	7.04	10.84
Surplus as percent of total cost	25	7	10

Appendix Table 3. Economic profitability in rice cultivation, Andhra Pradesh (dollars per ton of output at current price).

	1975-76	1984-85	1996-97
Tradable inputs	30.31	3.35	42.70
Seeds	6.09	3.70	3.73
Fertilizers	13.60	15.40	18.71
Pesticides	0.95	3.26	2.37
Capital services	7.27	12.85	14.42
Interest charges	2.39	3.35	3.47
Nontradable inputs	65.16	78.43	87.10
Manure	6.09	4.67	2.46
Animal power	6.80	10.48	3.84
Human labor	21.12	32.57	39.09
Land rental	31.15	30.72	41.72
Total cost	95.47	116.99	129.81
Output price	118.02	106.07	124.19
Operational surplus	22.95	–10.92	–5.62
Surplus as percent of total cost	24	–9	–4

Appendix Table 4. Economic profitability of rice cultivation in Punjab (dollars per ton of output at current price).

	1974-75	1984-85	1996-97
Tradable inputs	67.14	71.13	60.71
Seeds	5.97	2.64	2.17
Fertilizers	14.56	16.90	19.45
Pesticides	17.90	15.93	8.38
Capital services	24.82	31.87	27.12
Interest charges	3.94	3.79	3.58
Nontradable inputs	67.54	54.93	57.72
Manure	1.31	2.20	1.27
Animal power	8.00	3.70	0.20
Human labor	33.17	26.32	18.46
Land rental	25.06	22.71	37.79
Total cost	134.73	126.06	118.43
Output price	118.02	106.07	124.19
Operational surplus	–16.71	–19.99	5.76
Surplus as percent of total cost	–12	–16	5

Comparative advantage of rice production in Sri Lanka with special reference to irrigation costs

M. Kikuchi, R. Barker, M. Samad, and P. Weligamage

By estimating the domestic resource cost, this paper examines the changes in the comparative advantage of rice production in Sri Lanka during the last three decades. Although dramatic increases in productivity because of the Green Revolution occurred in the 1970s, rice production in the major irrigation regime has had no comparative advantage throughout the period as long as the cost of new irrigation construction is taken into account. Even if the cost of new irrigation construction is treated as a sunk cost, rice production had no comparative advantage before the Green Revolution. Within one decade after the Green Revolution, rice production became highly socially advantageous relative to rice imports because of the irrigation infrastructure. However, the comparative advantage has been eroded since the country attained self-sufficiency in rice in the mid-1980s. At present, rice production is nearly on a par with the international rice market. It has lost the comparative advantage it once enjoyed in the 1980s but it has not fallen into an overt comparative disadvantage either.

The major factor that has been pushing down the comparative advantage of rice production in recent years is the increase in the wage rate. Under the condition that it is difficult for Sri Lankan rice to find a market in world rice trade, the only option for maintaining domestic rice production that is economically sound is to increase labor productivity by pursuing economies of scale, which require significant increases in farm size. The rice sector in Sri Lanka has already entered the difficult stage of agricultural development and faces adjustment problems.

Rice has been the single most important peasant crop in many developing countries in monsoon Asia, and it has long been an important national target for attaining rice self-sufficiency in the region's traditional rice-importing countries. Thanks to massive public investments in irrigation infrastructure since the 1950s and to the technological advances in rice farming, popularly heralded as the Green Revolution, that have taken place since the late 1960s, the major rice-importing countries in South and

Southeast Asia have experienced rapid increases in rice production and have attained, or nearly attained, the rice self-sufficiency target (Barker et al 1985, Pingali et al 1997). The attainment of rice self-sufficiency and the concomitant declines in the crop's price have helped Asia's developing countries to experience rapid economic development.

How has this development process in the rice sector and the economy as a whole changed the comparative advantage of rice production in the developing countries of the Asian tropics, particularly in those that used to be rice importers? What are the future prospects for the comparative advantage of rice production in these countries? Taking Sri Lanka as an example, we try to shed light on these questions by examining the historical changes in the comparative advantage of rice production and by estimating the domestic resource cost (DRC)[1].

Definitions, data, and assumptions

Comparative advantage

According to Chenery (1961), a country has a comparative advantage in producing a good, rice in our case, if the social opportunity cost of producing a unit of rice in that country is lower than its international price. Using the concept of net social profitability (NSP) in the cost-benefit analysis, his definition can be paraphrased as follows. The social benefit of producing a unit of rice is evaluated using the shadow price. Since the shadow price of a tradable good, such as rice, is its international price, the social benefit of producing rice domestically is nothing but the amount of foreign exchange that can be earned when the country exports a unit of rice. On the other hand, the social opportunity cost of rice produced in a country is the value of domestic resources and tradable inputs that are used for producing a unit of rice, evaluated at their shadow prices. If the social benefit of rice is larger than its social opportunity cost or, equivalently, if the NSP, defined as the difference between the social benefit and the social opportunity cost, is positive, it is said that rice has a comparative advantage.

Production inputs can be classified into two groups, tradable inputs and nontradable domestic resources, and expressed in equations:

$$\begin{aligned} \text{NSP} &= \text{B} - \text{C} \\ &= \text{P}_\text{w}\,\text{SER} - (\Sigma_\text{i}^\text{k}\,\text{a}_\text{i}\,\text{P}_\text{i}\,\text{SER} + \Sigma_\text{j}^\text{m}\,\text{b}_\text{j}\,\text{P}_\text{j}) \\ &= (\text{P}_\text{w} - \Sigma_\text{i}^\text{k}\,\text{a}_\text{i}\,\text{P}_\text{i})\,\text{SER} - \Sigma_\text{j}^\text{m}\,\text{b}_\text{j}\,\text{P}_\text{j} \qquad (1) \end{aligned}$$

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[1] Two studies estimated the DRC of rice production in Sri Lanka: Edirisinghe (1991) and Shilpi (1995). The results of their estimations are in contrast: the former indicates some comparative advantage, whereas the latter insists upon no comparative advantage at all. A common defect in these two studies is that they used data obtained at one time point. This is a particular problem in the DRC estimation of agricultural crops that exhibit great varieties in yields over time. Such is the case of rice in Sri Lanka. One time-point estimate also makes it difficult to know the direction of change in comparative advantage over time. We try to overcome these defects by dealing with a long-term trend in rice production.

where NSP = net social profitability of producing a unit of rice, B = social benefit of producing a unit of rice, C = social opportunity cost required to produce a unit of rice, P_w = international price of rice in foreign currency, SER = shadow exchange rate, a_i = input coefficient of ith tradable input to produce rice, P_i = shadow price of ith tradable input in foreign currency, b_j = input coefficient of jth domestic resource to produce rice, and P_j = shadow price of jth domestic resource.

Rice production has a comparative advantage when

$$B > C, \text{ or } P_w \, SER > (\Sigma_i^k \, a_i \, P_i \, SER + \Sigma_j^m \, b_j \, P_j).$$

Now, define a SER such that NSP = 0. Denoting the SER satisfying this condition as SER*, we obtain from equation 1

$$SER^* = \frac{\Sigma_j^m \, b_j \, P_j}{(P_w - \Sigma_i^k \, a_i \, P_i)} \qquad (2)$$

This SER* is called the domestic resource cost (DRC). From equations 1 and 2, it is obvious that, if SER > SER* and NSP > 0, rice production has a comparative advantage. More conveniently, obtaining the resource cost ratio (RCR) by dividing DRC by SER, rice production has a comparative advantage if RCR < 1.

By totally differentiating equation 1, we obtain

$$\begin{aligned} d(NSP) = {} & SER[d(P_w) - \Sigma_i^k \, P_i \, d(a_i) - \Sigma_i^k \, a_i \, d(P_i)] \\ & + (P_w - \Sigma_i^k \, a_i \, P_i) \, d(SER) - \Sigma_j^m \, P_j \, d(b_j) - \Sigma_j^m \, b_j \, d(P_j) \qquad (3) \end{aligned}$$

The sources of change in comparative advantage for a certain period can be assessed by inserting the respective variables into equation 3. The NSP, that is, the comparative advantage, is improved when the international price of rice and/or the SER rise. It is also improved when the international prices of tradable inputs, such as commercial fertilizers, and/or the shadow prices of domestic resources, such as labor, fall. Technical changes that decrease the input coefficients help the NSP improve.

Costs of rice production[2]

The data needed to identify changes in the input coefficients (a_i and b_j) in rice production over time are obtained from the cost of cultivation of agricultural crops (CCAC) compiled by the Department of Agriculture from 1978-79 to now. Since this series reports the costs of rice production by irrigation regime, the "major irrigation" regime and the "rainfed" regime, the DRC is estimated for these two regimes separately[3]. Selecting four districts for the major irrigation regime and two districts for the rainfed

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[2] See Kikuchi (2000) for more details on rice production costs used in this paper.

[3] There is a third regime, the "minor irrigation" regime, whose rice production cost data are not sufficient for making a reliable estimation.

regime,[4] we first estimate input coefficients by district and by regime and then aggregate them to the major irrigation regime and the rainfed regime at the national level using the area sown to rice as a weighing factor. To even out short-term fluctuations in production and prices, the estimation is based on five-year averages centering on four time points, 1980, 1985, 1990, and 1995. Since the cost structure differs little between the maha (the northeast monsoon) season and yala (the southwest monsoon) season, the average of the two seasons is used in the analysis.

The CCAC data cover the years of the post-Green-Revolution period. To extend our data series to the years of the pre-Green-Revolution period, we use the data on rice production costs collected by Jogalatnam et al (n.d.) in nine major irrigation schemes for the 1967-68 maha season. To overcome the difficulty arising from a single-season survey, of the nine schemes, we select five as “typical” major irrigation schemes of normal-year conditions. For the major irrigation regime, therefore, the DRC is estimated for 1968 in addition to the above four years.

Prices

There is a consensus that the quality of rice produced in Sri Lanka is roughly equivalent to Thai 25% broken (Edwards 1993, Shilpi 1995), so we take the Colombo C&F equivalent of the FOB price at Bangkok of Thai 25% broken as the border price of rice (P_w). The shadow prices of tradable inputs (P_i) are estimated by applying the respective implicit tariff/subsidy coefficients to the domestic prices. The implicit tariff/subsidy coefficient of urea is obtained by estimating its border price based on its FOB price in Europe, then adjusting for freight and insurance. The same tariff/subsidy coefficient is assumed for other fertilizers. For seed paddy, the nominal protection coefficient for rice is used as the implicit tariff/subsidy coefficient. For the rest of the tradable inputs, the implicit tariff/subsidy coefficients used by Shilpi (1995) are adopted. For all the tradable inputs, their domestic components are estimated by adopting their percentage shares used by Shilpi (1995). Edirisinghe (1991) is also referred to on these aspects to check the reliability of the data used by Shilpi (1995).

The domestic (nontradable) resources used in rice production are labor, buffalo, land, and the interest earned on funds used in the production process. For labor inputs and buffalo service, the market prices are taken as their shadow prices (P_j). In other words, we assume that the markets for these domestic resources are working reasonably well.[5] No price data are available for land and capital interest in the cost of

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[4] The four sample districts selected for the major irrigation regime are Polonnaruwa, Kalawewa, Kurunegala, and Hambantota, and the two sample districts selected for the rainfed regime are Kurunegala and Galle.

[5] Symptoms of high unemployment rate in the rural areas, however, suggest the opposite. One may wonder if the assumption of well-working rural labor markets in Sri Lanka is tenable. Recent World Bank studies (World Bank 1995, 1996), however, find that the rural labor markets function far better than traditionally expected. There are some signs, besides those mentioned in these studies, that indicate a rapid integration of rural labor markets into the national labor market in recent years. For example, the variation of wage rates in rural labor markets across different regions, which used to be large until the early 1990s, has decreased significantly in recent years. In terms of five-year averages, the coefficient of variation (CV) of agricultural wage rates among the sample districts taken for our study was as high as 18% in 1990, but declined to a mere 8% in 1995. The CV was 18% in 1980 and 16% in 1995. Therefore, we do not make such an assumption as the shadow price of labor being 60% of the market wage rate, the assumption made by Edirisinghe (1991) based on the convention adopted by the National Planning Division of the government.

production surveys used in this study. It is hazardous to estimate the shadow price of land devoted to rice production, partly because of the paucity of available information and partly because of the malfunctioning land market. In this study, we try to evaluate the shadow value of land service by the factor share of land in rice production estimated as the residual after subtracting the nonland costs from the output value. The residual is supposed to consist of the returns to land and farmers' management, and profit. The residual represents the upper bound of returns to land, as long as the nonland costs are valued properly and the profit is close to zero as is supposed to be so in the long-run equilibrium. Following Shilpi (1995), the interest rate in rural areas is assumed to be 30% per year.

Shadow exchange rate

The shadow exchange rate (SER) is another variable hazardous to determine. Bhalla (1991) estimates that the official exchange rate (OER) was overvalued by 15% for 1966-70. For the 1980s and 1990s, Shilpi (1995) estimates that the OER was overvalued by 16% in the early 1980s and by 10% in the early 1990s. Edirisinghe (1991) assumes a 10% overvaluation of the OER around 1990 based on information from the National Planning Division. On the basis of these studies, let us assume 16% overvaluation for 1968, 1980, and 1985 and 10% for 1990 and 1995.[6]

Irrigation costs[7]

Irrigation has been the most critical factor determining the productivity of rice production in Sri Lanka. Considering its importance, we estimate the DRC for the major irrigation regime by four different levels of irrigation costs: (1) operation and maintenance (O&M) cost alone, (2) cost for new system construction and O&M cost, (3) cost for major system rehabilitation and O&M cost, and (4) cost for water management improvement with minor rehabilitation and O&M cost.

The cost of O&M for major irrigation systems is assumed to be Rs 1,800 (US$ 35.10) ha^{-1} in 1995 prices, the level the Irrigation Department sets as the "desired level" of O&M expenditure ha^{-1} for the major irrigation systems. It is assumed that this level of O&M activities can be carried out by using domestic resources. The cost of new irrigation construction is obtained based on the unit capital cost curve estimated from actual construction data.[8] For the cost of major irrigation rehabilitation, the unit cost of the Irrigation System Management Project (ISMP) implemented for 1987-92 is assumed. Among all the major rehabilitation projects implemented thus

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[6] It should be noted that the rate of currency overvaluation might have been higher than assumed here. Thorbecke and Svejnar (1987), for example, assume the rate of overvaluation on the order of more than 100% for the late 1960s based on the black-market exchange rate.

[7] For details on the estimation of public irrigation costs, see Kikuchi et al (2001a).

[8] The capital cost curve used is as follows: $\text{Ln } K = -106.3 + 0.0569\ t$, where K = capital cost ha^{-1} of new irrigation construction in 1995 prices (in Rs 000) including capital interest (10% y^{-1}) and t = time in years (Kikuchi et al 2001a).

far in Sri Lanka, the ISMP gives the least unit rehabilitation cost. The cost of minor rehabilitation is assumed to be the average of the two water management improvement projects with minor physical rehabilitation analyzed in Aluwihare and Kikuchi (1991).

For all these investment costs, the capital cost is annualized by applying the interest rate of 10% that is widely applied in this kind of study. The GDP implicit deflator for construction is used for all types of irrigation expenditures to convert the costs in constant prices to those in the years under study. The multiple cropping ratio of 1.4, the average for the major irrigation systems after 1980, is assumed for all types. Irrigation projects use traded as well as nontraded goods. The percentage share of traded goods in the total costs is assumed to be 7% for the new construction project and 27% for the major rehabilitation project, based on Shilpi (1995). The same share as for the major rehabilitation is assumed for the minor rehabilitation. Evaluation by shadow prices of these tradable goods used in the irrigation projects is made by applying the implicit tariff rates assumed in Shilpi (1995): 0% for the new construction and 20% for the major rehabilitation project.

In addition to the four levels above, which are all public investments/expenditures, we try to estimate the DRC with farmers' private investments in tubewells and pumps to irrigate their paddy fields in major irrigation schemes. The costs of tubewells and pumps are obtained from Kikuchi et al (2001b). Since these wells and pumps operate in major irrigation schemes, the O&M cost is added to their costs. Because of data limitations, the DRC estimation for this case will be made only for 1995. With water from tubewells and pumps in addition to surface water, rice yield is assumed to be 15% higher than without these facilities.

Development of rice production

The dramatic development of rice production in Sri Lanka over the last five decades can best be demonstrated by the changes in the rate of self-sufficiency in rice (Table 1 and Fig. 1). Just after independence in 1948, the country produced only 36% of the total rice requirement. In the mid-1990s, the rate of self-sufficiency was more than 90% and rice was even exported in some years. Sri Lanka has been enjoying virtual self-sufficiency in rice for the last two decades. For the national policy target of attaining rice self-sufficiency, Sri Lanka has achieved remarkable success.

Before and during the Green Revolution

Increases in rice production had been particularly rapid until 1980 (Table 1). This rapid development was due to the development and diffusion of the new rice technology. Unlike other countries in the Asian tropics where the Green Revolution in rice began in the late 1960s with the release of IR8 from the International Rice Research Institute in the Philippines, the seed-fertilizer revolution in Sri Lanka commenced much earlier—in the 1950s (Anderson et al 1991). Improved rice varieties (H series, called old improved varieties) were locally developed and began to be diffused in the late 1950s, and another series of improved varieties (BG series, called new improved

Table 1. Selected statistics on the rice sector in Sri Lanka, 1950-95.[a]

Year(s)	Paddy yield (t ha^{-1}) (1)[b]	Paddy harvested area (000 ha) (2)	Paddy production (000 t) (3)	Rice imports (000 t) (4)	Rice exports (000 t) (5)	Rice self-sufficiency rate (%) (6)[c]	Per capita rice consumption (kg) (7)[d]	MV ratio (%) (8)[e]	Nitrogen per ha (kg) (9)
1950	0.90	399	360	649	0	36	90	0	1
1960	1.58	547	864	739	0	54	109	13	12
1970	2.11	667	1,409	523	0	73	104	68	45
1980	2.56	807	2,065	271	3	89	107	87	82
1990	3.11	760	2,362	306	0	89	105	92	116
1995	3.12	791	2,473	244	23	92	100	96	136
Growth rate (% y^{-1})									
1950-60	5.8	3.2	9.2	1.3	–	4.2	1.9	–	27.8
1960-70	2.9	2.0	5.0	–3.4	–	3.1	–0.4	18.1	14.2
1970-80	1.9	1.9	3.9	–6.4	–	2.0	0.2	2.6	6.2
1980-90	2.0	–0.6	1.4	1.3	–16	0.0	–0.1	0.5	3.4
1990-95	0.1	0.8	0.9	–4.5	119	0.7	–1.0	0.8	3.3

[a] Five-year averages centering on the years shown, except for 1950. For 1950, 1949-51 average for (1) – (7) and 1950-51 average for (8) – (9). [b] (1) = (3)/(2). [c] (6) = (3)/[(3) + (4) – (5)]. [d] (7) = [(3) + (4) – (5)]/population. [e] The ratio of area planted with improved rice varieties (old and new) to total rice planted area.

Sources: See Aluwihare and Kikuchi (1991) except for (5). The data on rice exports are from FAOSTAT.

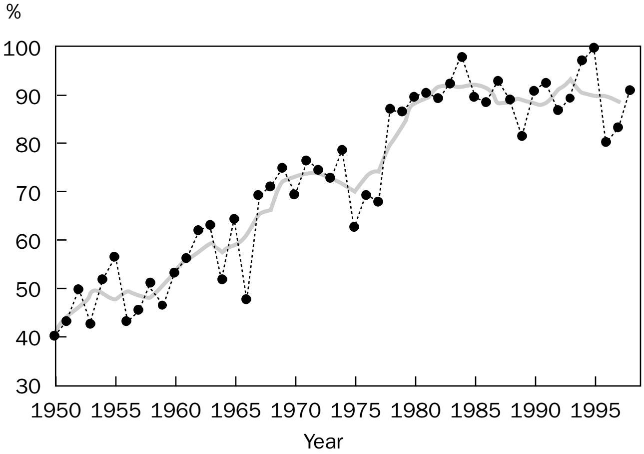

Fig. 1. Changes in rice self-sufficiency in Sri Lanka, 1950-98.

varieties), also locally developed, followed the old improved varieties after a decade. The diffusion of this Sri Lankan version of MVs and the corresponding increase in fertilizer intensity brought about rapid improvements in rice yield per hectare (Table 1).

Even more important than the Green Revolution technology for the dramatic increase in rice production in Sri Lanka has been the development of irrigation infrastructure since independence (Thorbecke and Svejnar 1987, Aluwihare and Kikuchi 1991). In pursuit of rice self-sufficiency, massive investments had been made toward the mid-1980s by the government, with more and more foreign assistance in later years, to renovate ancient tank systems abandoned in the medieval era and to construct new irrigation systems in the dry zone.[9] As shown in Figure 2, the share of irrigated area in the total area planted to rice increased from about 45% in the early 1950s to more than 70% in the mid-1990s. Particularly distinct was the significant increase in rice planted area irrigated by major irrigation schemes (schemes with a command area of more than 80 ha). It was on this irrigated land base that the Green Revolution technology was successfully introduced and diffused. At present, the irrigated rice planted area of about 70% produces nearly 80% of the country's total rice output.

Changes in input intensities in rice production by irrigation regime, estimated from the Jogalatnam and CCAC surveys, are presented in Table 2, together with land,

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[9] The irrigation sector took nearly 40% of the share in the total public investments around 1950, and the share was still as high as 20% around 1980 (Aluwihare and Kikuchi 1991).

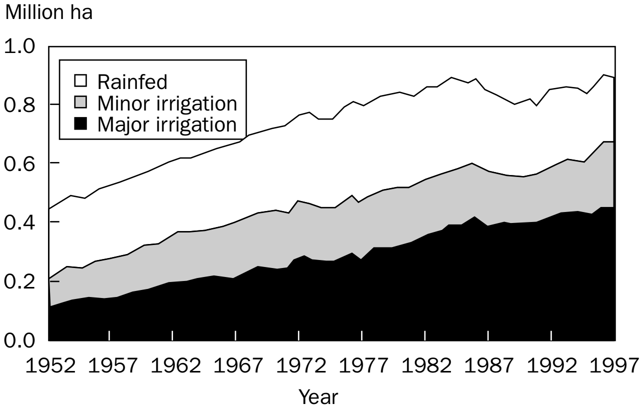

Fig. 2. Area planted to rice by type of irrigation regime in Sri Lanka, 5-year moving averages, 1952-97.

labor, and total factor productivities. For the major irrigation regime, major changes in rice production structure occurred from 1968 to 1980. The intensities of fertilizer and chemical inputs increased significantly. In that time, major rice varieties changed from traditional and old improved varieties to new improved varieties. The increases in fertilizer and chemical intensities reflect the nature of fertilizer and chemical use by the new improved varieties. Labor inputs per ha of planted area also increased about 40% from 1968 to 1980, suggesting the labor-absorbing nature of the seed-fertilizer technology. The effect of this technological change in rice farming on productivity was also substantial. Rice yield per ha (land productivity) increased by nearly two times and labor productivity improved in spite of the increase in labor intensity. Altogether, the total factor productivity increased by more than 60% in this period.

After the Green Revolution

The change of pace in the development of the rice sector after the virtual attainment of rice self-sufficiency in the mid-1980s is apparent. Though still increasing, growth in rice production has apparently decelerated since then (Table 1). This deceleration coincided to a large extent with the exhaustion of the yield potential of the Green Revolution technology. The land area planted to rice began to decrease in the mid-1980s (Fig. 2).

The deceleration in land productivity growth for the major irrigation regime in the 1980s and ’90s is obvious (Table 2). Fertilizer intensity continued to increase, but only marginally, and so did rice yield per ha. All this suggests that the yield potential of the seed-fertilizer technology had been exhausted by the early 1980s. On the other hand, some non-yield-increasing technical changes occurred. Most notably, land preparation by draft power was rapidly replaced by two-wheel tractors, which accompanied the substitution of capital services for labor. The quantity of seed paddy per ha showed a slightly increasing trend, reflecting the gradual shift in the method of crop establishment from transplanting to direct seeding. Since direct seeding requires less

Table 2. Rice yield, input intensities in rice production per ha of planted area, and productivities, Sri Lanka, 1968-95, by irrigation regime, averages of maha and yala seasons.[a]

		Input intensities									
Year	Rice yield (t)	Current inputs				Capital[e]			Labor (d)	Labor productivity (kg d^{-1})	Total factor productivity (index)
		Seed (kg)	Fertilizer[b] (kg)	Chemical[c] (L)	Fuel[d] (gal)	Buffalo (h)	2-wheel tractor (h)	4-wheel tractor (h)			
Major irrigation											
1968	2.00	103	172	0.2	10.6	156	0.0	6.0	102	20	61
1980	3.75	111	377	2.5	7.2	250	3.6	5.3	144	26	100
1985	4.04	116	382	2.5	5.9	138	17.5	4.3	130	31	111
1990	4.23	116	386	2.8	9.2	68	31.8	4.8	125	34	114
1995	4.44	128	422	2.9	11.6	3	37.2	5.0	107	42	123
Rainfed											
1980	2.65	104	380	1.7	1.2	174	3.0	0.7	129	21	100
1985	2.73	106	293	1.2	2.1	101	7.6	1.4	130	21	102
1990	2.60	113	277	1.6	4.4	116	11.1	2.9	116	22	95
1995	2.84	123	319	2.0	6.0	41	15.9	3.2	108	26	106

[a] Based on five-year averages centering on the years shown except for 1968. Estimated from the Cost of Cultivation of Agricultural Crops except for 1968. For 1968, from Jogalatnam (n.d.). [b] Simple summation of V-mix, urea, TDM, and other minor fertilizers. [c] Pesticides and herbicides in adzorin equivalent. [d] In diesel equivalent. [e] Sprayer services are included for 4-wheel tractor.

Source: Kikuchi (2000).

labor input, this technical change also contributed to reducing labor intensity. Underlying the adoption of these labor-saving techniques was the rise in agricultural wage rate relative to rice price and capital rental rates during the 1980s and ‘90s (Fig. 3). As a result, labor productivity grew much faster than land productivity, whereas the rates of improvements in total factor productivity were in between.[10]

The most notable change in the post-Green Revolution period is the decline in rice price (Fig. 4). In the international rice market, as the Green Revolution technology was adopted successfully in the developing countries in Asia starting in the late 1960s, the rice price in real terms peaked in the mid-1970s in terms of five-year moving averages, declined by the mid-1980s to a historic low level, and has shown no upward trend since then. The domestic rice price followed the world price, but the degree of decline was higher than that of the world price because of higher nominal protection rates in earlier years until the late 1970s. It is consumers who have received the benefits of the productivity increase in rice production in the form of a consumer surplus, in addition to the income transfer resulting from the reduction in the rate of protection for rice farmers.

Another important change that the rice sector in Sri Lanka faces is that consumers have been reducing their per capita consumption of rice since the mid-1980s (Fig. 5). During the early 1990s, rice tended to be replaced by wheat in food consumption, but,

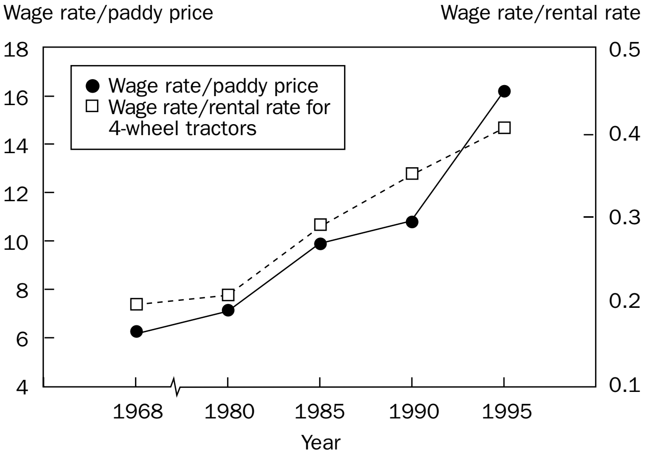

Fig. 3. Changes in real wage rate deflated by paddy price and wage-rental ratio, rice sector in Sri Lanka, 1968-95.

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[10] For the rainfed regime for which data are available only for 1980 and thereafter, there was no significant change in rice yield per ha. Fertilizer intensity was highest in 1980 when the fertilizer-rice relative price was lowest because of heavy fertilizer subsidies around that year. As in the major irrigation regime, the substitution of capital services for labor through tractorization and the labor saving from the gradual diffusion of direct seeding progressed. As a result, labor productivity improved, particularly in the 1990s, when increases in wage rate relative to rice and capital prices became more distinct. In terms of total factor productivity, however, rainfed rice farming has experienced little improvement in the last two decades.

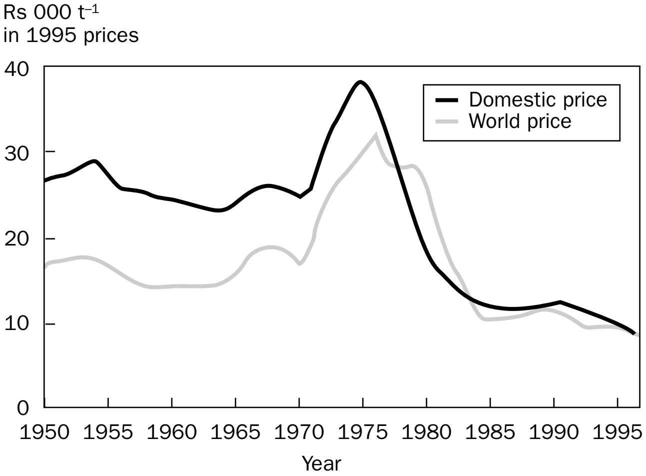

Fig. 4. World price (Colombo C&F price of Thai 25% broken) and domestic price of rice in Sri Lanka, deflated by gross domestic product deflator (1995 = 1), 5-year moving averages, 1950-97.

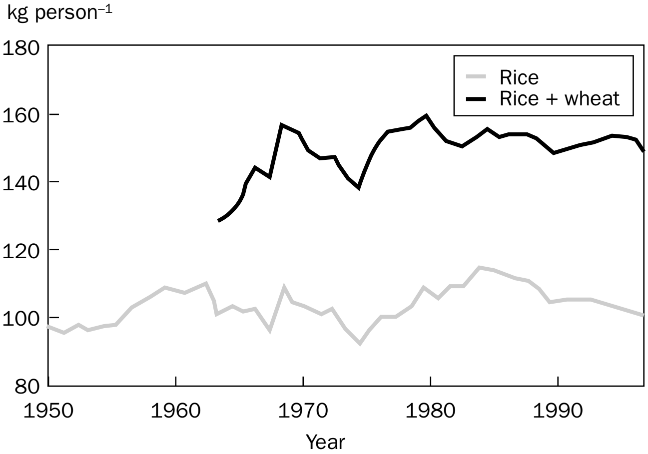

Fig. 5. Per capita consumption of rice and wheat in Sri Lanka, 5-year moving averages, 1950-96.

in recent years, the sum of rice and wheat consumption per capita has been declining. With a declining trend in per capita rice consumption, the overproduction of rice has been a real danger since 1990.[11]

The changes in the nominal protection rate (NPR) for rice shown in Figure 4 indicate changes in the policy stance of the government toward the rice sector. The

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[11] Sri Lankan rice is said to have quality that does not find a large demand abroad. If so, overproduction of some significant extent may create serious pressure in the domestic rice market.

NPR had been as high as 50–70% until the mid-1970s, suggesting a heavy bias toward protection in the government rice price policy. Around 1980, the rice sector was in the final approach in attaining self-sufficiency in rice and the government kept its traditional stance of boosting domestic rice production and protecting rice farmers by extending heavy subsidies for fertilizer and irrigation development, most notably the Accelerated Mahaweli Development Project. As the virtual self-sufficiency in rice was attained and the world rice price declined to the historic low level in the mid-1980s, the NPR became insignificant and has remained so thereafter. The fertilizer subsidy was given to rice farmers, but it was abolished in 1991 after the rate of subsidy had been reduced. It was restored again in 1994 by the new center-left government, but the rate of subsidy has been around 15%, much lower than the 40–70% in the 1970s and ’80s.

Changes in comparative advantage

The estimated domestic resource cost (DRC) and resource cost ratio (RCR) are presented in Table 3 by irrigation regime, together with the shadow exchange rate (SER). For rice production in the major irrigation regime, the estimation takes only O&M cost into account. Since the assumed level of O&M is the “desired level” with which major irrigation schemes are expected to sustain their operation for the designed usable life span of 50 years, we treat this as the basic case for the major irrigation regime.

It is estimated that the RCR for rice production in the major irrigation regime declined from 1.15 in 1968 to 0.58 in 1980, that is, rice production did not have a comparative advantage just before the adoption of the new improved varieties and associated seed-fertilizer technology, but, as the Green Revolution technology reached a high diffusion level, rice production turned out to have a comparative advantage later.[12] However, the comparative advantage diminished again toward 1990 and the RCR has been at about the breakeven level in the 1990s.

For the rainfed regime, data are available only in and after 1980. It is interesting to observe that, in spite of the much lower level of productivity, the level and trend of the RCR of the rainfed regime have been similar to those of the major irrigation regime. As a result, the RCR for the country as a whole, obtained by aggregating the RCR of these two regimes while assuming the average for the minor irrigation regime, followed more or less the same pattern as the major and rainfed regimes. For the rainfed regime and for the country as a whole, the RCR was far less than unity in 1980, increased but was still less than unity in 1985, increased to the breakeven level in 1990, and stayed nearly constant since then.

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[12] As explained earlier, the rate of adoption of old improved varieties (H series) that had been diffused since the late 1950s exceeded 50% by the late 1960s. The finding here suggests that the actual productivity effect of this H series was not as high as that of the new improved varieties (BG series) that began to be diffused in the late 1960s.

Table 3. Domestic resource cost (DRC), shadow exchange rate (SER), and resource cost ratio (RCR) of rice production by irrigation regime, Sri Lanka, 1968-95.[a]

Year	DRC (1)	SER[b] (2)	RCR (1)/(2)
Major irrigation[c]			
1968	7.4	6.4	1.15
1980	11.9	20.4	0.58
1985	26.2	31.0	1.85
1990	41.3	42.5	0.97
1995	56.0	57.9	0.97
Rainfed			
1980	12.0	20.4	0.59
1985	30.7	31.0	0.99
1990	44.7	42.5	1.05
1995	55.7	57.9	0.96
All country[d]			
1980	11.9	20.4	0.59
1985	28.1	31.0	0.91
1990	42.6	42.5	1.00
1995	55.9	57.9	0.97

[a]Five-year averages centering on the years shown. Average of maha and yala seasons. [b]Assumes 16% overvaluation in the exchange rate in the 1980s and earlier and 10% overvaluation in the exchange rate in the 1990s. [c]The ideal level of operation and maintenance expenditure is included as cost (Rs 1,828 ha^{-1} y^{-1} in 1995 prices). [d]Aggregated using the rice production in each regime as weights, while assuming the average of the two regimes for the minor irrigation regime.

Since the DRC estimates are subject to an unknown degree of statistical error, we have to be careful in drawing some conclusions from the results. However, for the periods in and after 1980 for which data are relatively more reliable, it would be safe to conclude that rice production in Sri Lanka definitely had a comparative advantage around 1980. The advantage has been eroded in the last two decades, but the rice sector does not face an overt comparative disadvantage yet. It may be worth emphasizing that rice production in the major irrigation regime that shares about 70% of the total rice production of the country is still socially profitable, as long as the investment costs of constructing these major irrigation schemes are treated as sunk costs.

Our results suggest that rice production had no comparative advantage before the diffusion of Green Revolution technology based on the new improved varieties began in the late 1960s. With the SER that was lower than the OER by 16%, the RCR in 1968 is estimated to be 1.15. It should be remembered that the reliability of data for 1968 is weaker than for the years in the 1980s and ’90s. In particular, the RCR depends critically on the rate of overvaluation of the OER. To the extent that the overvaluation had been larger than the level we assume, the RCR would have inched down toward unity, and, for the rate of overvaluation larger than 34%, it turns out to be less than unity. However, these results, coupled with the fact that the nominal protection rate for rice was extremely high in the 1950s and ’60s, seem to be sufficient to support our conjecture that, in the earlier years before the advent of the Green Revolution technology, rice production in Sri Lanka used to have a comparative disadvantage, but this situation improved significantly toward 1980.

How are the conclusions for the major irrigation regime modified, if other costs of irrigation are taken into account, in addition to the O&M cost? Table 4 presents the results of an RCR estimation that incorporates the cost of new construction/rehabilitation of major irrigation schemes. The cost of new construction refers to the investment costs for constructing new major irrigation schemes. New irrigation construction projects in Sri Lanka began just after independence at relatively easier sites and moved to more difficult ones (Aluwihare and Kikuchi 1991). The cost escalation of new construction involved in this process is reflected in our estimation.

As mentioned earlier, a newly constructed irrigation scheme is expected to continue its operation for several decades, if it is operated and maintained adequately. As in other developing countries, however, the O&M of these irrigation schemes has rarely been adequate, resulting in rapid deterioration in their quality and performance after their construction. Irrigation rehabilitation aims at restoring the quality of deteriorated schemes, or modernizing them, to a level higher than the original design. Rehabilitation projects can be grouped into two depending on their emphasis: major rehabilitation if the emphasis is more on improving the physical structures of irrigation schemes requiring higher unit project costs and minor rehabilitation if the emphasis is more on improving the management or institutional aspects of irrigation schemes requiring lower unit project costs. Since the need for these rehabilitation projects arose in and after the 1970s, in Table 4 the RCR estimates with the rehabilitation cost are given for 1980 and thereafter.

The inclusion of the new construction cost increases the RCR of rice production in the major irrigation regime drastically. Except 1980, when the RCR became closer to unity, throughout the period under study, it has far exceeded the breakeven level. This finding suggests that new irrigation construction in Sri Lanka has not been justified economically from the comparative advantage point of view since three decades

Table 4. Resource cost ratio of rice production under the major irrigation regime by type of irrigation investment, Sri Lanka, 1968-95. [a]

Year	O&M[b]	New construction[c]	Rehabilitation[d] alone	
			Minor	Major
1968	1.15	1.79	–	–
1980	0.58	1.11	0.59	0.62
1985	0.85	2.53	0.87	0.94
1990	0.97	3.46	1.00	1.07
1995	0.97	4.99	1.00	1.08

[a]Assumes overvaluation in the exchange rate of 16%, 16%, and 10% for 1968, the 1980s, and the 1990s, respectively. Five-year averages centering on the years shown. [b]O&M = operation and maintenance, with the ideal level of O&M expenditure. [c]The cost of constructing new irrigation systems in addition to O&M. [d]The cost of rehabilitating irrigation systems in addition to O&M.

ago or even earlier. This statement is unambiguously accepted for the years since the mid-1980s. With the escalation in investment cost for new irrigation construction in recent decades, particularly after the Accelerated Mahaweli Project began (Kikuchi et al 2001a), it is impossible to justify any large-scale new irrigation construction project as long as the new scheme is meant for rice production alone as before.

Likewise, the statement appears to be maintained with certainty for the 1960s and earlier. The RCR in 1968 is estimated to be 1.79 under the assumption that the exchange rate was overvalued by 16%. Even if we adopt the overvaluation rate of 100%, the RCR is still more than unity. Another sensitivity test may be to substitute the new construction cost of 1950 for that of 1968 in the DRC estimation. With the 1950 cost, which is less than one-third of the 1968 cost in real terms, the RCR is still as high as 1.4 under the assumption of the overvaluation rate of 16%. Combining this with the fact that the world rice price in the late 1960s was at its highest peak in the last four decades (Fig. 4), it is highly unlikely that rice production in the major irrigation regime, if the cost of new irrigation construction is included, had a comparative advantage in the 1960s and earlier.

The RCR being 1.11 under the same assumption, whether rice production in the major irrigation regime had a comparative advantage around 1980, the heyday of the Green Revolution, is debatable. One could argue that an 11% excess over the breakeven level would be well within a possible error margin. One might also claim that, before the Accelerated Mahaweli Project that accelerated the increase in the cost in the 1980s, the new irrigation construction cost should have been much lower in the 1970s. The sensitivity test of substituting the construction cost of 1970 into the DRC estimation for 1980 gives an RCR estimate of 0.88, confirming that rice production in the major irrigation regime under the conditions prevailing in 1980 with the new irrigation construction cost of the pre-Mahaweli level has a comparative advantage.[13]

These evidences may not be sufficient to conclude that the Green Revolution in the 1970s changed the position of rice production in the major irrigation regime in Sri Lanka from a traditional comparative disadvantage to a comparative advantage even for the case including the cost of new irrigation construction. It is certainly the case, however, that the traditional comparative disadvantage decreased significantly around 1980 and, if rice production with the construction of major irrigation schemes had ever had a comparative advantage in its history, it should have been in this period.

The inclusion of the minor rehabilitation cost in addition to the O&M cost changes the level of RCR little. Therefore, there is no need to alter the conclusion derived from the RCR series with the O&M cost alone: as long as the new irrigation construction cost is treated as a sunk cost, the social profitability of rice production with minor rehabilitation, which was high in 1980, has eroded to a level at par between domestic production and imports. The addition of the major rehabilitation cost gives a similar result, though the RCR increases to a level slightly more than unity in the 1990s.

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[13] The same exercise with the new irrigation construction cost of 1975 gives an RCR of 0.98.

It should be remarked that the major rehabilitation cost assumed in this paper is taken from a major rehabilitation project that had the lowest unit rehabilitation cost among all the major rehabilitation projects implemented thus far in Sri Lanka. All other major rehabilitation projects had a unit cost 50% to 250% higher than the assumed level. This means that rice production in the major irrigation regime with major rehabilitation has no comparative advantage at present and that, with an increasing trend in the RCR, the situation will get worse in the future. The desired level of O&M maintains the major irrigation schemes for decades, but it is the major rehabilitation projects that make the reproduction of the existing irrigation schemes in the long run possible. Our findings imply that, with the present level of rice technology, rice production in the major irrigation regime, while rehabilitating the major irrigation schemes, will entail a net social loss to the country unless the efficiency of the major rehabilitation projects improves significantly.

Since around 1990, the use of groundwater by pumping up water from open dug wells set up in the command area has rapidly become popular under farmers' own initiative in some major irrigation schemes in the northwestern part of the dry zone. With higher rice yield made possible by better water control resulting from the conjunctive use of surface water and groundwater, the RCR in 1995 for the case that includes the cost of dug wells and pumps in addition to the O&M cost is estimated to be 0.88. Compared to the RCR of 0.97 for the case without the dug wells and pumps, the comparative advantage has improved considerably.[14]

What about factors that have brought about changes in the comparative advantage in rice production? The net social profitability (NSP) of rice production in the major irrigation regime including only the O&M cost is presented in Table 5 and the sources of changes in the NSP are shown in Table 6. Corresponding to the levels of RCR, the NSP is negative in 1968 and positive for all other years. The NSP was largest in 1980 and has followed a declining trend since then. The increase in NSP was thus substantial from 1968 to 1980.

The factor contributing the most to this improvement in comparative advantage was the depreciation of the exchange rate, followed by the increase in world rice price brought about by the food crises in the 1970s. The effect of a significant increase in productivity because of the diffusion of Green Revolution technology from 1968 to 1980 was reflected in the reductions in the input coefficients of domestic resources. The contribution of the reduction in land coefficient was particularly large, though the increase in land rent brought about by the increase in land productivity caused by the technological advance worked in the opposite direction. In Table 5, this effect of technological change is observed in the fact that the share of domestic resources in a unit of rice decreased considerably from 93% to 47% from 1968 to 1980.

From 1980 to 1985, the NSP in the major irrigation regime showed a large decline, mainly because of the decline in rice price in the world market as a result of the

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[14] Farmers use water pumped up from tubewells much more for high-value nonrice crops than for rice. For more details on the diffusion of tubewells and pumps in Sri Lanka, see Kikuchi et al (2001b).

Table 5. Net social profitability (NSP) of rice production, major irrigation regime, Sri Lanka, 1968-95.[a]

	1968		1980		1985		1990		1995	
	(Rs t^{-1})	(%)	(Rs t^{-1})	(%)	(Rs t^{-1})	(%)	(Rs t^{-1})	(%)	(Rs t^{-1})	(%)
Rice price[b] (1)	611	100	4,302	100	4,173	100	6,657	100	9,082	100
Tradable inputs										
Fertilizer	38	6	524	12	472	11	923	14	1,038	11
Capital[c]	45	7	98	2	158	4	322	5	570	6
Others[d]	36	6	181	4	234	6	410	6	655	7
Total (2)	118	19	804	19	863	21	1,656	25	2,263	25
Domestic factors										
Labor	200	33	702	16	1,138	27	1,991	30	3,151	35
Land	263	43	961	22	1,050	25	1,774	27	1,813	20
Others[e]	105	17	376	9	614	15	1,091	16	1,627	18
Total (3)	568	93	2,039	47	2,802	67	4,856	73	6,590	73
Total (4) = (2) + (3)	686	112	2,843	66	3,665	88	6,512	98	8,853	97
NSP (1) – (4)	–76	–12	1,460	34	508	12	145	2	228	3

[a] Computed from Table 3. Five-year averages centering on the years shown. [b] Farm-gate equivalent border price of rice (in terms of paddy) converted to rupees by shadow exchange rate. [c] Two-wheel and 4-wheel tractors. [d] Seeds, agrochemicals, and fuel. [e] Buffalo, capital interest, irrigation (operation and maintenance), and domestic resource components in the marketing process of tradable inputs.

Table 6. Sources of change in net social profitability (NSP) of rice production (Rs t^{-1}), major irrigation regime, Sri Lanka, 1968-95. [a]

Variables	1968-80	1980-85	1985-90	1990-95
Change in NSP	1,535	–952	–363	83
Social value added				
Exchange value added	1,787	1,355	1,290	1,816
Rice price	1,488	–1,811	810	6
Input prices[b]	–290	248	–341	50
Input coefficients				
Biochemical inputs[c]	–38	28	8	–19
Mechanical inputs[d]	60	–8	–75	–35
Total	22	20	–67	–55
Total	3,006	–189	1,691	1,818
Social costs (deduct)				
Labor coefficient	–113	–171	–131	–552
Wage rate	616	606	984	1,712
Land coefficient	–434	–75	–66	–89
Land rent	1,132	164	790	128
Others[e]	271	239	476	536
Total	1,471	763	2,054	1,735

[a] Based on five-year averages shown in Table 5. [b] All tradable inputs combined. [c] Seeds, fertilizers, and chemicals. [d] Two-wheel tractor, 4-wheel tractor, and fuel. [e] Same as footnote *e* of Table 5.

success of the Green Revolution and irrigation development in the preceding decades in many developing countries in Asia including Sri Lanka. The absolute level of NSP as well as its change has become negligible since the mid-1980s; the continued depreciation of the exchange rate contributed to the amelioration of the comparative advantage, while increases in social costs counterbalanced this movement.

The stagnation of yield-increasing rice technology since the mid-1980s has been evident in the negligible changes in land coefficient. Instead, the reduction in labor coefficient because of the adoption of labor-saving technology has become increasingly important. Most noteworthy in recent years is the fact that the increase in wage rate has become a major factor that reduces the comparative advantage of rice production. In fact, the gain from the reduction in exchange rate was nearly canceled out by the increase in wage rate in 1995. A slightly faster growth in the wage rate, a slower improvement in labor productivity, and/or a reduced pace in the depreciation in exchange rate will easily turn the balance against rice production in the major irrigation regime.[15]

To have some hunches about future prospects in the comparative advantage, the RCRs under the major irrigation regime, estimated for different levels of critical variables while assuming that all other variables except for the one under question remain at the 1995 levels, are shown in Table 7. *Ceteris paribus*, a 50% increase in the wage rate over the 1995 level would bring the RCR up to a level far more than unity even for the case including the O&M cost alone. An improvement in labor productivity by one-third gives an effect in the opposite direction of nearly the same magnitude.

The degree of effect on the comparative advantage given by the world price of rice is much higher than that of the wage rate and the labor coefficient. A 50% rise in the world price lowers the RCR from 0.97 to 0.58 for the O&M-alone case. If the world price of rice rises to the level that prevailed during the food crisis of 1973-81, three times higher than the level prevailing in the mid-1990s, the RCR for the case including the cost of constructing new irrigation schemes improves to 1.11, which was the level Sri Lanka experienced once around 1980, the heyday of the Green Revolution (Table 4). Such results may be taken as indicating that, should the rice price soar up in the world market in the long run, as many food-crisis advocates insist, the domestic rice supply would increase through increases in irrigation investments in rehabilitation/modernization of existing irrigation infrastructure or even in constructing new infrastructure, whose investments are endorsed by their high net social profitability.

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[15] Tables 5 and 6 present the results only for the major irrigation regime. The level and changing pattern of the NSP of rice production in the rainfed regime are surprisingly similar to those in the major irrigation regime in spite of the significant difference in productivity. In the 1980s and '90s, factors bringing about changes in NSP were fairly common between the rainfed and major irrigation regimes. Reflecting a higher input coefficient of tradable inputs, most importantly of fertilizer, than for rice production in the major irrigation regime, changes in their shadow prices in foreign currency had larger effects on the NSP in the rainfed regime. The effects of increases in wage rate and in labor productivity were even more pronounced in the rainfed regime.

Table 7. Resource cost ratio (RCR) of rice production under the major irrigation regime in 1995 for different levels of the international price of rice, the wage rate, and the labor coefficient.[a]

Price scenarios	O&M[b] alone	New construction	Rehabilitation	
			Minor	Major
RCR in 1995	0.97	4.99	1.00	1.08
Changes in				
International price of rice				
50% higher	0.58	2.67	0.60	0.68
100% higher	0.41	1.82	0.40	0.43
200% higher	0.29	1.11	0.27	0.31
30% lower	1.61	1.04	1.67	1.96
Wage rate				
50% higher	1.20	5.30	1.24	1.40
100% higher	1.44	5.61	1.47	1.64
Labor coefficient				
33% less	0.81	4.79	0.99	0.84
50% less	0.73	4.68	0.91	0.76

[a]The RCR is estimated for the assumed change in the variable, while assuming that all other variables remain at the 1995 levels. [b]O&M = operation and maintenance.

Actually, the world price of rice has been stagnating at the historic low level, or even declining, without showing any sign of rebound (Fig. 4). If this declining trend continues, the comparative advantage of rice production will certainly be lost. The world price of rice in 1999, which was more than 30% lower than the 1993-97 average, makes the RCR for the O&M-alone case as high as 1.6.

Indeed, should a food crisis arrive tomorrow, it would occur because of the low rice prices in the world market today. Figure 6 shows the trends in irrigation investments in Sri Lanka for the past half century. When comparing Figures 4 and 6, it is apparent that public irrigation investments have been driven by the level of the world price of rice. The total public investment in irrigation, including new construction, rehabilitation, and O&M, increased to an unprecedented high peak toward the mid-1980s. This jump in investment was induced by the jumps in the rice price in the world market in the 1970s because of the two food crises. Following the dramatic decline in the rice price since the late 1970s, the total public irrigation investment shrank dramatically from the mid-1980s to the mid-1990s.

It should be obvious from the extremely high RCR (i.e., the extremely low NSP) of rice production for the case including the cost of new irrigation construction that the government has had no incentive to invest in constructing new irrigation infrastructure under the circumstances prevailing since the mid-1980s (Table 3). It is therefore understandable that the new construction investment has shrunk drastically to a nearly negligible level. The fact that the investment in rehabilitating the existing irri-

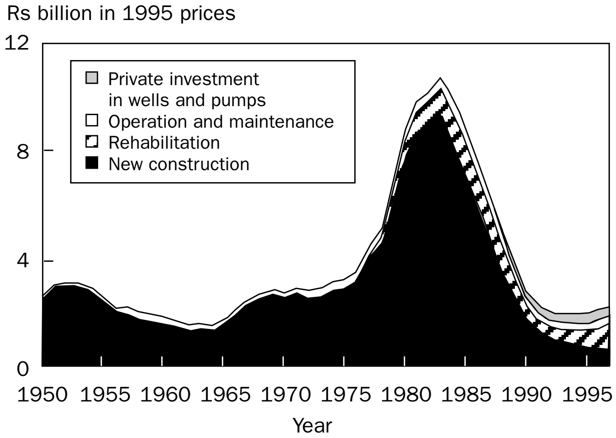

Fig. 6. Irrigation investments in Sri Lanka, 5-year moving averages, in 1995 constant prices, 1950-97.

gation infrastructure also decreased substantially from the mid-1980s to the early 1990s is less easy to explain, because the RCR for the case including the cost of rehabilitation did not become an overt disadvantage in the 1990s. In fact, Kikuchi et al (2001a) give rough estimates of the degree of underinvestment in irrigation rehabilitation as high as 50–60% in the early 1990s. The rehabilitation investment has shown an upward trend since the mid-1990s, but it was still underinvested by about 30% in 1997. Such estimates seem to suggest that the government and international donor agencies have overreacted to the low rice price, resulting in less-than-optimum rehabilitation investment.

Even more serious is the underspending on the O&M of the existing irrigation schemes. Since around 1970, the total O&M expenditure has been stagnant, or even decreasing, in spite of the positive NSP with O&M cost. Since a large tract of newly irrigated area was brought in by the investments made during the large investment peak in the 1980s, the actual O&M expenditure per ha of irrigated area has been declining rapidly, resulting in underspending as high as 60–70% in recent years (Kikuchi et al 2001a). Such a high degree of underspending on the O&M of the existing irrigation schemes continuing for a long time certainly results in a gradual quality deterioration of the schemes. This would in turn result in a deterioration of the comparative advantage of rice production through worsening input coefficients. Vulnerability thus accumulated gradually in irrigation schemes would eventually deprive the rice sector of resiliency in responding to the rise in the market price of rice. With such a situation prevailing not only in Sri Lanka but also in many other countries in monsoon Asia, a sudden rise in the rice price because of a demand-supply mismatch in a localized market could trigger a global food crisis.

Summary and implications

With few exceptions, insular or peninsular countries in the monsoon tropics in Asia used to be traditional rice importers. They were mostly exporters of estate crops, while importing rice. Many of these countries have actively pursued self-sufficiency in rice since the time of their independence in the late 1940s. Sri Lanka, among them, has attained the most outstanding success in this respect. Massive public investments in constructing irrigation infrastructure since the early 1950s and the diffusion of the Green Revolution technology since the late 1960s have been the major driving forces in achieving this success. This paper examined the level and trend in the comparative advantage of rice production in this development process with special reference to different types of irrigation investments. The major findings are summarized as follows:

1. Our estimation of the DRC indicates that, throughout the course of this development, rice production in the major irrigation regime has had no comparative advantage if the cost of new irrigation construction is taken into account. Drastic increases in productivity because of technological advances in the 1970s, together with the rise in rice price in the international market during the same decade, improved the social profitability of rice production considerably and might have given it a comparative advantage around 1980. However, the rapid cost escalation in new irrigation construction in the 1980s and thereafter that resulted from the shift of construction sites from easier to more difficult ones has made new irrigation construction out of the question from the comparative advantage point of view.
2. Even if we treat the cost of new irrigation construction as a sunk cost, taking into account only recurrent costs of operating and maintaining the existing irrigation schemes, rice production in the major irrigation regime had no comparative advantage prior to the diffusion of the Green Revolution technology. It is suggested that rice production in the rainfed regime also had no comparative advantage in those days. Within one decade after the introduction of the new seed-fertilizer technology, rice production in both regimes turned out to be highly socially advantageous relative to rice imports. Together with the possibility that rice production in the major irrigation regime even with the cost of new irrigation construction gained a comparative advantage during this period, our study demonstrates the profound effects that the Green Revolution technology had on rice production in Sri Lanka.
3. Given the irrigation infrastructure, the comparative advantage in rice production in the major irrigation regime has eroded since the time the country attained near self-sufficiency in rice in the mid-1980s. The same pattern has been followed by rice production in the rainfed regime. At present, rice production in Sri Lanka is nearly at par with the international rice market; it has lost the comparative advantage once enjoyed in the 1980s but it has not fallen into an overt comparative disadvantage either. This is so for rice production in the major irrigation regime even if the cost of minor rehabilitation projects is taken into

account. Even with major rehabilitation projects, the domestic resource cost ratio is not far above the breakeven level as long as the projects are implemented under reasonable conditions. The possibility of the conjunctive use of surface water and groundwater in major schemes by means of tubewells and pumps improves the comparative advantage considerably.

4. The major factor that has been pushing down the comparative advantage of rice production is the increase in the agricultural wage rate. As the nonrice sector, particularly the nonfarm sector, continues to develop, resulting in continuous increases in the real wage rate, the rice sector in Sri Lanka will lose its comparative advantage completely and certainly face, sooner or later, a worsening comparative disadvantage. Sri Lanka is thus returning to its traditional position of comparative disadvantage in rice production.
5. The world-rice-price elasticity of the comparative advantage is higher than the wage-rate elasticity, that is, a percentage change in the comparative advantage brought about by a percentage change in the international price of rice is larger than a percentage change in the comparative advantage brought about by a percentage change in the wage rate. Actual changes in the comparative advantage of rice production brought about by changes in the world rice price have been small in the 1990s, for the rice price has been stagnant at, or declining slightly from, the unprecedented low level that the international rice market experienced after the collapse of the commodity boom in the mid-1980s.

Of the findings above, the most important should be that Sri Lanka is losing its comparative advantage in rice production mainly because of the rise in the wage rate. This has been the case in many land-scarce Asian countries, typically in East Asia, but followed recently by many developing countries in rice-growing tropical Asia (Estudillo et al 1999). It is possible to counteract this declining trend in comparative advantage by increasing the productivity of rice production through some technological breakthrough, such as the Green Revolution three decades ago.[16] In the case of Sri Lanka, however, a large increase in domestic rice production resulting from such a technological breakthrough will almost immediately reach the consumption ceiling, forcing the country to face a serious rice surplus problem.

Under the condition that it is difficult for Sri Lankan rice to find a market in world rice trade because of its specific quality, the only option for maintaining domestic rice production that is economically sound is to increase labor productivity by pursuing economies of scale, which require significant increases in farm size. This necessitates the smooth transfer of domestic resources in the rice sector, labor in particular, to the rapidly developing nonfarm sector. This is a typical problem the peasant rice sector not only in Sri Lanka but in many other countries in Asia has to resolve in the adjustment phase of its agricultural development (Hayami 1988, Johnson 1991). The most important implication of this study is that the rice sector in Sri Lanka has already entered in this difficult stage of economic development.

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[16] This is a prescription given by Estudillo et al (1999) for the Philippines.

The most critical necessary condition for this structural adjustment in the rice sector to be successful is the existence of well-working labor and land markets, among others. The labor market in Sri Lanka works rather well (World Bank 1996), but the land market does not (Bloch 1995, Kikuchi 2000). The virtual nonexistence of the land market and persistent supra-economic values given to rice production in Sri Lanka would constrain the structural adjustment of the rice sector seriously. There will be a temptation for the government of developing countries like Sri Lanka to resort to the argument of multifunctional values of agriculture, now advanced primarily by industrialized countries in East Asia and the European Union in the face of the trade negotiations of the World Trade Organization, which may further blur the real need of this structural adjustment.

Rice policies in Sri Lanka have long been characterized by strong paternalism: the government is supposed to embrace and take care of all the rice farmers. Such a stance of the government is of course not suited at all in the adjustment phase. A clear change in the government stance toward rice production policies is most clearly observed in an interministerial policy proposal, in which it is discussed to apply rice production policies selectively to different groups of rice farmers with a view to strengthening the comparative advantage of rice production while avoiding overproduction (Ministry of Agriculture et al 2000). This makes it clear that the government is aware of the need to promote structural policies in the rice sector. But, how far the government succeeds in adopting necessary policies to promote, or in not adopting policies that are against, structural changes in the adjustment phase under the strong political pressure emanating from vested interest groups and agricultural fundamentalism is a different story.

Another interesting finding in this paper is that the rice-price elasticity of the comparative advantage of rice production is higher than the wage elasticity. This implies that the domestic rice supply would increase resiliently as the rice price rises in the international market. It is suggested, however, that the dynamic process of rice supply involving adjustments in irrigation infrastructure could not be perfectly reversible. The serious underinvestment in irrigation infrastructure, most notably in the O&M of the existing irrigation systems, resulted from the long-lasting low price regime in the international rice market, which might deprive the irrigation sector of this resiliency and be preparing conditions for future food crises. Adequate maintenance and appropriate rehabilitation of the existing irrigation infrastructure are a prerequisite for preventing the comparative advantage of rice production from falling into a disadvantage.

This paper also showed a possibility of improving the comparative advantage of rice production through the conjunctive use of surface water and groundwater. Indeed, the diffusion of tubewells and irrigation pumps has been quite rapid in Sri Lanka because of the high rate of return to well and pump investments by farmers (Kikuchi et al 2001b).[17] Since this diffusion began in Sri Lanka relatively recently, about a

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[17] As shown in Figure 6, the total private investments in tubewells and pumps far exceed the O&M expenditures at present.

decade ago, compared with other countries such as India, the overexploitation of groundwater has so far not become an overt problem. It is feared, however, that, if the rapid diffusion of tubewells and pumps continues, the groundwater resources in the country might be hurt irreversibly (Panabokke 1998). Together with increases in the urban and industrial demands for water, whether water becomes a constraint in the resiliency of the rice supply system in the long run must be studied carefully.

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Assessment of comparative advantage in rice cultivation in Bangladesh

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This paper examines the comparative advantage of rice using two indicators: net economic profitability and domestic resource cost ratio. The profitability estimates and estimated domestic cost ratio suggest that Bangladesh has a comparative advantage in rice production except for the upland aus crop and the deepwater aman rice. So, diversification in favor of nonrice economic activities for both uplands and extreme lowlands is socially justified. The comparative advantage in the cultivation of modern varieties is higher for wet-season aman rice, which is relatively low input-intensive, than for dry-season boro rice, although the average yield is substantially lower for the former than for the latter. Although there has been a substantial decline in the real rice price in both the domestic and world market, the comparative advantage has improved over the last two decades.

An analysis of comparative advantage can help in deriving meaningful policy conclusions on how to reorient farming systems toward economically efficient activities. Relative efficiency in production, as captured in comparative advantage analysis, depends on three factors: (1) technology (which determines production and influences rates of product transformation), (2) resource endowment (which affects the value of domestic resources such as land, labor, water, and capital), and (3) international prices (which directly determine the value of tradable inputs and output and indirectly influence the value of domestic resources).

Bangladesh, as a member of the World Trade Organization (WTO), is committed to the rules and regulations that the Uruguay Round (UR) applied to agriculture. The commitments cover a wide range of topics, including domestic support, market access, and export subsidies in agriculture. These commitments can be applied to commodities in various ways and the decisions made by the national authorities have a direct effect on agricultural production, processing, consumption, and trade. With multilateral trade negotiations to continue the reform process in agriculture expected to begin at the WTO soon, the importance of a thorough understanding of the consequences of these agreements has been recognized as a matter of urgency (Assaduzzaman 1999, Bakht 1999). This would also be an opportunity for Bangladesh to assess the implications of the UR agreements.

It is against this background that an exercise was undertaken to analyze the consequences of the UR agreements for the rice sector of Bangladesh. In undertaking this exercise, particular emphasis has been given to a thorough analysis of domestic support measures, import protection, and export subsidies in agriculture, as well as other UR-related issues (e.g., sanitary and phytosanitary, SPS, measures, trade-related aspects of intellectual property rights, TRIPs) that may influence the competitive position of Bangladesh agriculture. However, eventually, whether or not a country can take advantage of new trading opportunities would depend on its comparative advantage, without subsidies or with limited subsidies that are permitted for all trading partners by the rules governing the new trading environment.

Several studies estimated the comparative advantage of rice vis-à-vis alternative crops in Bangladesh for different ecologies and irrigation systems (Rahman 1994, Shahabuddin and Alam 1993, Morris et al 1997, Shilpi 1998, Shahabuddin 2000). Rahman used a rigorous methodology to estimate the equilibrium exchange rate, the border prices (world market prices adjusted for transport costs and trade margins) for various agricultural commodities and tradable inputs, and the opportunity costs of nontradable inputs, which were updated in the later studies. However, the weakness of these studies was that they used a fixed input coefficient (Zohir 1993) and applied price changes to assess the change in comparative advantage. Results available from large-scale sample farm household surveys, however, show that the use of labor in different crop varieties has been declining, while the use of chemical fertilizers and farm machinery has been on an upward trend. The point of departure for this study is the use of the estimated input coefficients from these surveys.

The second section of this paper discusses the methodology and sources of data used in the study. The major findings of the study, including an assessment of comparative advantage in recent years, are presented in the third section. The concluding observations are made in the fourth section.

Data and methods

Assessment of comparative advantage: methodology

Comparative advantage in the production of a given crop for a particular country is measured by imputing the value of production at the border price and comparing it with the social or economic opportunity costs of producing, processing, transporting, handling, and marketing an incremental unit of the commodity. If the opportunity costs are less than the border price, then the country has a comparative advantage in producing that crop. In most developing countries, social or economic profitability deviates from private profitability because of distortions in the factor and output markets, externalities, and government policy interventions that tend to distort relative prices. Comparative advantage or efficiency in Bangladesh agriculture is analyzed here using two indicators: (1) net economic profitability (NEP) and (2) domestic resource cost (DRC).

Net economic profitability. Financial profitability, which guides farmers' production decisions, is based on calculating the prices farmers actually receive or pay. These prices may diverge from the society's opportunity costs of inputs and outputs, as mentioned above, because of many distortions in the product and factor markets such as those arising from trade restrictions, government taxes or subsidies, monopoly elements in marketing, surplus labor conditions, and segmentation in the capital market. The results of an economic profitability exercise designed to assess the pattern of comparative advantage vis-à-vis financial profitability in crop production are reported here.

In this exercise, economic profitability of crops as distinct from private or financial profitability is estimated in terms of "net economic returns" per unit of cropped land measured in terms of a hectare, vis-à-vis net private or financial returns. The methodology followed is essentially an annualized version of the Little-Mirrless method of social cost-benefit analysis in which all costs and outputs are valued at their opportunity costs at border prices.

The estimation of net economic returns per unit of cropland is one way of looking at comparative advantage in terms of efficiency of resource use and land allocation for producing crops or crop mixes. However, to meaningfully interpret these estimates as an indicator of comparative advantage, it is necessary to know the nature and scope of competition or complementarity in the choice of crops. Although most nonrice crops compete for land in the dry season, there is not always a one-to-one substitution between the two crops. In some cropping patterns, the substitution of one dry-season crop for another may also entail changes in the choice of crops in other seasons because of overlapping crop-growing seasons and agroclimatic factors. In such a case, the appropriate profitability comparisons would be among the year-round cropping patterns rather than among individual seasonal crops (Mahmud et al 1994).

Domestic resource cost. Although economic profitability provides a measure for assessing the relative efficiency of alternative cropping activities, a comparison of net returns per unit of land area is sometimes complicated by activities that may differ greatly in their intensity of input use. Hence, the information used for the economic profitability analysis is used to calculate domestic resource costs (DRCs) for different crops. DRCs are unit-free ratios that express the efficiency of alternative domestic production activities by indicating the total value of domestic resources required to produce or save a unit of foreign exchange.

It can be mentioned here that the early practitioners of DRC analysis (Krueger 1966, Bruno 1967) calculated DRCs without explicitly estimating a shadow exchange rate; instead, they expressed economic (shadow) prices for domestic resources in local currency and economic (shadow) prices of tradable inputs in foreign currency, and ranked activities in terms of local currency costs per unit of foreign currency earned or saved. This "relative DRC" had the advantage of avoiding possible errors resulting from the incorrect calculation of the shadow exchange rate, but it could not be used to distinguish efficient from inefficient activities. However, more recent DRC practitioners (e.g., Srinivason and Bhagwati 1978, Scandizzo and Bruce 1980, Monke and Pearson 1989, and Tsakok 1990) have included the calculation of a shadow exchange rate, which allows all costs to be converted into a common currency. The resulting "absolute DRC" gives the same ranking as the relative DRC, but it has the additional advantage of incorporating the efficiency criteria. Interpretation of absolute DRCs is straightforward: efficient activities that contribute to national income have a DRC from 0 to 1, whereas inefficient activities that consume more domestic resources than they produce net value added to tradable goods and services have DRCs greater than 1.

The net economic benefit per unit of land is likely to be a more appropriate guide for the ranking of crops compared with that per unit (US dollar) of the domestic resources, which is what the inverse of the DRC coefficient essentially indicates (Scandizzo and Bruce 1980). However, the estimation of DRC can be a convenient method of generally assessing the comparative advantage of a single dominant crop in many Asian countries by indicating the economic profitability of keeping resources in its production instead of allocating them elsewhere (Anderson and Ahn 1984). In this study, comparing their advantages and disadvantages, we have decided to estimate both net economic returns per hectare (vis-à-vis net financial returns) and the DRC coefficients of different crop activities identified in our exercise.

Sources of data

The estimation of economic profitability or comparative advantage needs data on the following parameters: (1) input coefficients, (2) financial prices of crops and production inputs, (3) economic (shadow) prices of crops and production inputs, and the (4) shadow (equilibrium) price of foreign exchange.

Input coefficients. The data on input coefficients are derived from three large-scale nationally representative sample household surveys carried out at different times. The first survey was conducted by the International Fertilizer Development Center (IFDC) in collaboration with the Bangladesh Agricultural Research Council (BARC) from the aman 1979 to boro 1982 period with the main objective of identifying the nature of various farm-level constraints to fertilizer use and agricultural production (Sidhu et al 1982). The IFDC/BARC survey is the largest household-level survey ever conducted in Bangladesh, covering 2,400 randomly selected households from 16 out of 21 greater districts in Bangladesh. The input-output information on crops was collected from about 10,000 sample plots belonging to the selected households. Since the 1979 aman season was affected by severe droughts, we used the information for the 1980 aus to the 1981 boro period.

The second survey was conducted by the Bangladesh Institute of Development Studies (BIDS) in collaboration with the International Rice Research Institute (IRRI) from 1987 to 1988 with the objective of assessing the effect of the adoption of modern rice varieties on favorable and unfavorable rice-growing environments (Hossain et al 1994). A nationally representative sample was drawn using a multistage random sampling framework taking random samples at the union, village, and household levels. The survey covered 1,245 households from 62 villages belonging to 57 of the 64 districts. A detailed survey on input-output was undertaken for one parcel belonging to each of the sample households. The sample household was requested to provide information for the plot that was not affected by floods or droughts and for which the respondent could recall the input-output information.

The third survey was conducted by Socio-Consult Ltd. for an IRRI-sponsored study on the determinants of rural livelihoods in Bangladesh during 1999-2001. The survey was conducted in the same villages as under the 1987-88 study, but it selected 30 samples from each village using the participatory rural appraisal method of wealth ranking. The sample included the households covered by the 1987-88 survey. Again, the input-output information was obtained for one representative parcel not affected by natural disasters. For this study, we used the data from 32 villages for which the survey covered the aus 1999 to boro 2000 period.

The information obtained from the surveys on the use of two major inputs—chemical fertilizers and labor—is reported in Table 1. It can be noted that fertilizer use increased substantially in the cultivation of traditional varieties over the last two decades. The use of fertilizer in modern varieties was already high in 1980-81, increased further during the 1980s, but declined during the 1990s, particularly in the cultivation of rainfed modern varieties. The use of labor remained almost stagnant during the 1980s, but declined substantially during the 1990s in response to a faster increase in the wage rate in relation to output prices. The decline in labor use was compensated for, however, by the use of farm machinery, particularly for land preparation.

Financial prices of crops and production inputs. The financial profitability of different crops has been estimated using the set of financial prices (the actual market price received by farmers for outputs and paid-for inputs) during the three periods covered by the study (1980-81, 1987-88, and 1999-2000). The harvest prices of various crops were compiled from the Statistical Yearbooks published by the BBS for all years except for 1999-2000, whose prices were obtained from the sample survey for that period.

Table 1. Use of chemical fertilizers and labor in rice cultivation, 1980-81, 1987-88, and 1999-2000.

Crops	Chemical fertilizers (NPK kg ha^{-1})			Labor (d ha^{-1})		
	1980-81	1987-88	1999-2000	1980-81	1987-88	1999-2000
Wet-season rice						
Deepwater aman	3	4	24	126	137	118
Transplanted aman						
Traditional	23	42	55	135	136	93
Modern	75	146	86	181	170	119
Dry-season rice						
Aus, traditional	22	18	39	149	159	122
Aus, modern	99	162	83	213	233	120
Boro, traditional	7	–	–	210	198	160
Boro, modern	112	182	162	198	182	143

Sources: For 1980-81, BARC-IFDC survey; for 1987-88 and 1999-2000, BIDS-IRRI survey.

The financial profitability is estimated in this study on the basis of full-costing of inputs, that is, both cash-purchased and family-owned inputs are valued at market prices. In particular, the prevailing market wage rates have been used for valuing both family and hired labor. The wage rate was estimated for the specific crop variety from the survey data for 1987-88 and 1999-2000. Since the information was not available from the published report of the BARC/IFDC survey, we used a single wage rate for estimating the value of labor. The retail price of fertilizers was used to estimate the cost of fertilizer for 1980-81, but farm-level prices were used for 1987-88 and 1999-2000 using the household-level survey data.

Other financial costs incurred in crop production such as irrigation, pesticides, manure, and seeds/seedlings have been taken from the farm surveys. Appendix Table 1 presents the financial prices of different crops and production inputs used in this study.

Economic (shadow) prices of products and inputs. The choice of appropriate economic (shadow) prices for valuation of crop output should depend in principle on the assumption regarding whether additional output will be used for export or import substitution or domestic consumption. In practice, however, because of trade restrictions and a lack of market integration, it is not often easy to make a clear distinction in this respect. Hence, it may be worthwhile to derive profitability estimates under alternative assumptions. To avoid judgment, we have used both the import parity and the export parity price for rice. Since large amounts of pulses, wheat, spices, and oil are imported, the import parity price is the obvious choice for these crops. For jute, potato, and vegetables, we used the export parity price.

We have not estimated any import and/or export parity prices directly for this study either for crop output or for production inputs used in cultivation. Instead, the specific conversion factors (explicit or implicit) estimated in recent studies have been used to convert the financial prices into their respective economic (shadow) prices. The set of specific conversion factors estimated in different studies for both crops and production inputs is shown in Appendix Tables 2 and 3, respectively.

Shadow (equilibrium) price of foreign exchange. The extent of distortions in the exchange rate caused by trade policies can be measured by comparing the actual official exchange rate with the estimated free-trade equilibrium rate. The latter is an estimate of the exchange rate that would have prevailed in the absence of any trade interventions such as import tariffs, export taxes, and quota restrictions. Mahmud et al (1994) use a variant of the so-called “elasticity approach” developed by Krueger et al (1991) to estimate the equilibrium exchange rate for 1973-74 to 1990-91 based on the estimates of implicit import tariff and export tax rates along with the estimates of the price elasticity of import demand and export supply. Shilpi (1998) also uses the same approach to estimate the equilibrium exchange rates (and the extent of overvaluation in domestic currency) for 1986-87 to 1996-97. The overvaluation of the Bangladesh taka was estimated at 22% for 1980-81, 18% for 1987-88, and 10% for 1996-97. It is observed that the misalignment in foreign exchange and hence the extent of overvaluation in domestic currency has declined considerably in the current period compared with the base period, following significant trade liberalization since the early 1990s. We did not do a separate calculation for 1999-2000, for which we used the estimate for 1996-97.

Results and discussion

Unit cost of production and profits

Table 2 reports the estimates of the unit cost of production (US\$ t^{-1}) and profit rates for different rice varieties as obtained from the surveys. In estimating the unit costs, we have included the imputed value of land by the rent paid by tenant farmers and the interest charges on working capital. For owner-operators, land is a sunk investment and hence they may not consider the imputed rent in making their production decisions. In Bangladesh, only about 22% of the land is transacted under tenancy contracts. So, owner cultivation is the predominant mode of production. For 1999-2000, the unit cost of production was the lowest in the cultivation of modern variety aman (wet season) and the highest in the cultivation of traditional aus (dry season). For the dry season, the unit cost was about 25% lower for modern varieties (boro) than for the alternative traditional varieties. For the wet season, the choices are often dictated more by the topography of the land than by the relative profitability of alternative technologies. In 1999-2000, the unit cost in the cultivation of modern variety aman was only 7% lower than that of the traditional transplanted variety and about 19% lower than that of the deepwater broadcast aman, which is grown in deep flooded land.

The unit cost of production increased during the 1980s for the wet-season crops and also for traditional aman because of the reduction in subsidies from agricultural inputs and the slow increase in rice yields. The modern-variety boro crop, however, benefited from the increase in yield because of technological progress as well as from the expansion of minor irrigation under the private sector, which contributed to the reduction in the cost of irrigation and to more stable yield. The unit cost declined

Table 2. Unit cost of production and profits in rice cultivation, 1980-81, 1987-88, and 1999-2000.

Season/varieties[a]	Unit cost of production (US\$ t^{-1})			Profits (price-cost) (US\$ t^{-1})		
	1980-81	1987-88	1999-2000	1980-81	1987-88	1999-2000
Wet-season						
Deepwater aman	167	184	135	33	38	5
T. aman TV	152	172	118	48	50	22
T. aman MV	132	150	110	68	44	30
Dry-season						
Aus TV	195	230	162	–27	–27	–28
Boro TV	174	134	157	21	54	–29
Boro MV	161	154	123	22	34	4
Rice (total)	157	163	120	33	35	12

[a] T. aman TV = transplanted aman traditional variety, MV = modern variety.

substantially during the 1990s because of faster technological progress. For rice as a whole, the cost declined from US$163 in 1987-88 to $120 in 1999-2000.

The reduction in cost, however, did not have a positive effect on farmers' profits because of an adverse movement in agriculture's terms of trade. For example, the nominal price of the modern-variety boro rice increased by only 22% from 1987-88 to 1999-2000, when the price of fertilizers increased by 57%, the wage rate increased by 96%, and the wholesale price index increased by 67%. The price of rice also increased at a slower rate than the value of foreign exchange. The exchange rate for US dollars increased at 61% over the period. The net effect was a substantial reduction in profit per ton in rice cultivation. The unit profit declined from $35 per ton of rice (paddy equivalent) in 1987-88 to only $12 for 1999-2000. The highest rate of profit was in the cultivation of the transplanted aman rice grown in the wet season on medium-high land.

Value added and effective protection

Table 3 shows the estimates of the value added at prices received and paid by the farmers, and at shadow prices and opportunity costs of inputs. The estimate of value added shows the returns to primary inputs after deducting the cost of material inputs from the gross value of production. The estimate measures the contribution of the farm activity to gross domestic product. Among the alternative crops grown during the wet season, the value added was the highest in the cultivation of modern-variety aman and the lowest for the deepwater aman. The value added was about 52% higher

Table 3. Value added and effective protection for rice and nonrice crops, 1999-2000.

Crop	Value added (US$ ha^{-1})			Effective protection coefficient	
	Farm-level prices	Economic prices			
		Import parity	Export parity	Import parity	Export parity
Rice					
Deepwater aman	198	262	171	–26	16
Transplanted aman					
Traditional	282	362	240	–18	18
Modern	428	552	363	–22	18
Traditional aus	163	214	136	–24	20
Modern boro	394	565	317	–30	24
Wheat	280	273	ne[a]	3	ne
Jute	344	ne	428	ne	–20
Pulses	227	337	ne	–33	ne
Oilseeds	207	168	ne	23	ne
Potato	997	ne	453	ne	120
Vegetables	737	ne	909	ne	–19
Spices	455	350	ne	30	ne

[a]ne = not estimated.

for modern-variety aman than for the transplanted traditional variety. The findings suggest that the transfer of land from the traditional to modern variety contributes to a substantial increase in agricultural income.

For the dry season, farmers have more flexibility in choosing from a basket of crops. The development of irrigation has induced farmers to grow modern-variety boro rice during this season, thus replacing the area under aus rice and sometimes some nonrice crops such as jute, pulses, and oilseeds. The area under modern-variety boro has increased from 1.0 million ha in 1980-81 to about 3.4 million ha in 1999-2000. Table 3 shows that the value added from modern-variety boro cultivation is substantially higher than from aus, pulses, and oilseeds, but substantially lower than for potato and vegetables. Thus, diversification out of rice in favor of high-value crops may be desirable to increase agricultural income.

The effect of the divergence of input-output prices from the world market is measured by the coefficient of effective protection. It is the ratio of the value added measured at border prices (for tradable inputs and output) and opportunity costs (for nontradable inputs) to the value added measured at prices received and paid by the farmers. The estimates of the effective protection rates are also reported in Table 3. At the import parity price for rice, the effective protection rates are negative, indicating that Bangladeshi rice consumers enjoy a subsidy from having rice from domestic production rather than from importing it from the world market. The rate of subsidy was about 27% for 1999-2000. At the export parity price, the effective protection rate was 24% for modern-variety boro and 18% for modern-variety aman, which contributed the most to the increase in rice production. These numbers suggest that rice farmers would have lost if they had exported rice in the world market rather than selling it in the domestic market. Thus, the policy of self-sufficiency through domestic production, instead of through participation in the world market, has clearly benefited both rice producers and consumers in Bangladesh.

For the nonrice crops, farmers enjoy considerable subsidy in the production of oilseeds and spices but are penalized in the production of pulses. For the exportable nonrice crops such as jute and vegetables, considerable negative protection benefits domestic consumers more than producers.

Financial and economic returns

Table 4 reports the estimates of financial and economic returns for 1999-2000. In obtaining these estimates, the inputed value of land rent was not included. So, the estimates are for owner-farmers. A review of the numbers confirms that the farmers in Bangladesh are efficient producers of rice for import substitution. When compared with financial returns, economic returns at the import parity price are substantially higher for all varieties of rice. However, at the export parity price, the situation is reversed and the economic gain of the adoption of modern varieties is now greatly reduced. Moving to an export price regime implies a considerable decline in economic profitability for all rice crops. Among the rice crops, the modern-variety aman has the highest economic profitability, higher than that of the irrigated modern-variety boro grown during the dry season. However, boro had higher economic profitability than its main competitive crops, traditional aus and deepwater aman. A comparison of financial and economic profitability shows that for most rice varieties profitability increased from 1980-81 to 1987-88 but declined from 1987-88 to 1999-2000 (Table 5).

Although both the financial and economic returns of jute are quite low compared with those of most varieties of rice (Table 4), it appears to have higher economic profitability than local aus, its main competing crop. Moreover, the economic returns are observed to be much greater than the financial returns, indicating its comparative advantage in production for export. Over the last ten years (between our base and current period), both the financial and economic returns of jute have increased significantly. However, the returns are still much lower than those of the high-yielding varieties of rice, implying that jute can compete only with local varieties of rice.

Table 4. Financial and economic returns in the cultivation of rice versus nonrice crops, 1999-2000 (US$ ha^{-1}).

Crop	Financial returns	Economic returns	
		Import parity	Export parity
Rice	203	376	178
Deepwater aman	87	176	84
Traditional aus	22	110	34
Traditional aman	143	260	138
Modern aman	266	432	242
Modern boro	215	425	177
Wheat	178	184	–
Jute	163	–	273
Oilseeds	148	118	–
Pulses	176	294	–
Potato	690	–	192
Vegetables	522	–	723
Spices	194	126	–

Table 5. Changes in financial and economic returns in rice cultivation, 1980-81 to 1999-2000 (US$ ha^{-1}).

Season/variety	Financial returns			Economic returns at import parity price		
	1980-81	1987-88	1999-2000	1980-81	1987-88	1999-2000
Wet season						
Deepwater aman	134	158	87	229	293	176
T. aman traditional	206	212	143	330	362	260
T. aman modern	354	285	266	530	481	432
Dry season						
Aus traditional	16	28	22	91	144	111
Boro modern	224	290	215	360	493	425
Rice (all varieties)	193	221	203	316	391	376

The profitability estimates show low economic returns when import substitution of edible oil is considered because of the strong protection provided to both oilseeds and edible oils in Bangladesh and the inefficiency of the local oil-milling industry in the country. An implication of this is that the country would be better off by directly importing edible oil rather than processing imported oilseeds. In recent years, the economic returns are observed to be positive when import substitution of both oil and oilseeds is considered, but they still remain below the financial returns and are much lower than those of all varieties of rice, including local aus rice, thereby hardly displaying any comparative advantage for import substitution of either edible oil or oilseeds (Shahabuddin 1999).

Pulses, unlike oilseeds, appear to be quite competitive as a nonirrigated rabi crop in terms of both financial and economic profitability. Not only are the economic returns greater than the corresponding financial returns for both import substitution and export, but the financial returns have registered an increase over the last decade. However, pulses have traditionally been grown in dryland soils during seasonal intervals and they do not compete with modern-variety boro, because profits, though reasonably high for a nonirrigated rabi crop, are much lower than those of high-yielding varieties of rice (even some local varieties of rice). This is why, although domestic prices are generally lower than the import parity price, the country is on the verge of switching from self-sufficiency to an import regime with substantial imports taking place in deficit years and lean seasons.

The profitability estimates show that vegetables appear to be highly competitive in terms of both financial and economic returns. All vegetables (except radish) have highly favorable financial returns when compared with rice, even those of high-yielding varieties. One would therefore expect these products to be better represented in the production pattern currently prevalent in the country. That this is not so may have to do with the perishable nature of the product. The economic profitability of vegetable products for export appears to be fabulously high compared with that of most other crops. However, these exports are constrained by a lack of experience with these crops in Bangladesh as well as a variety of marketing problems such as product quality, acceptable packaging, high transport costs, and market access.

The financial profitability of potato would appear to be very high (similar to that of other items in the vegetable category except radish) and this is especially true for the modern varieties. What is more significant is that the strong financial profitability has persisted over the last decade. The estimated economic returns under both import and export parity prices indicate that the production of modern varieties of potato has a strong comparative advantage for import substitution, but not for export, although some export possibilities perhaps cannot be ruled out.

Domestic resource costs

As mentioned earlier, although economic profitability (net economic returns vis-à-vis net financial returns as estimated here) provides an indicator of the relative efficiency of domestic production, DRC indicates whether the domestic economy has a comparative advantage in producing a particular crop relative to other countries, as well as relative to other crops that can be produced. Comparing net returns per unit of land area is sometimes complicated by crop activities that may differ greatly in their intensity of input use. Therefore, the information used for the economic profitability analysis has been used to calculate DRC for different crops. To estimate the DRC ratios, we have used the rental charges for modern-variety aman as the opportunity cost of land for crops grown during the wet season and the rental charge for modern-variety boro as the opportunity cost of land for the dry-season crops.

A DRC ratio of greater than 1 implies that the economy loses foreign exchange through domestic production of the crop (in the sense that it consumes more domestic resources than it generates net value added to tradable goods and services), while a DRC ratio of less than 1 implies that the production is efficient and makes a positive contribution to domestic value added. It can be noted here that a country may have several efficient production opportunities, but, to maximize economic growth, should pursue those for which it exhibits the strongest comparative advantage (i.e., the lowest DRC).

Table 6 reports the estimates of DRC ratios for rice and nonrice crops for 1999-2000. These estimated DRC ratios are generally consistent with the results of the economic profitability analysis discussed above. The DRC ratios are less than unity not only for the modern varieties but also for the traditional transplanted aman rice. A DRC value of greater than unity for the traditional aus and deepwater aman means that the society will gain by reallocating resources from the cultivation of these crops to other economic activities.

The highest comparative advantage is for the cultivation of rice during the wet season. The modern-variety boro rice yields higher than the modern variety grown during the aman season, but, because of the heavy use of tradable inputs such as chemical fertilizers and irrigation, the domestic cost ratio of the modern rice varieties cultivated during this season is higher than that of the varieties cultivated during the

Table 6. Estimates of domestic resource cost ratio for rice versus nonrice crops, 1999-2000.

Crops/variety	Import parity price	Export parity price
Rice	0.65	0.87
Deepwater aman	1.29	1.49
T. aman traditional	0.61	0.76
T. aman modern	0.58	0.71
Aus traditional	1.63	1.97
Boro modern	0.69	0.97
Wheat	1.02	ne[a]
Jute	–	0.69
Oilseeds	1.43	ne
Pulses	0.69	ne
Potato	ne	1.00
Vegetables	ne	0.64
Spices	1.12	ne

[a] ne = not estimated.

aman season. At the export parity price, boro has a higher DRC than the cultivation of pulses, vegetables, and oilseeds. In other words, Bangladeshi farmers are efficient producers of rice for import substitution. They may have some export potential for the aman crops. But boro would not be able to compete in the world market. If an exportable surplus is produced in the cultivation of boro rice, an economically justified policy recommendation would be to diversify out of boro to pulses and vegetables.

The change in DRC ratios in rice cultivation over the last two decades can be reviewed in Table 7. The DRC ratio increased for the aman rice crops during the 1980s, but remained almost stagnant during the '90s. But, boro rice, which had a substantial comparative advantage in the 1980s, lost ground during the 1990s because of its heavy use of tradable inputs, the increase in the opportunity cost of labor, and the sharp decline in real rice prices.

Concluding remarks

The comparative advantage of different crops analyzed in the preceding sections reflects the actual farming practices under existing technology and, to a large extent, current world market conditions relevant to the specific periods of analysis (base and current periods as considered in this study). Relative profitability and domestic resource cost ratios can, however, change with technological improvements and changes in world market conditions. Although technological innovations would be reflected in the physical production coefficients, the changes in conditions in the world market are likely to be captured in the projected border prices of crops traded in the international market. An analysis of the dynamic comparative advantage of different crops that takes into account technology potentials is needed to guide policymakers in the discussion on trade opportunities and optimum allocation of resources.

Table 7. Changes in the domestic resource cost ratio for rice, 1980-81 to 1999-2000.

	1980-81		1987-88		1999-2000	
Season/variety	Import parity price	Export parity price	Import parity price	Export parity price	Import parity price	Export parity price
Wet season						
Deepwater aman	0.84	0.94	0.76	0.94	1.29	1.49
T. aman traditional	0.56	0.64	0.56	0.74	0.61	0.76
T. aman modern	0.46	0.55	0.55	0.75	0.58	0.71
Dry season						
Aus traditional	1.45	1.70	1.13	1.42	1.63	1.97
Boro modern	0.64	0.88	0.57	0.89	0.69	0.97
Rice (all varieties)	0.59	0.72	0.59	0.83	0.65	0.87

Research and extension activities in the past were biased in favor of rice to the neglect of most other crops. The profitability of high-yielding boro rice has worsened while substantial improvements in both economic and financial profitability are observed for vegetables, potato, and pulses. This result suggests that a policy shift toward crop diversification out of boro rice may be socially desirable and would be financially profitable for farmers.

It can be emphasized here that diversification into nonrice crops would require intensification of rice production, which will ensure household food security and at the same time free land for other crops. Priority for technology development should be given to aman crops, whose level of technology remains low. Successful diversification would also require a substantial reduction in the variability of prices for both rice and nonrice crops. Dissemination of improved technology and better farming practices will require reorientation and improvement in the current research and extension system and strengthened linkages between research and development agencies.

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Appendix tables

Table 1. Changes in product and input prices (Tk per t), 1980-81 to 1999-2000.

Products and inputs	1980-81	1987-88	1999-2000
Products			
Aus rice	2,557	5,716	6,778
Aman rice	3,020	6,241	7,093
Boro rice	2,855	5,273	6,457
Wheat	3,048	5,201	8,727
Jute	3,267	7,933	8,386
Rape and mustard	7,797	11,095	13,964
Pulses	5,445	10,897	15,892
Potato	916	2,286	5,288
Inputs			
Urea	4,267	4,703	6,190
Triple superphosphate	4,267	6,641	13,130
Muriate of potash	3,220	4,031	9,530
Pesticides (Tk kg^{-1})	27.66	73.57	137.07
Wage rate (Tk d^{-1})	13.97	31.15	61.00
Exchange rate (Tk per US$1)	16.72	31.34	50.56
Price index (1969-70 = 100)	540	1,048	1,753

Table 2. Conversion factors for output prices.

Output	1980-81	1987-88	1999-2000
Rice			
Import parity	1.26	1.28	1.29
Export parity	0.95	0.83	0.88
Wheat, import parity	0.92	0.97	1.07
Jute, export parity	1.19	1.51	1.35
Rape and mustard, import parity	0.71	0.61	0.86
Pulses, import parity	1.37	1.31	1.31
Potato, export parity	0.95	0.71	0.71
Sugarcane, import parity	0.43	0.43	0.65
Vegetables, import parity	1.26	1.26	1.26
Spices, export parity	0.95	0.88	0.88

Table 3. Conversion factors for input prices.

Input	1980-81	1987-88	1999-2000
Fertilizer	1.37	1.18	1.37
Urea	1.31	1.10	1.39
Triple superphosphate	1.55	1.46	0.77
Muriate of potash	1.38	1.10	0.98
Pesticides	0.73	0.87	0.91
Irrigation	1.53	1.37	0.86
Animal power	0.83	0.87	0.91
Human labor	0.67	0.75	0.85

The comparative advantage of rice production in the Philippines, 1966-99[1]

J.P. Estudillo, M. Fujimura, and M. Hossain

This study aims to assess the comparative advantage of rice production in the Philippines since 1966. We have found that the country gained a sharp improvement in the comparative advantage of rice production in 1979, when yield rose markedly because of the diffusion of pest- and disease-resistant modern rice varieties. Beginning in 1986, however, the country appears to have slowly lost its comparative advantage because of the decline in rice prices, stagnation in rice yield, and rising cost of domestic factors such as land and labor. By 1990, the country completely lost its comparative advantage in rice production.

A country has a comparative advantage in the production of a good if the domestic cost of its production is lower than the import price. In such a case, resource savings are gained if the good is produced in the local economy. A comparative advantage in rice production exists in areas where the costs of domestic factors of production such as land, labor, and water are low. Based on the country findings, Barker and Dawe (this volume) conclude that "the comparative advantage in rice production appears to be shifting back to Asia's major river deltas, where water is plentiful and labor is cheap."

Assessing a country's comparative advantage in rice production is of major academic interest as well as policy significance because rice production competes for key production inputs—land, labor, and water—that could have been used in alterna-

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[1] This paper is an update of Estudillo J.P., M. Fujimura, and M. Hossain (1999), "New Rice Technology and Comparative Advantage in Rice Production in the Philippines," published in *The Journal of Development Studies*, 35(5):162-184. This paper is published with permission from *The Journal of Development Studies*. Views expressed in this paper do not reflect the views of the institutions to which the authors belong. The authors would like to thank Prof. Yujiro Hayami for his insightful comments on an earlier draft and Fe Gascon for providing an excellent data set.

tive production activities. This paper aims to evaluate the comparative advantage of rice production in the Philippines and identify the factors responsible for the changes in comparative advantage since the beginning of the Green Revolution in 1966.

This paper is organized as follows. The next section, "Data and methods," presents the conceptual framework, the definition and measurement of prices and exchange rates, sources of data, and sample characteristics. The "Results and discussion" section describes the technological progress in rice production and resource savings and the trends in comparative advantage and private profitability. The section "Factors determining the trends in comparative advantage" identifies the factors responsible for the trends in private and social profitability and the impact of government policies. Finally, the conclusions are summarized in the last section.

Data and methods

Conceptual framework

A well-established method of presenting comparative advantage is to measure domestic resource cost (DRC). DRC compares the opportunity costs or shadow prices of domestic resources used in production with the value added that they generate, that is,

$$\text{DRC} = \frac{\begin{array}{l}\text{Domestic resources and nontraded inputs required}\\ \text{to produce one unit of the good, valued at shadow prices}\end{array}}{\begin{array}{l}\text{net foreign exchange earned or saved}\\ \text{by producing one unit of the good domestically}\end{array}}$$

A country has a comparative advantage in the production of a commodity if the social opportunity cost of producing an incremental unit is less than the border price of the commodity (Pearson et al 1976). This definition of comparative advantage or social profitability is essentially a simplified cost-benefit analysis and is equivalent to the country's potential capability for export or import substitution.

To bring the numerator and denominator of the DRC to the same numeraire, we divide the numerator by the shadow exchange rate (SER), or a shadow price of foreign exchange, and define it as the resource cost ratio (RCR). RCR is simply DRC/SER.[2] The value of RCR is compared with unity in order to judge the comparative advantage of the Philippines in rice production. When we express RCR in an equation form (denominator of RCR minus its numerator), it becomes a measure of net

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[2] The numerator of the DRC is expressed in domestic willingness to pay the numeraire, whereas the denominator is expressed in the foreign exchange numeraire. Assuming a small open economy, the shadow prices of tradable goods are equal to their border (world) prices. The SER or shadow price of foreign exchange used in cost-benefit analysis measures how many units of nontradable goods are exchanged for one dollar's worth of tradable goods. Therefore, it converts the world price of tradable goods into the value of domestic willingness.

social profitability (NSP). In summary, comparative advantage and disadvantage are defined as

Comparative advantage: DRC < SER or RCR < 1 or NSP > 0
Comparative disadvantage: DRC > SER or RCR > 1 or NSP < 0

RCR is a more convenient parameter to use when we want to see the trend in comparative advantage over time because, being in ratio form, it is not affected by changes in nominal prices. NSP is more convenient when we want to analyze the causes of changes in social profitability (see the section "Factors determining the trends in comparative advantage").

We can modify the above construct of RCR and NSP and define the private equivalent of comparative advantage and private profitability, in which we use market prices instead of shadow prices and the official exchange rate (OER) instead of SER. We denote RCR* = DRC*/OER (private equivalent of RCR) and NPP (net private profitability). In summary,

Private profitability: DRC* < OER or RCR* < 1 or NPP > 0
Private nonprofitability: DRC* > OER or RCR* > 1 or NPP < 0

Definition of terms and measurement of prices and exchange rates

Rice. The shadow price of rice is estimated as the five-year moving average centered on each survey year of the f.o.b. import price of milled rice 5% Thai brokens. To convert the border price of milled rice to rough rice equivalent, we adjust the border price of milled rice for marketing and processing costs of 25% and milling recovery rate of 65%.

Tradable inputs. The market prices of inputs such as seeds, fuel and oil, fertilizer, insecticides and herbicides, and those of tractors and threshers are converted to their shadow prices by subtracting legal tariff rates.

Animal service. The service of the bullock (carabao) is valued based on the prevailing custom rate.

Irrigation. The market value of irrigation water is the user fee, whereas the shadow price is the unit cost of construction per year of the life span of the system plus the yearly operation and maintenance expenditure of the National Irrigation Administration (NIA) per hectare of service area in the wet season.

Interest rates. The annualized interest rate of commercial banks on loans and discounts is used to impute the interest payment on preharvest costs to estimate private profitability. To compute social profitability, the shadow interest rate is assumed to be 10% plus the inflation rate.

Wage rates. The shadow price of labor is approximated by the market wage rate for simplicity. According to David and Otsuka (1994), the rural labor market is well integrated by the permanent and seasonal migration of landless workers from unfavorable production regions, where demand is low for labor, to favorable regions, where demand is high. Thus, wages across regions tend to become equalized.

Land prices. Land markets were well developed before the implementation of the land reform in 1972. The shadow price of land is the net rent payment by share-tenants in 1966, which is about 40% of the yield. Based on our data in 1966, the net rent payment by share-tenants commonly ranged from 38% to 42%.

Shadow exchange rate. SER is approximated by $(1 + \text{WATR}) \times \text{OER}$, where OER is the published official exchange rate and WATR is the weighted average tariff rate calculated as the total value of import tariff divided by the total value of imports.[3]

Sources of data and description of the samples

The data in this study came from a series of surveys conducted by the Social Sciences Division of the International Rice Research Institute (IRRI) in Central Luzon, the most progressive rice-producing area of the Philippines. The objective of the surveys has been to monitor changes in farmers' rice technology, cultural practices, land tenure, mechanization, and labor practices that occurred during the survey period from 1966 to 1999.[4] The data set is called the Central Luzon loop survey because the respondents are located along a loop of the major highways stretching north of Manila through the provinces of Bulacan, Nueva Ecija, Pangasinan, Tarlac, and Pampanga (Fig. 1).[5]

The respondents are fairly homogeneous, consisting of farmers with favorable access to technology information and markets. The loop survey covers areas that are either characterized by shallow, favorable rainfed environments common in the country or are fully irrigated by gravity irrigation systems. Central Luzon accounts for roughly one-fourth of the country's rough rice production (Philippine Yearbook 1995); thus, the trends in social profitability estimated from the survey farms may reflect the direction of change in social profitability in the Philippine rice sector as a whole. The samples used in this study were grouped based on the survey year and production environment (rainfed or irrigated). Although we computed the relevant statistics for both irrigated and rainfed farms, the results shown in the tables refer exclusively to irrigated farms. Proper citation of important results obtained from the rainfed farms is included in the text. We focus our discussion mainly on irrigated farms for two reasons: (1) the trends in comparative advantage and private profitability on irrigated and rainfed farms are similar and (2) irrigated rice is the more dominant production mode, which accounts for about 70% of total rice production.

The original sample consisted of 55 irrigated rice farmers in the wet season of 1966 (Table 1). The attrition rate was so high that by 1979 additional new samples were added, forming the sample farms from 1986 to 1999. Two surveys for one crop year extended from the wet season (July to November of the initial year) to the dry

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[3] This is a shortcut approach, which is commonly applied because of the lack of important data such as import and export elasticities for each survey year. See ADB (1997, Appendix 16, "Estimating shadow exchange rate factor") for more detailed estimation methods.

[4] Household income from different sources has also been collected, but for four survey years only: in 1966, 1986, 1990, and 1994 (Estudillo and Otsuka 1998).

[5] See Herdt (1987) for a comprehensive description of the data set.

Table 1. Number of sample farms and tenure, Central Luzon, Philippines, 1966-99.

Item	1966	1970	1979	1986	1990	1994	1999
Sample size							
Wet	55	22	91	58	56	56	53
Dry	17	13	81	64	56	54	46
Tenure (% area)[a]							
Owner[b]	14	9	12	8	15	26	49
Share-tenant	71	55	8	15	9	6	8
Leasehold[c]	15	36	80	77	76	68	43

[a]Refers to the wet-season sample. [b]Includes recipient of emancipation patent. [c]Includes recipient of certificate of land transfer.

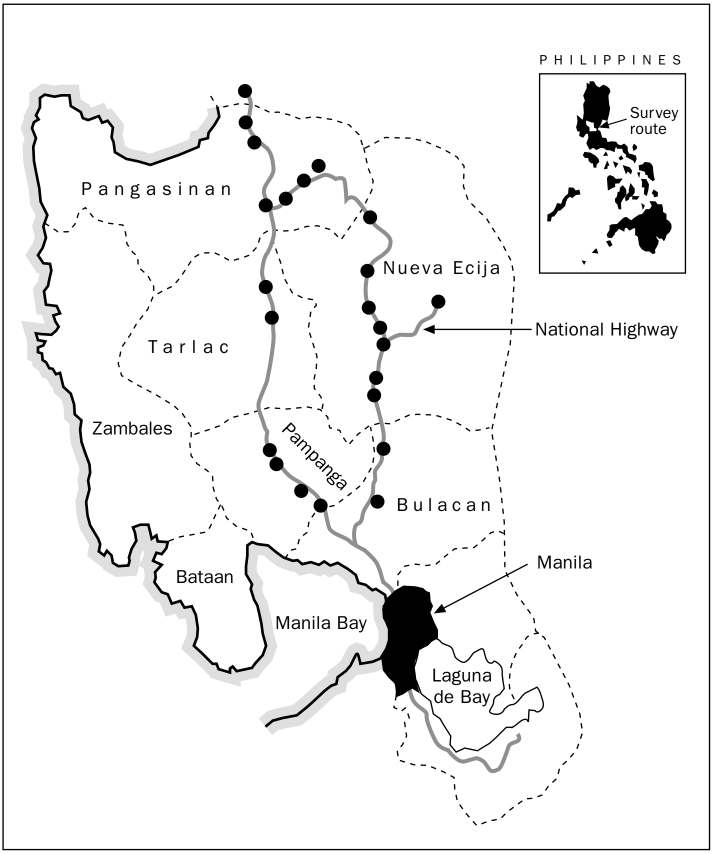

Fig. 1. Survey route.

season (December to June of the next year) in 1966, 1970, 1979, 1986, 1990, and 1994.[6] The latest survey refers to the 1998 dry season and 1999 wet season. The dry-season sample is generally smaller than the wet-season sample because only those farmers who planted rice in the dry season were included.

In 1966, share-tenancy was the most common form of land tenure. The tenurial structure has undergone marked changes since the implementation of the government's land reform program in 1972. The program attempted to convert share-tenants to leaseholders, in case the landlord owned less than 7 ha of land, or to amortizing owners, in case the landlord owned more than 7 ha of land (Hayami and Kikuchi 2000, Hayami et al 1990). A certificate of land transfer (CLT) was issued to amortizing owners, which promises the right to purchase the land by paying amortization fees over 15 years to the Land Bank of the Philippines. An emancipation patent will be issued to the farmer upon completion of the amortization payments. As a result of the land reform implementation, a major replacement of share-tenancy by leasehold-tenancy occurred from 1966 to 1979. The number of owner-cultivators increased in 1994 and 1999 because many CLT holders completed the amortization payments and received emancipation patents.

Results and discussion

Technological progress and changes in cost structure

Technological progress in rice production can come in the form of seed technology such as modern rice with better genetic traits, mechanical technologies such as tractors and threshers, and improved management practices in labor application and fertilizer use. In 1966, all of the sample farmers were planting traditional varieties (TVs) of rice (Table 2). Three major breakthroughs in rice research were achieved in the late 1960s with the introduction of the modern varieties (MVs) of rice.[7] The first was the development of nitrogen-responsive, photoperiod-insensitive cultivars with a yield capacity double that of TVs. These varieties (IR5 to IR34) were susceptible to attacks of pests and diseases. We call these rice varieties first-generation modern varieties (MV1). Our sample farmers planted this group of rice varieties in 1970.[8]

The second achievement was the development of cultivars that incorporated resistance against multiple pests and diseases and a shorter growth duration period. These cultivars introduced yield stability in MVs and some had higher yields than the early generation MVs (Otsuka et al 1994a). We call these varieties (IR36 to IR62) second-generation modern varieties (MV2). Our sample farmers adopted MV2 in 1979.

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[6] We did not include data from the 1974 survey because it was considered an abnormal year (when a big typhoon hit Central Luzon).

[7] The reader can refer to IRRI (1985) for the history of the IRRI rice breeding program and to IRRI (1997) for the direction of the current breeding program.

[8] The very first MV was IR8 released in 1966. But the more popular MV1 in Central Luzon in 1970 was IR5. IR5 was the variety then recommended for rainfed environments, which were common in the region in the early 1970s before the development of large-scale irrigation infrastructure. IR8 was more suitable for irrigated conditions.

Table 2. Technology adoption, Central Luzon, Philippines, 1966-99.

Item	1966[a]	1970	1979	1986	1990	1994	1999
Adoption of rice variety (% adopters)							
TV[b]	100	0	0	0	0	0	0
MV1[c]	0	100	0	0	0	0	0
MV2[d]	0	0	100	0	0	0	0
MV3[e]	0	0	0	100	100	100	100
Adoption of machine (% adopters)							
Tractor	14	45	77	91	100	100	100
Thresher	71	50	42	100	100	100	100

[a]Refers to the wet-season sample. [b]TV = traditional variety. [c]MV1 = first-generation modern variety. [d]MV2 = second-generation modern variety. [e]MV3 = third-generation modern variety.

The third achievement was the integration of traits of resistance to pests and diseases and improved eating quality, which commands a higher market price, thereby allowing farmers to gain larger profits for their produce. We call these rice varieties (IR64 to IR74 and the PSBRc series) third-generation modern varieties (MV3). The most popular MV3 is IR64, which has been repeatedly planted since 1986 because it has a higher market demand due to its superior grain quality.[9] These varieties were also of shorter maturity, enabling farmers to increase cropping intensity.

Mechanical technologies substitute for labor, thereby changing the input combination and altering the cost structure. The adoption of tractors predated the adoption of MVs.[10] The proportion of sample farmers who used tractors increased from 1966 to 1994, presumably because of the development of the tractor rental market and the increasing maintenance cost of carabaos as a result of the substantial reduction in grazing lands.

Similarly, the thresher was adopted before the advent of MVs. The *tilyadora* (a huge threshing machine) was already being used as early as the 1920s in the *haciendas* (large landholdings) to monitor easily the sharing of output between landlords and tenants (Hayami and Kikuchi 1982). When the haciendas were abolished following the successful implementation of land reform, many farmers shifted back to manual threshing in 1979. This was shown by a decline in the proportion of sample farmers who used the thresher. The tilyadora was completely gone by 1986, when all the sample farmers had adopted the portable axial-flow thresher developed and released by IRRI in 1974.

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[9] Our classification of MVs corresponds to the three decades of the Green Revolution. The MV1 varieties were released from the mid-1960s to the mid-'70s, representing the first decade of the Green Revolution. The MV2 varieties were released from the mid-1970s to the mid-'80s, representing the second decade, while the MV3 were released from the mid-1980s to the mid-'90s, representing the third decade.

[10] While concurrent progress is observed in the adoption of labor-saving technologies along with the diffusion of MVs (Lipton and Longhurst 1989), statistical evidence points to the contrary—the adoption of MVs did not induce the adoption of labor-saving technologies such as tractors, threshers, and direct-seeding (David and Otsuka 1990, Otsuka et al 1994b).

Labor input in rice production was affected by the introduction of MVs and the adoption of labor-saving technologies. The adoption of MVs increased the demand for labor, particularly in crop care activities—weeding and application of fertilizer—as well as in harvesting and threshing because of increased yield (Barker and Herdt 1985).

Total labor input increased modestly from 1966 to 1979 and then decreased toward 1999, indicating that the labor-using effect of MVs has been offset by the labor-saving effects of the adoption of mechanical technologies (Table 3). Hired labor input increased in response to the increase in total labor demand as family workers preferred leisure to labor with the increase in family income. Family labor input was mostly concentrated in preharvest activities, particularly in the application of chemical inputs, an activity that is not easy to monitor and is thus difficult to relegate to hired workers (Hayami and Otsuka 1993).

Preharvest labor activities—land preparation, crop establishment, repair and cleaning of dikes, weeding, and chemical input application—increased from 1966 to 1979 because more labor is needed for crop care activities with MV adoption. Preharvest labor intensity declined from 1979 to 1999 because of several factors: (1) increased adoption of the tractor (which reduced the labor required in land preparation), (2) the adoption of the direct-seeding method of crop establishment (which saved the labor used in the traditional method of transplanting seedlings), and (3) increased herbicide application (which substituted for manual weeding). Labor application increased in harvesting and threshing operations from 1966 to 1979, partly because of the higher yields associated with the adoption of the pest- and disease-resistant MV2 and the shift from the tilyadora to manual threshing.

Fertilizer use has increased sharply following the advent of MVs. The application of elemental N, P, and K increased from 9 kg ha^{-1} in 1966 to 29 in 1970, 62 in 1979, 67 in 1986, 70 in 1990, 93 in 1994, and 148 in 1999.

Table 3. Labor input in rice production (person-days ha^{-1}), Central Luzon, Philippines, 1966-99.

Item	1966[a]	1970	1979	1986	1990	1994	1999
Preharvest labor[b]	40	53	49	42	40	40	31
Family	21	32	22	14	14	13	9
Hired	19	21	27	28	26	27	22
Harvesting-threshing labor	20	21	28	19	29	28	27
Family	2	3	2	1	5	6	5
Hired	18	18	26	18	24	22	22
Total	60	74	77	61	69	68	58
Family	23	35	24	15	19	19	14
Hired	37	39	53	46	50	49	44

[a]Refers to the wet season. [b]Includes land preparation, crop establishment, repair and cleaning of dikes, weeding, and chemical input application.

New rice technology and resource savings

Savings in the amount of domestic resources—land and labor—required to produce one unit of rice are the major gain obtained from the adoption of new rice technology. These savings in domestic resources are brought about primarily by a yield increase. Following the yield increase, the amount of land needed to produce 1 t of rice has declined consistently since 1966, with the most spectacular decline observed in 1979 with the diffusion of MV2 (Table 4). The land requirement to produce a ton of rice declined by about 50% from 1966 to 1979 while labor input declined by 30%.

Yield on irrigated farms rose from 2.2 t ha^{-1} in 1966 when TVs were dominant to 2.5 t ha^{-1} in 1970 when MV1 were adopted. Yield rose significantly to 4.2 t ha^{-1} when the pest- and disease-resistant MV2 were adopted. Yield began to stagnate, however, in 1986 with the diffusion of MV3.

Trends in comparative advantage and private profitability

A comparative advantage in producing rice exists if RCR is less than unity, which means that the cost of producing one dollar's worth of rice domestically is less than the cost of importing rice. The lower the value of RCR, the higher is the potential of the country for import substitution. Similarly, if RCR* is less than unity, rice production is profitable from the farmer's perspective and thus there are private incentives to produce rice. Private incentives can be increased through government interventions in the form of higher output prices resulting from the restricted importation of rice; input subsidies such as those for chemical inputs, machinery, and irrigation water; and control of land rent when yields are rising, thereby creating a gap between the economic rent and the actual rent paid.

Table 5 shows the trends in RCR and RCR*. RCR in irrigated rice production was above unity in 1966, when TVs were planted, which means that the Philippines had no comparative advantage in producing TVs in irrigated ecosystems.[11] In contrast, RCR on rainfed farms was below unity in 1966, implying that a comparative advantage in producing TVs in rainfed ecosystems existed. In 1970, when MV1 were adopted,

Table 4. Yield trends (t ha^{-1}) and use of land (ha t^{-1}) and labor (person-days t^{-1}), Central Luzon, Philippines, 1966-99.

Item	1966[a]	1970	1979	1986	1990	1994	1999
Yield	2.2	2.5	4.2	4.0	4.2	4.3	4.2
Use of domestic factors							
Land	0.46	0.39	0.24	0.25	0.24	0.24	0.24
Labor	27	29	19	15	16	16	14

[a]Refers to the average of wet and dry seasons.

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[11] Our finding was similar to Unnehver's (1986). It seems most likely that the Philippines did not possess a comparative advantage in the production of TVs in the irrigated environment.

Table 5. Resource cost ratio in rice production, Central Luzon, Philippines, 1966-99.

Item	1966[a]	1970	1979	1986	1990	1994	1999
Social profitability							
RCR[b]	1.1	1.2	0.7	1.0	1.2	1.6	1.8
DRC[c]	4.8	8.1	6.4	23.5	33.8	47.9	81.3
SER[d]	4.5	6.7	8.9	23.7	28.0	30.1	45.6
Private profitability							
RCR*[e]	0.5	0.4	0.5	0.5	0.4	0.4	0.5
DRC*[e]	2.1	2.6	3.5	9.8	10.2	9.8	20.8
OER[f]	3.9	5.9	7.4	20.4	24.3	26.4	40.0

[a]Refers to the average of wet and dry seasons. [b]RCR = resource cost ratio. [c]DRC = domestic resource cost. [d]SER = shadow exchange rate. [e]RCR* is the private equivalent of RCR and DRC* is the private equivalent of DRC. [f]OER = official exchange rate.

RCR on irrigated farms was still above unity. A lower than potential yield was achieved because MV1 are susceptible to attacks of pests and diseases.

A substantial improvement in comparative advantage (sharp decline in RCR) was gained from 1970 to 1979 when yield rose remarkably after the diffusion of pest- and disease-resistant MV2. This holds true for both irrigated and rainfed farms, although the decline in RCR in 1979 was much higher for irrigated rice. The yield of MV2 in the irrigated environment was about 4.2 t ha^{-1} while yield in the rainfed environment was only about 3.0 t ha^{-1}.

Beginning in 1986, the Philippines appears to have slowly lost its gains in comparative advantage in rice production because yield began to stagnate and the cost of domestic factors increased, while the world price of rice declined by about 36% from 1979 to 1986 based on a five-year average centering on two survey years.[12] The Philippines had completely lost its comparative advantage (RCR is greater than unity) in rice production by 1990, caused primarily by the substantial increase in the cost of domestic factors.[13]

The comparative advantage in rice production declined sharply in 1994 because of a substantial increase in wages caused by the high economic growth experienced by the country. Wages have risen in the rice sector as a result of strong competition for labor, particularly from the growing nonfarm sector.

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[12] According to Pingali et al (1997), Hossain et al (1995), and Cassman and Pingali (1995), the yield frontier in rice production had already been exhausted as of the mid-1980s not only in the Philippines but also in other rice-producing countries of Asia. This is attributed to the decline in the international price of rice and the decline in production efficiency in terms of yield output per unit of input.

[13] Simple trade statistics can relate the trends of RCR to the direction of rice imports and exports. The Philippines was mostly self-sufficient in rice during the late 1960s, turning into a moderate importer in 1971-76 (World Rice Statistics n.d.). This change coincided with a slight loss in comparative advantage in this period; RCR rose in 1970 (Table 5). The Philippines became a moderate net exporter of rice in 1978-83 as reflected in a gain in comparative advantage (a decline in RCR in 1979). The country then became a net importer from 1984 to the 1990s as reflected in the decline in comparative advantage (a rising RCR beginning in 1986).

The country continued to experience a decline in comparative advantage from 1994 to 1999 (RCR increased from 1.6 to 1.8). Land and labor costs went up and the peso depreciated sharply during this period as a consequence of the Asian economic crisis. But, the depreciation of the peso, which can effectively decrease RCR or improve the comparative advantage, was not enough to overcome the negative effect of the rise in the costs of land and labor.

It is important to note that the value of RCR is sensitive to the values attached to the shadow price of land. We recalculated the RCR using the residual value in rice production to represent the shadow price of land. The residual is what remains after deducting from the gross revenue the value of all paid-out costs (current inputs, hired labor, and hired capital) and the imputed values of family labor and family-owned capital. The residual represents the competitive returns to land.

In general, the values of the residual were higher than the net rent payment by share-tenants in 1966 (40% of the yield). Using the residual as the shadow price of land, we found that the RCR assumed a value of greater than unity as early as 1986. Indeed, the Philippines might have started to lose its comparative advantage in rice production as early as the mid-1980s.

The trends in comparative advantage estimated in this paper are similar to those established by Herdt and Lacsina (1976), Unnehver (1986), and Inocencio and David (1993). Using 1974 farm-level data, Herdt and Lacsina (1976) showed that the Philippines had a comparative advantage in rice production but it was sensitive to marginal changes in rice prices. Unnehver (1986) and Inocencio and David (1993), using the loop survey data, showed substantial gains in comparative advantage in rice production in 1979 with the diffusion of MV2. These studies confirm that, until 1979, there were foreign exchange savings in producing rice domestically, although Herdt and Lacsina (1976) argued that possible gains in foreign exchange could be easily eroded by the downward swing in the world price of rice.

Private profitability in rice production has been positive since 1966 and the trend appears to have strengthened up to 1994 for both irrigated and rainfed farms even though private profitability is slightly higher in the rainfed ecosystem than in the irrigated one. The major factors contributing to private profitability are the high domestic price of rice, irrigation subsidy, and land tenure relations in favor of leasehold-tenancy, in which rents are fixed at levels lower than the economic value of the service of the land.

Comparing RCR and RCR*, it is evident that rice production is profitable to farmers but not to society (RCR > RCR*). An evident trend since 1979 (with the exception of 1999) seems to be toward an increase in private profitability but a decline in social profitability. This finding indicates that the social cost of rice production is becoming higher than the private cost because of the protection extended to rice producers formally (through irrigation subsidies, technology dissemination, and land reform) and informally (through higher domestic prices of rice brought about by the insulation of the domestic market from the international rice market through rice import restrictions).

Factors determining the trends in comparative advantage

Sources of changes in private profitability

Table 6 shows the sources of private profitability of rice production in pesos per ton of rough rice. The units in Tables 6 and 7 are in nominal terms. An adjustment to real terms was not attempted because of the absence of consistent time-series data on price changes specific to the rice production of the sample farmers. Therefore, the magnitudes of private and social profitability should be interpreted accordingly with caution.

Private profitability is measured by private surplus, which is what is retained after deducting from the price of rice the sum of paid-out costs consisting of tradable inputs and domestic factors as well as the value of family labor and owned capital. The existence of a surplus is the major motivation for adopting the latest-released rice varieties. Farmers were quick to adopt the newest seeds as they became available and there was no reversal back to the old seeds (Estudillo and Gascon 2002), which indicates that the newer seeds are much more profitable.

The private surplus in nominal terms has been rising over time but more evidently beginning in 1979 with the adoption of the pest- and disease-resistant MV2. The increase in private surplus can be traced to the sustained increase in domestic rice price while paid-out costs as well as the value of family labor and owned capital did

Table 6. Private profitability in rice production (pesos t^{-1}), Central Luzon, Philippines, 1966-99. The official exchange rate is US$1 = PhP3.90 in 1966, PhP5.91 in 1970, PhP7.38 in 1979, PhP20.39 in 1986, PhP24.31 in 1990, PhP26.41 in 1994, and PhP40.00 in 1998.

Item	1966[a]	1970	1979	1986	1990	1994	1999
Price of rice[b] (A)	441	519	1,137	2,881	4,791	6,479	7,608
Tradable inputs (B)	37	75	247	713	1,180	1,444	2,145
Fertilizer	13	37	106	210	415	516	588
Hired capital[c]	14	20	50	177	302	347	479
Other inputs[d]	10	18	91	326	463	581	1,078
Domestic factors (C)	214	192	420	1,029	1,533	1,749	2,822
Land	132	100	131	388	432	462	446
Hired labor	72	79	221	494	804	1,043	1,867
Hired capital[e]	2	1	1	5	12	14	14
Other costs[f]	8	12	67	142	285	230	495
Total cost (D = B + C)	251	267	667	1,742	2,713	3,193	4,967
Residual (E = A – D)	190	252	470	1,139	2,077	3,286	2,641
Family labor	44	66	92	139	316	688	512
Owned capital	18	34	75	133	151	146	374
Private surplus	128	152	303	867	1,610	2,452	1,755

[a]Refers to average of wet and dry seasons. [b]Average farm-gate price of rough rice in the wet and dry seasons. [c]Tractors and threshers. [d]Seeds, fuel and oil, herbicide, and insecticide. [e]Animals. [f]Irrigation and imputed interest payment on preharvest costs.

Table 7. Social profitability in rice production (pesos t ha^{-1}), Central Luzon, Philippines, 1966-99. The official exchange rate is US$1 = PhP3.90 in 1966, PhP5.91 in 1970, PhP7.38 in 1979, PhP20.39 in 1986, PhP24.31 in 1990, PhP26.41 in 1994, and PhP40.00 in 1998.

Item	1966[a]	1970	1979	1986	1990	1994	1999
Price of rice (A)[b]	371	532	1,630	2,791	4,110	4,517	5,440
Tradable inputs (B)	36	67	301	757	1,202	1,445	2,019
Fertilizer	14	27	97	142	280	361	353
Capital[c]	14	27	106	284	447	482	689
Other inputs[d]	9	13	97	331	475	602	977
Domestic factors (C)	356	557	966	2,025	3,510	4,888	6,102
Land	176	206	454	1,157	1,920	2,620	2,999
Labor	113	143	312	633	1,139	1,730	2,378
Capital[e]	20	32	13	14	31	22	34
Other costs[f]	47	176	187	221	420	516	691
Total cost (D = B + C)	392	624	1,267	2,782	4,712	6,333	8,121
Social surplus (E = A – D)	–21	–92	363	9	–602	–1,816	–2,681

[a]Refers to the average of wet and dry seasons. [b]Five-year average centered on the survey year of the border price of rice adjusted for 25% marketing costs and 65% milling recovery and converted to pesos t^{-1} by the shadow exchange rate. [c]Tractors and threshers. [d]Seeds, fuel and oil, herbicide, and insecticide. [e]Animals. [f]Irrigation and interest payment on preharvest costs.

not rise as much. Expenditures on fertilizer have also been rising over time because MVs are more productive (and thus more profitable) with a higher level of fertilizer application. The use of hired capital has been increasing because of the development of a rental market for carabao, tractors, and threshers. Expenditures on other tradable inputs corresponding to seeds, fuel and oil, herbicides, and insecticides increased because of the rise in fuel and oil prices and the increased application of herbicides and insecticides.

Land rent rose but not as much as the domestic rice price. Average land rent increased about threefold from 1966 to 1994, whereas the domestic price of rice increased about fifteen times. One major feature of the Philippine land reform program was the conversion of share-tenancy to leasehold-tenancy and the fixing of leasehold rent and annual amortization fees. When rice yield rose in the 1970s following the diffusion of MVs, the fixed leasehold rent and amortization payments diverged substantially from the economic rent accruing to the service of the land. Thus, a gap between actual land rent and true economic rent was created.

The cost of hired labor increased over time partly because of the increased demand for hired labor and the rise in wage rates. Other costs consisting of irrigation fees and forgone interest payments on preharvest costs rose substantially from 1970 to 1979 because of increased irrigation fees as a result of the opening of large-scale irrigation systems in Central Luzon. Beginning in 1986, the increase in other costs occurred on account of the increase in preharvest costs and the rise in the interest rate on loans and discounts in commercial banks.[14]

The value of family labor is imputed using the prevailing market wage rate corresponding to each rice production activity. The value of family labor increased only marginally until the mid-1980s, but increased sharply since then. The value of owned capital did not increase much because the trend in capital use has mostly been in favor of hired capital rather than owned capital. We impute the value of owned capital using the most prevalent custom rental rate for carabao, tractors, and threshers.

The private surplus has risen proportionately with the yield increase over time. While yield was rising, average land rent (converted to kg of rough rice) declined absolutely since 1966 partly because many share-tenants were converted to leaseholders from 1970 to 1979 and, in 1994, many amortizing owners received emancipation patents and became owner-cultivators. Private profitability declined from 1994 to 1999 mainly on account of the increase in the domestic cost of fuel and oil caused by the depreciation of the peso, the rise in the cost of labor, and the increased cost of tractor and thresher services.

In a regression analysis, Estudillo and Otsuka (2001) identified the following two major determinants of rice income per hectare received by farmers: (1) the ratio of irrigated area to total rice area and (2) the proportion of area under owner cultivation and under leasehold tenancy and a certificate of land transfer. Rice income per hectare rose sharply in 1979 as a result of the diffusion of MV2 and relatively low input prices, which complemented the positive effect of MV2 on rice income. Rice income has remained steady since 1986 when rice yield began to stagnate.

Sources of changes in social profitability

A comparative advantage in rice production exists if NSP is positive, which means that the social opportunity cost of domestic factors of production is less than the value added in world prices. In equation form,

$$NSP = (u - m)\, v_1 - \Sigma\, v_s f_s \qquad (1)$$

where u = the border price of rice in foreign currency, m = the total value of tradable inputs at border prices in foreign currency, v_1 = SER, v_s = the shadow price of the *s-th* factor of production, and f_s = the amount of the *s-th* factor of production used in the production.

The NSP in irrigated rice production was positive in 1979 and 1986 and a higher value of the NSP was achieved in 1979, when rice yield accelerated and the rice price increased while the cost of domestic factors and the value of tradables did not in-

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[14] Loans and discount rates rose from 5% per annum in 1966 to 8% in 1970 to 12.7% in 1979 to 17.3% in 1986 and to 24.3% in 1990 but declined to 15% in 1994 and 15.1% in 1999 (ADB 2000).

crease proportionately (Table 7). The trend, however, appears to be that of a declining NSP beginning in 1986. By 1990, the Philippines had lost its comparative advantage in irrigated rice production. On rainfed farms, NSP was positive from 1966 to 1986, which means that rice production was socially profitable in the rainfed ecosystem and that the Philippines had the potential for import substitution in rainfed rice production during that period. As on the irrigated farms, the highest NSP on rainfed farms was achieved in 1979. But, in 1986, the NSP began to decline and, by 1990, rice production in the rainfed ecosystem was no longer socially profitable. The value of NSP in irrigated rice was lower than in rainfed rice because of the cost of irrigation.

The border price of rice in domestic currency has increased over time mainly because of the depreciation of the exchange rate. Meanwhile, the world price of rice increased markedly in 1979 but stagnated in the mid-1980s as a result of the increased world supply of rice made possible by the development of irrigation infrastructure, the diffusion of MVs in the major rice-producing countries in Asia, and the introduction of institutional reforms in China. A spectacular growth in rice production in China and in the world was observed from 1978 to 1984. The cost in domestic currency of tradable inputs rose because of the depreciation of the exchange rate, the increase in fertilizer application, and the acceleration in mechanization. But the cost of tradable inputs in domestic currency increased rather slowly vis-à-vis the cost of domestic factors such as land and labor.

Changes in the NSP between two survey years are estimated but are not shown here.[15] The NSP declined in 1966-70 mainly because of the increase in irrigation costs. The NIA started to increase its investments in the construction of irrigation systems in the 1970s. The change in NSP was positive for 1970-79, the principal cause of which was the increase in the world price of rice and the depreciation of the exchange rate. The decline in NSP in 1979-86, 1986-90, and 1994-99 was brought about mainly by the decline in rice price, the increase in the wage cost, and the increase in the social value of land. To a lesser extent, the decline in NSP in 1986-90 occurred because of the increase in interest payments resulting from the increase in the inflation rate. The depreciation of the exchange rate in the 1990s did not take rice production far enough toward a comparative advantage, which has since been lost.

In brief, the decline in rice price and the rise in social costs of land and labor were the principal factors responsible for the decline in comparative advantage in rice production beginning in 1986.

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[15] To identify the major sources of change in NSP between survey years, we take the total differential of equation 1 and, using the mean level of prices and exchange rate, we evaluate the change in NSP as follows:

$$\Delta NSP = v_1 \Delta u - v_1 \Delta m + (u - m)\Delta v_1 - S v_s \Delta f_s - S \Delta v_s f_s \qquad (2)$$

where Δ indicates the difference in a variable between adjacent years and the terms u, m, v_1, v_s, and f_s are as defined earlier. The change in NSP is a function of the changes in the world price of rice, the value of tradable inputs, SER, and the value of domestic factors such as land, labor, capital, and other costs. An increase in the world price of rice and depreciation of the exchange rate will increase NSP, while an increase in the value of tradable inputs and domestic factor costs will reduce NSP.

Impact of government policies

Domestic prices of rice and tradable inputs differ from their border prices because of trade regulations such as tariffs and import or export quotas. Factor prices differ from their social opportunity costs because of government intervention in factor markets such as land rent and interest rate ceilings and various market failures.

In 1966, the domestic rice price was above the world price (Fig. 2) because of the farmers' strong lobby in the legislature, which delayed the approval of funding for government-controlled imports (Bouis 1982). The domestic rice price did not follow the sharp rise in the border price in the early 1970s in part because of the rapid increase in domestic rice supply as a result of the diffusion of modern rice varieties.

In the late 1970s and early '80s, domestic prices fell faster than world prices because of the robust growth in rice production and limited external market for low-quality Philippine rice. By the late 1980s, domestic rice prices rose higher than world prices because of the deceleration of production growth and the government's policy to provide incentive prices to farmers through controls on rice imports.

The government National Food Authority (NFA) has a monopoly on all rice imports. It is widely believed that the government's quantitative restriction on rice imports and the buffer stock operation of the NFA are the main causes of high domestic rice prices. The domestic wholesale prices of rice in the Philippines are two to three times higher than those of neighboring Vietnam and Thailand, while farmers do not receive favorable prices for their paddy (Tolentino, this volume). According to David and Roumasset (2001), the NFA's continued intervention in the rice market has led to considerable economic losses to consumers, farmers, and taxpayers. Moreover, the NFA's inefficient operation has often led to abnormal seasonal price fluctuations. For example, the principal cause of the severe rice shortage in 1994 was the failure of the government to anticipate a shortfall in domestic production and to plan imports in time to make up for the shortfall.

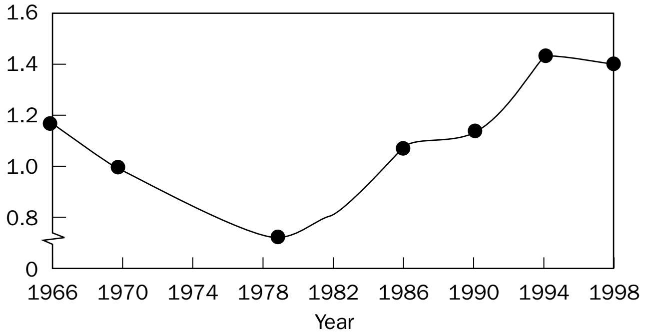

Fig. 2. Ratio of domestic price to border price of rice. The domestic price is the average of the wet- and dry-season rice prices obtained from the Central Luzon loop survey. The border price of rice is a five-year average centered on the survey year adjusted for 25% marketing costs and 65% milling recovery. The border price of rice is taken from World Rice Statistics (n.d.).

The domestic price of fertilizer has traditionally been higher than the border price because of quantity restrictions on imported fertilizer (Habito and Manasan 1992). The domestic prices of other tradable inputs such as herbicides and insecticides, fuel and oil, tractors, and threshers are also higher than their border prices because of tariffs.[16] The nominal protection rate for axial-flow threshers is zero because they are manufactured and distributed locally.

Government intervention in the market has helped sustain private profitability since the mid-1980s when social profitability began eroding. The private surplus minus the social surplus (estimated but not shown) has been positive over time (except in 1979). Private incentives appear to come mainly from higher domestic rice prices than border prices and lower land rental rates than the social opportunity cost of land, and to a lesser extent from irrigation subsidies. The sharp rise in the difference between private surplus and social surplus beginning in 1986 was caused primarily by higher domestic rice prices.

The depreciation of the exchange rate tended to increase both private and social costs of tradable inputs. The effect of depreciation was more pronounced beginning in 1979 when the application of imported chemical inputs and mechanization accelerated. Tariffs on tradable inputs increased private costs, while the suppression of land rent by land reform laws and irrigation subsidies decreased private costs. Interest rate regulations reduced private costs but their impact was almost negligible.

Government intervention and farmers' welfare

Is the continued intervention of the government in the rice market still justifiable? Given the lost comparative advantage in rice production and as the effective coverage of state intervention in the rice market becomes marginal, there seems to be little rationale for continued direct intervention (Roumasset 2000).

The goal to improve the welfare of rice farmers through price intervention is simply a political campaign based on the wrong presumption that rice-farming households are earning a substantial portion of their income from rice farming. According to Estudillo and Otsuka (1999), rice-farming households in Central Luzon have experienced a shift in household income structure from agricultural to nonagricultural sources. The proportion of household income from agriculture declined from 73% in 1966-67 to 37% in 1998-99, whereas the proportion of income coming from nonagriculture increased from 27% in 1966-67 to 63% in 1998-99 (Table 8). Income from rice farming declined from 57% in 1966-67 to 23% in 1998-99. Thus, NFA price intervention may not be effective at all in increasing the income of small farmers.

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[16] The weighted average tariff rate has been no more than 20% from 1966 to 1999.

Table 8. Household income in Central Luzon, Philippines, 1966-99. The official exchange rate is US$1 = PhP3.90 in 1966, PhP5.91 in 1970, PhP7.38 in 1979, PhP20.39 in 1986, PhP24.31 in 1990, PhP26.41 in 1994, and PhP40.00 in 1998.

Income	1966-67	1986-87	1990-91 (%)	1994-95	1998-99
Agriculture	73	62	59	49	37
Rice	57	46	38	39	23
Labor	11	7	5	8	2
Capital	7	4	4	3	2
Land	39	35	29	28	19
Nonrice	16	17	21	10	14
Nonagriculture	27	38	41	51	63
Total	100	100	100	100	100
Total (pesos year^{-1})[a]	2,011	30,056	73,801	90,047	113,545

[a] In nominal terms.
Source: Estudillo and Otsuka (1999).

Summary and conclusions

Using 33-year farm survey data collected in the most progressive rice-growing region in the Philippines, this study found that the Philippines increased its comparative advantage in rice production with the diffusion of new rice technology in the 1970s, but this advantage started to erode in the mid-1980s. Initial trends appear to show a gain in comparative advantage from 1966 to 1979, mainly because of the yield increase associated with the adoption of pest- and disease-resistant MVs. Beginning in 1986, the comparative advantage declined consistently as a result of the downward trend in the world rice price, the stagnation in yield as farmers reached the technological plateau in rice production, and the increase in the price of domestic factors such as land and labor. The country had completely lost its comparative advantage in rice production by 1990.

Private incentives to produce rice domestically are likely to be much less effective in the near future. President Arroyo, in her State of the Nation Address in July 2001, mentioned the plan to remove the monopolistic function of the NFA over rice imports.[17] If rice imports are liberalized, there will be an influx of cheap imported rice that could effectively lower domestic rice prices. Lower domestic rice prices in turn decrease private profitability because high domestic rice prices are the major source of private revenues in rice production.

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[17] She mentioned that "if a (rice) shortage seems likely, we will allow the private sector to import rice." She specifically mentioned that farmers will be allowed to import rice although she did not elaborate whether this meant groups of small farmers, individual farmers, or corporate producers.

Should the Philippines rely to a large extent on imported rice to satisfy domestic demand? Although rice imports are always an economic option for domestic food security, there is no reason why the government should not continue to exert efforts to reverse the comparative disadvantage in order to gain resource cost savings in rice production. The government should concentrate its efforts in the area of non-market-distorting measures to increase yields by developing and promoting modern varieties with higher yield potential and improving efficiency in input use through better crop management practices and better-quality irrigation.

Contrary to a widely held belief of commodity price volatility, relying on rice imports is not risky at least in the medium term. World rice prices have been low and stable for the past 15 years and there are indications that this trend will remain so in the near future. Stability in rice prices is due mainly to the relative stability of rice production resulting from the diffusion of pest- and disease-resistant rice varieties and the expansion of irrigation coverage in the major rice-producing countries.

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Section SIX

Total factor productivity analysis and its components in a high-potential rice-wheat system: a case study of the Indian Punjab

J. Singh and M. Hossain

In the high-potential rice-wheat system of agriculture in the Indian Punjab, a decline in total factor productivity growth was observed in spite of the positive contribution of technological improvements and technical change apart from an increase in input use. Thus, this paper has attempted to examine the effects of environmental degradation on total factor productivity growth.

Numerous efforts have been made to study total factor productivity (TFP) in different parts of the world and, in the process, subsequent improvements in the methodology to work out TFP and its components have been made. Kalirajan et al (1996) demonstrated the method to decompose TFP growth and made an empirical analysis of Chinese agriculture before and after the reforms. This is definitely an improvement over the attempt by Fan (1991), which assumed that the production function as well as technical change shift neutrally over time. They have decomposed TFP into two components: technological progress and change in technical efficiency of farm firms. The highest technical efficiency or frontier can be achieved if farmers follow the “best practice” method. In this paper, we attempt to estimate TFP and to examine the data of rice and wheat crops in the Indian Punjab, the high-potential rice-wheat cropping system belt of India, in the light of recent methodological improvements and to reexamine the components of TFP growth.

Study area and TFP estimates

Punjab is one of the smallest states of India, covering only 1.5% of the geographical area and producing about 10% of the nation’s rice and 20% of the wheat. Wheat is a traditional crop of the state but rice entered into the cropping pattern in the 1970s and became a major commercial crop. Rice occupies about 60% and wheat 80% of the cultivated area of the state in the summer and winter season, respectively. The average productivity of rice increased from only 4.5 t ha^{-1} in 1981-82 to a record level of

5.3 t ha^{-1} in 1987-88 but, after this, yield declined, reaching 4.73 t ha^{-1} in 1998-99. The compound growth rate (CGR) of rice productivity in the 1980s was 1.27% and this declined to –0.04% in the 1990s. Wheat showed an exemplary increase in productivity from 2.73 t ha^{-1} in 1980-81 to 4.33 t ha^{-1} in 1987-88, with a CGR of 3.00% in the 1980s, which slowed to 1.45% in the 1990s (Table 1).

Interestingly, quite a few studies have been carried out to estimate TFP in Punjab and invariably all of them have used the data collected in the "Comprehensive Scheme for the Study of Cost of Cultivation of Principal Crops" of the Directorate of Economics and Statistics, Government of India (2000). However, the period of analysis varied from one study to another depending on the availability of data. The estimated TFP in Punjab of these studies put together showed a lot of variation, without leading to a definite conclusion. Sidhu and Byerlee (1992) estimated slow growth in input use in wheat in Punjab and the TFP growth of 2% was mainly correlated with output growth. Kumar and Mruthyunjaya (1992) attributed the growth in TFP to the growth in yield in Punjab. To learn the determinants of TFP, it was regressed against a proxy for the variables of research, extension, skill improvement, infrastructure, and changes in technology (Rosegrant 1994, Kumar and Mittal 2000). Kumar et al (1999) estimated that TFP growth in Punjab agriculture declined from 3.2 in 1976-85 to 0.8 in 1985-92. Attributing TFP growth to technological progress, Janaiah and Hossain (2000) mentioned a decelerating trend in TFP growth for rice in the highly productive rice-wheat system of northern India. Murgai (2000) mentioned that the low TFP growth in Punjab agriculture during the Green Revolution was due to the increase in inputs.

Although the source of data for this analysis is also the same as in the above mentioned studies, a more logical split of the time frame has been made and more recent data were used. The trend fitted in the time series data for yield of rice and wheat in Punjab (Fig. 1) showed a kink in 1990-91, which was more pronounced for rice. Therefore, the TFP analysis was made separately for two periods, period 1 and period 2, that is, 1982-90 and 1990-97 for rice and 1982-90 and 1990-98 for wheat. At each time for which the analysis was done, two years' data were pooled to minimize the effect of weather.

Table 1. Compound growth rate of area, production, and average yield of rice and wheat in Punjab and in India.

Crop	Punjab state		India	
	1980-81 to 1989-90	1990-91 to 1998-99	1980-81 to 1989-90	1990-91 to 1998-99
Rice				
Area	5.47	2.15	0.41	0.53
Production	6.74	2.11	3.62	1.80
Av yield	1.27	–0.04	3.16	1.28
Wheat				
Area	1.26	0.13	0.46	1.70
Production	4.30	1.56	3.58	3.30
Av yield	3.00	1.45	3.10	1.58

The results in Table 2 showed that the input index has been consistently increasing over time in both crops. It increased from 0.26% and 0.57% in period 1 to 0.34% and 1.41% in period 2 for rice and wheat, respectively. The output index for rice, on the other hand, increased by 1.77% in period 1 but declined by 1.43% in period 2. However, wheat showed output growth of 2.70% from 1982 to 1990 and 2.25% from 1990 to 1997. Thus, compared with that of the output index, the growth in TFP increased more slowly in period 1 but declined more steeply in period 2. TFP growth in wheat in the former period was much higher, but the decline in the latter period was slower than that of rice. This highlights the fact that, in spite of the higher and higher use of inputs, it is difficult to sustain output growth; thus, TFP is declining. Second, sustainability is more associated with rice than with wheat.

The two component factors of TFP identified by Kalirajan et al (1996) can be viewed in the light of the declining TFP in Punjab agriculture. Obviously, the decline in TFP growth in this state does not mean that technological change, technical progress, or input use has not kept pace. Some new high-yielding varieties, pesticides, and other improved farm practices resulted during the 1990s. The technical change measured by farmers approaching the frontier yield can also not be denied because of the

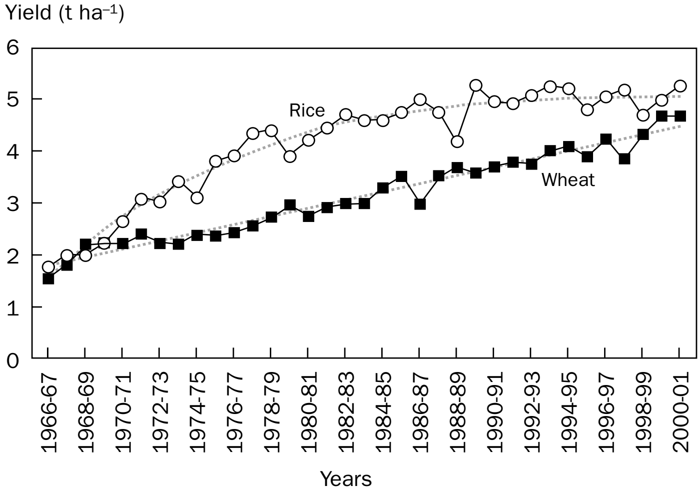

Fig. 1. Average productivity of rice and wheat in Punjab.

Table 2. Total factor productivity (TFP) growth of rice and wheat in Punjab (%).

Crop	Period	Input growth	Output growth	TFP growth
Rice	1982-83 to 1989-90	0.26	1.77	1.51
	1990-91 to 1996-97	0.34	–1.43	–1.77
Wheat	1982-83 to 1989-90	0.57	2.70	2.13
	1990-91 to 1997-98	1.01	2.25	1.24

high receptiveness of farmers to the new technology, improvements in education, and experience over time. Moreover, no significant structural change has occurred that could constrain technological progress. Input use has also increased, which is obvious from the rising input index discussed above. Thus, out of the three components of output growth identified by Kalirajan et al (1996), none appeared to have played a negative role that could have resulted in a decline in TFP. Questions thus arise as to why TFP in the state declined. Is there some unidentified component of TFP? If so, what is its contribution to TFP? These questions led us to rethink the problem and examine in depth the components of TFP.

Sustainability issues

When applying this model under the Indian Punjab situation, which showed fast growth in the productivity of rice and wheat during the 1970s and ’80s, we observed that, apart from these three components of TFP, the ecological aspect is likely to have made a significant, though negative, contribution to yield. For this purpose, the farm-level data of Punjab for rice and wheat, collected in the “Comprehensive Scheme for the Study of Cost of Cultivation of Principal Crops” for about 300 farm situations for different years, were used. The trends obtained by applying the maximum likelihood estimator on rice and wheat yields and costs of production (at constant prices) are shown in Figures 2 and 3. It has been clearly visualized that, in this high-potential area, the seed-irrigation-fertilizer technology brought about an upward shift in production function from the early 1980s to the late ’80s. Because the technology is scale-neutral, the shift in the production function was almost parallel. In the early 1990s, as a result of the increase in area under these crops, which make exhaustive use of soil nutrients and water, the state faced a problem of sustaining high yields. According to Singh et al (1997), “The change in production pattern, though, was mainly responsible for achieving a stellar growth, but this pursuit of monoculture over time has resulted in the manifestation of several adverse effects on environmen-

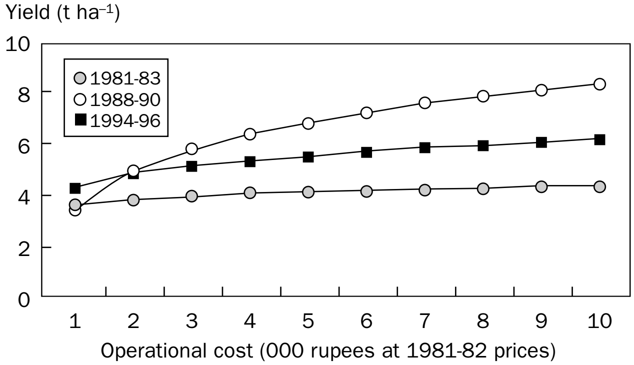

Fig. 2. Frontier yield of wheat in Punjab. (In 1983, US$1 = Rs 10.34.)

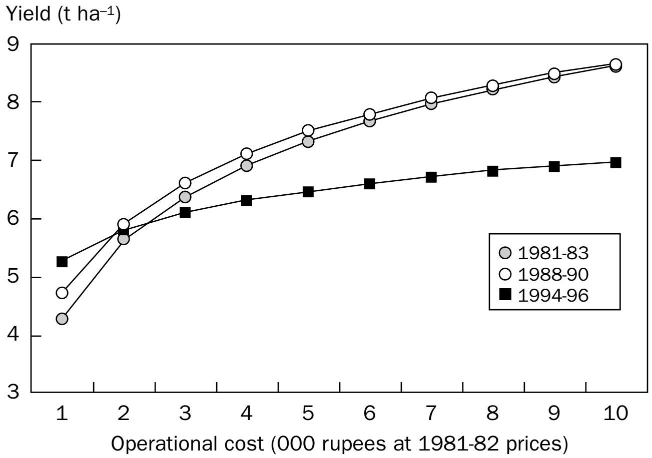

Fig. 3. Frontier yield of rice in Punjab.

tal and ecological balance. For instance, the groundwater table is receding; soil is getting degraded; nitrate-N content is increasing in the underground water because of high doses of fertilizer and deficiencies in several micronutrients have occurred; greater use of insecticides has contaminated the environment; and soil texture and structure have been adversely affected by puddling of land." Therefore, the frontier production curves drawn against the operational cost at 1981-82 prices for wheat and rice for 1994-96 (as presented in Figs. 2 and 3) indicate that, because of an improvement in management practices, the lower part of the curve representing mostly "resource-poor" farmers still has potential to shift upward, whereas the upper part is turning downward as a consequence of ecological degradation.

Decomposition of TFP

The model to demonstrate the decomposition of TFP growth into technical change and technological improvement components was made by Kalirajan et al (1996). When attempting to use this model under the Indian Punjab situation, which has almost exploited the available potential of soil, water, and other natural resources required, particularly for rice and wheat, we segregated out sustainability as a component of TFP.

To make it clearer, Figure 4 shows that the shift in the frontier curve should take place from F_1 to F'_2 but, because of ecological constraints, the upper part of the curve starts turning down toward the F_2 curve. This does not mean that F_1 and F'_2 are totally free from environmental degradation but it is validly assumed that both face an equal degree of such a problem. Therefore, F_1 and F_2 are realizable frontiers, whereas F'_2 is a hypothetical frontier, free from an additional sustainability problem, which the curve F_2 is facing. The 2-degree polynomial function was the best fit under such a situation. Let the yield level of a farm be Y_1 on the frontier F_1 and the technical inefficiency be

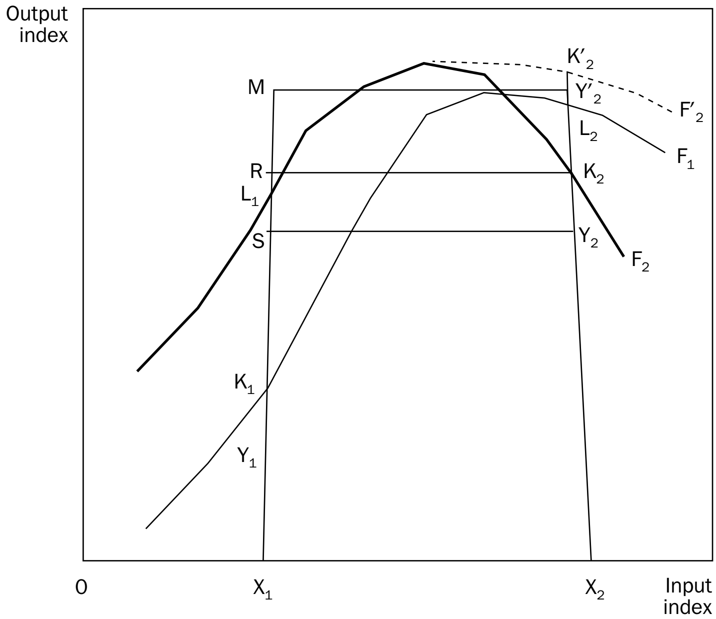

Fig. 4. Contribution of sustainability to total factor productivity.

K_1Y_1. Because of the increase in input use from X_1 to X_2 and technological improvement, yield reaches Y_2 and the technical inefficiency of the farm becomes K_2Y_2 on the F_2 frontier. The point Y'_2 is marked such that $K'_2Y'_2$ on the F'_2 frontier is equivalent to K_2Y_2. Following the split of TFP as suggested by Kalirajan et al (1996), the technical change, which should be $K_1Y_1 - K'_2Y'_2$ (the change in the gap between actual yield and frontier yield over time), is actually $K_1Y_1 - K_2Y_2$ as shown in Figure 4. Thus, the gap K'_2K_2 accounts for the sustainability of the crop, which should be estimated as a separate component along with technical change, improvement in technology, and higher input use.

To illustrate the decomposition of output growth further,

$$\begin{aligned}
(S - Y_1) &= (K_1 - Y_1) + (S - K_1) \\
&= (K_1 - Y_1) + (L_1 - K_1) + (R - L_1) - (R - S) \\
&= \{(K_1 - Y_1) - (R - S)\} + (L_1 - K_1) + (R - L_1) \\
&= (K_1 - Y_1) - \{(K'_2 - Y_2) - (K'_2 - K_2)\} + (L_1 - K_1) + (R - L_1)
\end{aligned}$$

where output growth measured by $(Y_2 - Y_1)$ or vertically by $(S - Y_1)$ is the sum of (1) $(L_1 - K_1)$, the contribution of technological improvement, (2) $(R - L_1)$, the effect of increased input from X_1 to X_2, and (3) $(K_1 - Y_1) - (K_2 - Y_2)$, the technical change caused by improvement in the efficiency of the farm measured by its distance from the corresponding frontier function, and is equal to $(K_1 - Y_1) - \{(K'_2 - Y_2) - (K'_2 - K_2)\}$.

In this component, $(K'_2 - Y_2) - (K'_2 - K_2)$ accounts for the visible change in farm efficiency and $(K'_2 - K_2)$ indicates the effect of environmental degradation. If this would not happen, the yield of the farm in question would have been Y'_2 rather than Y_2.

In this output growth analysis, component 2 accounts for input growth whereas 1 and 3 are the TFP components. As the issues concerning sustainability become more and more severe, its contribution to the decline in TFP becomes even more pronounced and may even camouflage the contribution of other factors. As Kalirajan et al (1996) put it, "Coexistence of a high rate of technological progress and a low rate of change in technical efficiency may reflect the failure in achieving technological mastery or adoption," which becomes illusory in such a situation. This emphasizes the need to identify and implement sustainable sources of productivity growth in the rice-wheat cropping system. Apparently, yield does not improve in spite of technological advances, a higher use of inputs and better education, and awareness and experience of farmers. New technology as such may be appropriate for one farm situation, whereas, for others, it needs to be tailored by the farmers themselves before its adoption in a suitable form for each specific situation. Therefore, the concept of "best practice" is the most appropriate for estimating the frontier level of yield.

Empirical analysis

The data collected under the Cost of Cultivation Scheme from 300 farmers in Punjab for different years were used to split TFP growth into three components: technical change, technological improvement, and environmental degradation as identified above. The contribution of technology was estimated through the coefficient of the dummy variable representing different time periods. The coefficient indicates a growth rate of 1.27% and 2.38% for rice and 2.97% and 1.81% for wheat during period 1 and period 2, respectively (Table 3 and Fig. 5). The contribution of technical efficiency of farms at different times, based on the frontier analysis, was also worked out. This indicated that the technical efficiency improved by 1.66% and 0.89% for rice during period 1 and period 2, respectively. However, for wheat, a slight decline occurred in the technical efficiency of farmers in period 1, whereas period 2 showed improvement by 1.01%. Both these components could not fully explain the growth in TFP, which is lower than the sum of the previous two components. The difference is attributed to the effect of environmental degradation ("unsustainability"). The value of this third component was –1.42% and –5.04% for rice and –0.74% and –1.58% for wheat

Table 3. Split of total factor productivity (TFP) growth into different components in Punjab (%).

Crop	Period	TFP growth	Technology	Technical change	Sustainability
Rice	1982-83 to 1989-90	1.51	1.27	1.66	–1.42
	1990-91 to 1996-97	–1.77	2.38	0.89	–5.04
Wheat	1982-83 to 1989-90	2.13	2.97	–0.10	–0.74
	1990-91 to 1997-98	1.24	1.81	1.01	–1.58

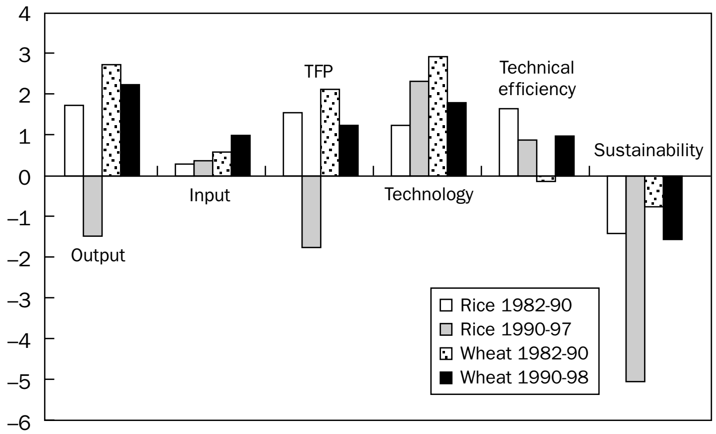

Fig. 5. Components of output growth in Punjab (%). TFP = total factor productivity.

in period 1 and period 2, respectively. “Unsustainability” is thus a catch-all factor and accounts mainly for obvious environmental degradation such as a decline in the water table, increasing incidence of pests, and deteriorating soil health. This further highlights the fact that a decline in TFP as explained by sustainability is becoming more alarming and rice is posing more of a danger than wheat in the rice-wheat system of Punjab.

Conclusions

The decomposition of productivity growth made by Kalirajan et al (1996) has demonstrated that the components of output growth are technical change, technological improvement, and increases in input use. The first two components account for TFP growth. When attempting to use this model under the Indian Punjab situation, which has almost completely exploited the available potential of soil, water, and other natural resources required, particularly for the rice crop, we segregated out environmental degradation as a component of TFP. We made an effort to apportion the contribution of that factor as an important determinant of TFP growth. The analysis shows that, in Punjab, the problem of resource degradation posed by rice is more serious than that posed by wheat. Further, the negative contribution of environmental degradation to TFP growth is increasing at an alarming rate. This calls for immediate policy interventions to arrest this trend by encouraging farmers to diversify out of intensive rice and wheat cultivation.

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Using El Niño/Southern Oscillation climate data to improve food policy planning in Indonesia

R.L. Naylor, W.P. Falcon, N. Wada, and D. Rochberg

Despite the strong effect of El Niño/Southern Oscillation (ENSO) events on climate in the Indo-Pacific region, models linking ENSO-based climate variability to Indonesian cereal production have not been well developed. This study successfully measures the connections among sea-surface temperature anomalies (SSTAs), rainfall, and rice and maize production in Indonesia during the past three decades. About half of the interannual variance in paddy *(gabah)* production during the main (wet) season is explained by year-to-year fluctuations in August SSTAs. These effects are cumulative for rice; during strong El Niño years, production shortfalls in the wet season are not made up later in the year. Econometric results for maize, while less consistent than those for rice, indicate a largely inverse pattern. The study shows that paddy production in Indonesia varies on average by about 1.4 million tons for every 1 °C change in the August SSTA for the central Pacific Ocean. It also illustrates how policymakers might use an SSTA model to improve food policy planning within Indonesia.

Climate patterns associated with El Niño and La Niña episodes exert dominant influences on agricultural production and food security in Southeast Asia. In Indonesia, the production of rice and maize is especially vulnerable to climate variability associated with El Niño/Southern Oscillation (ENSO) events. Two of the most significant El Niño events on record have occurred during the past 20 years and both led to severe droughts that delayed rice and maize harvests (Fox 2000, Safalsky 1994, Harger 1995, Amien et al 1996, Holmes 1999, personal communication). Harvest delays prolong the hungry season *(paceklek)* and, in the absence of interventions, exacerbate food insecurity among the poor.

The recurring pattern of interannual oscillations in both sea-surface temperature (referred to as El Niño and La Niña for warming and cooling periods, respectively) and sea-level pressure (Southern Oscillation) in the tropical Pacific shows strong correlations with climate patterns around the world. Sea-level pressure fluctuations are very pronounced over Indonesia and in nearby tropical Pacific areas (Trenberth et al 2001, Trenberth and Shea 1987, Trenberth and Hoar 1996). During El Niño warm-mode events, these pressure systems consistently induce dry climatic conditions and droughts. Long-term records from 1830 to 1953 show that 93% of droughts in Indonesia occurred in El Niño years (Quinn et al 1978).

Actual ENSO data and also ENSO forecasts—whose precision is quite reliable for periods of up to 6 months—are now recognized as an important tool for assessing food security in various parts of the world (Pfaff et al 1999). Studies have demonstrated ENSO's effect on maize yields in Zimbabwe (Cane et al 1994), soybean and maize yields in central-eastern Argentina (Podesta et al 1999), and soybean and maize production in the southeastern U.S. (Hansen et al 1998). Although the connection between ENSO and regional climate is much more remote for these regions than for the Indo-Pacific region, successful modeling of Indonesian cereal production in response to ENSO has been limited to date by the country's island geography and multiple-season crop year (Iglesias et al 1996). Prior models have typically relied on annual (calendar year) data and have resulted in climate-yield correlations for Indonesia that are statistically insignificant.

In this paper, we first describe the relationship between disaggregated climate and crop production data on Java, Indonesia's main rice- and maize-growing region. We then quantify the connections among ENSO indices, rainfall, and grain production. Our primary analysis covers the period from 1971 to 1998, when modern cereal varieties were widely used and agricultural production statistics were consistently maintained. Because the most comprehensive data are for Java, we first measure the connections between ENSO and rice and maize harvests there, then discuss the patterns for Indonesia as a whole.

The primary aims of our research are threefold: to add quantitative estimates of agricultural variability to the literature on climate change, to provide policymakers and food-policy analysts in Indonesia with a predictive tool for assessing crop variations in strong El Niño and La Niña years, and to put into the public domain a simple but robust climate model that can help to minimize the use and misuse of uninformed climate predictions for political purposes, including the call for additional budget support for agriculture in normal climate years.

Rice cropping patterns

Although declining in its overall economic importance, rice is still the primary food staple for most of Indonesia's 215 million people. Approximately 50 million tons of paddy (*gabah*) are produced each year on more than 11 million hectares (BPS 2000).

Roughly 60% of Indonesia's total rice and maize output is grown on the island of Java, mainly in lowland irrigated and rainfed ecosystems. Rice and maize planting patterns on Java follow the marked seasonality of rainfall (Fig. 1). In a typical year, rice is generally planted early in the "wet season" from October to December when moisture is sufficient to prepare the land for cultivation and to facilitate early rooting

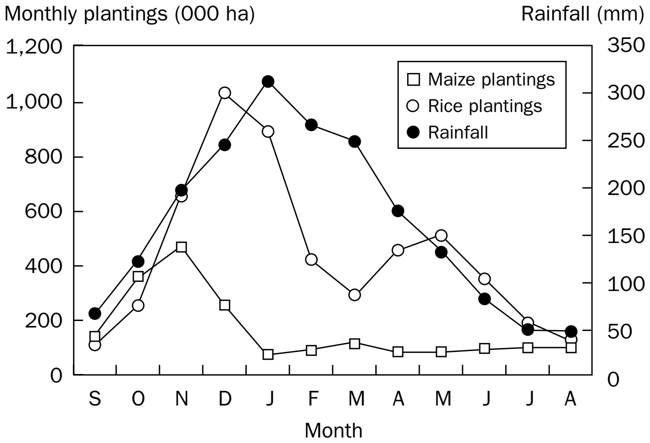


Fig. 1. Average monthly planting and rainfall patterns on Java, 1971-98.

of rice seedlings. Rainfall, and thus planting, typically begins a month or more earlier in West Java than in East Java.

The amount and timing of rainfall strongly influence crop rotations on Java. Rice requires 600–1,200 mm of water during its 90–120-day grow-out period from planting to harvest, depending on the agroecosystem and the timing of rainfall or irrigation (De Datta 1981). Rainfall patterns often also determine variety selection by farmers, for example, whether a shorter- or longer-duration variety is selected (Pandey 2001, personal communication). Since maize requires considerably less water during its grow-out period (Mink et al 1987), the ratio of maize to rice plantings typically increases during drought years. Nevertheless, it is not easy to discern the extent to which increases in maize area planted substitute for declines in rice area planted during the El Niño years. Substitution effects that arise from delays in planting become much more complicated when analyzed within farming systems that have multiple crop seasons in one calendar year.

During El Niño events, the eastward displacement of convection into the central Pacific delays the onset of rainfall over the key rice-producing zones by as much as two months. Rice plantings are typically delayed and reduced, prolonging the *paceklek* season before the start of the main wet-season harvest. Indeed, rainfall early in the wet season tends to dictate rice planting patterns for the next 8–9 months because delayed plantings in the wet season also delay plantings of rice in the dry season.

A principal finding of our analysis is that fluctuations in planted and harvested areas, not yields, largely determine the composition of, and variability in, grain production on Java. This result is somewhat counterintuitive since about 90% of rice on Java is grown under technically irrigated conditions. A question immediately arises as to why these irrigation systems do not buffer delays or shortfalls in rainfall, thereby eliminating variations in plantings during the September-November period.

A high proportion of the irrigation networks on Java are "run of the river" systems, that is, they do not operate until significant rains occur. There has been some growth recently in the number of irrigation wells that help to minimize planting delays, and a few of the larger irrigation systems on Java have dams and live storage of water that can be spilled during periods of drought. Even in the case of the latter systems, however, the empirical evidence suggests that they are managed as if they were run of the river systems. Detailed irrigation data by month and year are difficult to collect and assemble; summary data on irrigation systems can be found in World Bank (1990).

The data in Table l reveal both the limits of irrigation and the importance of rainfall in determining delays in planting. Rice plantings from three recent El Niño years are contrasted with those from three La Niña years. Cumulative plantings from September-November average about 500,000 ha for El Niño years and about 1,700,000 ha for La Niña years. Once the rains do come, however, technical irrigation provides sufficient water control to more or less equalize yields across "dry" and "rainy" years. By contrast, off Java, where a greater share of the grain is grown in rainfed farming systems, yield variability contributes—although marginally—to overall production variability.

These patterns help to explain why earlier attempts to model the effect of ENSO events on calendar-year rice production and rice yields have encountered difficulty. In our analysis, we focus instead on ENSO's effects on the timing and fluctuations in grain area planted and harvested in Indonesia.

Measuring ENSO's effects on rice area and production

To model the effects of climate variability on rice area and production, we first examined two intermediate linkages—the associations between ENSO and rainfall and between rainfall and rice production—and then examined the direct association between ENSO and rice area planted and harvested. We also measured the direct connection between ENSO and rice output in the wet season.

Table 1. Rice plantings on Java, Sep.-Nov., recent El Niño and La Niña years.

Year	September	October (000 ha)	November	Cumulative
El Niño years				
1997	68	81	338	487
1994	67	83	510	660
1982	65	55	232	352
La Niña years				
1998	233	523	1,065	1,821
1996	98	458	1,070	1,626
1992	114	558	1,050	1,722

Source: Badan Pusat Statistik, Survei Pertanian, Produksi Tanaman Padi dan Palawija di Indonesia, various years.

Several ENSO indices were candidates for our study. The Niño 3.4 sea-surface temperature anomalies (SSTAs), measured between the eastern equatorial Pacific and the central Pacific (at 170°W to 120°W and 5°N to 5°S), have increasingly become the standard used by most climate modelers; they were used in this study as well. The Niño 3.4 SSTAs measure the deviation in °C from a long-term monthly mean sea-surface temperature in the Pacific, calculated from a base period of 1950-79. This almost always lies between plus or minus 4 °C. El Niño (warming) periods are associated with high and positive SSTAs in the central Pacific, whereas La Niña (cooling) periods are linked to low and negative SSTAs. The Southern Oscillation Index (SOI) also performed quite well statistically in the experimental phase of our study. Although the SOI has often been used in climate research on Southeast Asia, we chose the SSTAs because they are thought to contain less high-frequency random variance associated with atmospheric fluctuations that are distinct from ENSO (Cane et al 1994).

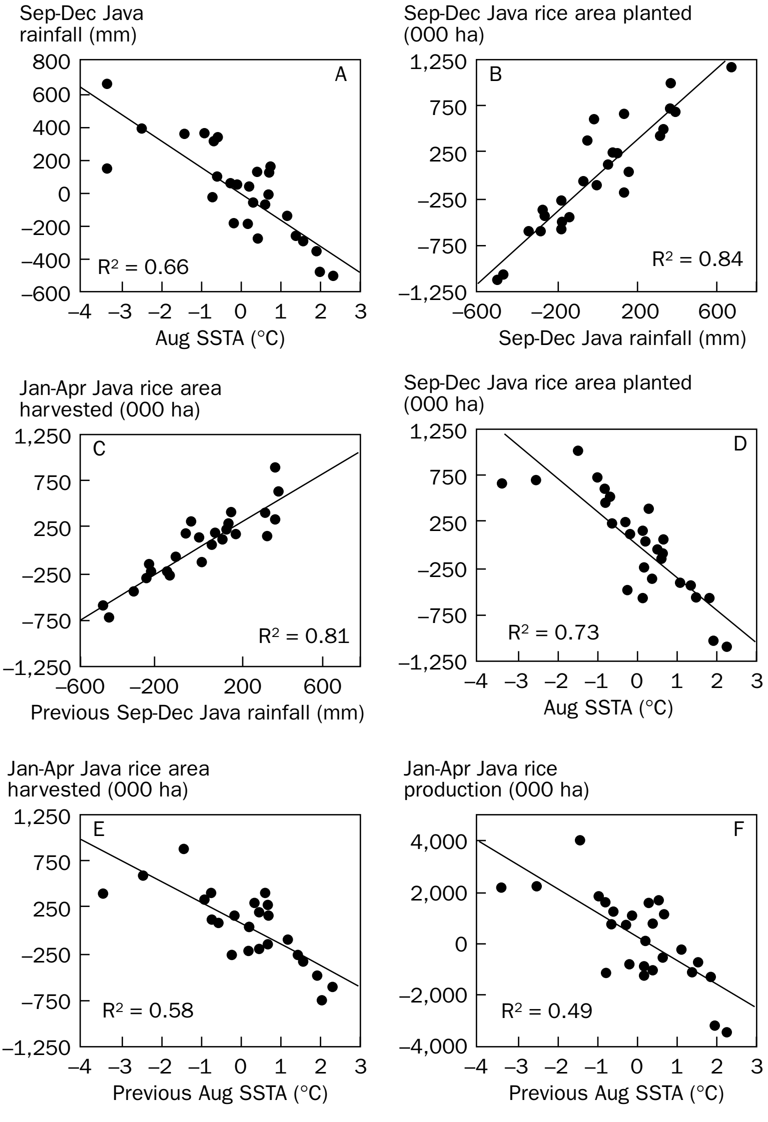
Monthly rainfall data were derived from spatially weighted averages of rain gauge reports on Java. Data were measured from 17 rain gauges on Java chosen for their locations relative to grain-producing regions. The data were obtained from NOAA (1999). These data were corroborated and supplemented by data from Derek Holmes, a long-time precipitation expert and consultant for the World Bank in Indonesia. For further reference to Holmes's analyses, see Holmes (1998).

Data on rice area planted, area harvested, production, and yield were collected in monthly and trimester (January-April, May-August, September-December) sets. Data were collected from the Biro Pusat Statistik (BPS) in Jakarta. Data on area planted were available in monthly form; data on area harvested, production, and yield were available only in trimester form. The ENSO, rainfall, and rice production data were then converted to first differences. This conversion permitted a direct analysis of year-to-year variability and helped to remove statistical problems of first-order autocorrelation among the residuals. In addition, year-to-year changes in production are more easily interpreted than deviations from hypothetical trends. Finally, the first-difference models performed consistently better econometrically (as measured by "t" statistics in the various estimating equations) than those that used deviations-from-trends as the dependent agricultural variables to be explained.

Rice production on Java

The results of our analysis confirm a clear connection between El Niño climate patterns and rainfall on Java during the wet season. Year-to-year changes in Niño 3.4 SSTAs are highly correlated with year-to-year changes in rainfall in September-December, when most rice is planted on Java. Warming periods in the central Pacific are associated with decreased rainfall and vice versa; 69% of the variance in year-to-year changes in September-December rainfall is explained by SSTAs measured in the same period.

A longer lead-time can be gained by assessing wet-season rainfall as a function of August SSTAs. It is a simple task to track a single month of SSTAs (actual and predicted), and Figure 2A shows that year-to-year changes in August SSTAs explain



	Regression equations	t_{nt}	t_{coeff}	D.W.
A	$\Delta Y = -0.56 - 161.40\ \Delta X$	0.02	–7.16	2.53
B	$\Delta Y = 29.12 + 1.93\ \Delta X$	0.64	11.81	2.62
C	$\Delta Y = 58.60 + 1.29\ \Delta X$	1.96	10.73	2.69
D	$\Delta Y = 26.81 - 355.46\ \Delta X$	0.45	–8.48	2.15
E	$\Delta Y = 62.22 - 217.23\ \Delta X$	1.39	–6.12	2.37
F	$\Delta Y = 382.14 - 936.84\ \Delta X$	1.65	–5.10	2.44

Fig. 2. Climate-rice relationships, Java (first differences), 1971-98.

66% of the interannual variance of changes in September-December rainfall. Comparable regressions using the May-August SSTAs index can be found in Naylor et al (2001). During El Niño events, rainfall in September-December can be more than 500 mm below the 625 mm average.

The effect of rainfall on rice production on Java is reflected mainly in the timing and extent of area planted and harvested by season. Low rainfall in September-December typically delays plantings until cumulative rainfall is adequate to permit the transplanting of seedlings (Heytens 1991). This pattern is shown in Figures 2B and 2C; 84% of the variance in area planted in September-December and 81% of the variance in area harvested in January-April is explained by September-December rainfall. For reasons noted earlier, rice yields in January-April (not shown) are not affected by rainfall (adjusted $R^2 = 0.002$).

These results provide the basis for linking ENSO directly to rice plantings in the wet season, when more than two-thirds of Java's cropped area is sown to rice (BPS 1997). El Niño-induced delays of both the wet- and dry-season plantings can be seen in the correlation coefficient matrix shown in Table 2. By focusing again on the August SSTAs, for example, it is clear that year-to-year increases in the SSTAs—marking El Niño warming periods—are negatively correlated with year-to-year changes in rice area planted in August-November, but positively correlated with rice area planted in January-March. The regression results shown in Figure 2D reinforce this pattern. Year-to-year fluctuations in August SSTAs are negatively and strongly correlated (adjusted $R^2 = 0.73$) to the interannual changes in September-December rice plantings.

Planting dates, in turn, directly affect the timing of the wet-season harvest. Late and reduced rainfall in the wet season caused by El Niño-induced warming will delay and reduce both plantings and harvests of rice. Figures 2E and 2F show that year-to-year fluctuations in August SSTAs explain 58% of the interannual variance in rice

Table 2. ENSO-Java rice plantings correlations (first differences), 1971-98. Shading denotes significance at 1% level (black = negative, gray = positive).

El Niño 3.4 SSTAs (first difference)	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
May	–0.27	–0.48	–0.46	–0.18	0.56	0.58	0.35	–0.48	0.01	0.54	0.36	0.18
Jun	–0.58	–0.72	–0.6	–0.20	0.65	0.68	0.48	–0.59	0.03	0.62	0.43	0.22
Jul	0.52	–0.69	–0.74	–0.26	0.65	0.74	0.58	–0.64	–0.08	0.67	0.50	0.21
Aug	–0.52	–0.71	–0.80	–0.33	0.71	0.81	0.63	–0.69	–0.02	0.73	0.56	0.23
Sep	–0.48	–0.66	–0.79	–0.38	0.66	0.82	0.65	–0.70	–0.02	0.69	0.51	0.21
Oct		0.68	–0.79	–0.40	0.69	0.83	0.69	–0.72	–0.01	0.70	0.54	0.22
Nov			–0.76	–0.41	0.68	0.84	0.68	–0.72	–0.02	0.69	0.57	0.26
Dec				–0.41	0.70	0.83	0.70	–0.67	0.00	0.66	0.58	0.30

area harvested and half of the interannual variance in rice production in January-April. The slope coefficient for Figure 2F indicates that a 1 °C increase in August SSTAs causes a decline in January-April (wet-season) paddy production on Java of more than 900,000 tons.

El Niño and La Niña events affect both the timing of rice plantings and the cumulative area of rice planted over the entire cropping year (August-July). Deviations from trends in monthly rice area planted on Java since 1971 are plotted in Figure 3A for the four strongest El Niño events and the four strongest La Niña events. In El Niño years, planted area is far below normal early in the rainy season and above normal late in the rainy season. This pattern represents a delay of normal wet-season cropping. Second-season planting is also delayed; April plantings are lower than normal, while June plantings are higher than normal. La Niña years show the opposite pattern, with above-normal plantings early in the rainy season.

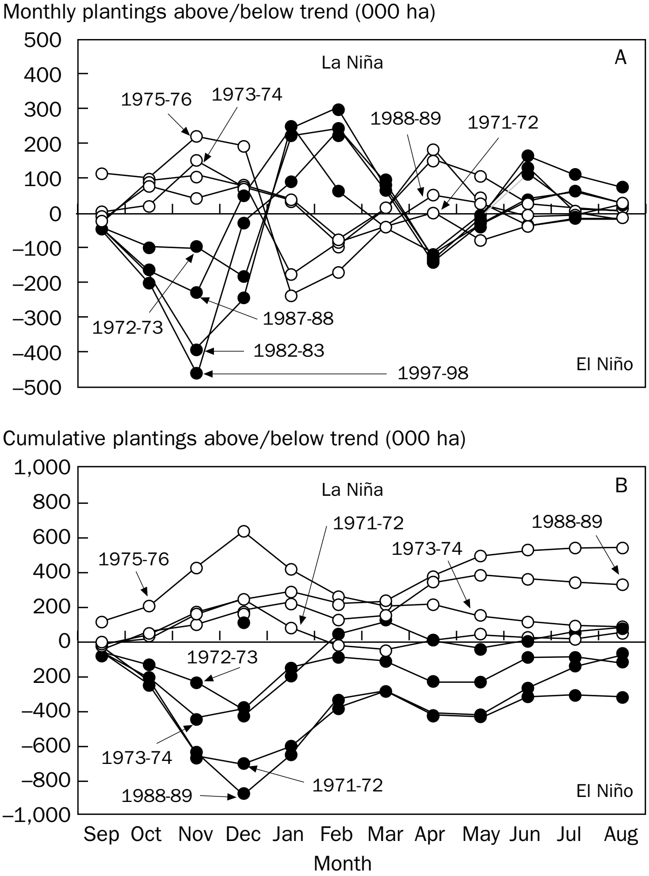


Fig. 3. Rice plantings above/below trend during strong ENSO events.

The cumulative residuals, depicting the extent to which early planting deficits are recovered later in the crop year in El Niño years (and vice versa for La Niña years), are shown in Figure 3B. By December during El Niño years, cumulative plantings are far below those of normal years. Cumulative area planted usually remains below normal throughout the entire cropping year during strong El Niño events; as a result, early losses in rice production are rarely recouped. During the most recent El Niño event in 1997-98, for example, rice area planted was below the trend by some 225,000 ha during May-August 1997 and was below the trend also by an additional 700,000 ha during September-December 1997. This reduction in planting translated into a deficit in September 1997-April 1998 rice production of about 4.8 million tons of *gabah*, or more than 3 million tons of milled rice.

More generally, changes in paddy production for the entire September-August crop year closely resemble those shown in Figure 2F for the January-April trimester. For the 1971-98 period, equation 1 indicates that the changes in the preceding August SSTAs explain 41% of the interannual changes in Java's yearly paddy production; specifically, a 1 °C change in the August SSTAs affects annual paddy production on Java by slightly more than 800,000 tons.

Δ Paddy production (thousand t) = 466.7 – (827.2) (Δ August Niño 3.4 SSTAs) (1)
Java, Sep.-Aug. (1.74) (–4.32) (t values)
Adjusted R^2 = 0.41 D.W. = 1.92

Rice production for Indonesia

The climate-induced variability in rice production documented above for Java is similar to the pattern of estimates observed for all of Indonesia. Unfortunately, production data for provinces off Java are significantly less complete than for those on Java, and trimester data for all-Indonesia are available only for a relatively short time series beginning in 1983. Even for this limited period, however, year-to-year changes in rice area and production for all-Indonesia are highly correlated ($r \geq 0.99$) to the corresponding data for Java.

The key relationships for rice and ENSO displayed for Java in Figure 2 are shown for all-Indonesia in Table 3A. In developing the all-Indonesia equations for rice, we first compared the shorter and longer series for Java to be certain that there had not been major structural changes during the more recent period. The slope coefficients for Java during the 1983-98 period were nearly identical with those shown in Table 2 for 1971-98. We were thus reassured about the validity of using the shorter time series to assess ENSO effects for all of Indonesia.

The wet-season coefficients are strikingly similar to those of Java, except for one important difference. The yield relationship for all-Indonesia is significantly correlated to the August Niño 3.4 index for the January-April period. Irrigation facilities off Java are much less widespread than on Java, and we believe that this difference in water control contributes directly to the significant yield relationship and indirectly to the significant production relationship for all-Indonesia.

Table 3A. All-Indonesia ENSO-rice relationships, Jan.-Apr. harvests, 1983-98.

	Regression equation	t_{int}	t_{coeff}	R^2	D.W.
1	ΔArea harvested = 112.4 – 252.9 ΔX^a	1.26	–3.65	0.47	1.78
2	ΔYield = –0.042 – 0.052 X^a	2.76	–4.36	0.56	1.36
3	ΔProduction = 630.9 – 1,310.7 ΔX^a	1.51	–4.03	0.52	1.79

[a] X = August Niño 3.4 sea surface (°C).

Table 3B. All-Indonesia ENSO-rice relationships, yearly (Sep.-Aug.) harvests, 1983-98.

	Regression equation	t_{int}	t_{coeff}	R^2	D.W.[b]
4	ΔArea harvested = 153.6 – 275.8 ΔX^a	1.78	–4.81	0.61	2.14
5	ΔYield = 0.019 – 0.021 X^a	1.04	–1.78	0.13	0.90
6	ΔProduction = 839.2 – 1,399.9 ΔX^a	1.91	–4.79	0.61	2.09

[a] X = August Niño 3.4 sea surface (°C). [b] At the 1% level (1 independent variable, 15 years), there is no significant serial correlation of the residuals if the computed Durbin-Watson statistic is between 1.07 and 2.93. The Durbin-Watson test is inconclusive with respect to positive serial correlation between 0.81 and 1.07.
Units: area harvested (000 ha), yield (t ha^{-1}), production (000 t).

Estimating equations for the entire cropping year (September-August) are shown in Table 3B. They indicate that more than 60% of the interannual variance in Indonesian rice production is explained by differences in the August Niño 3.4 index. For the September-August crop year in Indonesia, a change in area is the primary determinant of changes in paddy production. The yield relationship (Table 3B, equation 5) is statistically significant only at the 90% level. It is also borderline with respect to the positive serial correlation of its residuals and adds little to the explanation of changes in paddy production.

In El Niño years, rice harvests are both delayed and smaller in Indonesia; in La Niña years, the opposite is true. The key ENSO relationship (Table 3B, equation 6) indicates that a 1 °C change in the August Niño 3.4 SSTAs results in about a 1.4 million-ton decline in yearly (September-August) Indonesian *gabah* production. Year-to-year changes of 3.5 °C happen perhaps once a decade, and the corresponding aggregate change is about 5 million tons or about 10% of Indonesia's total paddy production.

These econometric results are quite robust, and the predictive strength (adjusted R^2s) of the equations is quite remarkable given the first-difference framework. Nevertheless, ENSO effects explain only about two-thirds of the interannual variation in rice production, the rest being determined by additional biological and behavioral factors. Inclusion of these variables is probably best accomplished by using a panel approach with provincial data. In any event, attempts to include the ratio of fertilizer prices to rice support prices in our earlier first-difference formulation for Java into equation 1 were not successful. While the sign of the price coefficient was correct, the estimate was not statistically significant.

Using an SSTA model in food policy planning

The statistical relationships presented here are among the first in the climate-change literature to measure ENSO effects within the context of multiple-season agriculture. It is a separate question, however, whether these equations are also useful to policymakers as they attempt to cope with the effects of production variability. The new structure of the world rice market means that Indonesian rice imports of 3–4 million tons during a severe El Niño year are unlikely to induce major increases in world prices. Dawe (2001) reports that, for the period 1970-85, the average tonnage of rice traded internationally was 10.4 million tons per year, the average nominal price was US\$301 t^{-1} (Thai 5% brokens, f.o.b. Bangkok), and the coefficient of variation for nominal rice prices was 0.39. For 1986-2000, the average tonnage increased to 17.0 million tons per year, average nominal price fell to \$274 t^{-1}, and the coefficient of variation for nominal rice prices fell to 0.15.

Since 1998, there has been a more open (and sometimes more disorganized) policy framework for rice within Indonesia than was evident during the preceding 25 years. The private sector can and does import grain subject (in principle) only to import tariffs. Privatization of the rice trade leaves policymakers with fewer direct policy instruments for rice. Nonetheless, they still face ENSO effects that may cause *gabah* production in Indonesia to vary by about 1.4 million tons for every 1 °C change in the SSTAs of the central Pacific Ocean. The question at issue, therefore, is whether the model presented here helps decision makers plan for and deal with weather-induced production variability.

We believe that the answer is yes, or at least that it could be yes. A transparent framing of likely ENSO effects would assist the private sector in responding sensibly to projected domestic shortfalls in rice production. In principle, the quantity of rice imports in El Niño years should be adjusted to cover significant shortfalls in production, and if orders are placed in an informed and orderly manner, there should be little effect on either international or domestic rice prices. In such a scenario, the government would play a key informational role by predicting likely ENSO effects with a lead time of at least 6 months, that is, after reading the change in the August Niño 3.4 index each year.

In practice, several things could go wrong with how our forecasting model might be used in this process. First, the first-difference model performs very well, but not with 100% certainty. It is likely to predict changes quite well for extreme El Niño or La Niña events, but it may predict changes less well when changes in the August Niño 3.4 index are relatively small. Second, a smoothly functioning private trade requires domestic price and tariff policies that are consistent and implemented with reasonable honesty. Third, the success of the information-based system outlined above is intimately linked to macro policies, and in particular to policies aimed at avoiding sudden movements in the rupiah-dollar exchange rate. When domestic rice shortages prevailed with the severe El Niño event of 1997-98, short-run domestic price signals within Indonesia had little to do with the El Niño event and a great deal to do with the rapid depreciation of the rupiah caused by political and financial events of the time. Fourth, if officials continue to issue El Niño forecasts based on inadequate information (or deliberate misinformation) to obtain additional budgetary support for “anticipated” disasters, climate forecasts will be discredited and they will soon lose their informational effect. A more general discussion of the misuse of ENSO data can be found in Broad and Agrawala (2000).

Altered circumstances in the world rice market and in climate forecasting thus provide the Indonesian government with an additional policy tool for rice-price stabilization. It is possible in principle for Indonesia to run an open trade plus (low) tariff system for rice and still maintain adequate rice supplies and reasonable domestic rice-price stability. However, the magnitude of extreme El Niño and La Niña events on Indonesian rice production demonstrated by our model also offers some strong policy warnings. A broad array of consistent macro, commodity, and climate-information policies is needed if poor households in Indonesia are not to become victims of food insecurity caused by climate-induced variations in food production and food prices.

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Conclusions and policy implications

The papers presented in the workshop focused on the forces influencing the supply and demand of rice, and presented a scenario on the supply-demand for individual countries that will affect international trade. The analysis shows that the supply-demand balances over the next few decades will continue to be influenced by the following factors.

Most Asian countries are making good progress in population control. The annual growth of population in Asian countries where rice is the dominant food staple has declined from 2.4% per annum in the 1960s to 1.4% in the 1990s. It is projected to decline further to 0.6% by 2020. With the decline in population growth, the demand for rice is going to slacken substantially. However, in the low-income regions with a high incidence of poverty, the population growth rate is still high and the decline has been modest. The recent census of India, for example, shows very little progress in population control in the poverty-stricken eastern part of the country compared with the southern and western parts where the incidence of poverty is low and the economy has been making good progress.

With high levels of per capita income reached in the middle- and high-income countries in Asia, and the growing middle class in the low-income countries, the dietary pattern of consumers has been changing in favor of a lower intake of rice. Consumers can now afford to have a more nutritionally balanced but high-cost diet with a higher intake of vegetables, fruits, fish, and livestock products than a few decades ago when meeting energy needs with staple grains was a more pressing concern. As a result, this is no longer a significant factor behind the increase in per capita demand for rice. Rather, many countries may experience an absolute decline in the per capita consumption of rice within the next few decades.

Another factor that will dampen the demand for rice is growing urbanization and women's participation in the labor force. Urbanization still remains low in Asia compared with other continents. The urban population is expected to increase from 35% now to about 55% by 2030. Urban people consume less rice than rural people at the same level of income. Also, with increased female participation in the workforce, the incidence of eating out increases, leading to lower consumption of staple food.

On the supply side, growth in the domestic production of rice is going to be affected by the growing scarcity of inputs and the change in the relative price of rice vis-à-vis other agricultural produce. A water crisis is looming in many countries in Asia and the governments must make hard decisions on allocating this scarce resource among alternative uses, particularly for industry and a supply of safe drinking water. Rice is a heavy water-using crop and is an inefficient user of water. Whether the water scarcity will affect rice production will depend on the development of water-saving technologies, particularly for transplanting and weed control, and changes in policies regarding the pricing of irrigation water so that farmers will have incentives to adopt water-saving technologies.

With growing urbanization and the development of rural nonfarm activities, the agricultural labor market is becoming tight and the wage rate has been increasing faster than rice prices. This development may not have much adverse impact on growth in rice production as farmers have been responding by adopting agricultural mechanization to save labor and other labor-saving practices such as direct seeding for crop establishment and the use of herbicides to replace manual weeding. In fact, the adoption of mechanized cultivation may help reduce the unit cost of production. The spread of mechanization in postharvest operations may help improve the quality of seeds, head rice recovery, and grain quality, thereby adding value to rice production. The constraint may come from the availability of appropriate farm machinery for small farmers and access to credit for the purchase of machinery or renting of services.

With the increase in per capita income and diversification of diets, the market for nonstaple foods has been growing faster, contributing to a negative downward trend in the relative price and profitability of rice. With trade liberalization and the opening up of the world market for low-cost rice producers, and the depreciation of Asian currencies vis-à-vis the U.S. dollar, the domestic price of rice has declined sharply in recent years compared with that of nontradable agricultural products. This development may provide further incentives to farmers to divert resources (land, labor, and capital) from rice cultivation to other farm and nonfarm activities, which would have an adverse effect on growth in rice production.

Studies have indicated that the world rice market is more stable now than in the past two decades. In addition to Thailand and Pakistan, several countries in Asia have now become major rice exporters. Vietnam overtook the U.S. as the world's second-largest rice exporter in 1996 as low production costs and improvements in rice milling and handling have enabled the country to capture a growing share of the world rice market. Similarly, India has become a major rice exporter in the last decade, with favorable production brought about by a long string of excellent monsoons, a slackening in the strongly held belief that the government should play a leading role in both the overall economy and the food sector, and the increasing private investments in the milling industry. With a very low unit cost of production because of low wage rates and subsidized irrigation, and government emphasis on improving grain quality, India may soon become the second major exporter of rice after Thailand. Myanmar and Cambodia may also emerge as important stabilizing forces. Export supplies are seen to be increasing in Myanmar as it continues to get its economic act together.

Exports from Cambodia are expected to increase from the current trickle to a significant tonnage.

Indeed, buying rice from the world market is projected to be much easier and to be much more affordable as rice exports expand and the rice price is maintained at low levels. This rosy picture is contingent on the continuation of favorable trends of several underlying drivers of world food markets as these are influenced by complex interactions among technology, policy, investment, environment, and the change in the mindset of policymakers. Failure in any one of these factors can change the course of events, which could have a substantial negative effect on future rice balances.

Because of their diversified nature in natural resources, political and economic status, and cultural milieu, the individual countries face issues that vary as these countries view the medium- and long-term prospects of the rice economy. These issues dictate the directions of future rice research. The rice-exporting countries will continue to grapple with the problem of the low international rice price as they further expand exports. This is not good for the numerous poor rice farmers who strive to improve their livelihood and economic welfare. Furthermore, it weakens the competitive strength of the commodity in the international market. The following options were identified to help solve this problem:

- Productivity and grain quality enhancement through improved and more efficient irrigation/water management and crop management techniques, and better postharvest handling of the commodity;
- The development of varieties specific to changing consumers' preferences, especially when markets are freed from government controls; and
- Crop diversification (especially in areas that are less suitable for rice cultivation) to promote high-value products such as livestock, fish, fruits, and vegetables, possibly for export.

The rice-importing countries, on the other hand, will have to make critical decisions to determine the extent that domestic demand will be met by imports. While the international rice market is now relatively stable, its size has remained small relative to the volume of rice consumption of major importing countries, such as Indonesia, Bangladesh, and the Philippines. This means that many of them cannot totally depend on imports for their domestic requirements because this would mean large price increases if a major harvest failure occurred. The political cost of failing to provide the basic staple food is so high that governments are not willing to give up local production in favor of buying supplies from countries with a comparative advantage in producing the commodity. The rice-importing countries will continue to explore the following options to achieve and sustain near self-sufficiency in rice production to minimize the political and social costs at times of scarcity:

- Land and irrigation development to enable wider coverage of high-yielding varieties;
- Improved varieties (higher yields and better quality) for unfavorable rice-growing environments;
- More effective crop and water management practices;
- Increased input-use efficiency to achieve more gains in input productivity;

— More effective protection of the environment to promote sustained production increases;
— Cost-effective mechanisms to promote stability and yet preserve as many of the benefits of free trade as possible;
— An efficient mechanism to cede the rice import business to the private sector; and
— Development of infrastructure for a more effective transmission of prices from the international market to domestic retail markets and, finally, to farmers.

The relevant issues remain as before—how to provide rice at affordable prices to the vast majority of the rural landless and the urban poor while sustaining incentives of farmers to continue increasing production at the rate at which demand has been growing. Rice continues to be the foundation of rural development and a key component in the strategy for maintaining food security in most Asian countries. The need to increase the productivity of land, labor, and water through technology development to reduce the unit cost of production is as pressing now as in past decades. Continued investment in research is critical if we are to increase and sustain rice productivity. The conduct of research becomes highly location-specific as the easy gains in technical change have already been reaped. But major advances in basic knowledge, particularly in molecular biology, geographic information systems, and remote sensing, and in information and communication technologies offer new opportunities for technological breakthroughs in areas that had a low probability of research success in the past and had an adequate allocation of research resources. These developments could lead to higher yield potentials in unfavorable rice-growing environments.

Equally necessary is a favorable policy environment that will encourage everyone to invest and work toward a more robust rice economy. An appropriate mix of policies in each country will have to be adopted to sustain the growth in production to meet domestic and international demand. The inappropriate design and inadequate enforcement of policies in the past have limited governments' effectiveness in addressing externalities. Efficiency and effectiveness in governance based on a strong political will are critical needs to bring about the desired changes in policies for achieving food security and reducing poverty.

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