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NATIONAL AND INTERNATIONAL AGRICULTURAL RESEARCH AND RURAL POVERTY: THE CASE OF RICE RESEARCH IN INDIA AND CHINA

Shenggen Fan, Connie Chan-Kang, Keming Qian, and K. Krishnaiah

Environment and Production Technology Division

International Food Policy Research Institute
2033 K Street, N.W.
Washington, D.C. 20006 U.S.A.

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ABSTRACT

The study attempts to measure the total benefits from rice varietal improvement research in China and India using variety adoption and performance data over the last two decades. It then uses genetic or pedigree information to partition the total benefits between these two countries and IRRI. Finally, the study uses reported elasticity of poverty reduction with respect to agricultural output growth to assess the effects of national and international research on poverty reduction in rural India and China. The results indicate that rice varietal improvement research has contributed tremendously to increase in rice production, accounting for 14–23 percent of total production value over the last two decades in both countries. Rice research has also helped reduce large numbers of rural poor. IRRI played a crucial role in these successes. In 1999, for every $1 million invested at IRRI, more than 800 and 15,000 rural poor were lifted above the poverty line in China and India, respectively. These poverty-reduction effects were even larger in the earlier years.

Contents

National and International Agricultural Research and Rural Poverty: The Case of Rice Research in India and China

Shenggen Fan,[1] Connie Chan-Kang,[2] Keming Qian,[3] and K. Krishnaiah[4]

1. INTRODUCTION

Agricultural research played an important role in agricultural production and productivity growth in many developing countries. The Green Revolution in the 1960s in Asia is a typical case. High-yielding varieties released by national and international agricultural research centers substantially increased crop production in many Asian countries, which had powerful poverty reducing effects. The rural poor benefited directly from income increases as a result of production growth. In addition, rapid agricultural growth stimulated broader economic development that led to the regional economic boom of the 1980s and 1990s (Rosegrant and Hazell 2001). Thus, rural poverty also declined through these indirect effects in the region, and the predicted food shortage never occurred. While there have been many studies on the effects of the Green Revolution on production and productivity growth in the 1970s and 1980s, the question today is whether these national and international efforts will continue to have high payoffs in further growth in agricultural production.[5] In addition, what role the Consultative Group for International Agricultural Research (CGIAR) centers have played as a partner in this

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[1] Shenggen Fan is a senior research fellow at the International Food Policy Research Institute, Washington .,
[2] Connie Chan-Kang is a research analyst at the International Food Policy Research Institute, Washington
[3] Keming Qian is the director-general of the Institute of Agricultural Economics, Chinese Academy of Agricultural Sciences.
[4] K. Krishnaiah is a former director of the Directorate of Rice Research, Hyderabad, India.
[5] These studies include Hayami and Ruttan (1985) and Hazell and Ramasamy (1991).

process has not been well documented.[6] Moreover, there have been few attempts to link agricultural research investments to rural poverty reduction.[7] This study is designed to help fill these gaps using the case of rice in India and China. The study measures the impact at national levels, taking account of the important ways, direct and indirect, in which the poor can be affected. Information on the poverty effects of agricultural research investments will help national and international policymakers mobilize resources and set priorities for agricultural research in the future.

India and China are the two most populous countries in the world, together accounting for more than 38 percent of the total population and almost 50 percent of rural residents. In spite of recent rapid economic growth in both countries, many people still live under the poverty line. India has an estimated 200 million and China 30 million rural people under the poverty line. However, if the poverty line of US$1 per day measured in purchasing power parity is used, China would have substantially more poor than the official figure. Using this line, China had more than 100 million rural poor in 1998 (World Bank 2000).

Rice is a major staple food crop for many developing countries, not only as a main source of calories but also as an important source of income and employment for many farmers, particularly poor households. For developing countries as a whole, rice accounted for 34 percent of cereal area and 47 percent of cereal production in 2000. Rice is, in fact, the dominant cereal in China and India, occupying 35 and 45 percent of total cereal area

[6] CGIAR, created in 1971, is an association of public and private members supporting a system of 16 international agricultural centers that work in more than 100 countries. CGIAR's aim is to reduce hunger and poverty, improve human nutrition and health, and protect the environment.
[7] Evenson and Gollin (2002) estimated economic returns to varietal improvement of CGIAR research.

respectively in 2000. For that same year, rice accounted for 45 and 57 percent of total cereal production in China and India.

China and India are the two leading rice-producing countries and have been so since 1961, the first year that data became available from FAOSTAT. In 2001, they jointly produced 53 percent of the world's rice on 48 percent of world rice area. In China and India, rice is the most important food crop, accounting for about 30 percent of food energy intake (FAO 2002).

The International Rice Research Institute (IRRI) has been collaborating with China and India for the past several decades. The major modes of collaboration have been joint research and exchanges of human resources, scientific information, and germplasm. We selected rice in these two countries to evaluate the total benefits from varietal improvement research, attempt to partition these benefits to IRRI and others, and estimate the contribution of rice breeding research to poverty reduction.

In contrast to the traditional econometric approach proposed by Griliches (1957), this study uses extensive data on the adoption and performance of the rice varieties used by Chinese and Indian farmers to evaluate the total benefits from rice varietal improvement research. The study then relies on pedigree information to analyze how international agricultural research has contributed to productivity gains in Chinese and Indian rice production. Finally, the study uses the calculated benefits, together with poverty impact parameters reported in recent IFPRI studies, to assess indicatively how domestic and international rice research has contributed to poverty reduction.

2. RURAL POVERTY IN CHINA AND INDIA

Headcount ratio, the percentage of the population falling below the poverty line, is the most widely used measure of poverty incidence. The poverty line used in India is defined as 49 rupees per month at 1973–74 prices (Datt and Ravallion 1997). This poverty line is equivalent to $0.965 per person per day measured in 1993 purchasing power parity (PPP), only slightly below the $1 per day widely used for cross-country comparison by the World Bank and others. China adjusts its official poverty line annually (China State Statistics Bureau 1999). In 1990, the official poverty line was 300 yuan per person per year, equivalent to $0.67 per day measured in 1990 PPP. The poverty line was raised to 635 yuan in 1998, equivalent to $0.84 per person per day.

Using these poverty lines, the incidence of poverty declined dramatically over the last several decades in both countries. In India, rural poverty fluctuated from 50 to 65 percent in the 1950s and early 1960s before beginning a steady decline from about two-thirds of the rural population in the mid-1960s to one-third of the rural population in the late 1980s. Rural poverty increased to about 40 percent in the early 1990s when economic policy reforms were initiated. Recent official data show that the poverty rate declined to 27 percent in 1999.

The long downward trend in poverty in rural India from 1967 to 1999 coincided with several important developments. The rapid adoption of high-yielding varieties (HYVs), together with improved irrigation and the use of fertilizer, increased agricultural production and productivity sharply. This change in technology was a direct result of increased government investment in agricultural research and extension, infrastructure, irrigation, and education during the 1960s, 1970s, and 1980s. The increase in government investments also improved nonagricultural employment opportunities and wages, which contributed to further reductions in rural poverty.

For the past two decades, China achieved remarkable progress in reducing rural poverty. Following rural reforms, per capita income increased from 220 yuan in 1978 to 522 yuan in 1984 (1990 prices), an average growth rate of 15 percent per annum. The income gains were shared widely enough to cut the poverty rate by more than half. By 1984, only 11 percent of the rural population was below the official poverty line, compared to 33 percent in 1978. Because of equitable land distribution, income inequality as measured by the Gini coefficient increased only slightly despite the sharp income increase observed between 1978 and 1984.

From 1985 to 1989, rural income continued to increase, but at a much slower pace, averaging 3 percent per annum. This was due mainly to the stagnation of agricultural production after the reforms. By the end of 1984, the effects of fast agricultural growth on rural poverty were largely exhausted. Rural income distribution became less egalitarian, and the Gini coefficient rose from 0.264 in 1985 to 0.301 in 1989 (China State Statistics Bureau 1990). As a result, the number of poor increased from 89 million in 1984 to 103 million in 1989. Only in 1990 did rural poverty begin to decline again. The number of rural poor dropped from 103 million in 1989 to 34 million in 2000, equivalent to an average reduction of 9 percent per annum.

The above discussion suggests that agricultural growth, including that spurred by agricultural research, plays a key role in reducing rural poverty.

3. RICE RESEARCH AND RICE PRODUCTION[8]

For thousands of years, farmers in Asia have improved their rice yields by selecting and saving seed from the higher yielding plants in local fields. Modern national and international rice breeding programs have developed more formal and structured methods in crossing and selecting improved rice varieties. The international exchange of genetic resources in various forms (landraces and advanced lines) has become an important feature of modern rice breeding.

IRRI's rice breeding program began in October 1961, and in the following year 38 crosses were made. IR8, released in 1966, changed the face of Asian agriculture with yields ranging from 6 to 8 t/ha in experimental fields. IRRI crosses grew in number and complexity over time, and by 1975, 29 IR varieties had been released. Breeding research gave greater emphasis to insect and disease resistance and adaptability to unfavorable environments, resulting in greater geographic spread, higher yields, and improved yield grain stability. In addition, newer varieties grew faster, meaning that they used less water, were exposed to field hazards for a shorter period of time, and facilitated multiple cropping.

Rice research in India has a long history and has been one of the top priorities of the government-supported research program. Core activities of varietal development and related activities are performed by a number of research institutions: (i) the Directorate of Rice Research (DRR) and its funded centers (about 54) located across the country in all the states; (ii) the Central Rice Research Institute (CRRI) in Cuttack, Orissa, and its substations; and (iii) a half-dozen institutes affiliated with the Indian Council of

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[8] The history of international rice research draws heavily from various IRRI publications and Dalrymple (1986), while the evolution of Chinese and Indian rice research programs is drawn from their respective government documents.

Agricultural Research (ICAR). The state universities, such as those in Tamil Nadu, Andhra Pradesh, West Bengal, and Punjab, are also conducting Rice research.

The introduction of semidwarf varieties from IRRI to India occurred in 1964 when C. Subramaniam, Minister of Food and Agriculture, visited IRRI and was given seeds of new rice varieties that included TN-1. By 1966, IR8 and other IRRI lines were tested in various experimental fields in India. Shortly after their introduction, these IRRI varieties were crossed with local varieties, and by 1998 about three-quarters of the rice area in India was sown to HYVs (Indiastat 2002).

Conventional rice breeding began in China in 1906. However, systematic and well-targeted breeding using rigorous methods did not start until 1919 when the Nanjing Higher Agricultural School and Guangzhou Agricultural Specialized School set up breeding programs. Following the establishment of the People's Republic in 1949, the government paid greater attention to rice breeding. The development of the rice breeding program is characterized by three stages. During the first stage, from 1950 to the beginning of the 1960s, great efforts were made in the selection, evaluation, and use of local rice varieties. The second stage of rice breeding, from the beginning of the 1960s to the beginning of the 1970s, focused on the breeding of dwarf varieties.[9] The third stage is characterized by the development of hybrid rice, in which China was a pioneer. Research on hybrid rice in China began in the mid-1960s, and in 1976 China became the first

[9] After a farmer found a dwarf plant (only 70 cm tall) in 1956, Chinese scientists began the breeding program that led to the development of the first high-yielding dwarf variety of rice, Guang Chang Ai, in 1957, a few years before the foundation of IRRI (Shen 1980; Dalrymple 1986). Guang Chang Ai an *Indica* variety and its offspring were quickly adopted in southern China. The first semidwarf *japonica* variety introduced to China in 1957 was Nongken 58, a selection from a Japanese variety, which was crossed with various local varieties.

country to commercially use hybrid rice varieties.[10] Since then, the area under hybrid rice has increased steadily. In 1981, hybrid rice accounted for 23 percent of total rice production, but two decades later it accounted for 61 percent of total production.[11]

The more formal IRRI involvement in China's rice breeding program began in the 1970s although IR8 was introduced and tested in Guangdong in 1967. In the early 1970s, a delegation of Chinese officials visited the Philippines and was given a bag of rice seeds developed at IRRI. This marked the first formal cooperation between IRRI and China.

As a result of these national and international efforts, rice crop production in both China and India has increased substantially for the past several decades. From 1961 to 2001, rice production grew at an average of 2.7 percent per year in India and by 2.6 percent per year in China, much higher than their respective population growth rates of 2.1 and 1.6 percent. Much of the increase in rice production was a result of a gain in yield. In India, yield increase accounted for 77 percent of the total increase in rice production, while in China almost all the production increase came from yield increase. In India, yield doubled from .15 t/ha in 1961 to .30 t/ha in 2001, while in China yield tripled from .21 to .63 t/ha over the same period (Table 1). The development of improved or modern rice varieties in conjunction with irrigation and the greater use of modern inputs (such as fertilizer and pesticides) have been instrumental in achieving these yield increases.

[10] In 1974, professor Yuan Long Ping, from the Hybrid Rice Research Center in Hunan, and his team successfully developed the first hybrid rice variety.

[11] China has never officially published rice output by type. The shares reported here are calculated by the authors using area-by-variety data from the Ministry of Agriculture.

Table 1. Trends in rice area, production, and yield

Item	1961	1970	1980	1990	2000	2001	Growth rate (%)
Area harvested (million ha)							
India	34.7	37.6	40.2	42.7	44.8	44.5	0.6
China	27.0	33.1	34.5	33.5	30.3	28.6	0.02
World	115.5	133.1	144.6	146.9	154.1	151.5	0.58
Production (million t)							
India	53.5	63.3	80.3	111.5	129.4	131.9	2.71
China	56.2	113.1	142.9	191.6	189.8	181.5	2.62
World	215.7	316.4	396.8	518.2	600.6	592.8	2.54
Yield (kg ha^{-1})							
India	1,542	1,685	2,000	2,613	2,890	2,964	2.09
China	2,079	3,416	4,144	5,717	6,264	6,350	2.60
World	1,867	2,377	2,745	3,529	3,897	3,912	1.95

Source: FAO (2002).

4. RESEARCH BENEFITS AND CONTRIBUTION OF INTERNATIONAL RESEARCH

In this section, we quantify the economic impact arising from the development of improved rice varieties in India and China. We begin by estimating the total benefits from rice varietal improvement research irrespective of the sources of the gains. Next, we use genetic or pedigree information on each variety planted in the two countries to assess the contribution of IRRI to these benefits.

ESTIMATION OF BENEFITS

The economic benefits from rice varietal improvement research result mostly from the productivity gains that farmers experienced after adopting improved varieties. Typically, measuring these benefits is based on comparing a "with research" scenario to a counterfactual scenario (Heisey and Morris 2002; Pardey et al. 1996; Pardey et al. 2002). The first step toward measuring these benefits is to determine the gain in yield resulting from the development and adoption of HYVs. To isolate the genetic contribution of improved varieties to yield increase from other factors, we collected experimental yield data of adopted rice varieties in India and China.[12] Experimental yields have the advantage of holding many of the variables influencing yields constant, and hence may provide a good approximation of the genetic contribution to yield gains. Empirical evidence shows that absolute yields achieved in experimental trials are higher than those in farmers' fields. However, it is uncertain whether relative yield gains in trials are also

12 Experimental yield data for China were obtained from the Chinese National Rice Research Institute in Hangzhou, China. Data for India are from the coordinated trials of AICRIP of the Directorate of Rice Research.

greater (Heisey and Morris 2002; Pardey et al. 1996). Here we assume that the proportional gains achieved in experimental trials are representative of the proportional gains realized by farmers. Using the experimental yield data, we selected numeraire varieties specific to each country. The numeraire should be a variety that was widely adopted in either China or India before the establishment of their respective rice research programs, and which has been grown as a control variety at research stations ever since. We then compute the yield premium of newer adopted varieties against the numeraire variety.[13] Suppose that before variety B was released, it was tested against the numeraire variety, A. The yield premium of variety B is given by

$$P_B = (Y_B/Y_A)-1,$$

where P_B is the yield premium of variety *B*, Y_B the yield of variety *B,* and Y_A is the yield of the numeraire variety *A*. As the check variety used in experimental trials changes over time, we use the chain rule to link back to the numeraire variety *A*. Thus before variety C was released, variety B was used as a check variety. The yield premium of variety C over the numeraire variety A is given by

$$P_C = [(Y_C/Y_{B'})*(Y_B/Y_A)-1$$

Note that Y_B and $Y_{B'}$ are not equal since they are the yields of the same variety tested at different times. While the yield premium gives the relative gain in yield, the absolute yield gain of variety C against the numeraire variety A is estimated as follows:

$$\Delta Y_C = Y_C - Y_A = [P_C \times Y_A]$$

[13] Pardey et al. (1996) used a similar procedure.

The benefits for each variety are calculated by multiplying the yield gain by price, and again by area sown to the variety. For region *R,* year *T,* and variety *I*, the total benefits are simply the sum of those for all varieties and can be written as

$$B = \Sigma_I \Delta Y_{IR} A_{I RT} AP_{RT},$$

where A_{IRT} represents the area of variety *I* in region *R* at time *T* and AP_{RT} is the average of the counterfactual and actual producer price of rice at region *R* at time *T*. The counterfactual price captures the price-reducing effect of improved rice varieties, that is, what the price of rice would have been in the absence of the development and adoption of improved rice varieties. Under unitary demand and supply elasticities, the proportional shift in supply translates to the same proportional shift in prices. Assuming that the price of rice in 2000 was under a perfect market, we estimated the counterfactual and average price series as follows:

$$CP_{RT} = Pr_{2000} \, x \, (1 + k_{rt})$$

$$AP_{RT} = (CP_{RT} + P_{r2000})/2$$

where CP_{rt} is the counterfactual price at region *r* and time *t*, P_{r2000} is the price of rice in region *r* in 2000, and k_{rt} is the supply shift in region *r* and time *t*. Under neutral technical change with fixed factor proportions, the percentage increase in experimental yield P_{IRT} translates into an equal, proportional, rightward shift in supply (Alston et al.1995, 339).

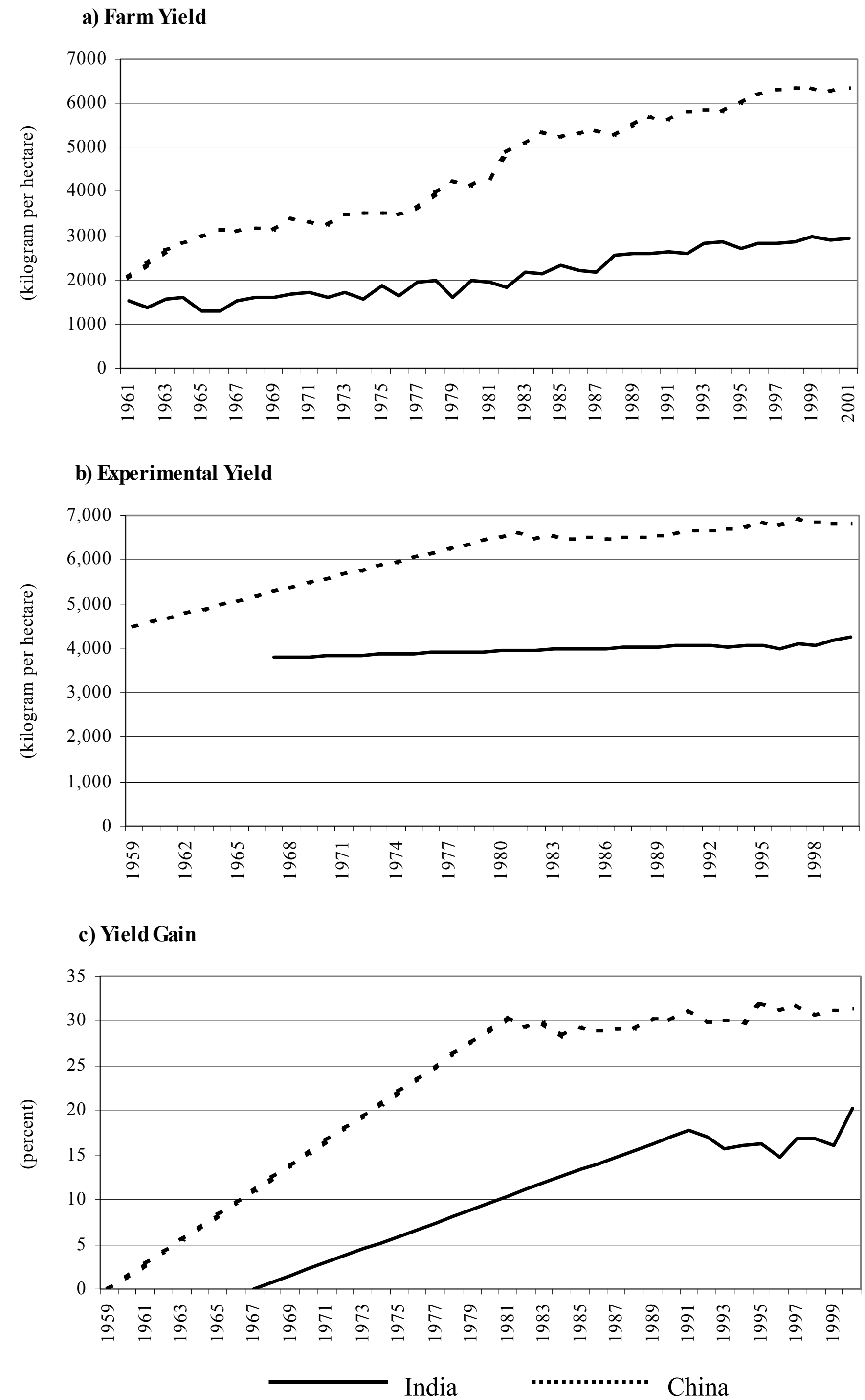
Three major types of rice are planted in China, namely *Indica*, *Japonica*, and hybrid. Therefore, it is necessary to choose a numeraire variety specific to each type of rice**.** The numeraire variety we chose for conventional *Indica* rice is Bao Tai Ai, a variety released in 1959 by the Yulin Regional Agricultural Experiment Station in Guangxi. Due to data limitations, we choose Nongken 58, a variety introduced from Japan in the 1950s, as our numeraire for *Japonica* varieties. Since all early hybrid varieties had an IRRI parent, the numeraire we chose for hybrid rice is Zhen Zhu Ai, a conventional *Indica* variety that does not have any IRRI ancestry.[14] These numeraire varieties were all widely adopted and used as breeding materials for subsequent varieties.

For India, we choose a numeraire variety specific to each state. These numeraire varieties were local varieties widely adopted by farmers in the early 1960s before the introduction of IR8 to India. The numeraire varieties used for each state are the following: Andhra Pradesh: HR67; Assam (Latisail, Bihar): N136; Gujurat (Mashuri, Haryana, Himachal, and Punjab): Jhona349; Karnataka: SR26 B; Kerala: Ptb 10; Madya Pradesh: Safri17; Maharashtra: Ratnagiri1; Orissa: T141; Tamil Nadul: CO25; Uttar Pradesh: Sarjoo49; and West Bengal: NC1263.[15]

Figure 1 compares rice farm yield and experimental yield achieved in India and China. Figure 1A shows that farm yield doubled from .15 to .3 t/ha in India from 1961 to 2001. In China, the observed increase in yield was even more significant, tripling from .21 t/ha in 1961 to .63 t/ha in 2001. Compared with farm yield, experimental yield increased substantially less over time in both India and China (see Fig. 1B). This is because the increased use of inputs such as fertilizer also contributed to farm yield, while the increased use of inputs has been controlled for in the experimental tests.

[14] This was recommended to us by Professor Yuan Long Ping at the China National Hybrid Rice Research Center.
[15] Our source of experimental yield data in India was AICRIP (All India Coordinated Rice Improvement Program).

Figures 1A, 1B, and 1C. Average farm field yield and experimental yield in India and China



Source: Industry yield compiled by authors from FAOS (2002); authors from collected experimental yield data, compiled experimental yield, and yield gain.

On average, experimental yield increased from .38 to .43 t/ha from 1967 to 2000 in India. For comparison purposes, TFP for the Indian agricultural sector as a whole barely budged in the 1970s but grew quickly in the 1980s and 1990s (Fan et al.1999). In contrast, Evenson et al. (1998) found that growth in TFP for the Indian crop sector slowed down during the 1980s. In China, after a rapid increase from .45 t/ha in 1959 to .66 t/ha in 1981, experimental yield increased little in the 1980s and 1990s, ranging from .65 t/ha to .68 t/ha. Similar to these trends, Rozelle et al. (2003) found that the TFP for rice increased little from the mid-1980s to the mid-1990s.

Figure 1C shows the average yield gain over the numeraire variety. In China, the gain in yield resulting from new varieties accelerated from 1959 to the early 1980s and plateaued afterward. In India, the average gain in yield increased sharply from 1967 to the early 1990s, remained constant in the following years, and increased again in the late 1990s. Overall, the yield gain realized in China was higher than in India. In 2000, the average gain in yield with respect to the numeraire was 31 and 20 percent in China and India respectively.

Table 2 presents the estimated benefits from rice research reported in constant 2000 prices. In India, the benefits from rice research increased from $3.9 billion in 1991 to $3.6 billion in 2000. In China, the benefits from rice research amounted to $5.2 billion in 2000. The source of these benefits changed significantly over time.

Table 2. Benefits from rice research

	China					India	
	Indica	*Japonica*	Hybrid	All rice	Agricultural research expenditures	All rice	Agricultural research expenditures
					(millions of 2000 US$)		
1981	3,833	187	1,304	5,324	237		
1982	4,674	187	928	5,789	246		
1983	3,810	203	1,329	5,342	306		
1984	3,225	204	1,917	5,347	349		
1985	3,501	262	1,547	5,311	342		
1986	3,293	305	1,520	5,118	347		
1987	2,584	296	1,818	4,698	328		
1988	2,566	362	2,540	5,468	384		
1989	2,583	461	2,487	5,531	399		
1990	2,474	433	3,378	6,284	361		
1991	1,342	506	2,963	4,812	387	3,930	300
1992	1,944	718	3,352	6,014	454	3,916	299
1993	1,494	747	3,099	5,340	473	3,907	294
1994	1,805	682	3,194	5,681	506	3,842	310
1995	1,108	593	3,676	5,377	503	4,012	325
1996	1,581	632	4,163	6,376	522	3,587	333
1997	1,277	1,262	4,574	7,113	483	4,233	352
1998	1,284	907	4,658	6,849	573	4,217	361
1999	1,153	651	4,317	6,121	660	4,020	455
2000	849	650	3,729	5,228		3,615	

Source: compiled by the authors.

In 1981, *Indica* rice accounted for 72 percent of the total rice research benefits, while *Japonica* and hybrid rice accounted for 4 and 24 percent, respectively. In 2000, 72 percent of the rice research benefits were attributed to hybrid rice, whereas the share of *Indica* rice declined to only 16 percent and *Japonica* rice accounted for 12 percent. India's research benefits as a share of total rice production value ranged between 20 and 24 percent between 1991 and 2000 (Table 3). In China, rice research benefits accounted for a similar share of rice production value, averaging 20.1 percent in 1981 and 17.1 percent in 2000.

Table 3. Rice research benefits as a share of production value

	China				India
	Indica	*Japonica*	Hybrid	All rice	All rice
			(percent)		
1981	24.5	3.8	21.8	20.1	
1982	24.1	3.2	20.1	19.4	
1983	21.2	3.5	17.9	17.2	
1984	21.4	3.2	17.7	16.5	
1985	23.6	4.2	16.3	17.4	
1986	23.3	4.9	14.4	16.5	
1987	21.0	4.6	14.3	15.0	
1988	25.0	6.3	17.3	17.8	
1989	24.7	6.6	16.3	17.0	
1990	26.1	6.4	18.9	18.5	
1991	17.7	7.5	15.9	14.6	23.9
1992	24.3	10.5	17.9	17.9	22.0
1993	23.1	10.9	16.6	16.7	21.5
1994	23.4	10.3	18.3	17.9	22.4
1995	18.3	10.8	16.9	16.2	21.9
1996	21.7	8.4	20.1	17.9	19.5
1997	23.0	13.6	20.7	19.2	21.7
1998	21.6	9.9	21.6	18.7	21.1
1999	19.7	7.0	20.1	16.7	21.1
2000	19.5	7.7	21.1	17.1	22.7

Source: compiled by the authors.

BENEFITS ATTRIBUTION

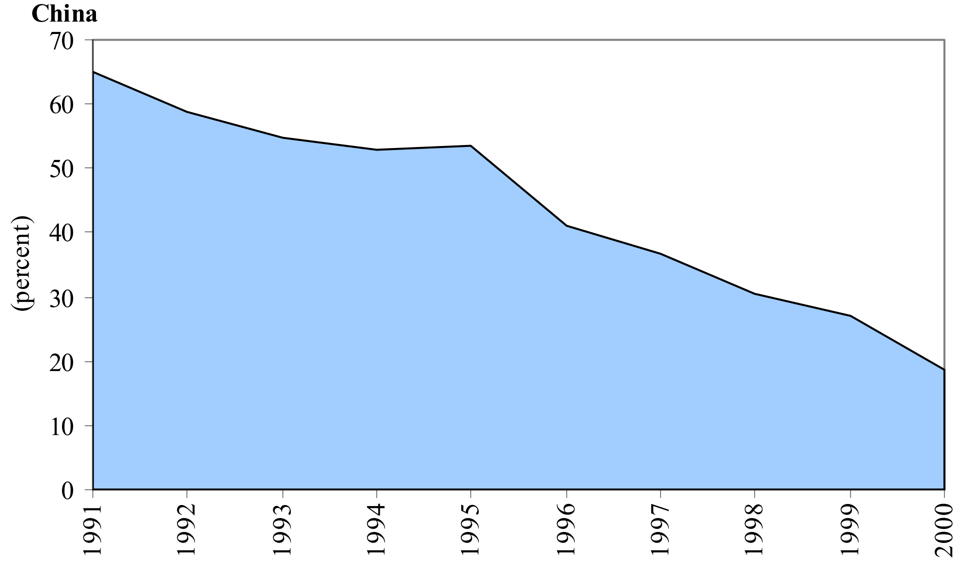
The use of IRRI varieties by the national agricultural research system falls within the following categories: (1) direct use of IR varieties under either direct IR names or local names, (2) direct use of IR breeding lines or crosses under either IR numbers or local names, and (3) use of IR varieties or lines as parents in local breeding programs. To gain some insight into IRRI's impact in China and India, we first examined the share of rice area sown to varieties that have IRRI ancestry (Table 4 and Figure 2). In China, the share increased from 23 percent in 1981 to a peak of 65 percent in 1991, then declined to nearly 20 percent in 2000 in 1997. Table 4 and Figure 2 also reveal that the impact of IRRI in China occurred mostly through the use of IRRI varieties as breeding material rather than through direct adoption.

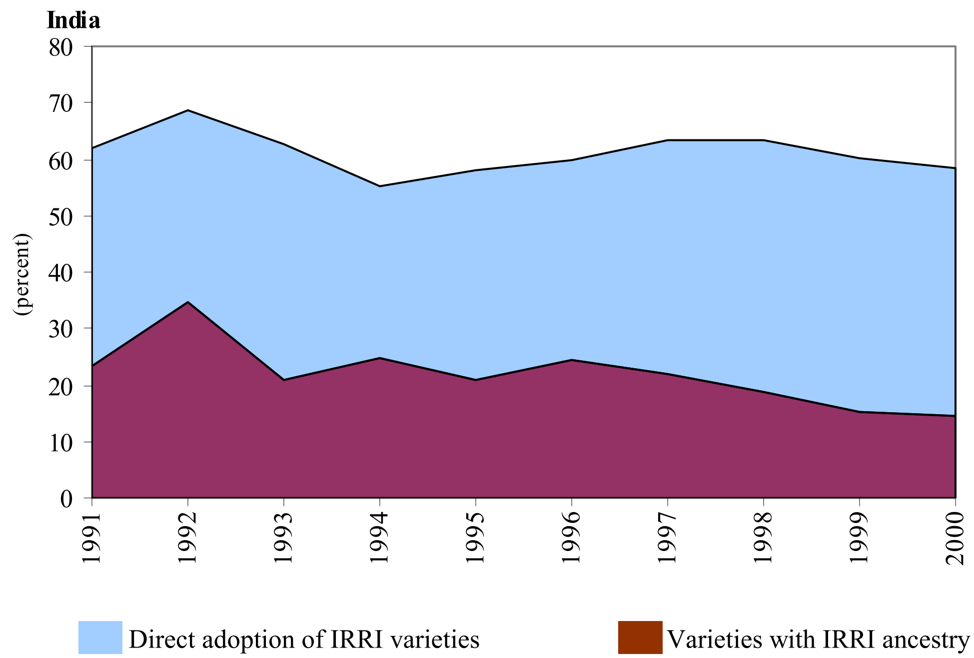
Table 4. Rice area planted with IRRI ancestors

Year	China			India		
	Direct adoption	With IRRI ancestry	Total IRRI (%)	Direct adoption	With IRRI ancestry	Total IRRI
1981	0	23.0	23.0			
1982	0.2	23.9	24.1			
1983	0.1	29.3	29.4			
1984	0.1	36.0	36.1			
1985	0.0	38.7	38.7			
1986	0.2	45.3	45.5			
1987	0	49.6	49.6			
1988	0	58.8	58.8			
1989	0	56.2	56.2			
1990	0	62.6	62.6			
1991	0	64.9	64.9	23.2	38.8	62.0
1992	0	58.9	58.9	34.7	34.0	68.7
1993	0	54.7	54.7	21.0	41.6	62.6
1994	0	53.0	53.0	25.0	30.3	55.3
1995	0	53.6	53.6	20.8	37.3	58.1
1996	0	41.1	41.1	24.4	35.3	59.8
1997	0	36.8	36.8	21.9	41.7	63.5
1998	0	30.5	30.5	18.7	44.5	63.3
1999	0	27.2	27.2	15.3	44.8	60.1
2000	0	18.7	18.7	14.4	43.9	58.3

Source: compiled by the authors.

Figure 2. Area planted to IRRI varieties in China (A) and India (B)





Moreover, IRRI contributed mostly to hybrid rice, whereas practically none of the *Japonica* varieties were bred with IRRI materials. In 1997, 50 percent of hybrid, 31 percent of *Indica,* and only 0.5 percent of *Japonica* varieties had an IRRI ancestor in their pedigree. In India, IRRI's impact is found in both the direct adoption of IRRI varieties and the use of breeding materials from IRRI. In 2000, the area of varieties with IRRI ancestry (including direct adoption) accounted for nearly 60 percent of total rice area in India, and about 14 percent of the varieties adopted were IRRI-released.

To attribute the shares of the rice benefits to IRRI, we followed the method described in Pardey et al. (1996), which developed various rules to attribute benefits to a specific research or breeding program, in this case to IRRI research. These rules take into consideration various factors involved in varietal development such as the recent versus the earlier research, and breeding efforts versus heritability of traits. The binary-parents rule gives full credit to IRRI if the two parents of a variety or any of its ancestors were IRRI-released. If only one set of parents was IRRI-released or had IRRI ancestry, then the variety was considered 50 percent IRRI. The all-antecedents rule assigns equal weights to the variety and each of its ancestors. Thus, if we trace the pedigree back to the grandparent level, the variety and each of its ancestors is given a weight of 1/7 if released by IRRI. The geometric rule assigns higher weight for the recent generations and lower weight for the early generations. The all-credit-to-last-cross rule takes only the last cross into account. Thus, if the variety was released by IRRI, it gets all credit; otherwise, it gets none. Finally, the any-ancestor rule gives credit to IRRI if a variety or any of its ancestors was released by IRRI. The all-credit-to-last-cross rule and the any-ancestor rule represent polar cases: the former is the most conservative rule and the latter is the least conservative.

Using these various attribution rules, we present in Table 5 the contribution of IRRI to the total benefits from rice varietal improvement research in India and China. IRRI accounted for a sizable share of rice research benefits in India.

Table 5. Rice research benefits attributed to IRRI under alternative attribution rules

	China					India				
	Binary parents	All ante-cedents	Geometric	All credit to last cross	Any ancestry	Binary parents	All ante-cedents	Geometric	All credit to last cross	Any ancestry
					(percent)					
1981	14.1	7.6	5.1	0.0	23.2					
1982	13.8	7.4	5.0	0.2	22.8					
1983	17.4	10.5	6.7	0.2	28.9					
1984	20.9	13.3	8.2	0.1	36.8					
1985	21.5	13.0	7.5	0.1	36.5					
1986	25.9	12.9	7.0	0.2	41.7					
1987	31.9	15.0	7.4	0.0	50.0					
1988	34.6	14.6	7.0	0.0	57.9					
1989	31.4	12.3	5.7	0.0	54.2					
1990	36.1	14.4	6.6	0.0	62.1					
1991	39.2	15.0	6.8	0.0	68.9	75.3	40.5	55.2	63.4	81.0
1992	33.0	12.5	5.8	0.0	59.5	77.2	41.0	56.4	65.7	81.8
1993	31.2	11.2	5.2	0.0	57.4	56.5	27.9	36.8	40.3	67.4
1994	28.7	10.2	4.8	0.0	53.3	57.0	28.4	36.8	40.9	64.9
1995	27.6	9.1	4.1	0.0	50.2	44.7	19.8	22.1	20.5	58.6
1996	21.9	7.3	3.3	0.0	40.5	42.6	20.2	22.5	19.8	55.7
1997	18.8	6.1	2.8	0.0	35.5	42.0	20.4	21.1	17.0	57.1
1998	16.8	5.3	2.4	0.0	31.7	48.3	24.0	24.3	19.4	63.8
1999	16.2	5.0	2.2	0.0	29.9	44.9	19.3	18.1	13.2	63.0
2000	11.9	3.8	1.7	0.0	21.6	46.8	20.9	18.6	11.8	63.5

Source: Estimated by the authors.

With the any-ancestor rule, IRRI accounted for 81 percent of the rice research benefits in 1991 and for 63 percent in 2000. With the most conservative scenario (all-credit-to-last-cross rule), IRRI's contribution was still important, accounting for 63 percent of the research benefits in 1991 and for 12 percent in 2000. According to the binary-parents, all-antecedents, and geometric rule, IRRI's contribution to research benefits ranged from 18 to 77 percent from 1991 to 2000.

In contrast, the share of the rice benefits attributable to IRRI was smaller in China. IRRI's varieties were mostly used as breeding materials in China and were not directly adopted by farmers. As a result, the all-credit-to-last-cross rule gives overall 0 percent of the research benefits to IRRI. With the any-ancestor rule, IRRI's share of research benefits was 23 percent in 1981, increasing to 69 percent in 1991, but declining gradually to 22 percent in 2000. With the geometric rule, IRRI's contribution to total benefits ranged from 1.7 to 8.2 percent over the 1981–2000 period compared with 12 to 39 percent with the binary-parents rule and 4 to 15 percent with the all-antecedents rule. Table 6 compares the benefits and costs of IRRI's research. The benefits attributed to IRRI using the geometric-attribution rule are presented next to IRRI's total budget and China's and India's contribution to IRRI.

Table 6. International rice research benefits and costs

Year	Research benefits contributed by IRRI		IRRI's Expenditures		
	China	India	Total	China's contribution	India's contribution
	(thousands of 2000 US$)				
1981	270,402		38,942		
1982	290,109		40,761		187
1983	356,711		38,350		195
1984	440,074		40,429	150	188
1985	396,607		45,592	146	218
1986	356,467		42,435	171	178
1987	346,393		45,243	69	173
1988	383,977		41,395	67	166
1989	317,536		47,010	64	129
1990	415,284		51,668	62	124
1991	328,615	2,167,777	46,224	60	119
1992	348,260	2,206,824	48,616	93	117
1993	277,479	1,436,881	50,993	103	114
1994	270,443	1,415,077	44,631	100	112
1995	221,254	887,621	44,008	98	219
1996	211,383	807,302	42,877	96	187
1997	196,548	892,439	36,736	95	158
1998	165,085	1,022,552	36,310	na	na
1999	136,553	729,510	35,875	na	na
2000	88,924	671,972	32,600	130	158

Source: Research benefits are compiled by the authors. Only the very conservative attribution rule, geometric, was used here. IRRI expenditures from 1981 to 1997 are from the CGIAR secretariat; 1998 to 2000 expenditures are taken from the CGIAR 1999 financial report and the 2000 annual report, respectively. China's and India's contribution to IRRI from 1982 to 1997 are from IRRI's "Facts about Cooperation—People's Republic of China and IRRI" and "Facts about Cooperation—India and IRRI"; China's and India's contribution to IRRI in 2000 are from the IRRI 2000 annual report. na = not available.

The geometric attribution is one of the most conservative rules, taking into account not only the recent crosses but also past breeding efforts. More weights assigned to the recent crosses than the earlier ones attribute more benefits to the national agricultural research system than to IRRI. Even using this conservative rule, the benefits from IRRI's research in India and China well exceed both countries' contributions. In 2000, benefits attributed to IRRI are 684 times China's funding contribution to IRRI while they are over 4,000 times India's. The benefits from IRRI research in China were nearly threefold greater than

IRRI's budget, while in India the benefits were 20-fold greater than IRRI's total budget. Total benefits attributed to IRRI from China and India are $761 million in 2000. This amount is twice as large as CGIAR's annual budget.

5. IMPACT ON POVERTY

New technology resulting from agricultural research can help alleviate poverty in several ways. First, following the releases of new and improved cultivars, farmers can produce more output at the same cost (or the same level of output at a lower cost), which directly improve farmers' income (Kerr and Kolavalli 1999). Second, the diffusion of modern varieties resulted in lower food prices as demonstrated in a number of studies such as Ruttan (1977), Lipton and Longhurst (1989), and more recently Datt and Ravallion (1998). This is critical given that the poorest people spent a large share of their income on food. Third, the productivity consequences of improved varieties resulted in greater demand for labor and wages. Hossain (1988), for example, studied the effects of technological progress in rice cultivation in Bangladesh, and found that the poor benefited from the new technology as a result of greater employment opportunities as well as the upward pressure on wage rate in the labor market. This finding concurs with a number of past studies such as Jayasuriya and Shand (1986), Quizon and Binswanger (1986), Basant (1987), Acharya (1989), and David and Otsuka (1994).

The benefits arising from rice varietal improvement research are distributed between producers and consumers. Producers gain from expanded production due to reduced production cost. On the other hand, they may lose due to lowered price. The net gain by producers can be either positive or negative. For consumers, their gain will always be positive due to lowered price. This study focuses on the impact on rural poor. The benefits to urban poor can be equally large as Fan (2003), and Fan, Fang, and Zhang (2003) have shown. Therefore, our estimates on the impact on poverty reduction are at the lower side. We use the following steps to estimate the impact of national and international rice varietal improvement research on poverty reduction. First, we calculate the marginal impact on poverty reduction of an increase in agricultural production value. This measure gives the number of poor reduced per additional unit of agricultural production value. The parameters needed are reported by two recent IFPRI publications (Fan, Hazell, and Thorat 2000; Fan, Zhang, and Zhang 2002). Second, we calculate the total number of poor reduced from rice varietal improvement research by considering the estimated research benefits as the additional increase in agricultural production value. Finally, we use IRRI's share of total rice research benefits estimated from the geometric attribution rule to estimate the poverty reduction impact attributed to IRRI. These are lower bound estimates since the geometric rule is one of the most conservative.

Fan, Hazell, and Thorat (2000) estimated a system of econometric equations to calculate the impact of different types of government spending on agricultural growth and rural poverty reduction in India using state-level data for 1970–93. The model is structured to enable the identification of the various channels through which different types of government expenditures affect the poor. The study distinguishes between direct and indirect effects of agricultural growth due to agricultural research. The direct effects arise in the form of benefits the poor receive from higher income through growth in agricultural production. The indirect effects come from increased rural wages and employment and changed food prices. This approach has two advantages. First, both direct and indirect effects of agricultural growth were estimated. Second, other types of investment such as infrastructure, education, and health were also included to avoid at least some of the potentially upward-biased estimates of research investment impact.

The estimated poverty equation in the cited system shows that with every 1 percent increase in agricultural production or productivity growth, the total number of rural poor in India is reduced by 0.241 percent as a result of all direct and indirect effects. Using this total elasticity, we can calculate the marginal impact of an additional unit in agricultural production value on poverty reduction. Multiplying this marginal poverty impact by the estimated productivity benefits from rice research gives the total number of poor reduced due to rice variety improvement research. Table 7 shows the estimated results for India. The number of poor reduced as a result of rice varietal improvement research increased from 4.95 million in 1991 to 4.81 million in 1997 then declined to 3.06 million in 1999.

Table 7. Poverty impact of rice research in India

	Rural poor	Poor reduced from rice research	Reduction as a percent of total poor	No. of poor reduced from IRRI's research	No. of poor reduced per $1 million of IRRI spending
	(million)	*(million)*	*(%)*	*(million)*	
1991	233	4.95	2.12	2.73	59,040
1992	237	5.12	2.16	2.89	59,379
1993	242	4.90	2.03	1.80	35,372
1994	274	5.29	1.93	1.95	43,629
1995	252	4.81	1.91	1.07	24,203
1996	251	4.39	1.75	0.99	23,033
1997	249	4.81	1.93	1.01	27,590
1998	212	4.23	1.99	1.02	28,221
1999	169	3.06	1.81	0.56	15,490

This annual reduction expressed as a percentage of total rural poor ranges from 2.12 percent in 1991 to 1.81 percent in 1999. Turning to the impact of IRRI varietal improvement research on rural poverty reduction, Table 7 shows that in 1991, some 2.73 million rural poor were lifted above the poverty line because of IRRI's research. In 1999, the estimated reduction of rural poor due to IRRI varietal improvement research was some 0.56 million. We also calculated the reduction in the poor per $1 million of IRRI spending (Table 7). We simply divided the total number of poor reduced due to IRRI's research by IRRI's annual spending.[16] For India, every $1 million invested by IRRI lifted 59,040 above the poverty line in 1991, and 15,490 in 1999. There is no sign of any significant decline in the poverty-reduction effects of rice varietal improvement research, suggesting that rice research will continue to be a factor in promoting rural poverty reduction in the future.

[16]A more complete analysis would have allowed for the lagged relationships between agricultural research expenditures and their productivity increases by calculating research stocks from past investment data and using estimated lagged structures (as in Fan, Hazell, and Thorat (2000) and Fan, Zhang, and Zhang (2002)). However, we do not have enough years of rice expenditure data to undertake these calculations here.

Similar to the India study, Fan, Zhang, and Zhang (2002) developed and estimated a simultaneous equation model to estimate the effects of different types of government expenditure in China using provincial-level data for 1970–97. From their estimated poverty equation, the total elasticity of poverty reduction with respect to agricultural output growth is 1.924 percent. As for India, we use this elasticity to calculate the number of poor reduced per unit of increase in agricultural production value, and the number of poor reduced from IRRI rice varietal improvement research.

The total reduction in rural poor through rice research in China has been much larger than that in India (Table 8).

Table 8. Poverty impact of rice research in China

	Rural poor	Poor reduced from rice research	Reduction as percentage of total poor	No. of poor reduced due to IRRI's research	No. of poor reduced per $1 million of IRRI spending
	(million)	*(million)*	*(%)*	*(million)*	
1981	194	23.07	11.89	1.02	26,083
1982	140	16.23	11.60	0.70	17,259
1983	123	12.06	9.80	0.70	18,224
1984	89	7.54	8.48	0.54	13,443
1985	96	7.85	8.17	0.51	11,211
1986	97	7.24	7.46	0.44	10,416
1987	91	5.71	6.27	0.37	8,197
1988	86	5.92	6.88	0.37	8,883
1989	103	7.63	7.41	0.39	8,229
1990	97	7.15	7.37	0.42	8,104
1991	95	5.20	5.47	0.32	6,828
1992	90	5.89	6.54	0.30	6,224
1993	80	4.40	5.50	0.20	3,978
1994	70	3.57	5.10	0.15	3,362
1995	65	2.85	4.39	0.10	2,345
1996	58	2.98	5.13	0.09	2,022
1997	50	2.77	5.53	0.07	1,828
1998	42	2.15	5.12	0.05	1,254
1999	34	1.53	4.51	0.03	839

In 1981, 23 million came out of poverty as a result of rice varietal improvement research. However in 1999, only 1.53 million rural poor made such an escape from poverty because of rice research. In relative terms, escape from poverty through rice research as a proportion of the total number of rural poor was 12 percent in 1981 and 5 percent in 1999. Table 8 also shows that the number of poor reduced from IRRI's varietal improvement research declined from 1,016,000 in 1981 to 30,000 in 1999. Finally, the number of poor reduced per $1 million of IRRI spending was 26,083 in 1981. Due to the rapid reduction in rural poverty, the number of poor reduced for every $1 million spent by IRRI declined to 839 in 1999.

6. CONCLUSIONS

The Green Revolution, characterized by the adoption of HYVs, resulted in very high economic payoff and contributed to the eradication of starvation and hunger in many Asian developing countries. However, the question remains whether Green Revolution technology still has positive economic returns today and how it has helped to reduce rural poverty. Using varietal adoption and performance data, this study calculated the total benefits from rice varietal improvement research in China and India for the past two decades. We then used genetic or pedigree information to partition the total benefits between these two countries and IRRI. Finally, we used reported elasticity of poverty reduction with respect to agricultural output growth to assess the effects of national and international research on poverty reduction in rural India and China.

The results indicated that rice varietal improvement research has contributed tremendously to increased rice production in both countries. In China, research benefits as a share of rice production value range from 14 to 20 percent.[17] In India, they range from 20 to 24 percent. In both countries, the benefits produced just from rice research are, on average, 10 times higher than their respective total agricultural research investment.

Rice research has also helped reduce large numbers of rural poor.[18] Without research investments in rice, the number of poor would be much higher today. For every $1 million invested at IRRI in 1999, more than 800 and 15,000 rural poor were lifted above the poverty line in China and India respectively. A similar or even larger poverty impact is observed in Indonesia, Vietnam, and Bangladesh, although formal analyses have not been done yet in these countries.

However, most of these benefits are the results of research conducted in the 1960s, 1970s, and 1980s. For both China and India, the increase in experimental yield has slowed in the 1990s. One of the reasons is the lack of agricultural research investment at both the national and international levels. As a percentage of agricultural gross domestic product, agricultural research investment in both countries was relatively low, 0.3 percent for China and 0.4 percent for India. For other low-income Asian countries, the percentages are in the range of 0.5 to 1. For developed countries, the range is as high as 2 to 4 percent.

IRRI's budget has been severely cut in recent years. IRRI's budget of $32.6 million in 2000 was the lowest in 20 years, and was only 63 percent of its peak of $51.6 million (measured in 2000 prices) in 1990. Worldwide there are still more than 1 billion poor, and most of them depend on agriculture. It has been established that national and

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[17] This is consistent with the findings of Fan and Pardey (1997), who concluded that about 20 percent of the total production value from 1965 to 1993 is from the increased agricultural research investment.

[18] In separate studies, Fan et al. (2003) and Fan (2003) concluded that the effects of agricultural research on urban poverty are as large as those on rural poverty, and agricultural research may play an even larger role in helping the urban poor in the future as more poor will be concentrated in the urban centers.

international agricultural research has made a large impact on poverty reduction in the past.

Together with improvements in rural infrastructure, education, and health, agricultural research will play an even larger role in the future in reducing poverty in developing countries. However, increased and stable funding for national and international agricultural research will be necessary to reduce both rural and urban poverty.

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