Journal of Rural Developement 23 (Summer 2000): 33～70

ASSESSING THE CONTRIBUTION OF RESEARCH SYSTEM AND CG GENETIC MATERIALS TO THE TOTAL FACTOR PRODUCTIVITY OF RICE IN CHINA

Ruifa Hu, Jikun Huang
Songqing Jin, Scott Rozelle*

ABSTRACT

The overall goal of our paper is to create a framework for studying the impact of national investment into research and extension in China and to measure the impact that such investments have had on creating productivity-increasing technology. Our purpose is to provide more convincing measures of the impacts of crop-specific investment in national research programs and the import of materials from the CG system. Specifically, we use a new measure of seed technology to track the changes in the quantity and quality of genetic resources in China's major rice producing provinces from 1982 to 1995. We find that new technology has provided almost all of the growth of China's TFP of rice. The International Rice Research Institute has supplied an important part of China's rice germplasm and positively contributed to the health of China's rice sector.

---

* Jikun Huang is director and Ruifa Hu is research fellow, Center for Chinese Agricultural Policy (CCAP), Chinese Academy of Agricultural Sciences, Beijing, China. Scott Rozelle and Songqing Jin are Associate Professor and Graduate Student in the Department of Agricultural and Resource Economics, University of California, Davis.

We would like to thank the research staff of CCAP for the literally thousands of hours of time that they have put in collecting and cleaning the data and assistance in computing. We also thank Julian Alston, John Antle, Cristina David, Xinshen Diao, Robert Evenson, Shenggen Fan, Erika Meng, Michael Morris, Prabhu Pingali, Carl Pray, and Melinda Smale have provided insights on the data and methodology. The financial support from CGIAR, the Rockfeller Foundation's Agricultural Science Foundation, and China National Outstanding Youth Science Foundation is gratefully acknowledged. Rozelle is a member of the Gianninni Foundation.

I. Introduction

The rise of rice supply in Asia during the last quarter of the 20th century is truly one of the most remarkable stories of success in science and policy making. From dire prediction of food shortfalls and nearly unavoidable widespread of starvation and malnutrition in the post-war years, Asia has seen its rice supplies outpace demand. Falling rice prices contributed to falling poverty rates. The health of the agricultural sector provided the foundation for the miracle development of the economies in all corners of Asia.

Many different factors contributed to the sharp increases in production (Barker, Herdt, and Rose 1985). Although Green Revolution technology transformed rice production in every decade since the 1960s (Pingali, Hossein, and Gerpacio 1997), rising supply also depended on other inputs. Increasing availability of water, inorganic fertilizer, and other farm chemicals overcame many constraints that had held back yields. Migration from poorer to richer areas provided the labor for the higher yielding rice crops (David and Otsuka 1994). Institutional change also stimulated production in some countries (e.g. China-Lin 1992).

Future gains, however, may not have so many sources and may mostly rely on further technological breakthroughs. High input levels in many countries and diminishing marginal returns mean 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 from investment in water control. Institutional change in many cases provide only one-time changes, and have been shown to be largely exhausted in countries (like 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, Hossein, and Gerpacio 1997). Unfortunately little is known about the process by which new technologies are created in developing countries and their impact on total factor productivity (TFP).

Past analyses of technology mostly have two shortcomings, both of which have limited the ability to closely investigate the way technology affects productivity. First, researchers typically have focused on supply or yield response or production function analysis and have not examined the impact on total factor productivity (TFP). Even those looking at the determinants of TFP elsewhere, with the exception of Rosegrant and Evenson (1992), the analysis has been highly aggregated, across states or provinces and especially across crops. Second, the research methods and measures of technological inputs also have limited the explanatory power of research analyzing the impact of research and extension investment. Most researchers use only rough proxies, such as time trends, research expenditures, or percentage of high yielding varieties. Many studies ignore the complexity of the research production, extension, and adoption processes. In a large part, the shortcomings have ultimately been due to lack of data. But, regardless of the reasons, without a conceptual and methodological framework that encompasses the important components of the research process, it is difficult to identify and accurately assess the impact of the research output from a national program or its international partners.

Not surprisingly, without convincing evidence of the impact that investment in research and the genetic material it has created, leaders and agricultural officials in both developed and developing countries typically have become increasingly reticent to provide more support for programs calling for large increases in agricultural research. Especially in developing countries, few policy makers will commit their scarce time or financial resources for research unless the impact on production and productivity of not only research creation, but also its dissemination, is well-documented. Careful, crop-specific analysis is needed to separate out the impact of different factors, including the contribution of national (NARS) and international breeding programs (CG) to the creation of new germplasm, and the impact that the germplasm has on productivity, net of other factors.

The overall goal of our paper is to create a framework for studying the impact of national investment into research and extension in China and to measure the impact that such investments have had on creating productivity-increasing technology. Investments also include the establishment of relationships with international centers of agricultural research. Our purpose is to provide more convincing measures of the impacts of crop-specific investment in national research programs and the import of materials from the CG system. Specifically, we use a new measure of seed technology to track the changes in the quantity and quality of genetic resources in China's major rice producing provinces from 1982 to 1995. We also analyze how the technology, the research program and extension system that produces and disseminates it, affect changes in provincial-level productivity of rice over the same period.

We have chosen to limit the scope of our project to rice mainly due to the enormous data requirements and time constraint. Examining rice is also justified because it is the most important staple food crop in China. On average, rice sown area is about 30 percent of total grain sown area in China and rice production accounts for 45 percent of total grain production. Moreover, rice consists of 40 percent of calorie intake in China (Huang and Rozelle 1996). We also limit our analysis to key rice growing provinces.[1]

II. Analyzing Productivity in Reform China

During China's reform period, the rapid and monotonic expansion of the real output of major food crops ranks as one of the nation's great achievements, though a significant portion of that

---

[1] The 16 rice growing provinces are Heilongjiang, Jilin, Liaoning, Hebei, Jiangsu, Anhui, Hubei, Hunan, Jiangxi, Zhejiang, Fujian, Guangdong, Guangxi, Yunnan, Guizhou, and Sichuan. Together the 16 rice-growing provinces make up more than 90 percent of China's rice sown area and output in 1995.

gain arises from the mobilization of inputs. Rice output indices, that is price-weighted output of rice, increased by 20 percent between 1982 to 1995 (Panel A of Figure 1). At this point in China's development, however, technological improve- ments do not account for all of the growth. Tornqvist-Theil indices of aggregated inputs including land, labor, fertilizer, and other material inputs (see methods and data section for more details), actually fell (Panel A of Figure 1), but this is mainly due to the decline of labor in the early reform period and sown area later. Material inputs including fertilizer, pesticide and other factors rose sharply. Aggregate data show that the materials input use of rice production increased at an annul rate of 32 percent (rates consistent with the overall trends of fertilizer use in China (State Statistical Bureau 1998)).

While the mobilization of inputs has been a major part of the increase in food during the last 20 years, China's future food supply increases may not be able to rely on inputs as much as in the past. The rise in fertilizer and pesticide use slowed in the 1990s. High levels of fertilizer and pesticide use in many regions of the country mean that these trends may continue. Other correlates of development, such as rising wage rates, environmental awareness, and resource limitations, mean that pressures will be on farmers to reduce inputs more. When countries near input plateaus, further growth in output must begin to rely more on technological change. As the importance of technological change grows, our need to understand the record of past TFP performance and its determinants also rises.

1. The Historic Record on TFP

Historically, estimates of China's cropping TFP have been controversial. Differences in the estimates between Tang and Stone (1980) and Wiens (1982) created a debate on the success of pre-reform agriculture. The major work documenting TFP growth in the reform era, Wen (1993), confirmed the efficiency analyses of McMillan, Whalley, and Zhu (1989) and Lin (1992), showing that rapid TFP growth partly contributed to the rural economy's miracle growth in the early 1980s. Wen's work, which only used data until 1990, created the impression that the agricultural sector was in trouble, since his aggregate measure of TFP growth stagnated after 1985. But, some have doubted that productivity could have fallen in the late 1980s, since output of the entire agricultural sector was still growing at over 5 percent per year.

Poor data and ad hoc weights may account for the debates and uncertainty over pre- and post- reform productivity studies. Researchers gleaned data from a variety of sources; they warn readers of the poor quality of many of the input and output series. Stone and Rozelle (1995) caution that the trends of all pre-reform TFP estimates heavily depend upon the nature of the assumed factor proportions that are used to aggregate inputs. Wen (1993), unable to resolve which set of weights is most believable, resorts to sensitivity analysis, updating aggregate TFP until 1990 with all of the weights devised by earlier analysts.

2. Data and Methodology for Creating TFP Measures

In this paper, we overcome some of the shortcomings of the earlier literatures by taking advantage of data that have been collected for the past 20 years by the State Price Bureau. Using a sampling framework with more than 20,000 households, enumerators collect data on the costs of production of all of China's major crops. The data set contains information on quantities and total expenditures of all major inputs, as well as expenditure on a large number of miscellaneous costs. Each farmer also reports output and the total revenues earned from the crop. Provincial surveys by the same unit supply unit costs for labor that reflect the opportunity cost of the daily wage foregone by farmers that work in cropping. During the last several years, these data have been published by the State Development and Planning Commission ("The Compiled Materials of Costs and Profits of Agricultural Products of China," SPB, 1988-1998).

The key information that we bring to the analysis is a set of land rental rates. In 1995, we conducted a survey in 230 villages in 8 provinces, and obtained estimates of the average per hectare rental rate that farmers were willing to pay for farming. These rates were clearly asked net of all other payments that are often associated with land transfer transactions in China (e.g. taxes), but which are picked up as part of the regular cost of production survey. The data have previously been used in analyses on China's agricultural supply and input demand (Huang and Rozelle 1996; Scott, Huang and Rosegrant 1996; World Bank 1997).

Our methodological approach is similar to that of Rosegrant and Evenson (1992) and Fan (1997) in that we use standard Tornqvist-Theil index methods to calculate TFP. In essence, TFP measures the difference between aggregate output and aggregate inputs. Conceptually, it can be thought of as the gap between the output and input index lines in Panel A of Figure 1.

3. TFP Trends in Reform China

Although we ultimately use provincial TFP in our determinants analysis, national aggregates illustrate an upward, but variable, trend productivity (Panel B of Figure 1).[2] The TFP rose rapidly in the early 1980s, the earliest period of China's reforms. TFP increased by more than 40 percent between 1980 and 1985.

Such an unparalleled rise in TFPs, however, could not be sustained. The average TFP of our sample provinces were at about the same level in 1989 as they were in 1985. The stagnant TFP trends discussed by Wen (1993), who looks at the entire agricultural sector, are also evident in rice. There is great discussion in China over what has caused yield slowdowns during this period, a debate that usually focuses on land rights,

---

[2] Pairwise correlation coefficients among our index and three other indices (two used in Wen (1993); and one used in Lin 1990) all exceed 0.95. The rise in the early 1980s undoubtedly is at least in part caused by the new incentives (Lin 1992). Huang and Rozelle (1996), however, show that public investment in research and irrigation also contributed at least as much to TFP as increased incentive during the early reform.

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, food security conscious policy makers were concerned.

The rise in TFP, however, restarts in the 1990s. Our data show a 20 percentage points gain in TFP between 1989 and 1993. While difficult to pinpoint, refinements in hybrid rice technology may be behind part of the gains (Lin 1991), especially those in poor areas. Since the release of hybrid rice in the late 1970s, new cultivars have allowed hybrid rice to push into higher elevation micro-climates. The movement to single-season rice in the lower Yang-tze River Valley in the early 1990s, described in Huang and Rozelle (1996), may also have contributed to rises in productivity. The productivity indices fall, however in 1994 and 1995, though it is unclear whether this is the start of the leveling off trend or in part the result of a drought in East China in 1995.

Provincial trends in TFP mirror those at the national level, but there is considerable differences among provinces (Table 1). The overall gain in TFP ranges from 21 percentage points in Hebei Province to more than 140 percentage point rise in Jilin Province. Large gains in poorer, inland areas almost certainly reflect the rapid diffusion of hybrid. While the somewhat weaker performance of traditional East and South China has observers concerned, it may be that the switch to higher quality varieties with somewhat lower yields is partially responsible. If true, such trends might be different has value of output been available at the provincial level.

III. Rice Technology in China

China has traditionally had one of the strongest research systems in the world. China's agricultural scientists and the government support system developed and disseminated technology throughout the People's Republic Period. Before the rest of the world had experienced the Green Revolution, China's breeders released improved, semi-dwarf rice varieties (Stone 1988). Disease resistant varieties were developed and extended throughout the late 1970s and 1980s.

One of the largest breakthroughs, 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 F1 hybrid rice varieties for use by farmers. With a potential 15-20 percent yield advantage over conventional high yielding varieties, the area under hybrid rice expanded rapidly from 4.3 million hectare in 1978 to 15.9 million hectares in 1990, increasing from 12.6 percent of rice sown area to 41.2 percent (Huang and Rozelle 1996). After 1990, however, due to concerns about quality, hybrid use fell sharply. Nevertheless, in 1995, farmers still used hybrid varieties on 37 percent of total rice sown area in 1995.

1. The Nature of Technological Change in China: Quality and Quantity of New Rice Varieties

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 2). Since 1982, rice farmers in China have used about 400 "major" varieties each year (column 1),[3] which implies that farmers in each province use around 25 rice varieties per year. However, this number varies greatly across regions, ranging from less than 10 in Hebei to around 50 in Guangdong. The number of varieties in a specific province might be a reflection of the size of rice production, cropping pattern (one rice season verse two rice seasons), rice types (conventional, hybrid, indica and japonica) and the supply of rice

---

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

varieties (i.e. the level of its own rice breeding research). For example, farmers in Guangdong and Hunan planted more varieties than all other provinces perhaps because they have all these features: they are two of the largest rice growing provinces in the country; most farmers plant two seasons of rice; there are both hybrid and conventional varieties; and both have strong rice breeding system. In contrast, the North-east provinces (Liaoning, Jilin and Heilongjiang) have relatively small numbers of variety not only because they are small rice growing provinces, but because they are single japonica rice regions as well. While it is beyond the scope of this paper to explain the relative performance of China's breeding programs, most likely, it is a combination of historic investment priorities, fortunate breakthroughs and availability of international germplasm.

China's breeding efforts also have 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 "adopted yield potential" variable.[4] 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 provinces of each province's research system. 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 two measures, China's research system has created a steady stream of quality technology (Table 3). The yield frontiers for rice moved up at 2.3 percent per year between 1980 and 1995, most likely a function of the development of

---

[4] "Yield frontier" is defined to be non-decreasing. If a major variety (defined in footnote 3) which is 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, farmers have stopped using that vareity and all other varieties have lower certified yields in the following years.

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 per year during the reforms (Table 3, row 2). When compared to the farmers' actual yields in 1980 (row 3), the difference is 31 percent, gap that is not high by the standard of developing countries (Pingali, Hussein, and Gerpacio 1997; Pingali and Rosegrant 1995, rows 4, 8, and 12). In part reflecting the rapid rise in material inputs (see discussion above), the gap fell from 31 percent to 14 percent during the period of 1980 to 1995.

There are two ways to interpret the yield gaps that currently exist in China. On the one hand, there appears to be a great deal of yield potential left in varieties in the field (the difference between the adopted yield potential and the actual yield), and even more when considering the differences between the yield frontier and the actual yield.[5] On the other hand, it can be argued that, in fact, the relatively low level of 14 percent and narrowing trend of the percentage difference between actual yield and adopted yield potential mean that China's yield potential is not that large, and the nation will need more breeding breakthroughs if the pace of yield growth is to be maintained on the effort of its domestic research system. The gap between adopted yield potential and actual yield for rice is small when compared to other rice countries. In 1987, China's gap was only 1.0 ton per hectare (or 15 percent), similar (although not exactly comparable) gaps ranged from 5 tons per hectare (or 65 percent) with Philippines and 3.5 tons per hectare (or 58 percent) in India (Pingali, Hossein and Gerpacio 1997). Relatively low yield gaps may imply that the further gains in realized total factor productivity of rice in China may be more difficult since most of

---

[5] The researchers that argue that the yield gap is “big” and that there is a lot of potential left in China's current germplasm technology are bolstered by the fact that China's yields may be understated because sown area is likely understated.

it must come from increases in the creating and adoption of new varieties.

Interests, the gap between the yield frontier (row 1) and adopted yield potential (row 2) has grown, a fact that also has a number of different implications for China's future yield growth. It may be that high yielding varieties are not 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 rather than the highest yielding ones, are the most effective at their farm level profits. The large changes in the rice market (Rozelle et al., forthcoming; Luo 1999) may partially explain the fact that the gap between the yield frontier and adopted yield potential has grown substantially.

2. Creating and Spreading New Rice Varieties in China

One of most impressive accomplishments of China's research system is that it has been able to consistently create and deliver to the field varieties demanded by farmers, inducing them to constantly upgrade their seed stock. Our data shows that Chinese farmers adopt new varieties with great regularity (Appendix 1). The rate of turnover of rice in China is quite impressive.[6] Between the early 1980s and 1995, China's farmers turn their rice varieties over at a rate that ranges from about 20 percent to 30 percent. This means that every 4 years farmers on average replace all of the varieties in their fields. From conversations with those familiar with rice cultivation in the Philippines and India, as national averages, the turnover rates rival those found in the rice bowls of the developing and developed world.

China's domestic research system has produced most of the new technology. The rise of the stock of research in the early reform era mostly reflects the commitment of the leadership during the Mao era (Stone 1988). In our analysis, however, we

---

[6] Variety turnover is a measure of how fast major varieties that first appear in China's field are able to replace the older varieties. Details of the calculations are provided in the data section.

only want to include that part of the research stock that is used to produce new varieties. To make the adjustment to our research investment series to make it include only crop research, we note that according to the Ministry of Agriculture Statistics (MOA 1996), since at least 1980 (and according to interviews, even before 1980), research administrators have consistently invested between 69 and 71 percent of its annual research budget to crop research. Of this, most of the crop research budget goes for plant breeding and closely related research projects. Therefore, in the creation of our research stock figure, we multiply the total annual research expenditure by the proportion of the budget that is allocated to crop research and apply the procedure used in Pardey et al. (1992), to create our measure of crop research stock. The resulting series trends up sharply through the 1980s and the early 1990s until the rising trend decelerates in the mid-1990s, reflecting slowing rates of research investment in the 1980s.

Researchers differ in their view about the record of performance of the government in their investment in research and extension in recent years and the implication of the trends for the state of China's research system. Adjusting the data as suggested by Rozelle, Pray, and Huang (1998), research investment falls or is stagnant from 1985 to early 1990.[7] In the early 1990s, investment levels rise at a slow pace, until 1995 when they move up sharply. Extension expenditure trends follow a similar pattern. Slowing investment trends for long stretches of time during the 1980s, given research lags, would most likely

---

[7] Our data covers the agricultural research conducted at CAS, at CAAS, the provincial and prefectural academies of agricultural sciences, and universities. We assume that all income is spent and thus these numbers are government expenditures. However, unlike Fan and Pardey (1997) we do not assume that all income is spent on research. The major source of growth in research system income since 1985 is “development income” from the commercial enterprises that research institutes first established in the 1980s. If all of development income is counted as expenditures, then research expenditures rise through the late 1980s and 1990s. In contrast, our interviews and surveys show that only 15 percent of development income ends up supporting research.

start to show up as stagnating research stock in the mid- to late 1990s.

China also has access to genetic materials from international sources for rice (Table 4). China has drawn heavily on the international research system for genetic material.[8] For example, material from the International Rice Research Institute (IRRI) comprises a large share of China's rice germplasm. Nationwide, we can trace around 20 percent of the germplasm to IRRI varieties (Table 4, column 1). The proportion varies over time (from 16 to 25 percent) and also varies by province (Table 4, columns 2 to 17). Our data suggest a positive correlation between IRRI materials and the proportion of indica rice in the total rice sown area in each province, finding that may not be surprising since most varieties or genetic materials developed by IRRI use indica-based materials, and also provinces with more hybrids tend to have more IRRI materials since several of the most successful hybrid rice varieties (Shanyou 63, Shanyou 10) have parental materials from IRRI. IRRI materials reached more than 40 percent in Hunan Province, one of China's largest hybrid rice growing provinces. Since most of indica and hybrid provinces also happen to be relatively poor (e.g. Jiangxi, Anhui, Sichuan, Guizhou, Yunnan), IRRI materials have contributed more than in the rich provinces. If technology is the key to the growth of productivity, IRRI materials almost certainly can be said to have helped the poor.

In summary, China's research system has created large amounts of new rice technology and it has succeeded in getting farmers to adopt it at an impressively rapid pace. The technology embodies significant levels of yield-increasing material that may prove to be an important determinant of productivity. The national research effort also is aided by the international agricultural research system. The rate of adoption of the highest yielding material, however, is somewhat slower than the rise in

---

[8] It should also be remembered that China also has contributed significantly to the world stock of genetic resources for rice.

yields. China's yields and output also have grown due to increased use of inputs. In the rest of this paper, we undertake an analysis of the determinants of TFP growth in an effort to understand the extent to which technology affects productivity.

Ⅳ. A General Framework of Endogenous Technology and Productivity Growth

1. Determinants of TFP and Model Specification

Total Factor Productivity indices for rice in China vary not only across province but also over time. Factors that could account for variations in TFP include changes in technology, institutional reform, infrastructure development, improvements to human capital, and other factors. Whether human capital should be included in the determinants of TFP depends on how the measure is generated. For example, if current wages are used as a weight for labor input (as we do in this paper), human capital is typically assumed to be already accounted for. Given our data and research question, a framework for explaining TFP changes overtime can be specified as:

(2) $TFP = f\,(\text{Technology, Infrastructure, Institutional Reforms, } Z)$

where Z is a vector of control variables with the elements representing weather, agro-climatic zones, and some fixed but unobserved factors that differ across regions. In most countries, technology and infrastructure are thought to be the major factors that drive the long term TFP growth (Rosegrant and Evenson 1992). Most of other determinants contribute either to short term fluctuations or one-time only fixed shifts in TFP over time.

In this paper, two measures on seed technology are specified, varietal turnover (VT_1 and VT_2), where VT is defined as:

(3) $VT_t = 1$ for $t=1$, and

$$VT_t = VT_{t-1} + \sum_k \left[V_{kt} = W_{kt} - W_{kt-1} \text{ if } W_{kt} - W_{kt-1} > 0, \text{ otherwise } V_{kt} = 0\right] \text{ for } t>1,$$

where V_k is the area share change for those varieties that have positive sign, and W_k is the area share of k^{th} variety in total rice sown area for VT_1, and W_k is the area share of k^{th} variety in the *sown area of all major varieties for* VT_2.[9] Equation (3) defines seed technological change as the extent to which newly introduced varieties replace existing varieties and the extent to which existing higher yielding varieties replace existing inferior varieties. Assuming farmers are rational, variety replacement occurs if and only if the new variety is of a higher "quality" than the variety it is replacing, where quality can be cost-reducing, yield-enhancing, or include some new taste characteristics. One of the main questions in the paper is answered by examining the coefficient of the VT variable in an equation explaining TFP.

A potentially serious statistical issue arises, however, if one is to try to use VT as a measure to test the effect of technology on TFP, as in equation (2). Since the farmer may be simultaneously making production decisions that affect both TFP and technology adoption, an OLS regression of TFP on VT likely is problematic because the error term may be correlated with VT. To avoid the endogeneity of VT in the estimation of the TFP equation, we take an instrumental variables approach. Our strategy for identifying the effects of technology on TFP uses the assumption that the technology delivered by the national and international research systems affects technology adoption (and hence VT), but does not affect TFP except through the seeds farmers adopt. If the assumptions are valid, we can use three variables as instruments: the investments made by the government in crop research (or more precisely the nation's stock of crop research); germplasm that flows into each province from the research system and from international agricultural research centers as instruments; and yield frontier, a variable representing the yield-increasing potential of technology generated by the research system.[10]

---

[9] Major varieties are defined in footnote 3.

Based on the discussion above, we use a simultaneous, two stage least squares (2SLS) estimator to estimate the effect of technology and other variables (infrastructure, institutional change, etc.) on TFP. The empirical specifications of endogenously determined technology, VT, and the determinants of TFP models are:

(5) $\text{TFP}_{ht} = f(\text{VT}_{ht}, \text{Extension}_{t}, \text{Irrigation}_{ht}, D_{90\text{-}95}, \text{Weather Event Index}_{ht}, \text{Provincial Dummies}) + e1_{ht}$

(6) $\text{VT}_{ht} = g(\text{Extension}_{t}, \text{Irrigation}_{ht}, D_{90\text{-}95}, \text{Weather Event Index}_{ht}, \text{Provincial Dummies}; \text{Research Stock}_{t}, \text{CG}_{ht}, \text{Yield Frontier}_{ht}) + e2_{ht}$

where h indexes provinces; total factor productivity *(TFP)* and *VT* are defined as above; *extension* is a variable reflecting all expenditures made on the extension system, aggregated to the national level; *Irrigation* Index is measured as the ratio of irrigated land to cultivated land; and, $D_{90\text{-}95}$ is an indicator variable which equals 1 for the period between 1990 and 1995 and is included to measure the effect of other period varying excluded factors on TFP during the period of market liberalization that China experienced in the early 1990s. We also include two variables to account for yield

---

[10] We utilize three variables as instrumental variables to identify the VT. First, crop breeding research stock is used as a proxy for public investment in the creation of new varieties. Since most research is either embodied in the seed itself, or requires delivery by the extension system, the effect of which we already account for, this is a conceptually sound instrument. Second, a measure of the yield frontier, a variable representing the yield-increasing potential of technology generated by the research system (which is defined as the maximum yield of any variety in the field up to time period t), also is a variable that conceptually should explain the adoption of new seed technology, but have no effect of its own on TFP. Finally, we define a variable that represents the proportion of genetic material in China's germplasm for rice that comes from the CG system (CG Contribution). This variables is created using pedigree data for all varieties in the field in each period, and assigning geometric weights to parents (0.25/parent), grandparents (0.06/grandparent), and so on. CG contribution represents the proportion of germplasm that have parents and grandparents or older generations that are identified as being from IRRI.

fluctuations due to the effect of flood and drought events (*Flood and Drought Index*), and provincial dummies to control for unobserved fixed effects associated with each province. The three instruments in equation (6), Research Stock$_t$, CG$_{ht}$, Yield Frontier$_{ht}$, are defined in footnote 11.

2. Data

In addition to the cost of production used in the creation of the TFP indices, we also compiled from numerous sources a nation-wide data base on China's major rice, wheat, and maize varieties. Information on crop-specific varieties and the amount of area sown to each variety in each province are from the Ministry of Agriculture (MOA, 1981 to 1997). This MOA compendium reports on “major” varieties that cover at least 100,000 mu (6667 hectares) in a province in any one year. Varietal yield information and pedigree data were mostly collected by authors through an extensive desk survey that included use of materials in national pedigree data bases (published and on-line), information in the national library, and records in the national seed company. After the desk survey, however, information on some crops of some years and some provinces were still missing. Our data collection team made calls and visits to hundreds of provincial and prefectural research institutes, breeding stations, seed companies, individual breeders, and bureaus of agriculture.

V. Results

1. The Determinants of New Technology

In both their role of creating instruments for the TFP equation and as an equation of interest in its own right, the technology (VT) equations perform well (Table 5, columns 2 and 4).[11] The

---

[11] Our analysis only runs through 1995 since we have only been able to collect information on varieties and their characteristics up through that year. Much of these data come from primary survey and interviews with breeders and so such data can not be updated without extensive additional fieldwork.

R-squares in OLS versions of the technology equations exceed 0.90 in both VT1 and VT2 cases. Hausman tests for exclusion restrictions (1983) that are designed to test the validity of the instruments show our three instruments are statistically valid.[12] Statistically, we have instruments that have a high degree of explanatory power on technology, but do not affect TFP except through their influence on varietal adoption.

Substantively, the first-stage equations provide interesting insights on the process of the technology creation in China. The positive and highly significant sign on the Research Stock variable demonstrate the effectiveness of investments in the research system. Higher levels of national stocks accelerate the pace of varietal turnover (Table 5, columns 2 and 4, row 7). If technology is the engine that will drive China's food supply in the future (Huang and Rozelle 1996), the results here emphasize the necessity of maintaining the level and growth of public investment in crop research and development. The negative sign on the market liberalization period dummy variable in the first stage equations (VT) calls for heightened attention to the health of the research system. The factors that have slowed technological change in the 1990s appear to be the source of fall of TFP in the 1994 and 1995.

The impact of the yield-increasing technology (created by

---

[12] Since the farmers are simultaneously making production decisions that affect both TFP and technology adoption, the variable measuring technology adoption, VT, likely is endogenous. To properly account for the endogeneity, the predicted values from the technology equations can be used as instruments if the variables on the right hand side of the technology equations affect technology but are uncorrelated with the structural disturbances of the TFP equation. To test if the set of identifying instruments are exogenous, a Lagrange multiplier test can be used (Hausman 1983). The chi-square distributed test statistic with 3 degrees of freedom, is N*R2 , where N is the number of observations, and R2 is the measure of goodness of fit of the regression of the residues from the TFP equation on the variables which are exogenous to the system. The test statistics are 0.86 and 0.22 (with VT1 and VT2 specifications respectively) which indicate that the null hypothesis that there is no correlation between the exogenous instruments and the disturbance term from TFP equation can not be rejected.

each province's research system—the Yield Frontier variable) is consistent with our gap analysis in a previous section. Higher values of Yield Frontier variables are associated with slower turnover (Table 5, columns 2 and 4, row 9). Such a finding may reflect the fact rice farmers in the mid- to late-reform period prefer adopting higher quality varieties, even though higher yielding varieties are available.

2. The Impact of CG Material

The impact of the materials from the CG system on rice TFP is mainly a story of the China's breeders using IRRI varieties for the yield enhancement of their seed stock, especially the use of IRRI materials in hybrid rice. If it can be assumed that, when China's breeders incorporate foreign germplasm into its varieties, the material contributes to its share of the rise in productivity, then the test of the direct impact of CG material is seen in the results of the TFP equation (next sub-section). If technology is important in all the TFP equations, by virtue of the fact that IRRI's materials account for 20 percent or more of the China's rice genetic material, it is making a great contribution to China's TFP in the reform era.

It is possible, however, that foreign material may be bringing in an extra “boost” of productivity, beyond its contribution to the varieties themselves, by increasing the rate of turnover of new varieties.[13] Such an effect would show up in the VT equations. If the coefficients of the CG variables were positive and significant, they would indicate that the presence of material from CG centers makes the varieties more attractive to

---

[13] One alternative way to identify the “extra” impact of CG material on TFP is to interacted it with VT in the TFP equation directly. Since this variable is also simultaneously determined with TFP, we would have to estimate another equation to create an instrument for use in the second stage equation. We estimate one equation for VT and one for VT*CG and use the predicted values from these equations in the TFP equations, estimating the three equations as a system. The results are shown in Table 7, column 4 to 7. The results are similar to our less formal test; varieties with high content of CG germplasm do not have a an “extra” effect.

farmers and contribute to technological change in China in a second way. In fact, there is not particularly strong evidence that increases in the presence of IRRI material is important in increasing the turnover of rice varieties (Table 5, row 8-the coefficients are either negative and insignificant, column 2, or only marginally significant and positive, column 4). If farmers are in fact mainly looking for characteristics that are not associated with higher yields, it could be that IRRI material is making its primary impact on yields and only secondary impact the other traits that have been more important in inducing adoption in the reform period.

3. Technology, Extension, and Productivity

Our results, presented in Table 5, generally perform well. The goodness of fit measures (for OLS versions of the equations) range from 0.80 to 0.85, quite high for determinants of TFP equations. In other work, in India for example, the fit of the specification was only 0.17 (Rosegrant and Evenson 1992).

The signs of most of the coefficients are as expected and many of the standard errors are relatively low.[14] For example, the coefficients of the weather indices are negative and significant in the TFP equations under both VT1 and VT2 specifications (Table 5, rows 3 and 4). Flood and drought events, as expected, push

---

[14] One of the most surprising exceptions is the negative sign of the irrigation variable's coefficient. According to our results, the ratio of irrigated to cultivated land negatively affects rice TFP. It certainly may be that for any number of measurement or statistical reasons, we are not measuring the true relationship between marginal increases in irrigation area and TFP. However, it may be, as also found by Rosegrant and Evenson (1992), the value of irrigation is already embodied in the land input variable (since areas with high land values have high levels of irrigation), so its positive impact is already removed. Additionally, the negative value may appear since the area in which most of China's new irrigation projects have occurred are not naturally conducive to rice cultivation. In the south, China's main rice growing region, irrigated area has expanded little, if any, in most provinces during the reform. In north China, if newly irrigated area does lead to new rice cultivation, it may be that the new land brought into production is inherently less productive than the average rice area already being farmed. Such an explanation is consistent with our results.

down TFP measures, since they often adversely affect output but not inputs (which in many cases are made before the onset of bad weather).

Perhaps the most robust and important finding of our analysis is that technology has a large and positive influence on TFP. The positive and highly significant coefficients on both measures of the rate of varietal turnovers (VT_1 and VT_2) show that as new technology is adopted by farmers it increases TFP (Table 5, columns 1 and 3, row 1). Following from this, the positive contributions of China's research system and the presence of CG material both imply that domestic investments in agricultural R & D and ties with the international agricultural research system have contributed (and plausibly will continue to do so) to a healthy agricultural sector.

Further analysis is conducted to attempt to overcome one possible shortcoming of using VT as a measure of technological change. It could be that an omitted variable is obscuring the true relationship between VT and TFP. As varieties age, the yield potential may deteriorate (Pingali, Hossein, and Gerpacio 1997). In order to try to isolate the age effect from the new technology effect (given the definition of VT, this may be a problem), we add a variable measuring the average age of the varieties (Waveage—Table 7, column 1 to 3). We find no apparent negative age impact on TFP, this finding reinforce the basic message of the importance of technology.

The role of extension is less simple. The impact of extension can occur through its effect on spreading new seed technologies (which will be measured by the coefficient on the Extension variable in the VT equation) and through its provision of other services that enhance farmer productivity (which will be measured by the coefficient on the Extension variable in the TFP equation). The positive and significant coefficients on the extension variable in all of the VT technology equations for all crops demonstrate the importance of extension in facilitating farmer adoption (Table 5, columns 2 and 4, row 2). Extension, however, plays less of an independent role (or none at all) in increasing the yield potential of varieties that have been adopted by farmers, perhaps an unsurprising results given the reforms that have shifted the extension from an all around advisory body to one that is supporting itself, often through the sale of seed (Huang et al. 1999).

4. Sources of TFP Growth

Between 1981 and 1995, China's rice total factor productivity grew on a per annum basis by 2.0 percent. However, the TFP growth was not constant over time. TFP grew faster during the early reform period, 1981-84 (9.4 percent), and slowed down in the later period, 1984-95 (1.11 percent). Our regression results (above) have identified a number of factors that have impacted the growth of China's rice total factor productivity. In order to understand the importance of these individual factors on the growth in China's rice TFP and to understand whether the sources of TFP growth differ between the early reform period (1981-84) and more recent time (1984-1995), we conduct a decomposition analysis of China's rice TFP growth over two sub-periods, 1981-84, and 1984-95. Based on the regression results reported in Table 5, the decomposition results are reported in Table 6. We only report the decomposition results for VT2 equation (although the results for VT1 are similar).

The decomposition results in Table 6 show that technology and stock of research are the two key factors that are driving the sharp increase in TFP in the early reform period. Improvement in technology (measured by varietal turnover) contributed by far the largest share, augmenting the annual growth rate of TFP by 6.01 percent (63.61 percent of the total growth rate). Research stock also contributed significantly to the growth of TFP. Moreover, the higher level of research stock primarily drives the growth of TFP by accelerating the pace of varietal turnover. Research investment contributed 2.60 percent to the growth rate of TFP during this period (or 27.53 percent of the total growth rate). Interestingly, expenditure on extension, however, did not help the growth of TFP. Germplasm from international institutes contributed slightly to growth (contributing about 0.32 percent to TFP growth, or about 3 percent of the growth rate).

In the late reform period, 1984 to 1995, technology and research stock remain the most important sources of TFP growth. In fact, during this period, they are actually the only factors that underlie the positive growth of TFP during that period. If it had not been for other negative factors, these two factors would have caused TFP to grow by 4.17 percent (instead of actual 1.11 percent). Factors associated with the 1990-95 time dummy variable (such as the continuing break-down of the seed and extension systems) help explain why TFP did not grow faster. Factors associated with the 1990-95 time dummy variables slowed down TFP through its negative impact on varietal turnover. Another factor that significantly reduced the growth of TFP is the irrigation index, an explanation of which is in footnote 14.

VI. Conclusions

Our paper, more than anything, establishes a basis for China's (and international) leaders and policy makers who are committed to keeping a strong rice supply capacity to confidently invest in the nation's agricultural research system. The basis for doing so primarily rest on the importance that technology and the institutions that create, import, and spread it have had on TFP in the past. TFP has continued to rise in the reform period primarily due to past contributions of technology. This will almost certainly play an increasing role as China begins to integrate into the world economy even more after its entry into the WTO. Huang et al (1999) show that investment in research will minimize the need for China to rely on imports in a more open trading regime and in fact may provide opportunities for rice farmers to export.

The picture sketched by our paper demonstrates that the impact of investment in new technology is many faceted. Public investments in rice breeding pay off in terms of higher TFP. The form of the technology matters, however, not only in how rich it is in terms of yield-enhancing material, but also in whether or not farmers will adopt it. Although its breeders are increasing the yield frontier at a rate slightly faster than the rate of actual yield rise (and demand growth for that matter), the increases in TFP often appear to come from the farmers demand for other productivity enhancing traits that are embodied in the germplasm from domestic and foreign sources. If these traits can be identified and combined with the varieties with the higher yields, the future of China's rice supply appears sound.

Our results raise doubts about the all-around effectiveness of China's extension system in increasing TFP. While higher extension expenditures have led to higher levels of varietal turnover (which may mean the system is still carrying out its function of seed promotion), apart from this impact, extension in rice growing areas reduces TFP. This may mean that the recent moves to allow extension agents to supplement their incomes from sales of fertilizers, pesticides and other farm inputs has created a situation where they may be pushing inputs that are not leading to rises in output in a way that leads to higher productivity. Recent interviews with officials in China's Ministry of Agriculture have found that proposed reforms of the system are based on the premise that the current extension system is a total failure.

We have, however, been focused primarily on the past and marginal effects of research and extension on TFP. If trends begin to fall because of the inattention to the breeding system, then productivity, according to these results, will also fall. Because future yields appear to rely more on productivity increases than ever before, China's ability to meet its food economy goals are going to depend heavily on how it manages to continue to increase the productivity of its sector. The negative and significant sign on the dummy variable for the 1990s in the VT equations (Table 5, row 6) is cause for concern.

The results on the impact of the CG system are encouraging and suggest that China should continue to maintain and strengthen its ties to the rest of the world. In an era of uncertainty of the future flows of germplasm across national boundaries, China should do all it can to ensure it can access stocks of genetic material from abroad.

REFERENCES

Barker, R., R.H. Herdt and B. Rose. 1985. "The Rice Economy of Asia." Washington, D.C.: Resource for the Future.

Capalbo, S.M. and T.T. Vo. 1998. "A Review of the Evidence on Agricultural Productivity and Aggregate Technology." S.M. Capabo and J.M. Antle. (ed.) *Agricultural Productivity: Measurement and Explanation.* Washington, D.C.: Resource for the Future.

Caves, D.W., L.R. Christensen, and W.E. Diewert. 1982. "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity." *Econometrica* 50: 1393-1414.

Diewert, W.E. 1976. "Exact and Superlative Index Numbers." *Journal of Econometrics* 4: 115-45.

David, C. and K. Otsuka. 1994. *Modern Rice Technology and Income Distribution in Asia.* International Rice Research Institute. Boulder and London: Rienner; Manila.

Fan, S. 1997. "Production and Productivity Growth in Chinese Agriculture: New Measurement and Evidence." *Food Policy* 22(3): 213-28.

Fan, S. and P. Pardey. 1997. "Research, Productivity, and Output Growth in Chinese Agriculture." *Journal-of-Development-Economics* 53(1): 115-37.

Hausman, J. 1983. "Specification and Estimation of Simultaneous Equations Models." Z. Griliches and M. Intriligator (eds.). *Handbook of Economics North Holland Press.* Amsterdam.

Huang, J.K., C.L. Chen, and S. Rozelle. 1999. "Reform, Trade Liberalization, and Their Impacts on China's Agriculture." paper presented at the Symposium, China's Agricultural Trade and Policy: Issues, Analysis, and Global Consequences, June 25-26, 1999 in San Francisco, California, USA.

Huang, J.K., R.F. Hu, F.B. Qiao, and Scott Rozelle. 1999. "Extension in Reform China." working paper. Center for Chinese Agricultural Policy, Beijing, China.

Huang, J.K., and S. Rozelle. 1996. "Technological Change: Rediscovery of the Engine of Productivity Growth in China's Rural Economy." *Journal of Development Economics* 49: 337-369.

Lin, J.Y. 1990. "Rural Reforms and Agricultural Productivity Growth in China." working paper, Beijing University, Beijing, China.

______. 1991. "The Household Responsibility System Reform and the Adoption of Hybrid Rice in China." *Journal of Development Economics* 36: 353-373.

______. 1992. "Rural Reform and Agricultural Growth in China." *American Economics Review* 82(1): 34-51.

Luo, Xiaopeng. 1999. "Rice Markets and Liberalization in China." unpublished doctoral dissertation. Department of Applied Economics, University of Minnesota, Minneapolis, MN.

MOA 1986-1997. "Statistical Compendium, China's Major Varieties." unpublished statistical volume. Ministry of Agriculture, Beijing, China.

McMillan, J., J. Whalley, and L. Zhu. 1989. "The Impact of China's Economic Reforms on Agricultural Productivity Growth." *Journal of Political Economy* 97: 781-807.

Pardey, Phil, R. Lindner, E. Abdurachman, S. Wood, S. Fan, W. Eveleens, B. Zhang, J. Alston. 1992. "The Economic Returns to Indonesian Rice and Soybean Research." report prepared by the Agency for Agricultural Research and Development (AARD) and the International Service for National Agricultural Research (ISNAR).

Pingali, P., M. Hossein, and R. Gerpacio. 1997. *Asian Rice Bowls*. London, UK: CAB Press.

Pingali, P. and Rosegrant. 1995. "Green Revolution Blues." paper presented at the Preconference on Development. American Agricultural Economics Association. Orlando, FL.

Rosegrant M.W., and R.E. Evenson. 1992. "Agricultural Productivity and Sources of Growth in South Asia." *American Journal of Agricultural Economics*: 757-761.

Rozelle, S., J.K. Huang, and M. Rosegrant. 1996. "How China Will Not Starve the World." Choice First Quarter: 12-17.

Rozelle, S., A. Park, H.H. Jin, J.K. Huang. Forthcoming. “Bureaucrats to Entrepreneurs: The Changing Role of the State in China's Transitional Commodity Economy." *Economic Development and Cultural Change.*

Rozelle, S., C. Pray and J. Huang. 1998. “Agricultural Research Policy in China: Testing the Limits of Commercialization-led Reform." *Contemporary Economic Policy*: 1-20.

State Price Bureau (SPB). 1988-1992. *Quanguo Nongchanpin Chengben Shouyi Ziliao Huibian* [*National Agricultural Production Cost and Revenue Information Summary*]. Beijing: China Price Bureau Press.

State Statistical Bureau (SSB)--ZGTJNJ. 1980-98. *Zhongguo Tongji Nianjian* [*China Statistical Yearbook*]. Beijing, China: China Statistical Press.

Stone, B. 1988. "Development in Agricultural Technology." *China Quarterly* 116.

Stone, B., and S. Rozelle. 1995. “Foodcrop Production Variability in China, 1931-1985." *The School for Oriental and African Studies, Research and Notes Monograph Series* 9. London.

Tang, A.M., and B. Stone. 1980. *Food Production in the People's Republic of China*, International Food Policy Research Institute (IFPRI) Report.

Wen, G.Z. 1993. “Total Factor Productivity Change in China's Farming Sector: 1952-1989." *Economic Development and Cultural Change*: 1-41.

Wien, T.J. 1982. “Technological Change." R. Barker and R. Sinha (ed.). *The Chinese Agricultural Economy.* (Boulder, Colo.: Westview).

World Bank. 1997. “At China's Table." monograph. World Bank. Washington DC.

TABLE 1. Total Factor Productivity of Rice in China, 1979 to 1995.

	Hebei	Liaoning	Jilin	HLJ[a]	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Hubei	Hunan	Guangdong	Guangxi	Sichuan	Guizhou	Yunnan
1979	100[b]	110	83	118	102	125	101	98	96	110	101	91	93	86	95	80
1980	103	113	102	126	95	120	95	111	96	89	98	99	91	97	105	74
1981	89	127	121	82	115	119	131	119	108	116	107	91	93	104	93	89
1982	113	136	141	105	146	148	148	134	124	140	129	103	110	132	113	95
1983	141	146	165	122	166	150	142	142	114	144	141	112	114	151	121	88
1984	124	171	193	149	194	167	146	146	127	158	146	121	109	158	134	96
1985	152	143	197	137	190	151	146	146	127	160	139	121	107	159	105	98
1986	153	173	166	145	199	153	137	147	126	161	158	120	94	167	108	94
1987	156	175	192	133	185	150	141	141	130	159	159	130	112	167	104	99
1988	151	165	194	156	183	146	135	135	122	154	146	127	95	165	97	100
1989	124	125	140	134	194	149	144	144	119	160	156	137	108	172	100	99
1990	134	163	209	159	192	149	144	144	132	163	151	144	116	178	112	104
1991	116	159	203	155	189	170	150	150	135	143	163	153	120	179	130	110
1992	135	170	191	162	196	157	144	144	135	156	165	162	122	191	115	108
1993	144	189	196	175	216	155	153	153	133	188	170	159	130	171	127	116
1994	144	168	193	183	191	167	140	140	129	192	152	167	108	165	126	116
1995	121	145	206	152	198	165	141	141	124	191	153	142	117	179	129	123

[a] HLJ refers to Heilongjiang province.

[b] The TFP index for Hebei in 1979 is set at 100, all the other TFP indices are normalized based on this number.

TABLE 2. Average Number of Major Varieties Planted by Farmers in China's Rice Growing Provinces, 1982 to 1995.

	National Total[a]	Average Number by Province															
		Hebei	Liaoning	Jilin	HLJ[b]	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Hubei	Hunan	Guangdong	Guangxi	Sichuan	Guizhou	Yunnan
1982	379	3	9	6	10	32	26	34	51	37	19	43	43	25	21	11	9
1983	333	4	8	6	8	43	33	40	43	29	17	20	19	23	18	11	11
1984	380	5	7	9	8	42	31	33	47	40	20	24	48	26	16	10	14
1985	424	6	10	4	11	43	35	45	41	52	17	30	57	29	14	12	18
1986	419	6	13	6	16	45	29	34	36	43	17	31	58	37	18	12	18
1987	373	4	10	7	14	35	33	30	22	46	19	34	42	26	24	8	19
1988	381	5	11	12	15	29	32	30	28	40	21	41	52	26	18	9	12
1989	365	7	14	7	12	36	21	33	21	15	18	47	59	26	21	13	15
1990	412	3	13	1	10	29	40	39	23	43	19	56	56	34	23	9	14
1991	395	2	14	5	12	24	43	38	29	15	17	56	64	28	15	14	19
1992	403	3	15	12	17	28	48	36	27	17	19	55	54	34	6	11	21
1993	392	6	16	14	15	24	48	39	21	11	24	51	44	35	7	19	18
1994	416	3	17	5	14	28	48	35	17	50	13	71	31	39	8	17	20
1995	391	4	24	4	17	27	30	25	29	20	14	54	49	35	25	13	21

[a] National total is the sum of all the sample provinces.
[b] HLJ refers to Heilongjiang province.
Source: Authors' data gathered from the Ministry of Agriculture.

TABLE 3. Experiment Station Yields (Yield Frontiers and Adopted Yield Potential), Actual Yields, and Yield Gaps in Sample Rice Growing Provinces in China, 1980 to 1995.

	1980 (Tons / hectare)	1995 (tons / hectare)	Annual Growth Rate (percent)[c]
Yield Frontier[a]	6.6	9.1	2.3
Adopted Yield Potential[b]	6.1	7.2	1.4
Actual Yield	4.2	6.2	2.1
Percent Gap between Adopted Yield Potential and Actual Yields	31%	14%	

[a] Yield Frontier is the highest experiment station yield of a variety that has been extended to the field. The variable is non-decreasing in the sense that if in some subsequent year the highest yielding variety has a lower yield, the previous period's yield is maintained. In this table, the figure is the average of sample provinces.

[b] Adopted Yield Potential is the average experiment station yields of all varieties being adopted by farmers. In this table, the figure is the average of sample provinces.

[c] Annual growth rates are calculated by running a regression of natural log of various yields on a time trend.

Source: Yield Frontier and Average Experiment Station Yields from authors' data. Actual yield from State Statistical Bureau-ZGTJNJ, 1981, 1983. and 1996.

TABLE 4. Contributions of GGIAR Centers (IRRI) to Rice Varieties in China, 1982 to 1995

	National Average[a]	CG Contribution by Year by Province for Rice															
		Hebei	Liaoning	Jilin	HLJ[b]	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Hubei	Hunan	Guangdong	Guangxi	Sichuan	Guizhou	Yunnan
1982	0.16	0.04	0.04	0.18	0.00	0.15	0.16	0.17	0.12	0.16	0.27	0.28	0.11	0.02	0.20	0.11	0.02
1983	0.18	0.03	0.04	0.00	0.00	0.30	0.16	0.19	0.20	0.16	0.27	0.30	0.13	0.02	0.24	0.04	0.01
1984	0.22	0.03	0.04	0.00	0.01	0.33	0.20	0.23	0.19	0.16	0.34	0.31	0.24	0.01	0.35	0.10	0.07
1985	0.23	0.02	0.01	0.01	0.01	0.26	0.23	0.28	0.23	0.22	0.39	0.34	0.12	0.02	0.33	0.14	0.09
1986	0.23	0.00	0.03	0.04	0.01	0.21	0.26	0.30	0.16	0.27	0.36	0.33	0.11	0.08	0.23	0.18	0.31
1987	0.25	0.00	0.02	0.04	0.01	0.21	0.28	0.29	0.28	0.33	0.32	0.41	0.15	0.17	0.22	0.22	0.11
1988	0.25	0.00	0.02	0.03	0.01	0.15	0.28	0.30	0.29	0.31	0.32	0.41	0.14	0.19	0.24	0.12	0.13
1989	0.24	0.00	0.03	0.03	0.01	0.16	0.15	0.29	0.28	0.34	0.30	0.38	0.14	0.20	0.24	0.21	0.13
1990	0.25	0.00	0.02	0.00	0.01	0.15	0.20	0.27	0.29	0.28	0.37	0.40	0.18	0.27	0.24	0.25	0.14
1991	0.24	0.00	0.05	0.00	0.01	0.11	0.22	0.26	0.27	0.29	0.31	0.37	0.17	0.30	0.25	0.26	0.14
1992	0.22	0.00	0.07	0.01	0.01	0.11	0.16	0.24	0.23	0.27	0.29	0.33	0.16	0.26	0.25	0.28	0.16
1993	0.22	0.00	0.05	0.00	0.00	0.12	0.12	0.19	0.24	0.30	0.30	0.31	0.17	0.27	0.25	0.27	0.15
1994	0.20	0.00	0.02	0.00	0.01	0.10	0.09	0.24	0.23	0.23	0.33	0.25	0.18	0.24	0.22	20.7	0.14
1995	0.18	0.00	0.03	0.00	0.00	0.09	0.09	0.24	0.23	0.21	0.30	0.22	0.14	0.21	0.18	0.24	0.16

Note: . The CG variable is one that represents the proportion of genetic material in China's germplasm for each crop that comes from the CG system (*CG Contribution*). This variables is created using pedigree data for all varieties in the field in each period, and assigning geometric weights to parents (0.25/parent), grandparents (0.06/grandparent), and so on. CG contribution represents the proportion of germplasm that have parents and grandparents or older generations that are identified as being from an international center (IRRI for rice).

[a] National average is the sown area weighted average of the sampled provinces.

[b] HLJ is Heilongjiang Province

TABLE 5. Two Stage Least Squares Estimates of the Determinants of Total Factor Productivity for Rice in China

	Model 1		Model 2	
	TFP	Technology (VT1)	TFP	Technology (VT2)
Technology Variables				
Varietal turnover (VT1 or VT2)	15.50 (9.25)***		10.50 (9.18)***	
Extension	-0.014 (1.68)*	0.0004 (2.29)**	-0.01 (1.66)*	0.0007 (3.14)***
Weather, Irrigation, and Period Dummy				
Flood index	-8.63 (1.76)*	0.04 (0.37)	-8.44 (1.70)*	0.03 (0.25)
Drought index	-23.83 (2.56)**	-0.30 (1.42)	-21.29 (2.26)**	-0.73 (2.91)***
Irrigation index	-100.05 (3.19)***	-0.92 (1.26)	-91.82 (2.91)***	-2.32 (2.68)***
D90-95 (Index for 1990s)	1.54 (0.40)	-0.29 (3.15)***	2.25 (0.58)	-0.46 (4.29)***
Instruments				
Research stock		0.02 (19.65)***		0.02 (23.96)***
CG contribution		-0.27 (0.76)		0.68 (1.64)*
Yield frontier		-0.002 (3.03)***		-0.003 (3.78)***
No. of observation	240	240	240	240

Note: All regression equations include provincial dummies to hold constant unobserved fixed effects. For definition of variables, see Table 2 and methodological section. T-ratios in parentheses. ***, **, and * signify that the coefficients are statistically significant at the 1, 5, and 10 percent levels.

TABLE 6. Decomposition of the Sources of Rice TFP Growth in China

		1981-1984			1984-1995		
	TFP	Factor annual	Sources of growth		Factor annual	Sources of growth	
	elasticities[a]	growth rate[b]	rate[c]	percent[d]	growth rate	Rate	percent
Varietal Turnover (VT2)	0.28	21.47	6.01	63.61	7.81	2.19	197.01
Research Stock	0.43	6.05	2.60	27.53	4.60	1.98	178.20
Extension	-0.02	2.03	-0.04	-0.43	3.96	-0.08	-7.14
CG Contribution	0.01	31.50	0.32	3.33	-1.57	-0.02	-1.41
Yield Frontier	-0.12	3.71	-0.45	-4.71	1.79	-0.21	-19.35
Flood Index	-0.01	29.02	-0.18		9.26	-0.06	-5.19
Drought Index	-0.02	-13.17	0.21		1.24	-0.02	-1.80
Irrigation Index	-0.34	0.70	-0.24		1.29	-0.44	-39.50
D90-95 (Index for 1990s)[e]						-1.93	-173.87
Residual			1.21	10.62		-0.30	-26.94
Actual growth rates			9.45	100		1.11	100

[a] TFP elasticity with respect to each factor is calculated on the basis of coefficients from Model 2 in Table 5.

[b] TFP and factor growth rates are computed by a least square estimate.

[c] Growth rate contributed by each factor is calculated by multiplying factor growth rate (column 2) by elasticity (column1).

[d] The percentage of total TFP growth explained by each factor is the corresponding figure in column 3, divided by the total growth rate of TFP (which for the period of 1981-90 was 9.45 percent).

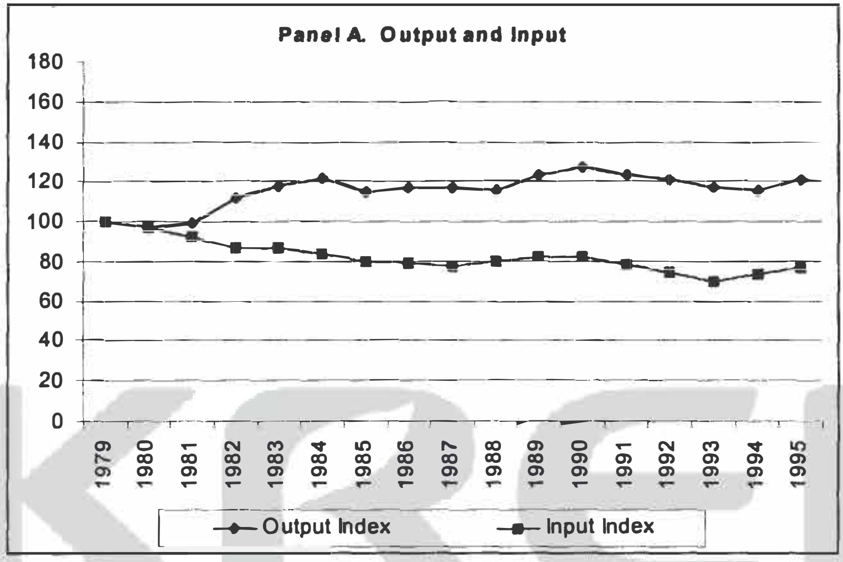
[e] There are only indirect impacts of the D90-95 variable (the time dummy for period of 1990-95) because D90-95 is insignificant in TFP equation, while significant in Technology equation in Table 5. The indirect impact of D90-95 on the growth rate of rice TFP through varietal turnover is calculated by the following two steps: i) The TFP change each year during the period of 1990-95 due to the indirect time dummy effect is the product of three things: the estimated coefficients of D90-95 variable in technology equation (-0.46 in VT2 equation), the estimated coefficient of varietal turnover in TFP equation (10.50 in Model 2) and VT2; and ii) these changes in TFP due to D90-95 are then transformed into changes in annual growth rates.

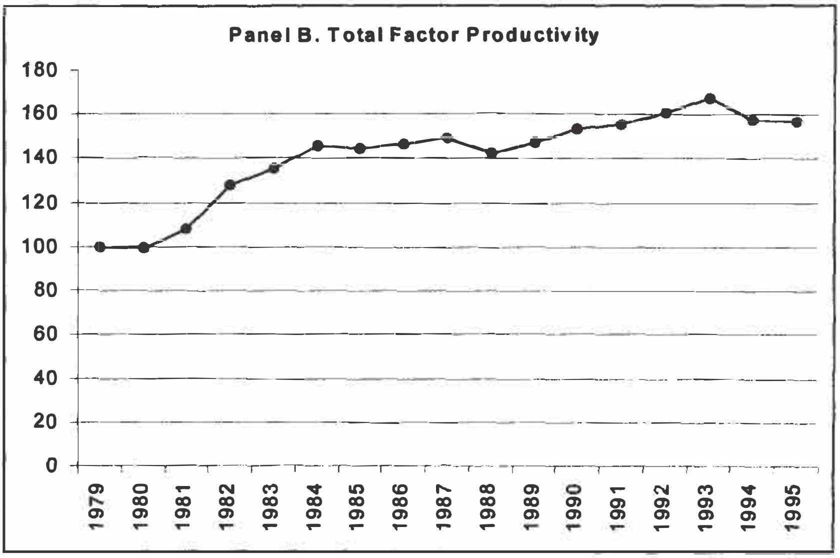
TABLE 7. Two Stage Least Squares Estimates of the Determinants of Total Factor Productivity for Rice in China, Further Analysis.

	Weighted Average Age Included			Interaction bewteen VT1 and WCG Included		
	TFP	VT1	Wavage	TFP	VT1	VT1*WCG
Technology Variables						
Varietal Turnover Index 1 (VT1)	12.93 (4.72)***			14.48 (5.30)***		
Weighted Average Age (Wavage)	-3.26 (1.22)					
Interaction of Varietal Turnover and CG Contribution (VT1*WCG)				5.26 (0.50)		
Extension	-0.01 (1.18)	0.0004 (2.29)**		-0.01 (1.40)	0.0004 (2.40)**	-0.0002 (1.20)
Weather & Irrigation						
Flood Index	-8.53 (1.66)*	0.04 (0.37)	0.11 (0.20)	-9.13 (1.84)*	0.04 (0.37)	0.06 (1.02)
Drought Index	-23.44 (2.39)**	-0.30 (1.42)	0.62 (0.56)	-25.04 (2.62)***	-0.31 (1.45)	0.11 (0.94)
Irrigation Index	-61.20 (1.34)	-0.92 (1.26)	12.02 (3.15)***	-101.16 (3.24)***	-0.97 (1.33)	0.47 (0.39)
D90-95 (Index for 1990s)	3.68 (0.84)	-0.29 (3.15)***	0.63 (1.32)	1.50 (0.40)	-0.28 (3.09)***	-0.005 (0.09)
Instruments						
Research Stock		0.02 (19.65)***	-0.007 (1.29)		0.02 (19.66)***	0.001 (2.20)**
CG Contribution		-0.27 (0.76)	-4.28 (2.35)**			
Yield frontier		-0.002 (3.03)***	-0.005 (1.20)		-0.002 (3.29)***	0.0025 (6.47)***
No. of Observation	240	240	240	240	240	240

Note: All regression equations include provincial dummies to hold constant unobserved fixed effects. For definition of Variables, see Table 2 and methodological section. T-ratios in parentheses. ***, **, and * signify that the coefficients are statistically significant at the 1, 5, and 10 percent levels.

FIGURE 1. Output, Input and Total Factor Productivity Indices for Major Rice Growing Provinces in China (Sown Area Weighted Average), 1979-1995.





Appendix 1
Estimation of Total Factor Productivity

Total factor productivity (TFP) measures the changes in total output not accounted for by the changes in total inputs. For a homogenous commodity, TFP can be computed as a ratio of output to an aggregated index of inputs used in the production of the output. In our study, a Tornqvist-Theil index is applied to compute individual crop TFPs by province. Expressed in logarithmic form, the Tornqvist-Theil TFP index for crop i is defined as:

$$(1)\quad \ln\,(TFP_t/TFP_{t-1})=\ln\,(Q_t/Q_{t-1})-1/2\,\sum_j\,(S_{jt}+S_{jt-1})\,\ln\,(X_{jt}/X_{jt-1})$$

where Q is rice production (output); S_{jt} is the share of input j in total cost of rice production; X_j is input j used in the production of rice , and t indexes time (year).

Setting TFP in the base year to 100 and accumulating the changes over time based on equation (1) provides a time series of TFP index for each province. The Tornqvist-Theil index is a superlative index that is exact for the linear homogeneous translog production function (Diewert 1976), and superlative under very general production structures, i.e., nonhomogeneous and nonconstant returns to scale (Caves, et al. 1982). It also provides consistent aggregation of inputs and outputs under the assumptions of competitive behavior, constant returns to scale, Hicks-neutral technical change, and input and output separability. Because current factor prices are used in the construction of the weights in aggregating the input index, quality improvements in inputs are incorporated (Capalbo and Vo 1988). A similar approach is used in agricultural productivity analysis by Rosegrant and Evenson (1992) in South Asia.

TFP analysis conducted in this paper is a crop specific analysis. The output index is just rice output index. Data on inputs of rice production are used in the computation for rice TFP and includes series for sown area, labor, seed, fertilizer, pesticide, farm plastic film, pesticide, animal traction, machinery and equipment, and other material inputs.

Appendix 2. Varietal Turnover (VT1) in China's Rice Growing Provinces, 1982 to 1995

	National Average[a]	Varietal Turnover by year by province for Rice						
		Hebei	Liaoning	Jilin	HLJ[b]	Jiangsu	Zhejiang	Anhui
1982	0.35	0.65	0.74	0.66	0.51	0.21	0.38	0.31
1983	0.22	0.15	0.22	0.30	0.64	0.56	0.20	0.27
1984	0.20	0.17	0.26	0.27	0.12	0.25	0.14	0.26
1985	0.19	0.18	0.08	0.06	0.29	0.26	0.25	0.17
1986	0.28	0.54	0.60	0.43	0.57	0.41	0.16	0.27
1987	0.28	0.36	0.28	0.11	0.53	0.31	0.16	0.27
1988	0.26	0.06	0.34	0.00	0.34	0.18	0.12	0.19
1989	0.17	0.20	0.25	0.83	0.25	0.18	0.14	0.13
1990	0.24	0.23	0.19	0.00	0.12	0.17	0.55	0.19
1991	0.13	0.26	0.35	0.40	0.05	0.14	0.24	0.12
1992	0.29	0.06	0.37	0.50	0.34	0.25	0.30	0.12
1993	0.19	0.67	0.35	1.26	0.36	0.16	0.24	0.23
1994	0.25	0.17	0.72	0.20	0.07	0.22	0.28	0.20
1995	0.22	0.20	0.32	0.16	0.27	0.14	0.11	0.08

Varietal Turnover by year by province for Rice								
Fujian	Jiangxi	Hubei	Hunan	Guangdong	Guangxi	Sichuan	Guizhou	Yunnan
0.58	0.46	0.29	0.58	0.24	0.24	0.39	0.34	0.17
0.36	0.18	0.16	0.07	0.07	0.36	0.26	0.09	0.07
0.28	0.11	0.14	0.14	0.45	0.14	0.15	0.11	0.09
0.24	0.37	0.15	0.15	0.24	0.09	0.03	0.21	0.11
0.33	0.30	0.42	0.18	0.23	0.17	0.35	0.07	0.18
0.31	0.21	0.17	0.56	0.14	0.32	0.21	0.20	0.20
0.15	0.35	0.2[illegible]	0.18	0.47	0.21	0.44	0.30	0.08
0.14	0.11	0.13	0.19	0.22	0.17	0.13	0.25	0.13
0.09	0.43	0.15	0.19	0.28	0.35	0.10	0.19	0.06
0.17	0.15	0.05	0.21	0.00	0.23	0.00	0.00	0.14
0.22	0.19	0.05	0.27	0.79	0.26	0.12	0.81	0.15
0.10	0.05	0.19	0.18	0.29	0.21	0.17	0.13	0.10
0.08	0.12	0.12	0.31	0.13	0.23	0.27	0.24	0.13
0.36	0.18	0.18	0.27	0.04	0.19	0.48	0.24	0.21

Note: see endnote 6 for definition and computation of varietal turnover.

[a] National average is the sown area weighted average of the sampled provinces.

[b] HLJ is Heilongjiang Province