The Creation and Spread of Technology and Total Factor Productivity in China's Agriculture

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Working Paper No. 01-014

December, 2001

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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, D. Gale Johnson, 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 Rockeller Foundation's Agricultural Science Foundation, and China National Outstanding Youth Science Foundation is gratefully acknowledged. Rozelle is a member of the Giannini Foundation.

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Abstract

Songqing Jin, Jikun Huang, Ruifa Hu, and Scott Rozelle*

The study’s overall goal is to create a framework for assessing the trends of China’s national and international investment in agricultural research and to measure its impact on total factor productivity. The main methodological contribution is to provide more convincing measures of crop-specific technologies from China’s national research program and of those imported from the international agricultural research system. Our results find that from 1980-95, China’s total factor productivity for rice, wheat and maize grew rapidly and new technology accounts for most of the productivity growth.

Key words: agriculture, China, maize, productivity, rice, technology, wheat

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Scientists and policy makers in the international community, in both developing and developed countries, recognize the importance that agricultural technology and its extension has played in promoting the expansion of supply and increased productivity in the world over the past 30 years. Rosegrant and Evenson have documented the importance of new varieties and extension effort on Indian total factor productivity. Pingali, Hussein, and Gerpacio review the contributions made by the Green Revolution in South and Southeast Asia. Although Rozelle, Huang and Rosegrant, Fan and Pardey, and Lin (1991) measure the impact of agricultural research investment on China's agricultural output, no one has systematically analyzed the determinants of total factor productivity. Understanding the process of technological impact on the productivity of food production in developing world's largest country is important, since it is the main engine of production growth and increases in income from farming in countries after they have modernized their economies (Huang and Rozelle)

Past analyses, however, 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) and, with the exception of Rosegrant and Evenson, 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 and 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 encompassing 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 contributions of national agricultural research systems (NARS) and international breeding programs (specifically from institutes that are part of the Consultative Group on International Agricultural Research or the CG system), to the creation of new germplasm and the impact that the germplasm has on productivity.

The overall goal of this article 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, wheat, and maize producing provinces from 1981 to 1995 for rice and from 1983 to 1995 for wheat and maize. We also analyze how the technology, the research program and extension system producing and disseminating it, affect changes in provincial-level productivity of rice, wheat, and maize over the same period.

We have chosen to limit the scope of our study in several ways due to the data requirements. Since information is needed on the names, traits, pedigrees, and extent of adoption of every major variety in each province for each year as well as measures of other factors that make up and explain TFP, we had to limit our attention to major grain crops (those crops account for 76 percent of total grain crop sown area in 1995, State Statistical Bureau, 1996) and to key rice, wheat, and maize growing provinces.[1] The difficulty in getting the data on other cash crops precludes the inclusion of other crops.

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 gain arises from the mobilization of inputs. Output indices, or price-weighted output data series of rice, wheat, and maize, rose sharply between 1982 and 1995 (Figure 1). Rice output increased by 20 percent, wheat by 80 percent, and maize by 95 percent. At this point in China's development, however, technological improvements do not account for all of the growth. Divisia indices of aggregated inputs for rice, wheat, and maize, including land, labor, fertilizer, and other inputs, such as machinery, herbicide, seed and other capital goods (see below for a complete description of the methodology), actually fell for all the crops, 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, increasing at an annual rate of 32 percent for rice, 26 percent for wheat and 30 percent for maize (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 sharply slowed in the 1990s. High levels of fertilizer and pesticide use in many regions of the country mean that the decelerating 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 of the record of past TFP performance and its determinants also rises.

The Historic Record on TFP

Historically estimates of China's cropping TFP have been controversial. Differences in the estimates between Tang and Stone and Wiens created a debate on the success of pre-reform agriculture. The major work documenting TFP growth in the reform era presented by Wen confirmed the efficiency analyses of McMillan, Whalley, and Zhu 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 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, 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.

Data and Methodology for Creating TFP Measures

In this article, 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 reflecting the opportunity cost of the daily wage foregone by farmers working 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; Rozelle, Huang and Rosegrant; World Bank).

Our methodological approach is similar to that of Rosegrant and Evenson and Fan in that we use standard Divisia index methods to calculate TFP. Expressed in logarithmic form, the Tornquist-Theil TFP index for crop i is defined as:

(1) $\ln (TFP_{it}/TFP_{it-1}) = \ln (Q_{it}/Q_{it-1}) - \_ \Sigma_j (S_{ijt} + S_{ijt-1}) \ln (X_{ijt}/X_{ijt-1})$

where Q_i is crop production (output) for crop i; S_{ijt} is the share of input j in total cost for crop i; X_{ij} is input j used in the production of crop i, 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.

TFP analysis is conducted for rice, wheat and maize separately. The output index is just a single crop output index. Data on crop-specific inputs are used in the computation for each crop's TFP and includes series for sown area, labor, seed, fertilizer, pesticide, farm plastic film, pesticide, animal traction, machinery and equipment, and other material inputs.

TFP Trends in Reform China

Although we ultimately use provincial TFP in our determinants analysis, national aggregates illustrate an upward, but variable, trend in rice, wheat, and maize productivity (Figure 2).[2] In general, the TFP of all crops rise rapidly in the early 1980s, the earliest period of China's reforms. Wheat increased by more than 60 percent between 1980 and 1985; maize by 55 percent; rice by more than 40 percent.

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 1990 as they were in 1985 for all crops. The stagnant TFP trends discussed by Wen, who looks at the entire agricultural sector, are also evident in rice, wheat, and maize. There is great discussion in China over what has caused yield slowdowns during this period, a debate that usually focuses on land rights, commodity pricing policy, the availability and price of inputs, and the structural transformation of the rural economy (i.e., the expansion of rural industries, rising wages and rural income diversification). Regardless of the ultimate reason for the slowdown, food security conscious policy makers were concerned.

The rise in TFP, however, restarts in the 1990s. Productivity of wheat, the most successful crop, rises by more than 20 percentage points between 1990 and 1995. If one discounts 1994 and 1995, the TFP growth rates of rice and maize nearly match that of wheat. Rice and maize productivity indices fall in the mid-1990s. Although TFP growth patterns for all of the crops aggregated to the national level are similar, trends of the various sample provinces—even within a crop--vary sharply. For example, wheat TFP rises 3 to 4 percent annually in Hebei and Shandong Provinces, but less than 1.5 percent annually in Sichuan and Shanxi.

Agricultural Technology in China

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

By the early 1980s, China's research and development system for agriculture reached its peak, having 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. Building on their past achievements, reform era breeders have turned out a constant stream of varieties (Table 1). Since 1982, rice farmers in China have used about 400 "major" varieties each year (column 1).[3] In our sample, farmers in each province use around 25 rice varieties per year (column 2). In the case of wheat, because no single variety dominates like hybrid rice (for which several varieties make up a significant fraction of the nation's sown area), the total number of varieties per year nationally and the number per province might be expected to be bigger. In fact, wheat and maize breeders enjoyed less success. Wheat farmers in each province use around 23 varieties each year (column 3 and 4); maize farmers, on average, use 12 varieties per province (column 5 and 6). While it is beyond the scope of this article 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 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 2). The yield frontiers for rice moved up at 2.3 percent per year those for maize at 2.5 percent at year between 1980 and 1995, most likely a function of the development of hybrid cultivars. Although more modest, the yield frontier of wheat also has risen significantly during the reforms (1.3 percent).

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 between 1.0 (wheat) and 1.4 (rice) tons/ha per year during the reforms (Table 2, rows, 2, 6, and 10). When compared to the farmers' actual yields in 1980 (rows 3, 7, and 11), the differences ranged from 31 to 58 percent, gaps that are 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 for all crops, though that for wheat narrowed more than those for rice and maize (ranging from 31 percent to 14 percent for rice, from 58 to31 for wheat and from 51 to 38 for maize).

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 (between 14 to 38 percent) and narrowing trend of the percentage difference between actual yields 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 compared to wheat and maize, it is even smaller 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) for the Philippines and 3.5 tons per hectare (or 58 percent) for 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 it must come from increases in the creation and adoption of new varieties.

The narrowing gap between the yield frontier (Table 2, rows 1, 5 and 9) and adopted yield potential (rows 2, 6 and 10) has a number of other 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 in enhancing farm level profits. The large changes in the rice markets (Rozelle et al.; Luo) may partially explain the fact that the gap between the yield frontier and adopted yield potential has grown by two to three times that for either wheat or maize.

Creating and Spreading New 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 (Table 3, columns 1, 2 and 3).[6] For example, maize farmers turn their varieties over the fastest, averaging more than 33 percent per year. Every 3 years farmers *on average* replace all of the varieties in their fields. In the case of rice, farmers replace all of the varieties in their field every 4 years and wheat farmers adopt varieties at the slowest rate, changing their varieties every 5 years. From conversations with those familiar with grain cultivation in the US, Mexico, and India, as national averages, the turnover rates rival those found in the rice bowls and wheat baskets 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 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., to create our measure of crop research stock.[7] The resulting series trend 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.

Once the new technology has been created, China's agricultural leaders have extended new varieties to the farmer through the national extension system. In the counties, extension agents work with village officials and farmers to get them to adopt new products. We measure extension effort by the amount of funding dedicated by the government to support such work.

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, research investment falls or is stagnant from 1985 to early 1990.[8] 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 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 all the three crops (Table 3, columns 4, 5 and 6). Especially for rice, China has drawn heavily on the international research system for genetic material.[9] 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. The proportion varies over time (from 16 to 25 percent) and also varies by province, reaching more than 40 percent in Hunan Province, one of China's largest rice growing provinces, in the late 1980s. Although the national use of wheat and maize materials from the CG system (mostly from CIMMYT) is lower (columns 5 and 6), there does exist great variability among provinces, and in some provinces material from the CG system (i.e., especially those in CIMMYT's mandate area, for example, Yunnan Province for wheat or Guangxi Province for maize) makes up around half of the germplasm.[10] The new varieties and germplasm material, once they are introduced into the country, are used by breeders in China's NARS and then extended through the domestic extension system.

In summary, China's research system has created large amounts of new technology and it has succeeded in getting farmers to adopt it at an impressively rapid pace. The technology appears to embody 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 yields; yields and output have grown in the past, at least in part due to increased use of inputs. If future yield increases from higher input levels are limited by already high levels of input use, future growth in yields will more increasingly rely on rise in TFP, which most likely needs to be driven by new technology.

A General Framework of Endogenous Technology and Productivity Growth

Determinants of TFP and Model Specification

Total Factor Productivity indices for rice, wheat, and maize in China vary not only across province but also over time. Factors that may account for variations in TFP include changes in technology, institutions, infrastructure, and improvements to human capital. 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

article), human capital is typically assumed to already be accounted for. Given our data and research question, a framework for explaining TFP changes overtime can be specified as:

(2) TFP = f (Technology, Infrastructure, Institutional Reforms, Z)

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

A measure of seed technology (VT) is specified:

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

where t is the first year of the sample (e.g., 1981 for rice), and

(4) $VT_t = VT_{t-1} + \Sigma_k V_{kt}$,

where $V_{kt} = W_{kt} - W_{k\,t-1}$ if $W_{kt} - W_{k\,t-1} > 0$, or $V_{kt} = 0$, otherwise, for $t > 1$. In this expression V_k is the area share *change* for those varieties that have positive sign (that is the varieties that have increased their area share during the year), and W_k is the *area share* of k^{th} variety in *total sown area.* Equation (4) defines seed technological change as the extent to which newly introduced varieties replace existing varieties. For equation (4) to be a measure of technology improvement, we implicitly assume that farmers are rational and replace varieties when a new variety is of a higher "quality" than the variety it is replacing. A new variety is higher quality if it helps the farmer enhance yields or reduce costs or if it includes a new taste characteristic.

A potential statistical issue arises, however, when VT is used as a measure to test the effect of technology on TFP, as in equation (2). Since the farmer may be simultaneously making decisions affecting 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 variable (IV) approach.

Using predictions from an equation explaining technology as an instrument ($\hat{VT}$), our identification strategy assumes that the varieties created by national and international research institutes affect technology, but do 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 breeding research (or a measure of the nation's stock of crop research--Research Stock); germplasm flowing into each province from international agricultural research centers (CG);[11] and, yield-enhancing germplasm from China's NARS (Yield Frontier).

To specify a technology adoption equation, we turn to Feder and Umali's review of the agricultural innovation adoption literature for guidance. Their article shows that a large number of factors affect adoption. The size of the technology set – that is the range of choices of new technology that farmers have when they are making planting decisions – is one of the most important determinants. In addition, researchers have found that the quality of information about available technology is also necessary. In particular, a good extension system provides information to the agricultural community about available new technology while farmer learning and human capital facilitate its adoption. Both the physical environment and infrastructure also affect adoption. In areas with better natural climate and improved infrastructure (such as irrigation), farmers were found to adopt new varieties more rapidly. Finally, the completeness of markets facilitates technology adoption, as does the existence of other local institutions that support the search for and adoption of new technology. Hence, a close reading of Feder and Umali suggests a model of technology adoption should include measures of the availability of new technology, the extension system, the nature of the physical environment, infrastructure, and market environment, and, if possible, measures of human capital.

Based on the discussion above, we use a three stage least squares (3SLS) estimator to estimate the effect of technology and other variables on TFP. The empirical specifications of endogenously determined technology, VT, and the determinants of TFP models are:

(5) $TFP_{iht} = f_i\ (VT_{iht}, \text{Extension}_t, \text{Irrigation}_{ht}, D_{1990S}, \text{Weather Event Index}_{ht}, \text{Provincial Dummies}) + e1_{iht}$

(6) $VT_{iht} = g_i\ (\text{Extension}_t, \text{Irrigation}_{ht}, D_{1990S}, \text{Weather Event Index}_{ht}, \text{Provincial Dummies}; \text{Research Stock}_t, CG_{iht}, \text{Yield Frontier}_{iht}) + e2_{iht}$

where i indexes crops; h indexes provinces; total factor productivity (*TFP*) and *VT* are defined as above; e*xtension* is a variable reflecting all expenditures made on the extension system, aggregated to the national level;[12] *Irrigation Index* is measured as the ratio of irrigated land to cultivated land; and, D_{1990S} is an indicator variable which equals 1 for the period between 1990 and 1995 and is included to measure the effect of period-varying 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 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_{iht}, $\text{Yield Frontier}_{iht}$, are discussed and defined above.

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 rice, wheat, and maize varieties and the area sown to each variety in each province are from the Ministry of Agriculture (MOA, Varieties—1981 to 1997). This MOA compendium reports on “major” varieties covering at least 10,000 mu (667 hectares) in a province in any one year. Variety-specific yield information and pedigree data were mostly collected by the 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 for some crops for 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.

Results

The Determinants of New Technology

In both their role of creating instruments for the TFP equations and as equations of interest in their own right, the technology (VT) equations perform well (Table 4, columns 2, 4 and 6). The R-squares in OLS versions of the technology equations exceed 0.90 for all three crops. Hausman tests for exclusion restrictions that are designed to test the validity of the instruments show our three instruments are statistically valid.[13]

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 in all of the specifications for all crops demonstrate the effectiveness of investments in the research system. Higher levels of national stocks accelerate the pace of varietal turnover (Table 4, columns 2 and 4, row 7). If technology is the engine driving 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 all but one of 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. However, this may be too strong of a conclusion;

the negative sign may only be picking up the fact that this just happens to be a period when China's agricultural TFP growth is temporarily stagnant, a phenomenon that periodically occurs in every country. For example, even in the U.S. where researchers have documented the fact that TFP has grown steadily during the entire post-WWII period (Jorgenson), there have been at least two 5-year time periods in which TFP growth has been near zero or negative and two more that the growth rate of TFP has been only one percent, less than the rate of growth of the U.S. population.

The impact of the yield-increasing technology (created by each province's research system--the *Yield Frontier* variable) is more complicated. Breakthroughs in higher yields lead to faster spread and replacement of new varieties for some crops but not others. The positive and significant signs of the *Yield Frontier* variables in the wheat VT equations (Table 4, column 4, row 9) demonstrate that when higher yielding wheat varieties appear in their provinces farmers turn their varieties over more frequently. The correlation between a higher yield frontier and more rapid turnover may explain why wheat yields outperformed other major grains during the reform period. In contrast, higher values of *Yield Frontier* variables in the rice and one of the maize equations are associated with slower turnover (Table 4, columns 2 and 6, row 9). Such a finding is consistent with our gap analysis and may reflect the fact farmers (especially those cultivating rice) in the mid- to late-reform period prefer adopting higher quality rice varieties, even though higher yielding varieties are available.

The Impact of CG Material

The impact of the materials from the CG system is mainly a story of the China's breeders using IRRI and CIMMYT varieties for the yield enhancement of their seed stock. If it can be assumed that, when China's breeder incorporate foreign germplasm into its varieties, the material contributes to part of the rise in productivity, then the test of the direct impact of CG material is seen in the results of the TFP equation. If technology is important in all the TFP equations, by virtue of the fact that IRRI's material is used more frequently by China's rice breeders, compared to that used by wheat and maize breeders, it is making the largest contribution of the CG system 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.[14] 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 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 4, row 8—the coefficients is insignificant, column 2). 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 a secondary impact on the other traits that have been more important in inducing adoption in the reform period. A similar cautious interpretation is called for in the case of wheat and maize (Table 4, columns 4 and 6, row 8) where the standard errors are large relative to the size of the coefficient in all but one case.

But although the contribution of CIMMYT wheat and maize germplasm to China, according to this analysis, may be smaller, in some provinces the contribution of CIMMYT’s material has been large and may have extraordinary effects on the productivity of some of China’s poorest areas. For example, the CG genetic materials contributes more than 50 percent of Yunnan Province’s wheat varieties and more than 40 percent of Guangxi Province’s maize varieties in the late 1980s and early 1990s. Yunnan and Guangxi Provinces are both very poor provinces and some of the poorest populations in China are in the mountainous maize growing areas. Elsewhere (Rozelle et al.), we have shown that the impact of CG material in poor provinces, in general, is more important than its effect in rich areas—both directly and in some cases in terms of inducing more rapid turnover. Such a pattern of findings is consistent with a story that although the focus of the CG system on tropical and subtropical wheat and maize varieties has limited its impact on China productivity as a whole, it has played a role in increasing technology in poor areas, a chronic weakness of China’s research system (Stone, 1993).

Technology, Extension, and Productivity

Our results for the TFP equation, presented in Table 4, also 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). The signs of most of the coefficients also are as expected and many of the standard errors are relatively low.[15] For example, the coefficients of the weather indices are negative and significant in the TFP equations in the rice, wheat, and maize specifications (Tables 4, rows 3 and 4). Flood and drought events, as expected, push down TFP measures, since they often adversely affect output but not inputs (which for many crops 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 finding holds over all crops, and all measures of technology. The positive and highly significant coefficients on both measures of the rate of varietal turnover (*VT*) show that as new technology is adopted by farmers it increases TFP (Table 4, 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 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). We add a variable measuring the average age of the varieties (results not shown for brevity) to isolate the age effect from the new technology effect (given the definition of VT, this may be a problem). Although we find no apparent negative age impact on TFP in any of the equations (the coefficient is actually positive in the case of maize), in a number of the regressions, the coefficient of

VT variable in the TFP equation actually rises, a finding that reinforces 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 enhancing 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 4, columns 2 and 4, row 2). Extension, however, plays less of an independent role in increasing the yield potential of varieties that have been adopted by farmers, perhaps an unsurprising result given the reforms that have shifted the extension from an advisory body to one that is supporting itself, often through the sale of seed (Huang et al.)

Conclusions

This article establishes a basis for China's (and international) leaders and policy makers who are committed to keeping a strong agricultural supply capacity to confidently invest in the nation's agricultural research system. The basis for doing so primarily rests 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.

The picture sketched by this article demonstrates that investment in new technology is many faceted. Public investments in breeding and the extension pay off in terms of higher TFP. The form of the technology matters, no only in how rich it is in terms of yield-enhancing material, but also in whether or not farmers will adopt it. In the case of rice, although its breeders are increasing yield frontiers at a rate 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. If these traits can be identified and combined with the varieties with the higher yields, the future of China's rice supply appears sound.

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 may be cause for concern.

The results on the impact of the CG system are encouraging about future prospect for yield gains from foreign sources and suggest the China should continue to maintain and strengthen its ties to the rest of the world. In an era of uncertainty concerning 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. The results suggest that by moving into more temperate materials, CIMMYT might be able to increase its contribution to China, though it is unclear if it would be adding value or substituting alliances that China already has with other countries.

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Table 1. Total and Provincial Averaged of the Number of Major Varieties Planted by Farmers in China's Rice, Wheat and Maize Growing Provinces, 1982-95.

	Rice		Wheat		Maize	
	Total	Average per Province	Total	Average per Province	Total	Average per Province
1982	379	24	211	15	130	10
1983	333	21	274	20	130	10
1984	380	24	277	20	130	10
1985	424	27	313	22	156	12
1986	419	26	303	22	156	12
1987	373	23	313	22	156	12
1988	381	24	301	22	130	10
1989	365	23	337	24	143	11
1990	412	26	333	24	156	12
1991	395	25	350	25	156	12
1992	403	25	338	24	156	12
1993	392	25	341	24	182	14
1994	416	26	330	24	182	14
1995	391	24	311	22	208	16

Notes: These are totals for the 16 rice growing provinces, 14 wheat-growing provinces and 15 maize growing provinces in our sample. See endnote 1 for list of provinces.

Source: Authors’ data gathered from the Ministry of Agriculture.

Table 2. Experiment Station Yields (Yield Frontiers and Adopted Yield Potential), Actual Yields, and Yield Gaps in Sample Provinces in China, 1980 to 1995.

	1980 (Tons / Hectare)	1995 (Tons / Hectare)	Annual Growth Rate (Percent) [c]
Rice			
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%	
Wheat [c]			
Yield Frontier [a]	6.3	7.5	1.3
Adopted Yield Potential [b]	4.6	5.2	1.0
Actual Yield	1.9	3.6	3.2
Percent Gap between Adopted Yield Potential and Actual Yields	58%	31%	
Maize			
Yield Frontier [a]	7.6	11.0	2.5
Adopted Yield Potential [b]	6.1	7.9	1.8
Actual Yield	3.0	4.9	3.2
Percent Gap between Adopted Yield Potential and Actual Yields	51%	38%	

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

[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 periods 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.

Table 3. Proportion of Area Planted with New Varieties and the Contribution of the International Germplasm to China's Varieties, 1982-1995.

	Varietal Turnover[a]			CG Contribution[b]		
	Rice	Wheat	Maize	Rice	Wheat	Maize
1982	0.35	n.a.	0.47	16	1	2
1983	0.22	0.35	0.43	18	2	2
1984	0.20	0.26	0.40	22	2	2
1985	0.19	0.24	0.37	23	3	2
1986	0.28	0.27	0.41	23	3	2
1987	0.28	0.20	0.45	25	3	2
1988	0.26	0.19	0.34	25	3	3
1989	0.17	0.19	0.24	24	4	2
1990	0.24	0.21	0.24	25	4	2
1991	0.13	0.25	0.33	24	4	3
1992	0.29	0.22	0.32	22	3	1
1993	0.19	0.26	0.25	22	3	4
1994	0.25	0.23	0.32	20	3	1
1995	0.22	0.27	0.28	18	3	2

[a] 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.

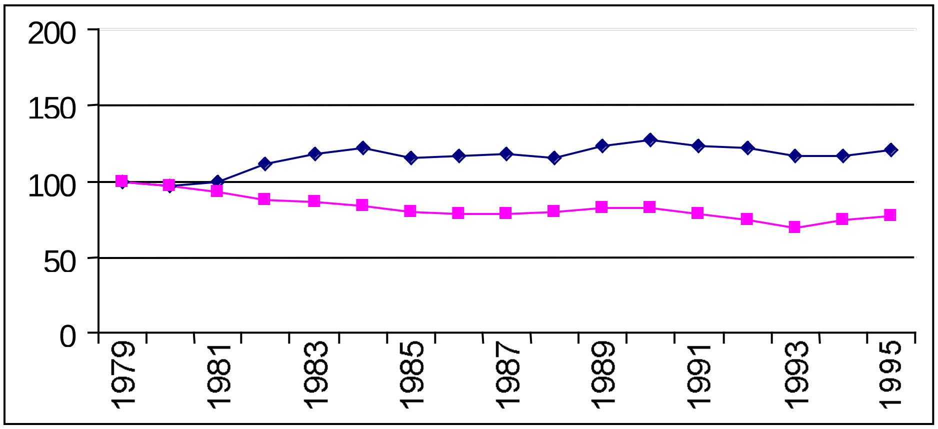
[b] *CG Contribution* represents the proportion of genetic material in China's germplasm for each crop that comes from the CG system. This variables is created using pedigree data for all varieties in the field in each period, and assigning geometric weights to parents (0.25/parent), grandparents (0.06/grandparent), 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; CIMMYT for wheat and maize).

Table 4. Three Stage Least Squares Estimates of the Determinants of Total Factor Productivity for Rice, Wheat and Maize in China.

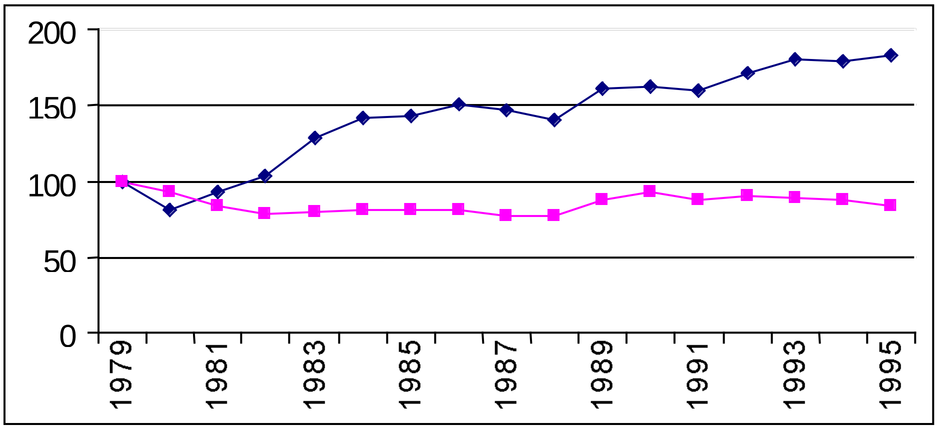
	Rice		Wheat		Maize	
	TFP	Technology (VT$_1$)	TFP	Technology (VT$_1$)	TFP	Technology (VT$_1$)
Technology Variables						
Varietal Turnover (VT$_1$)	15.50 (9.70)***		18.65 (6.16)***		15.75 (6.85)***	
Extension	-0.014 (1.77)*	0.0004 (2.45)**	-0.02 (1.46)	0.0008 (5.79)***	-0.06 (3.02)***	0.0005 (1.44)
Weather, Irrigation, and Period Dummy						
Flood Index	-8.63 (1.85)*	0.04 (0.38)	-102.29 (5.51)***	0.04 (0.24)	-13.92 (2.04)**	0.02 (0.21)
Drought Index	-23.83 (2.68)**	-0.30 (1.51)	-51.81 (3.25)***	-0.11 (0.69)	-38.72 (5.88)***	-0.08 (0.69)
Irrigation Index	-100.05 (3.35)***	-0.92 (1.34)	-87.09 (1.26)	-1.24 (1.79)*	-14.45 (4.15)***	-0.08 (1.43)
D_{1990S} (Index for 1990s)	1.54 (0.42)	-0.28 (3.29)***	6.65 (1.01)	-0.14 (2.08)**	11.60 (1.32)	-0.55 (3.48)***
Instruments						
Research Stock		0.02 (20.81)***		0.015 (24.31)***		0.03 (23.74)***
CG Contribution		-0.18 (0.55)		0.012 (2.95)***		0.81 (1.31)
Yield frontier		-0.002 (3.22)***		0.003 (5.54)***		-0.002 (3.50)***
# of Observation	240	240	196	196	195	195

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.

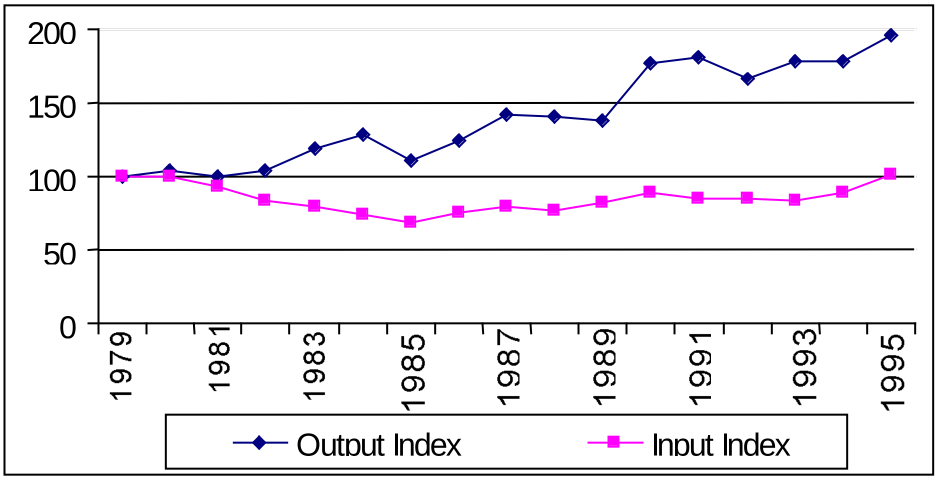
Panel A. Rice



Panel B. Wheat



Panel C. Maize



Source: Authors' Calculation based on Divisia-Tornquist Formula

Figure 1. Output and Input Indices for Major Rice, Wheat and Maize Growing Provincs in China, 1979-1995

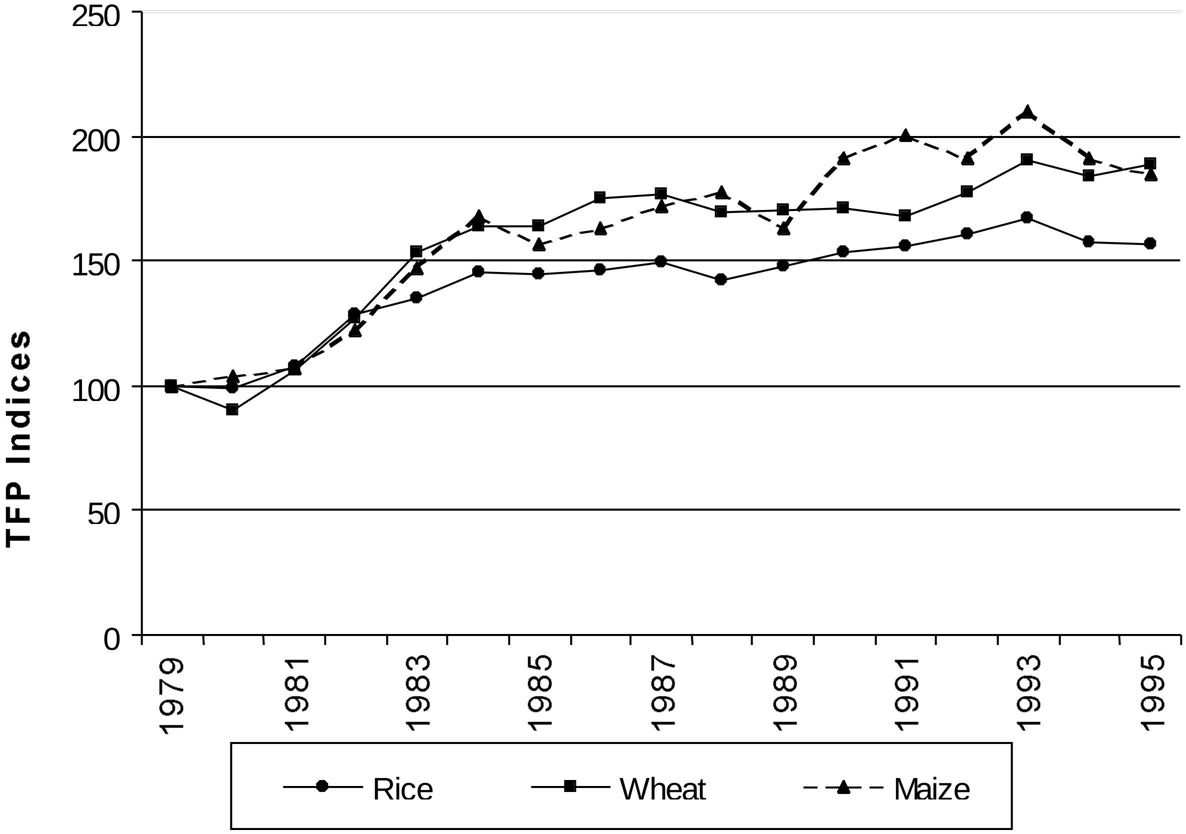


Figure 2. Total Factor Producivity Indices (Sown Area Weighted Average) for Rice, Wheat and Maize in China, 1979-1995

Endnotes

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[1] The 16 rice growing provinces are Heilongjiang, Jilin, Liaoning, Hebei, Jiangsu, Anhui, Hubei, Hunan, Jiangxi, Zhejiang, Fujian, Guangdong, Guangxi, Yunnan, Guizhou, and Sichuan. The 14 wheat-growing provinces are Hebei, Shanxi, Jiangsu, Anhui, Shandong, Henan, Sichuan, Gansu, Guizhou, Heilongjiang, Hubei, Shaanxi, Yunnan and Xingjiang. The 13 maize growing provinces include Guangxi, Hebei, Heilongjiang, Henan, Jiangsu, Jilin, Liaoning, Shanxi, Shandong, Shaanxi, Sichuan, Xingjiang and Yunnan.

[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.

[3] A "major" variety in our sample is any variety that covers at least 10,000 *mu* (or 667 hectares) in a province. For the rice, wheat, and most of maize growing sample provinces, the proportion of area covered by "major" varieties exceeds 90 percent in each province.

[4] "Yield frontier" is defined to be non-decreasing. If a major variety (defined in endnote 3) 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.

[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.

[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.

[7] Measuring the research stock is more complex, and takes into account the longer lags which exist between the time of an expenditure and the period when it affects production. The stock also depreciates over time. The research variables is estimated as:

$$z_r(t) = \sum_{t=0}^{n} \alpha(t)\dot{z}_r(t)$$

where $z_r(t)$ is the research stock in period t, $\dot{z}_r$ is the current expenditure from the national budget on research, $\alpha(t)$ is the timing weight for accumulation of new research expenditures to the stock of research. Since there is little theoretical guidance for determining these weights for China, a set of weights estimated by Pardey et al. (1992) for Indonesia is used.

[8] Our data covers the agricultural research conducted at Chinese Academy of Sciences (CAS), and at Chinese Academy of Agricultural Sciences (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, but only 15 percent of development income ends up supporting research.

[9] China also has contributed significantly to the world stock of genetic resources.

[10] The low overall contribution of the CG system to wheat and maize stems from the fact that CIMMYT's mandate area only covers tropical and subtropical environments.

[11] We define a variable 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; CIMMYT for wheat and maize).

[12] Our variable measuring the impact of extension on TFP is not province varying because the data do not exist at the provincial level. We actually tried initially to create such a data series as part of this series but were unsuccessful.

[13] 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

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$N*R^2$, where N is the measure of observations, and R^2 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 for rice, and 0.25 for wheat which indicate that the null hypothesis that there is no correlation between the exogenous instruments and the disturbance term from TFP equation for rice and wheat can not be rejected. However, the case for maize is less clear. The test statistic is 11, so the hypothesis of no correlation between the exogenous instruments and the disturbance term from TFP equation is rejected for VT_1 specification. When only two instrument variables, research stock and wcg, are used in the system, the test statistic is 0.02 which indicates that these two instrument variables are not correlated with the disturbance term from TFP equation.

[14] One alternative way to identify the "extra" impact of CG material on TFP is to interact 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 similar to our less formal test; varieties with high content of CG germplasm do not have an "extra" effect (results not shown for brevity).

[15] One of the most surprising exceptions is the insignificant or negative sign of the irrigation variable's coefficient. According to our results, the ratio of irrigated to cultivated land does not positively influence wheat productivity and negatively affects that of rice and maize. As found by Rosegrant and Evenson (1992), it may be that 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.