Discussion Paper

No. 92-03 Revised January 1993

Research, Productivity and Output Growth in Chinese Agriculture

Shenggen Fan
Associate Officer, Research Policies & System Strategies Program
ISNAR

Philip G. Pardey
Senior Officer, Research Policies & System Strategies Program
ISNAR

International Service
for National Agricultural Research (ISNAR)
P.O. Box 93375
2509 AJ The Hague
The Netherlands
tel: (31) (70) 349-6100
fax: (31) (70) 381-9677
email: Dialcom (CGNET): 157:CGI601
or Internet: ISNAR@CGNET.COM

RESEARCH, PRODUCTIVITY AND OUTPUT GROWTH IN CHINESE AGRICULTURE

Shenggen Fan
University of Arkansas, USA

Philip G. Pardey
International Service for National Agricultural Research, The Hague, The Netherlands
University of Minnesota, St. Paul, USA*

January 1993

ABSTRACT

Recent attempts to quantify the sources of growth in Chinese agriculture have all attributed an exceptionally large share of this growth to the contemporary market reforms within China. To analyze this important issue we use a newly constructed panel data set that includes an agricultural research or stock-of-knowledge variable. Our results suggest that, while still a significant source of growth, the longer-run, growth-promoting impacts coming as a *direct* consequence of these market reforms have been largely overstated by these earlier studies. Research-induced technical change accounts for about 20% of the growth in aggregate agricultural output since 1965. Disaggregating the results within China reveals substantial interregional variability in the sources of local growth, as would be expected in such a large and diverse country.

Correspondence to: Philip Pardey, International Service for National Agricultural Research, P.O. Box 93375, 2509 AJ The Hague, The Netherlands

*The views expressed here are those of the authors. This work was sponsored by the Rockefeller Foundation, the International Service for National Agricultural Research, and the Center for International Food and Agricultural Policy, University of Minnesota, and carried out in collaboration with the Institute of Agricultural Economics, Chinese Academy of Agricultural Sciences. The authors received helpful comments from Howard Elliott, Niu Ruofeng, Zhu Xigang, Kym Anderson, Stanley Wood, Vernon Ruttan, Christian Bonte-Friedheim, and Justin Lin on an earlier version of this work. Senior authorship is unassigned.

RESEARCH, PRODUCTIVITY AND OUTPUT GROWTH IN CHINESE AGRICULTURE

1. Introduction

Much has been written about the economic impacts of the Chinese government's institutional reforms that got underway in late 1978. But comparatively little attention has focused on the agricultural productivity (not simply growth) consequences of these reforms or the likely nature and sources of future productivity gains in Chinese agriculture. Certainly the increased quantity, quality and intensity of use of conventional inputs accounts for a sizable portion of the growth in output over the past few decades. And while continuing market reforms offer the promise of further growth, it is investment in capital, be it human, physical, or "technological", that will play an ever increasing role in shaping Chinese agriculture's longer run growth prospects as the shorter run gains from such reforms work their way through the system.

A good deal of the new technologies, techniques and know-how required for sustained productivity gains in agriculture come from investments in agricultural research. But just how successful past research investments have been in contributing to agricultural output and productivity growth in China has yet to be determined. This is the focus of our attention in this paper.

By way of introduction we briefly review the growth of China's agricultural sector over the past several decades. Several partial productivity indicators are then used to assess the biased nature of technical change. China is a large and diverse country. To provide additional perspectives on this factor bias issue we disaggregated the national statistics to a manageable but revealing set of agricultural regions. We then summarize our new, time-series data on agricultural research investments in China.

All of this serves as background for our analysis of the sources of growth in Chinese agriculture. Some recent studies have attempted to identify the influence of market reforms on agricultural growth[1] but none have sought to also identify the growth-promoting effects of agricultural research as we do here. In addition, disaggregating our analysis to a regional level makes it possible to expose the substantial interregional variability in the growth-promoting impact of all these factors (i.e., conventional inputs, market reforms, and agricultural research) that has hitherto received scant attention.

2. Agricultural Output Trends

The value of aggregate agricultural output in China grew at a compound rate of 5% a year from 1965 to 1990 (table 1). Up until 1980 the annual rate was 4%, then jumped to 8.1% for the years 1980 to 1985, but thereafter declined to (a still highly respectable) 4.7% per annum. Given substantial regional differences in resource endowments, it is not surprising that there were marked, regional deviations from the pattern of growth at the national level. In three regions[2], the north, northeast and southeast, agricultural output increased at a faster rate than the national average while, somewhat unexpectedly, the central region (one of the major agricultural areas in China) and, perhaps not so surprisingly, the northwest and southwest regions (which account for the smallest share of agricultural output in the nation) had long- run rates of growth some 12% to 16% below the national average.

[insert table 1 here]

The evolving pattern of production at the commodity level is shown in table 2. China's grain production has grown on average by 3.2% per annum over the past 40 years -- some 1.1% faster than the growth in population over the corresponding period. Cash crop

---

[1]See Lin (1989, 1992), McMillan et al. (1989), Wen (1989) and Fan (1990, 1991).

[2]See notes to table 1 for definition of these agricultural regions.

production (including cotton, oil crops, and fruits) has achieved notable success, generally exceeding the increase in food grain production. Over the longer run, increased grain production has come about largely through intensifying farming practices, i.e., by increasing yields rather than a sustained increase in area sown. In fact the national rate of increase in grain yields averaged slightly above 3% per annum over the 1949 - 90 period with the 113.5 million hectares sown to grains in 1990 being only marginal higher than the 110 million hectares sown in 1949.[3] By contrast, the growth in cash crops has resulted from both intensifying and extensifying farming practices, i.e., through the increase of both yields and sown area (up from 12.5 million hectares in 1954 to 21.4 million hectares in 1990, with much of this growth occurring in the past decade). The performance of the animal and fishery sectors has been even more impressive than that of the crop sector, achieving growth rates between 6% and 8% per annum from 1950 to 1990.

[insert table 2 here]

These cross-commodity differences in the rate of output growth gave rise to marked shifts in the structure of agricultural production. Livestock products now account for over 25% of the total value of agricultural output, more than double their share back in 1949. At 4.3% and 6.2% respectively (in 1990), forestry and fish products account for a smaller but similarly increasing share in the value of production. These changing patterns of production are no doubt a response to shifts of demand into income-elastic fruit and vegetable, livestock, and feed grain products[4] that have followed from the quite rapid growth in per capita income

[3]These end points mask the fact that the area sown to grains was quite volatile over the intervening years. It increased markedly throughout the 1950s to peak at 136 million hectares in 1956, declined to around 120 million hectares by the early 1960s where it more-or-less remained until 1978. Thereafter it declined fairly steadily over the ensuing decade, only to grow in the subsequent two years for which data are available.

[4]Given the widespread use of crop residues, industrial and, especially, household by-products and wastes as well as green manures for livestock feed it is difficult to get accurate measures of the trends in feed-grain consumption. Nevertheless, per capita grain consumption has more than doubled since 1949, with most of this

over the past 25 years, as well as China's increased level of participation in international agricultural product markets. This switch to higher-valued crops and livestock products is precisely what occurred in earlier decades elsewhere in East Asia as incomes grew (Anderson 1990).

3. Agricultural Productivity Patterns and Input Use

In thinking about the factors that influence observed patterns of change in production and productivity, Alston and Pardey (1991) found it useful to characterize economizing responses according to their length of run such that (a) short-run choices are made concerning total input use and input combinations for a given technology (i.e., factor use decisions), (b) intermediate-run choices are made concerning the choice of technology from the existing set of technologies (i.e., adoption decisions), and (c) longer-run choices are made concerning investments in R&D and new technologies (i.e., research decisions). Hayami and Ruttan (1970 and 1985) popularized the idea that all of these choices are directly influenced by relative prices which act as market indicators of underlying relative factor endowments.

But, there are a number of reasons why this factor scarcity view of technical change may fail to correspond closely with observed behavior. In market economies, distortions in factor as well as product markets can result in a pattern of relative factor prices that in the short, intermediate, and (in some instances) even longer run bear little resemblance to underlying factor endowments (de Janvry and Deither 1985; Alston and Pardey 1991). While centrally-planned economies commonly operate with distorted relative prices it is also the case that factor markets are often missing or incomplete in such economies.

---

increase coming from the use of feed grains in livestock products. The main sources of feed, particularly for pigs and poultry, are grains (including potatoes) and grain by-products and, to a more limited extent, protein meals such as fish meal, meat and bone meal, cotton seed meal and oil seed meal, brewers wastes etc. (World Bank 1987 and 1991).

In China, land markets are still rudimentary while labor and capital markets remain quite distorted in spite of the institutional reforms that have taken place over more recent years. Notwithstanding these market imperfections recent empirical work by Lin (1991), using provincial-level data, and by Fan and Ruttan (1992), using aggregate national data, suggests that the contemporary pattern of Chinese agricultural development is broadly consistent with the factor scarcity version of the induced-innovation model. In this case, central planning appears to substitute, albeit imperfectly, for missing or imperfect factor markets in ways that preserve the factor-saving bias of technology innovation and choice that would be expected of a market economy with similar resource endowments.

Regional patterns of land and labor productivity are presented diagrammatically in figure 1. The land variable is the total hectares of land in agriculture as measured by area sown to crops plus the sown-area equivalent of grasslands. The labor variable is a person-year-equivalent measure of the workers engaged in agricultural production, while the agricultural output estimate explicitly excludes off-farm value-added in agriculture in order to more closely match the coverage of the input variables. All of the productivity paths move in a northeasterly direction starting in 1965 and ending in 1990. The diagonals indicate constant factor ratios. A productivity path that crosses such a diagonal from right to left indicates a decrease in the number of hectares per worker. The longer a productivity path, the greater the ***percentage*** change in productivity.

[insert figure 1 here]

Source: Authors' calculations based on data in Fan and Pardey (1992).

China's measured level of labor productivity in agriculture is low compared with that of many other developing or (former) socialist countries (Wong and Ruttan 1988), a situation that is consistent with the country's exceptionally low land-to-labor ratio[5]. However, from 1965 to 1990 China's labor productivity grew substantially despite a tendency for land area per unit of labor to decrease (table 3). The growth rate was 3.7% a year from 1965 to 1990 -- 2.7% prior to the reforms that began to have impact in 1979, 7.7% from 1980 to 1985, declining to 3.3% per year from 1985 to 1990. For the country as a whole, the rate of growth in land productivity averaged about 5.4% per annum from 1965 to 1990 -- 4.4% prior to 1980, 8.5% from 1980 to 1985, and 5.3% over the following five years. It is noteworthy that land productivity grew more rapidly than labor productivity, indicating a general tendency to adopt land-saving and labor-using technologies throughout the country.

[insert table 3 here]

Closer inspection, however, reveals considerable differences across regions both in the levels of these partial productivity measures and their paths over time. The highest measured output per hectare occurs in the south and southeast, and the lowest in the northeast and northwest. Output per worker is highest in the northeast and lowest in the central region. There has been a persistent and reasonably strong, positive correspondence between rates of increase in land and labor productivity. Over the longer run both productivity measures grew fastest in the north and southeast and most slowly in the southwest and northwest. In more recent years it is the south and northwest regions that have shown the largest land and labor productivity gains, while the central and southwest regions experienced the smallest gains in both productivity measures.

Using similarly regionalized productivity data for US agriculture, Craig and Pardey (1990) showed that over the 1949-85 period, spatial variation in the average productivity of

[5]This follows because a labor-productivity ratio (Q/L) can be partitioned into two components, a land-to-labor ratio (A/L) and a land-productivity ratio (Q/A) so that $Q/L = (A/L)\ (Q/A)$.

labor narrowed more rapidly than that of land, even after differences in the mix (or quality) of land and labor across states had been accounted for. Since land is completely immobile across states and is not nearly as mobile intersectorally as labor, it is not surprising that land productivity still remains variable even within one country. On the other hand, because regional labor markets are increasingly integrated within the US, it is to be expected that, over time, significant differences in the marginal product of labor will be eroded. In such economies with well-functioning factor markets, workers in all regions will leave agriculture largely in response to opportunities outside the sector (Kislev and Peterson 1982), thereby enabling interregional differences in returns to agricultural workers to be eliminated.

At least at the level of spatial aggregation used for this study, there is no clear evidence that regional differences in either land or labor productivity within China have converged over time. In most cases, those regions with relatively low land productivity in the mid-1960s showed no propensity to catch up with the more productive regions over the ensuing two and one half decades. Nor was there a systematic tendency to close the gap with regard to regional labor productivity differentials. While two of the regions did manage to do so, two more maintained their labor productivity differential with respect to the northeast -- the region that had consistently outperformed all other regions in this regard since 1965 -- while the remaining two actually lost ground. Given the essentially regional rather than national character of labor markets in China and the continuing (although increasingly muted) intersectoral rigidities in the nation's labor markets this lack of convergence in regional labor productivities is not so surprising.

Careful interpretation of these partial productivity measures requires some recognition of problems with mismeasured and omitted variables, as well as limitations of the measures themselves. Clearly land and labor endowments cannot tell the whole story when there is the possibility of substituting other inputs for these primary factors of production. While it is difficult to imagine a perfect substitute for land, there are many ways to alter the productivity of any given unit of land through complementary inputs such as fertilizers, modern seeds, pesticides, irrigation, and both physical and human capital. The same purchased inputs can also augment the productivity of labor.

In order to gain richer insights into the sources of economic growth, "total" rather than partial productivity indices are often constructed, since they make it possible to account for the role played by all measurable inputs. However, regardless of the input coverage of productivity indices -- be it a single input as in the case of the partial productivity measures reported here or a more comprehensive set of inputs as with a total factor measure -- describing and comparing the evolution of productivity over time or across regions poses the same methodological problems. Of particular importance is the need to disaggregate inputs in order to account for quality differences, as occurs across different types of agricultural land (e.g., arid pastureland versus irrigated cropland) or classes of agricultural labor (e.g., well-educated farmers versus unskilled hired labor). Analytical work by Star (1974) implies that growth rates of either partial or total factor productivity will be reduced if the faster-growing inputs are higher-quality inputs. These results have a direct bearing on the partial productivity measures reported here. Data limitations meant we had no option but to use preaggregated land and labor measures, thereby giving rise to partial productivity measures that subsume the impact of land and labor quality differentials.[6]

Over the past 25 years the number of workers in Chinese agriculture has increased

[6]This may be especially an issue for the measure of labor used here which does not account for cross-sectional, over-time differences in the quality of the rural labor force. By most accounts literacy rates have risen substantially in post-revolution China (Perkins and Yusuf 1984) while primary school enrollment ratios have been at or above 90% (even for most rural areas) for the past three decades and secondary school enrollments (including, presumably, high schools and technical vocational schools) have risen from around 20% in the early 1960s to around 40% over more recent years (Craig, Pardey and Roseboom 1991).

across all regions and grown nationally at an average rate of 1.2% per annum (table 4). At the same time, the total area under agriculture rose at an annual rate of 0.4% per annum although it contracted in the north and northwest, the former region having experienced the most rapid increase in land and labor productivity growth of any part of the country. Consistent with the land rather than the labor productivity bias of Chinese agricultural development, land-to-labor ratios declined for all regions, especially the northwest where 1965 land to labor ratios of 1.32 hectares per worker were over twice the national average of that time.

[insert table 4 here]

There has been a concomitant and especially rapid increase in the use of modern inputs by Chinese agriculture since 1965 (table 5). With application rates of 180 kilograms per hectare, Chinese farmers still rely heavily on manurial fertilizers. This level of use represents a 30% increase over the rates that prevailed 25 years earlier, compared with a 12-fold increase in the rate of chemical fertilizer applications.[7] The marginal gains from additional manurial fertilizer use appear to be diminishing (Fan 1991) but still worthwhile from a farmer's perspective. Nevertheless, continuing development of the nonfarm (input-supply) sector as witnessed over the past decade, coupled with an increase in the opportunity cost of farm labor, are likely to result in further but moderating substitution of chemical fertilizers for (labor-intensive) manurial fertilizers.

[insert table 5 here]

There are marked regional disparities in the rates of application of both chemical and

[7]By comparison, fertilizer use increased, on average, by ninefold in the less-developed countries and only twofold in the more-developed countries. China's 1981-85 average application rate was 167 kg per hectare, compared with corresponding less- and more-developed country averages of 54 and 119 kgs per hectare respectively (Craig, Pardey and Roseboom 1991).

manurial fertilizer. Chemical fertilizer distribution has long been used by government as an instrument of state policy with respect to crop production. The goal had been to maximize national benefits of fertilizer application by favoring certain areas, generally those with a higher (natural) yield potential in priority crops and those with better irrigation facilities.

With just under half its arable land irrigated, China is second only to Japan in this regard. And the 58% increase in irrigated area over the past 25 years is only part of the story. An even more dramatic threefold increase in power-irrigated area -- which translates to an eightfold increase in the horsepower used for irrigation per worker in agriculture -- indicates that the quality of irrigated areas has improved significantly.[8] As a consequence, the increased proportion of arable land under irrigation will be an understated measure of the increased use of irrigation services to the extent that it omits these substantive quality improvements.

But even these shifts in factor proportions are eclipsed by the ratio of nonirrigation horsepower per worker, which has increased by a factor of 34-fold since 1965. Much of this machinery has been used for plowing, harvesting, threshing and transportation operations, with repair service facilities and, in the case of smaller machinery, production facilities being provided by local rural industries. In part this increased use of mechanized inputs reflects the government's well-known ideological or policy bias toward a capital-intensive development strategy (Fan and Ruttan 1991).

To sum up, the evolving patterns of land and labor productivity in Chinese agriculture have been influenced by shifts in the intensity of use and the quality of the land and labor inputs themselves, as well as a marked increase in the level and intensity of use of other

---

[8]Converting from gravity-fed, windmill or manual irrigation systems to mechanized irrigation systems can increase yields by increasing the reliability and timely delivery of irrigation water.

inputs. Our attempts to distinguish the separate influences of each of these inputs on the growth of agricultural output in China since 1965 are reported later in this paper.

4. Agricultural Research Investments[9]

Since 1961 there has been an annual 8.5% rate of growth in research personnel and a corresponding 5.9% rate of growth in real research expenditures. Both these rates of growth have accelerated over recent years so that by 1988, the latest year for which figures are available, there were over 55,000 agricultural scientists and nearly 30,000 technical support staff in the Chinese agricultural research system (table 6). Universities account for a growing but still relatively minor share of the nation's agricultural research resources. In the early 1960s only 6% of the researchers and 2% of the research expenditures were in the university sector but by the late 1980s these percentages were 15.6% and 6% respectively.

[insert table 6 here]

While the Chinese agricultural research system dwarfs all other public-sector systems -- in fact it is even four times larger in researcher terms than its nearest developing-country rival, India -- the number of researchers with formal scientific qualifications is quite meager. Only 5%-6% of its researchers hold a post graduate degree compared with 60%-70% in other less-developed Asian NARSs. Even in Chinese terms the agricultural scientific community fares badly in this regard. The share of scientists and engineers with PhDs across all sectors averaged 0.4% in 1988 (SSTC 1989), which is double the corresponding percentage for agriculture. Those holding MSc degrees were 5.1% for all-sectors and 4.6% for agriculture. This state of affairs is no doubt a legacy of the industry-led development strategies of the 1950s and 1960s and the anti-intellectual climate of the Cultural Revolution years. It is to be expected that over the next few years this situation will redress itself somewhat with the

---

[9]For a more complete account of the data summarized here consult Fan and Pardey (1992).

expected influx of graduates into the research system from the surge of enrollments in China's agricultural universities during the late 1970s and early 1980s.

China's agricultural research-intensity (ARI) ratio -- measuring agricultural research investments relative to AgGDP -- was above the less-developed country (weighted) average of 0.24% in the early 1960s. Even during the Cultural Revolution in the second half of the 1960s, China maintained a respectable official level of investment in agricultural research. But the relative stability in China's ARI over the ensuing one and one-half decades contrasts markedly with a good number of other less-developed countries -- particularly in Asia -- whose ARIs rose over this same period. By the mid-1980's, the latest year for which comparative data is available, China spent slightly less than the less-developed country average on research and had an ARI ratio that was less than one-quarter the more-developed country average. Agricultural research expenditures are generally positively related to growth in per capita income but (given probable economies of size and economies of scope in research) rise less than proportionally with agricultural output (Alston and Pardey 1991). In keeping with these general tendencies the rapid growth in per capita GDP throughout this period would be expected to lead to increased ARI ratios. But in China's case, this tendency has been offset by the exceptionally high rate of growth (6.5% per annum) in AgGDP that occurred in the post-1980 period. Thus the stable ARIs over the more recent years did not stem from a contracting or stagnating level of agricultural research expenditures; its principal origins are to be found in the high rate of growth in agricultural output during the 1980s.

Much of China's agricultural research is crop related. In 1987 nearly two-thirds of its research personnel and 57% of its expenditures were crop-production oriented. Around 17% of the research personnel work on fisheries problems, 8% on forestry, but only 11% on livestock production issues -- a subsector that accounts for around 25% of the value of agricultural output.

Agricultural research in China is also institutionally fragmented. In 1989 only 17% of the scientists and engineers working in the ministry part of the system[10] were based in national-level institutes. The overwhelming majority of researchers (53%) work in institutes administered (and often largely financed) at the provincial level with the remaining 30% working in prefectural institutes. National institutes focus on more basic or pre-technology lines of research while the applied and adaptive research and development work at the provincial and prefectural institutes is targeted more to local production problems and thereby tends to have a higher site-specific orientation. The national institutes are predominantly to be found in the eastern part of the country. If the institutional coverage is broadened to also include provincial- and prefectural-level institutes the research institute, personnel, and expenditure shares for each region of the country are roughly congruent with the corresponding agricultural output, population and arable land data (Fan and Pardey 1992). But, there are some notable exceptions. In terms of their congruence with agricultural output, for instance, the northeast and northwest regions appear to substantially overinvest in agricultural research while the north and, to a lesser degree, the southwest regions underinvest in research.[11] Be that as it may, this spatial variability in research effort will be captured in the growth accounting analysis to follow.

5. Accounting for the Impact of Agricultural Research

Measuring the productivity or impact of agricultural research is often handicapped by the paucity of suitable data. This problem is no less serious in the case of China. There are

---

[10]Given data limitations the university section is excluded here.

[11]To do justice to a consideration of spatial congruence requires a more thorough assessment of issues such as the site-specificity of each region's program of research and the degree to which new technologies and knowledge developed in one region can potentially spill over to another (Pardey and Wood 1991).

reasonably abundant data on crop production and the overall use of inputs but rather less on technology dissemination and very little on the costs of research for different commodities or geographic regions. Notwithstanding these difficulties, statistically decomposing agricultural growth into its respective parts is a challenging but potentially fruitful line of enquiry to which we now turn.

5.1 Data, Measurement and Estimation Issues

The marked changes in the composition of agricultural output plus the substantial cross-commodity differences in the rate of growth noted earlier suggests that a more complete and representative accounting of the growth performance of the agricultural sector is best served by taking a broad-based measure of agricultural output. For this and other measurement-related reasons,[12] the approach we took was to express aggregate agricultural output, Y, as a function of conventional inputs including land, labor, fertilizer, power, and area irrigated -- denoted by X_i, $i=1,\ldots,5$ --, and a research investment or stock of useable knowledge variable, $X_i=X_6$. Also included were a set of regional dummy variables, D_g, $g=2,\ldots,7$, presumed here to represent time-persistent, regional differences in social, economic and natural endowments not accounted for by the other variables, a time trend, t, and a time-specific dummy D_I, capturing the effects of the post-1978 economic reforms, and a disturbance term e_{jt}.

To keep the estimation exercise tractable, while still preserving a reasonable degree of flexibility, we chose the following functional form:

[12]Most notably, the data to meaningfully partition factors such as land, labor and purchased modern inputs into commodity-specific uses are presently not available.

$$lnY_{jt} = \alpha_0 + (\alpha_1+\alpha_2 t)t + \sum_{i=1}^{6}(\beta_{1i}+\beta_{2i}t)lnX_{ijt} + \beta_I D_I + \sum_{g=2}^{7}(\beta_g+\beta_{Ig}D_I)\,D_g + e_{jt} \quad (1)$$

where provinces are denoted by $j=1,...29$ and $t=1,6,11,...,24$ denotes annual observations for the years 1965, 70, 75, 76, ..., 89 to give a total of 493 observations. This quasi-translog function represents a compromise between a translog specification, which admits interaction effects between all inputs and, in this case, a time trend, and a Cobb-Douglas production function, which imposes separability between all inputs and time. Given the strongly trending nature of many inputs into Chinese agriculture over this 25-year period, multicollinearity problems pose significant estimation difficulties in the translog case. Constancy in production elasticities as implied by the Cobb-Douglas form appear unrealistic over this lengthy and institutionally-volatile period during which the biased nature of the technical change noted earlier would cause factor shares to vary over time. The quasi-translog specification imposes separability between all measured inputs but not between these inputs and a time trend. In this way the "effectiveness" of each measured input is allowed to vary overtime even though the effects among inputs are indirect through time. So while this specification reduces to a Cobb-Douglas form in any particular year, its production elasticities vary over time.

In this instance output is the value of agricultural production measured in 1980 local prices where agriculture is defined in a broad sense to include crop, livestock, forestry and fishery production. The land variable is taken to be land in agriculture as measured by area sown to crops plus the sown-area equivalent of grasslands. The labor variable is a person-year equivalent measure of the workers engaged in agricultural production, fertilizer inputs are a pure-nutrient equivalent estimate of the chemical and manurial fertilizers used in agriculture, the power variable is an aggregation of total machinery horsepower plus draft animals measured in "horsepower equivalents", while the irrigation variable is an estimate of the total irrigated area in agriculture.[13]

Developing plausible measures of the market reforms initiated in late 1978 for inclusion in a growth accounting framework is problematic. At the outset these rural reforms were seen primarily as a means of freeing up rural trade fairs or "free markets" whose main function was to provide an outlet for produce grown on the private plots of farm households working in their spare time. But events rather quickly overtook these quite modest aims and have subsequently led to, among other things, a radical overhaul of the collective system of farm production and management, and a relaxation of regional self-sufficiency requirements. There were also important moves to liberalize and decentralize many factor and product markets that included significant increases in the prices paid for state-purchased farm produce.[14] While some analysts have sought to identify the specific effects of individual components of this reform program these exercises pose significant problems of measurement and interpretation. Inevitably there is incomplete coverage of the measures used to proxy the various aspects of the reform program (especially with regard to economy-wide measures that have an important bearing on the agricultural sector such as the trade liberalization and exchange rate adjustments), and further difficulties in capturing the varying time-, commodity- and even location-specific effects of the reform measures that are included. This all points to the possibility of potentially-misleading aggregation and omitted-variable bias when apportioning the measured growth in output to any particular element of the reform

[13]A more complete description of the data used here and their sources is given in the appendix.

[14]These new policies sought to move away from a lopsided stress on grain production, by encouraging diversification of the rural economy as well as product specialization and crop selection that was more in accord with regional comparative advantage. Most importantly, they also sought to restore the primacy of the individual household as the basic unit of production and management in rural China. See Johnson (1988), Perkins (1988), Sicular (1988), Gunasekera et al. (1991) and Putterman (1992) for details.

program. For these reasons we opted for a straightforward, reduced-form approach to this aspect of the measurement and accounting problem. While recognizing we have artificially collapsed the reform impacts to an essentially one-shot (but nevertheless locally-variable) effect, our results were insensitive to econometric experiments wherein the switching point from the post- to pre-reform era ranged from 1978 through 1983.

Investments in agricultural research eventually add to the stock of useful knowledge which in turn leads to productivity gains in agriculture. But the production of new knowledge and technologies is a complex, risky and time-intensive process. For instance, the lags between investing in research and developing new knowledge and agriculture technologies depend on a host of factors not least the commodity, scientific discipline and research problems under consideration. There are further lags in the uptake of these new technologies and often site-specific variation in their productivity effects. Search, screening and selection activities on the part of farmers, commune leaders or whoever, and the availability and effectiveness of extension services all play a role in this regard. Linking research investments directly to changes in an aggregate measure of agricultural output, as we do here, is clearly a reduced-form specification but one that does enable us to examine quantitatively the productivity effects of research. Temporal and spatial differences in input quality (including that of labor as commonly signaled by educational levels), extension services, and the like, which also contribute to the measured growth of the agricultural sector, are subsumed in the time and dummy variables included in equation (1). This quasi-translog specification has the attractive feature that it allows the impact of research on agricultural output to be conditioned by these omitted variables through time. Moveover, it does this in a way that skirts some of the multicollinearity and degrees of freedom problems that are associated with more general forms of the production function.

One of the thornier problems to resolve when including a research variable in an aggregate production function concerns the choice of an appropriate lag structure. Studies using long-run US data suggest that the productivity effects of agricultural research can persist for upwards of 30 years (Pardey and Craig 1989). There is some evidence that substantially shorter lags may be appropriate for China, especially for the post-1965 period under study here. Stone (1990) notes that some of the regional research systems in China move varietal improvement research, at least for wheat and rice, through development, testing and registration procedures, and on to seed production and extension in just three to five years. In these more advanced regions major varieties may well turn over every two to three years, with a national average of just twice this rate. Given that only the more applied and adaptive types of research performed at the provincial and prefectural level are captured by the research variable in equation (1), the lag until research begins to impact output may be relatively short and it may also take substantially less time before the research is either obsolete or fully depreciated. With this in mind[15] we included a research or stock of useable knowledge variable that was a deflated, weighted sum of past research expenditures r_{t-i} given by

$$X_{6t} = \sum_{i=1}^{7} w_i r_{t-i} \qquad (2)$$

where the weights are defined as $w_1 = w_7 = 0.05$, $w_2 = w_6 = 0.1$, $w_3 = w_5 = 0.2$ and $w_4 = 0.3$. Given the unavoidable uncertainty concerning the structure of this lagged relationship some sensitivity analyses were performed in which both the lag length and its form (as

[15]Some Chinese research on this point (CAAS 1986) was also taken into account in the specification used here.

represented by the weights placed on the lagged research expenditures) were varied. This work indicated that neither the qualitative nor quantitative details reported below were appreciably altered as a consequence.

5.2 Results

The ordinary least squares estimates of equation (1) are reported in table 7, which for comparative purposes includes estimates of the Cobb-Douglas version of the production function as well. With one or two exceptions the coefficient estimates are relatively robust to choice of functional form. All of the coefficients on the conventional inputs are positive and most are significant at the usual levels of acceptance. A good number of the conventional input-by-time interaction variables were also statistically significant. The sum of the coefficients on the conventional inputs range from a low of 0.884 for model (2) to 0.979 (evaluated at $t=0$) for model (4), suggesting near constant returns to scale in the conventional variables in this latter case. While this (base year) constant returns to scale feature of the quasi-translog specification persisted over the ensuing two and one half decades, individual production elasticities were quite variable over time. In particular, since 1965 the elasticities on traditional inputs such as land and labor declined at an average annual rate of 7.9% and 10.5% respectively. By contrast, modern inputs such as fertilizer, power and irrigation services have a much larger, marginal impact on output in the late 1980s than they did in the mid-1960s. Similarly the research coefficient grew by 2.7% per annum suggesting that the marginal returns from research are now much higher than they were in earlier years.

5.3 Sources of Growth

To account for the separate contribution of each input (including research) to production growth in agriculture, the first derivative of (1) with respect to t was taken so that for each region g the rate of growth in total production can be expressed as

$$\partial lnY_t/\partial t = \sum_{i=1}^{6} \beta_{kt}\partial lnX_{it}/\partial t + \sum_{i=1}^{6} lnX_{it}\partial\beta_{kt}/\partial t$$
$$+(\beta_I+\beta_{Ig}D_g)\partial D_I/\partial t + \partial A_t/\partial t \qquad (3)$$

where $A_t = \alpha_0 + (\alpha_1 + \alpha_2 t)t + e_t$ and $\beta_{kt} = \beta_{1i} + \beta_{2i}t$.

The first term measures the effect of increased use of inputs on production growth. It is the sum of growth rates in inputs weighted by the respective production elasticities. The direct impact of agricultural research on production growth is identified through this term[16]. The second term captures the impact of biased technical change through its influence on the coefficients of production; a positive sign on this term indicates that biasing technology in this way enhances output. The third term reflects the region-specific effects of institutional change on production growth and the last term captures the time-varying influences on output growth not already accounted for. This includes such things as neutral technical change (aside from the direct impacts of research) plus region-specific differences in the quality and intensity of factor use, agricultural infrastructure, weather, and the like. Since our primary purpose is to measure the relative contribution of agricultural research on production growth, it is convenient to treat terms two and four as a "residual" effect. Dividing each of the terms in equation (3) by $\partial \ln Y_t/\partial t$ and setting the left hand side equal to 100 we can then interpret each of the right hand side terms as measuring the percentage contribution of each factor to regional and national production growth. The results of this calculation based on the production elasticities from model 4 in table 7 are summarized in table 8.

[insert table 8 here]

[16]In this specification, if the provision of extension services is proportional to that of research, then the impact of extension services is duly captured by the research variable. Any deviations of extension services from this proportionality would be captured by the last term of equation 3.

We have grouped the data in table 8 in a way that readily identifies the share of overall growth in agricultural output coming from the increased use of conventional inputs, the increased stock of useable knowledge arising from local investments in agricultural research, and some additional sources of growth. The latter group captures the growth-promoting effects arising from the radical changes in the institutional environment that took place after 1978, as well as those due, among other things, to improvements in rural infrastructure and extension services, unmeasured changes in the quality of the conventional inputs themselves, as well as the factor biased technical change due to investments in research.

For the whole country, agricultural output grew at an annual average rate of 4.9% over the 1965 to 1989 period. The measured use of conventional inputs accounted for about 39% of this growth with manurial and, especially, chemical fertilizers alone accounting for 21% of the growth. The shift towards more capital- and energy-intensive production systems, that came with increased levels of mechanization throughout Chinese agriculture, accounted for about 12% of the increased output. Although the number of workers in agriculture grew by 1.6% per annum over the 1965-89 period (table 3) their low marginal products meant that only 3.4% of the growth in output could be attributed to labor. Land also made negligible contributions to growth over this period. A decline in sown area had a small, adverse effect on output growth and our results also suggest that the expansion of irrigated area over this period has not contributed to the growth in agricultural output to the degree that might have been expected. But, as was evident from the data in table 5, much of the improvements in irrigation came about through an increase in the infrastructural aspects of irrigation (and in particular, the mechanization of many irrigation facilities) rather than a growth in irrigated areas per se. Part of this infrastructural effect is likely to be captured by the power variable included in this study.

As a group, the additional sources of growth accounted for 42% of the output gains at the national level. By our reckoning, the improvements in technical and allocative efficiency stemming *directly* from the series of institutional reforms that got underway in the late 1970s accounted for about 14% of the nation's growth in agricultural output. While certainly not denying the significant growth-promoting impacts of these market reforms our results indicate that their direct effects (aside from their induced effects with regard to factor and technology use) may not constitute the dominant source of growth as suggested by others who have empirically studied this issue. In addition to the difficulties of coming up with representative measures of specific components of the market reform package,[17] there are other reasons why this may be so. The time period used for this study is longer than most others. So, if the predominant impact of the reform programs initiated so far were realized during the early 1980s then their share of a longer run pattern of growth that extends through to the late 1980s would naturally be lower. More fundamentally though, all of these earlier studies omitted any explicit consideration of the output gains to be had from research-induced technical change. Thus, despite the substantial growth effects arising from the increased use of purchased inputs such as energy, fertilizer and irrigation services, the direct effects of agricultural research accounted for almost 20% of the growth in Chinese agricultural output

[17]Lin (1992) also faults the previous studies by McMillan et al. (1989), Wen (1989) and Lin (1989) with regard to various estimation, sample size, and growth accounting issues, but introduces a number of additional concerns in his own study. The production function estimates used in his growth accounting exercise were obtained by regressing an output measure covering only seven grain and twelve cash crops on capital and chemical fertilizer variables (inter alia) that represented the use of these inputs across the totality of agricultural production. A measure of labor used in crop production was derived using a variant of the highly questionable "labor requirements" method previously used, but now abandoned, by USDA when constructing their labor-in-agriculture series (Short 1987), while important inputs such as manurial fertilizers and irrigation services were omitted altogether. The most telling problem concerns the coefficients on the two land-related variables (i.e., cultivated land and a multiple cropping index) which jointly imply a coefficient on an *area sown* measure of at least 0.67 -- an implausibly high value for a labor-intensive agricultural system such as China.

since 1965.

Significantly, the growth promoting effects of research -- and also many of the other inputs discussed here -- were not uniform throughout the country. Over one-third of the increase in agricultural output in the southeast stemmed from local investment in agricultural research, and in the northeast and southwest research contributed around 30% and 23% respectively to the growth in agricultural output. In the north, a region which experienced the highest rate of growth in agricultural output since 1965 (table 5), research accounted for only 9% of this growth. Much of the gains in this instance came from the increased use of fertilizers and energy as well as the market reforms of the past decade or so. In fact the limited contributions of research to output growth in the north, northwest and central regions may well stem in part from the relatively low levels of investments in agricultural research throughout these regions.

6. Final Comments

The remarkable growth performance of the Chinese agricultural sector over the recent past gives cause for guarded optimism when thinking about the potential of poorly performing agricultural sectors in other less-developed or former-socialist countries. In China's case the increased use of traditional inputs such as land and labor, at least when measured in quality-unadjusted terms, contributed little to contemporary gains in agricultural output, while the increased use of modern inputs like power and fertilizer explained nearly a third of the growth in output. Our analysis confirms the findings of previous studies on the important growth-promoting effects of "getting markets right", at least over the shorter term. However, for the somewhat longer time horizon included in this study, these influences are overshadowed by the contributions of research in this regard.

These growth accounting results give summary indications of the sources of growth in Chinese agriculture that while informative should not be overinterpreted, especially in light of the substantive and complex structural changes that occurred during the period under evaluation. There are also subtle length-of-run considerations to be borne in mind when assessing the growth promoting impacts of institutional and technical change. While the growth effects of the market reforms currently in place were realized quite rapidly, our results provide evidence that investing in a functioning and productive technology generation system is a prudent way of ensuring the process of market liberalization comes closer to realizing its full growth-promoting potential over the longer run.

Appendix: Data Sources and Measurement

All of the agricultural output and input data used for this study include only primary agricultural production (and related sideline) activities and explicitly exclude (off-farm) rural industries and service-related activities.

Output -- Provincial-level agricultural output is measured as gross agricultural production value. It was derived by taking physical output data at the commodity level and weighing by 1980 average prices received by farmers (*China's Statistical Yearbook 1991*, 1991, pp. 73 and 384). Gross agricultural production data prior to 1980 were taken from *National Income Statistics, 1949-1985* (State Statistical Bureau 1987). The more recent data are reported in various issues of *China's Statistical Yearbook* and *China's Rural Statistical Yearbook* (State Statistical Bureau)

Labor -- Labor is measured in stock terms as the number of persons engaged in agricultural production at the end of each year. Provincial data prior to 1980 are calculated using the following formula

$$L_{jt}=P_{jt} * \frac{r_{j,80}}{r_{n,80}} * r_{n,t} \tag{1}$$

where L_{jt} denotes j_{th} region's labor input in year t; P_{jt}, j_{th} region's agricultural population in year t; $r_{j,80}$, j_{th} region's ratio of agricultural labor to agricultural population for 1980; $r_{n,80}$, national ratio of agricultural labor to agricultural population in 1980, $r_{n,t}$, national ratio of agricultural labor to agricultural population in year t. The agricultural population data are taken from *National Agricultural Statistical Materials for 30 Years, 1949-1979* (State Statistical Bureau 1980). The data for later years are reported in various issues of *China's Statistical Yearbook* and *China's Rural Statistical Yearbook* (State Statistical Bureau).

Land -- Land in agriculture is taken to be the weighted sum of sown area and grassland. (A weight of 0.0124 is used to convert a unit of grassland into its sown-area-equivalent where the weight represents the relative production values of grazed to cropped areas [*China's Statistical Yearbook 1985*, 1986]. Land quality varies markedly across China. The relatively poor quality of the average hectare of grassland reflects the exceptionally large, low-grade, grazing areas in the Northern and Northwestern parts of the country that support only transhumance production systems). This measure was chosen for several reasons. First it approximates a flow-type variable in that *sown area* captures the over-time and, especially, cross-sectional variation in multiple cropping patterns. Second it is a more broadly-based estimate of the total land used in agriculture than alternative arable land measures (which are limited strictly to cropped areas) and, in the way it is constructed here, at least makes some attempt to account for differences in the quality of cropped versus grazed areas. Finally, the accuracy of official statistic on arable (i.e., cultivated) land have commonly been called in to question (*China's Statistical Yearbook 1991*, 1992, p. 314). The data for sown area prior to 1980 are taken from *National Agricultural Statistical Materials for 30 Years, 1949-1979* (State Statistical Bureau 1980), and those for later years were taken from various issues of *China's Statistical Yearbook* and *China's Rural Statistical Yearbook* (State Statistical Bureau).

Fertilizer -- Fertilizer is measured as the aggregate of both chemical and manurial fertilizers, both measured in pure nutrient terms. The data for chemical fertilizer prior to 1980 are reported in *National Agricultural Statistical Materials for 30 Years, 1949-1979* (State Statistical Bureau 1980). The remaining data are taken from various issues of *China's Statistical Yearbook* and *China's Rural Statistical Yearbook* (State Statistical Bureau). The data for manurial fertilizer are calculated by the authors. The FAO (1977) estimated that one animal (horse unit) produces about 4 tons of manure per year and a person produces 0.25 tons per year. The elemental nutrient component of manure is about 2.2% while the manure actually used is about 75% of total availability. Therefore, the quantity of manurial fertilizers used per year was estimated as ((0.25 * Rural Population + 4 * Numbers of Livestock)*0.022)*0.75).

Power -- Power input is measured as the aggregate of machinery horsepower and draft animals. The data on machinery horsepower in 1965 and 1970 are based on interpolated tractor number data, while those after 1970 are reported in *National Agricultural Statistical Materials for 30 Years, 1949-1979* (State Statistical Bureau, 1980), and various issues of *China's Agricultural Yearbook* and *China's Statistical Yearbook* (State Statistical Bureau, various years). The number of draft animals prior to 1980 are taken from *National Agricultural Statistical Materials for 30 Years, 1949-1979* (State Statistical Bureau 1980), and those after 1979 are reported in various issues of *China's Statistical Yearbooks* and *China's Rural Statistical Yearbook* (State Statistical Bureau, various years).

Irrigation --Irrigation input is measured as irrigated area. The data on irrigated area prior to 1980 are reported in *National Agricultural Statistical Materials for 30 Years, 1949-1979* (State Statistical Bureau 1980). The remaining data are reported in the various issues of *China's Statistical Yearbook* and *China's Rural Statistical Yearbook* (State Statistical Bureau).

Research -- The research or stock of knowledge variable is based on provincial-level research expenditure estimates deflated to 1980 constant prices. Provincial research expenditure data for the years following 1986 were taken from various issues of *Statistical Materials on Agricultural Science and Technology* (Ministry of Agriculture). The 1986 estimates were derived using 1987 spending per scientist data, in conjunction with provincial level scientist estimates and national-level expenditure totals based on the assumption that changes in national-level expenditures from 1987 to 1986 approximated the changes in spending per scientist at the provincial level. Data for earlier years were obtained by econometrically extrapolating the provincial trends from 1989 to 1986 back to 1950 then recalibrating the extrapolated series for each province by comparing the sum of these provincial estimates with the aggregate expenditure data (net of expenditures by national institutes) found in Fan and Pardey (1992). The nominal research expenditure data were deflated to constant 1980 yuan using the national retail price index taken from *China's Statistical Yearbook* (1991).

References

Alston, Julian M. and Philip G. Pardey, 1991, Technical change, constraints and incentives: the damaging consequences of getting policies wrong. Paper presented at the World Bank conference on Agricultural technology: current policy issues for the international community and the World Bank, Airlie House, 21-23 October, 1991.

Anderson, Kym, 1990, Changing comparative advantages in china: effects on food, feed and fibre markets. (Paris: Organization for Economic Cooperation and Development).

CAAS, 1986, Research report on agricultural research funding. (Beijing: Chinese Academy of Agricultural Sciences). Mimeo (in Chinese).

Craig, Barbara J. and Philip G. Pardey, 1990, Patterns of agricultural development in the United States. Staff paper series P90-72. (St Paul, University of Minnesota).

Craig, Barbara J., Philip G. Pardey, and Johannes Roseboom, 1991, Patterns of agricultural growth and economic development, in: P.G. Pardey, J. Roseboom, and J.R. Anderson (eds.) Agricultural research policy: international quantitative perspectives. (Cambridge: Cambridge University Press).

de Janvry, Alain and Jean-Jaques Deither, 1985, The political economy of rate and bias of technological innovation in agriculture. Working paper no. 341. (Department of Agricultural and Resource Economics, University of California, Berkley).

Fan, Shenggen, 1990, Regional productivity growth in China's agriculture. (Boulder: Westview Press).

Fan, Shenggen, 1991, Effects of technological change and institutional reform on production growth in Chinese agriculture. American Journal of Agricultural Economics 73, no. 2, 266-275.

Fan, Shenggen and Philip G. Pardey, 1992, Agricultural research in China: its institutional development and impact. (The Hague: International Service for National Agricultural Research).

Fan, Shenggen and Vernon Ruttan, 1992, Technical change in centrally planned economies. Agricultural Economics 6, no. 4, 301-314.

FAO, 1977, China: Recycling of organic wastes in agriculture. Soils bulletin no. 40. (Rome: FAO).

Gunasekera, H. Don B.H., et al., 1991, Agricultural policy reform in China. Discussion paper 91.4, (Canberra: Australian Bureau of Agricultural and Resource Economics).

Hayami, Yujiro and Vernon W. Ruttan, 1970, Factor prices and technical change in agricultural development: the United States and Japan, 1880-1960. Journal of Political Economy 78, 1115-1141.

Hayami, Yujiro and Vernon W. Ruttan, 1985, Agricultural development: an international perspective. (Baltimore: The Johns Hopkins University Press).

Johnson, D. Gale, 1988, Economic reforms in the People's Republic of China. Economic Development and Cultural Change 36, no. 6, S225-S245.

Kislev, Yoav and Willis L. Peterson, 1982, Prices, technology, and farm size. Journal of Political Economy 90, no. 3, 578-595.

Lin, Justin Yifu, 1989, The household responsibility system in China's rural reform. in: Allen Mander and Alberto Valdes, eds. Agriculture and governments in an interdependent world: Proceedings of the XX international conference of agricultural economists (Aldershot, U.K.: Dartmouth).

Lin, Justin Yifu, 1991, Public research resource allocation in Chinese agriculture: a test of induced technological innovation hypotheses. Economic Development and Cultural Change 40, no. 1, 55-73.

Lin, Justin Yifu, 1992, Rural reforms and agricultural growth in China. American Economic Review 82, no. 1, 34-51.

McMillan, John, John Whalley, and Lijing Zhu, 1989, The impact of China's economic reforms on agricultural productivity growth. Journal of Political Economy no. 97, 781-807.

Ministry of Agriculture. 1987, 1988, 1989, Statistical materials on agricultural science and technology. (Beijing: Ministry of Agriculture) (in Chinese).

Pardey, Philip G. and Barbara Craig, 1989, Causal relationships between public sector agricultural research expenditures and output. American Journal of Agricultural Economics 71, no. 1, 9-19.

Pardey, Philip G. and Stanley Wood, 1991, Targeting research by agricultural environments, paper presented at the World Bank conference on agricultural technology: current policy issues for the international community

and the World Bank. Airlie House, 21-33 October, 1991.
Perkins, Dwight, 1988, Reforming China's economic system. Journal of Economic Literature XXVI, 601-645.
Perkins, Dwight and Shahid Yusuf, 1984, Rural development in China. (Baltimore: Johns Hopkins University Press).
Putterman, Louis, 1992, Dualism and reform in China. Economic Development and Cultural Change 40, no. 3, 467-493.
Short, Sara D., 1987, Measuring agricultural labor hours and the rate of return to equity in farm assets in USDA. Economic indicators of the farm sector: production and efficiency statistics, ECIFS 5-5, (Washington, D.C.: United States Department of Agriculture).
Sicular, Terry, 1988, Plan and market in China's agricultural commerce. Journal of Political Economy 92, no. 2, 283-307.
Star, Spencer, 1974, Accounting for the growth of output. American Economic Review 64, no. 1, 123-35.
State Statistical Bureau, 1980, National agricultural statistics for 30 Years, 1949-1979. (Beijing: State Statistical Bureau) (in Chinese).
State Statistical Bureau, Agricultural Statistics Division, 1985, 1986, 1987, 1988, 1989 and 1990, China's Rural Statistical Yearbook. (Beijing: China Statistical Press). (in Chinese)
State Statistical Bureau, Editorial Office, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990 and 1991, China's Statistical Yearbook (various years). (Beijing: China Statistical Press) (in Chinese).
State Statistical Bureau, National Economy Division, 1987, National income statistics, 1949-1985. (Beijing: China Statistical Press).
State Science and Technology Commission of PRC, 1989, Guide to China's science and technology policy (1989). (Beijing: State Science and Technology Commission of PRC) (in Chinese).
Stone, Bruce, 1990, Evolution and diffusion of agricultural technology in China. chapter 3 in: Sharing innovation: global perspectives on food, agriculture, and rural development ed. N.G. Kottle. (Washington, D.C.: Smithsonian Institute Press) 39-93.
Summers, Robert and Alan Heston, 1991, The Penn world table (mark 5): an expanded set of international comparisons, 1950-1988. Quarterly Journal of Economics CVI, 327-68.
Wen, Guanzhong J., 1989, The current land tenure system and its impact on long term performance of the farming sector: the case of modern China, unpublished Ph.D. dissertation. (Chicago: University of Chicago).
Wong, Lung-Fai and Vernon W. Ruttan, 1988, Sources of differences in agricultural productivity growth among socialist countries, in: Dogramaci, Ali and Rolf Fare. Application of modern production theory: efficiency and productivity. (Boston: Kluwer Academic Publishers).
World Bank, 1987, China: the livestock sector. A World Bank country study. (Washington, D.C.: World Bank).
World Bank. 1991, China: options for reform in the grain sectors. A World Bank country study. (Washington, D.C.: World Bank).

Figure 1: Comparison of land and labor productivity, 1965-90

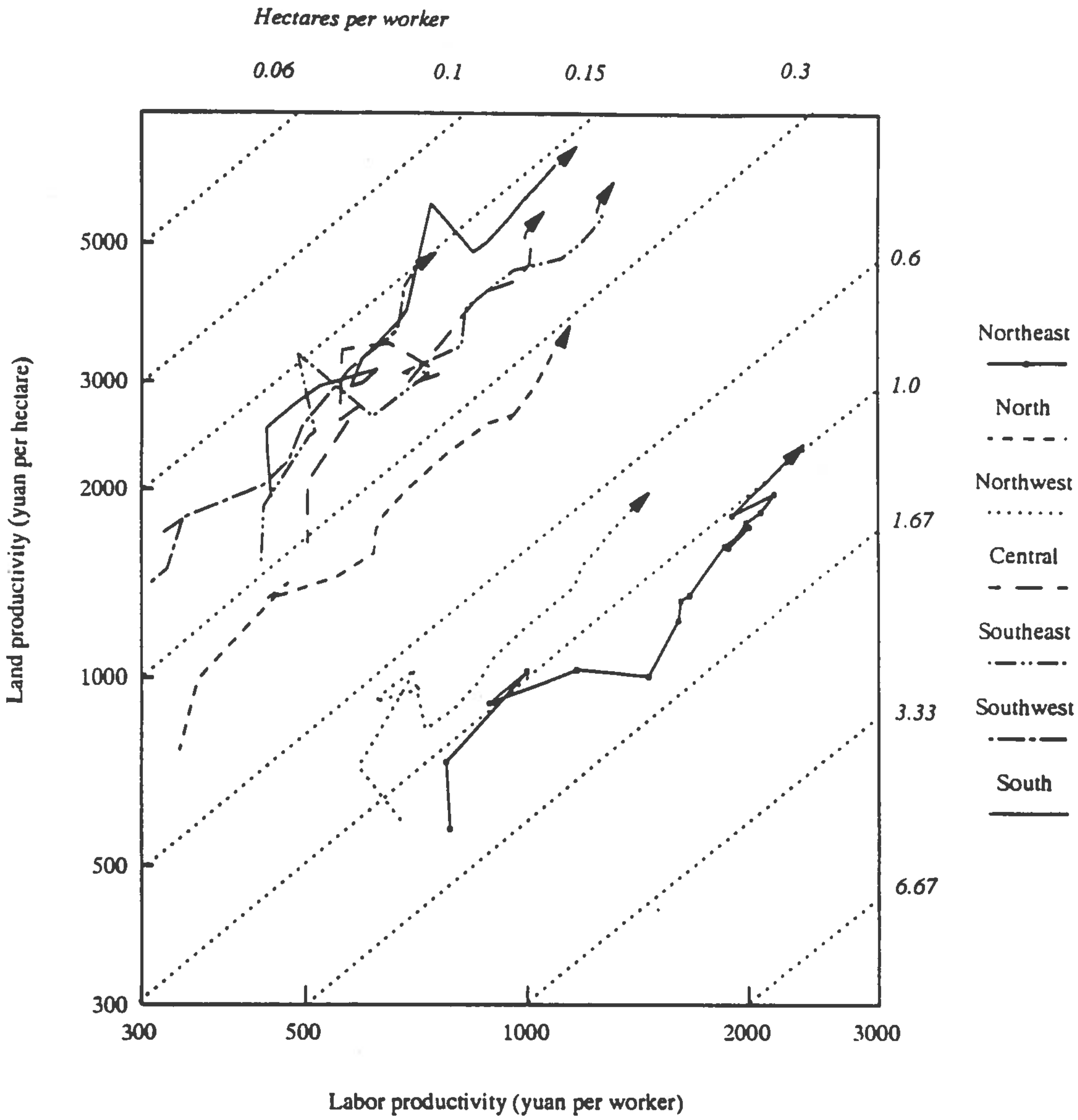

Table 1: *Regional Agricultural Production Growth Indices, 1965 = 100*[a]

Year	Region[b]							
	Northeast	North	Northwest	Central	Southeast	Southwest	South	National
1965	100	100	100	100	100	100	100	100
1970	137	124	105	120	119	102	119	118
1975	192	174	139	155	152	120	132	153
1976	171	163	130	146	154	114	144	147
1977	173	162	123	146	145	123	155	148
1978	198	175	130	149	162	136	165	160
1979	190	190	131	173	191	149	158	173
1980	210	208	136	164	191	166	162	180
1981	216	218	145	178	210	175	171	192
1982	226	239	160	200	237	195	196	213
1983	273	273	173	204	241	209	203	230
1984	294	309	193	227	278	230	219	257
1985	270	318	215	241	292	237	242	267
1986	294	315	222	250	307	247	254	276
1987	307	342	233	261	318	258	276	292
1988	327	356	254	260	330	266	289	304
1989	301	375	262	273	334	276	311	313
1990	374	398	296	287	345	291	333	337
Growth rate[c]								
	%	%	%	%	%	%	%	%
1965-80	5.1	5.1	2.1	3.4	4.4	3.6	3.3	4.0
1980-85	5.1	8.9	9.5	8.0	8.9	6.8	8.5	8.1
1985-90	6.7	4.6	6.6	3.6	3.4	4.1	6.5	4.7
1965-90	*5.4*	*5.7*	*4.4*	*4.3*	*5.1*	*4.4*	*4.9*	*5.0*

Source: *China's Statistical Yearbook* (various issues), *China's Agricultural Yearbook* (various issues), *National Income Statistics, 1949-1985* (1987).

[a] Agricultural production is taken to be the gross domestic production value (AgGPV) measured in constant 1980 local prices. Rural industry (i.e., off-farm) output is excluded from the estimates reported here.

[b] China currently has 30 provincial-level units (of which 22 are classed as provinces, five as autonomous regions, and three as municipalities), 336 prefectural-level units (including both prefectures and prefectural-level cities or municipalities) and 2,182 county-level units. For our purposes, the country is divided into seven regions according to agricultural characteristics: *northeast* – Heilongjiang, Liaoning, and Jilin provinces; *north* – municipalities of Beijing and Tianjin, and Hebei, Henan, Shandong, Shanxi, and Shaanxi provinces; *northwest* – autonomous regions of Nei Monggol, Ningxia, Xinjiang, and Tibet, and Qinghai and Gansu provinces; *central* – Jiangxi, Hunan, and Hubei provinces; *southeast* – Shanghai municipality, and Jiangsu, Zhejiang, and Anhui provinces; *southwest* – Sichuan, Guizhou, and Yunnan provinces; *south* – Guangxi autonomous region, and Fujian, Hainan, and Guangdong provinces.

[c] Compound annual growth rates.

Table 2: *Production of Major Agricultural Commodities, 1950-90*

	1950	1960	1970	1980	1985	1990	Annual growth rates 1950-1990
	(*million metric tonnes*)						%
Rice[a]	55.1	59.7	110.0	139.9	168.6	189.3	3.1
Wheat	14.5	22.2	29.2	55.2	85.8	98.2	4.9
Corn	16.9[f]	15.5[g]	33.0	62.6	63.8	96.8	4.5
All grains[b]	119.7	123.2	213.3	291.9	353.1	418.8	3.2
Roots & tubers[c]	15.5	20.3	26.7	28.7	26.0	27.4	1.4
Cotton	0.7	1.1	2.3	2.7	4.1	4.5	4.8
Oil crops[d]	3.0	1.9	3.8	7.7	15.8	16.1	4.3
Fruits[e]	1.3	4.0	3.7	6.8	11.6	18.7	6.9
Pork, beef & mutton	2.2[h]	-	6.0	12.1	17.6	25.1	6.3
Aquatic products	0.5[i]	2.3[j]	3.1	4.5	7.1	12.3	8.6

Source: *China's Statistical Yearbook* (1991).

[a] In Chinese statistics, grain production data are reported in paddy-rice terms. To convert these data to the more standard milled-rice equivalent would require multiplying by the milling rate conversion factor of 0.7.

[b] Includes soybeans and coarse grains such as millet and sorghum as well as other unspecified grains.

[c] Roots and tubers are reported in "grain-equivalent" terms where one unit of fresh roots and tubers equals 0.2 units of grain.

[d] Includes peanuts, rapeseed, sunflower seed, sesame seed, linseed and other oil crops.

[e] Includes apples, citrus, pears, grapes, bananas and other fresh fruits.

[f] 1952 data. [g] 1961 data. [h] 1949 data. [i] 1949 data. [j] 1962 data.

Table 3: *Rate of Growth of Regional Land and Labor Productivity, 1965-90*

Year	Region							
	Northeast	North	Northwest	Central	Southeast	Southwest	South	National
	%	%	%	%	%	%	%	%
Labor productivity[a]								
1965-80	4.9	4.2	0.8	2.1	3.0	1.8	1.7	2.7
1980-85	3.2	8.9	8.2	7.2	10.5	5.1	8.0	7.7
1985-90	4.0	2.9	4.4	1.2	2.4	1.4	5.3	3.3
1965-90	*4.4*	*4.8*	*3.0*	*2.9*	*4.3*	*2.4*	*3.6*	*3.7*
Land productivity[b]								
1965-80	5.2	5.6	2.2	4.0	4.8	4.0	2.8	4.4
1980-85	5.5	9.0	10.4	8.7	8.8	6.9	4.0	8.5
1985-90	7.0	5.4	6.9	4.0	4.2	4.8	6.5	5.3
1965-90	*5.6*	*6.2*	*4.7*	*4.9*	*5.5*	*4.7*	*5.0*	*5.4*

Source: Agricultural land and output data taken from *China's Statistical Yearbook* (various years) and *National Agricultural Statistics for 30 Years, 1949 to 1979* (1980). Agricultural labor after 1979 is taken from *China's Rural Statistical Yearbook* (various years). Labor inputs before 1979 are estimated from a agricultural population, where agricultural population is taken from *National Agricultural Statistics for 30 Years, 1949 to 1979,* (1980).

[a] Labor productivity is measured as total agricultural production divided by total labor input measured in person-year equivalent terms. Rural (nonfarm) industry is excluded from agricultural production.

[b] Agricultural land is measured in terms of sown area plus grassland sown-area-equivalent. One hectare of grassland was set equal to 0.0124 hectares of sown area in accordance with information obtained from *China's Statistical Yearbook 1985* (1986). Rural (nonfarm) industry is exclucced from agricultural production.

Table 4: *Land and Labor Use in Agriculture, 1965-90*

		Region							
	Year	Northeast	North	Northwest	Central	Southeast	Southwest	South	National
Labor[a]	1965	12.52	72.91	12.42	34.47	42.20	43.19	30.12	247.83
(million workers)	1970	17.40	85.53	14.87	41.48	49.81	52.92	36.33	298.34
	1980	12.88	82.22	14.95	41.67	51.77	56.58	38.01	298.08
	1990	16.17	89.06	17.60	48.64	50.49	70.23	41.24	333.36
Land[b]	1965	16.08	43.01	16.45	20.43	20.84	17.16	12.90	146.87
(million hectares)	1970	16.08	43.05	16.61	20.43	20.84	17.16	12.90	147.08
	1980	16.96	41.04	16.12	20.94	21.88	18.98	14.06	149.98
	1990	16.22	41.50	13.00	21.07	21.59	20.55	14.38	148.41
Land/Labor	1965	1.28	.59	1.32	.59	.49	.40	.43	.59
(hectares per worker)	1970	.92	.50	1.12	.49	.42	.32	.36	.49
	1980	1.32	.50	1.08	.50	.42	.33	.37	.50
	1990	1.01	.47	.74	.43	.43	.29	.35	.45

Source: *China's Statistical Yearbook* (various issues) and *National Agricultural Statistics for 30 Years, 1949-1979* (1980).

[a] Workers engaged in agricultural production.
[b] Area sown to crops plus the sown-area equivalent of grasslands.

Table 5: *Secondary Input Use, 1965-90*

	Year	Region							
		Northeast	North	Northwest	Central	Southeast	Southwest	South	National
Chemical Fertilizer[a]	1965	6.5	9.4	3.6	15.8	21.0	11.5	44.1	14.3
(kg per hectare)	1980	74.7	87.4	23.9	82.4	116.8	83.0	113.4	84.6
	1990	149.6	180.2	100.0	170.0	225.0	139.5	234.5	174.5
Manurial Fertilizer[a]	1965	88.4	92.7	218.3	112.4	109.7	210.2	157.5	130.9
(kg per hectare)	1980	96.5	113.9	252.7	121.8	107.0	243.3	162.1	147.9
	1990	103.3	140.8	320.8	160.0	128.1	288.1	214.8	180.4
Total Irrigated Area[b]	1965	5.1	20.9	33.7	65.8	49.6	29.4	58.4	31.3
(% arable land)	1980	12.9	49.2	37.1	66.8	68.3	38.7	58.6	44.8
	1990	18.5	52.3	42.1	74.8	76.0	40.1	64.2	49.5
Power Irrigated Area	1965	-	-	-	-	-	-	-	7.7
(% arable land)	1980	8.8	39.9	6.9	29.8	55.9	6.9	13.8	25.3
	1990	13.0	43.5	11.9	30.3	60.2	8.0	12.5	28.4
Non-Irrigation Power[c]	1965	0.22	0.03	0.13	0.02	0.02	0.006	0.02	0.025
(hp per ag worker)	1980	1.40	0.44	0.82	0.35	0.41	0.17	0.36	0.42
	1990	1.99	1.08	1.47	0.60	1.03	0.35	0.81	0.88
Irrigation power	1965	0.03	0.03	0.02	0.05	0.05	0.01	0.03	0.03
(hp per ag worker)	1980	0.34	0.43	0.28	0.20	0.25	0.10	0.10	0.25
	1990	0.38	0.59	0.24	0.23	0.26	0.07	0.11	0.29

Table 5: *Secondary Input Use, 1965-90 (contd.)*

	Northeast	North	Northwest	Central	Southeast	Southwest	South	National
	(compound annual growth, 1965-1990)							
	%	%	%	%	%	%	%	%
Chemical Fertilizer	13.4	12.5	14.2	10.0	10.0	10.5	6.9	11.1
Manurial Fertilizer	0.7	1.8	1.6	1.5	0.6	0.3	1.3	1.3
Total Irrigated Area	5.3	3.7	0.9	0.5	1.7	1.2	0.4	1.9
Power Irrigated Area	-	-	-	-	-	-	-	5.4
Non-Irrigation Power[d]	9.3	15.9	10.1	14.5	17.9	17.5	16.0	16.3
Irrigation Power	10.7	12.7	10.5	6.3	6.8	8.1	5.3	9.5

Source: *China's Statistical Yearbook* (various issues), *China's Agricultural Yearbook* (various issues), *China's Rural Statistical Yearbook* (various issues), *National Agricultural Statistics for 30 Years, 1949-1979* (1980).

[a] Fertilizer is measured in pure nutrient terms while land area represents arable land. Data on chemical fertilizer use was compiled in standard gross weight units then converted to its elemental nutrient equivalent using the following percentages: 20% for ammonium sulphate, 18.7% for super phosphate, and 40% for potassium sulphate. Manurial fertilizer includes animal, human, and crop wastes, green manures, and water plants. These data were derived using the procedures detailed in Fan (1990).

[b] Irrigated areas include level land with a water source and a complete set of irrigation facilities to lift and move water adequate for irrigation purposes in a normal year.

[c] Non-irrigation power includes power used for agricultural practices such as cultivating, spraying, harvesting, drafting, and animal husbandry, as well as the power used by forestry and fishery machinery. These data exclude a draft-animal component.

[d] We regressed non-irrigation horsepower at the national level against corresponding tractor numbers and a time trend for the 1962-80 period. Given the strong correspondence between tractor numbers and non-irrigation horsepower, we used this information to estimate the rate of growth in non-irrigation power. This growth rate was in turn used to calculate the non-irrigation horsepower estimate for 1965 given in the upper half of this table.

Table 6: *Quantitative Development of Agricultural Research, 1953-88*

	1953-57	1958-60	1961-65	1966-76	1977-85	1986-87	1988
			(full-time equivalents)				
Research personnel							
Scientists and engineers[a]							
Research institutes	-	-	6,966	11,118	27,207	41,808	46,649
Universities	193	363	504	503	3,051	6,728	8,597
Total	-	-	*7,669*	*11,621*	*30,257*	*48,536*	*55,246*
Technical support staff[b]							
Research institutes	-	-	4,644	7,411	17,921	30,043	28,895
Universities			66	82	400	943	927
Total	-	-	*4,710*	*7,494*	*18,320*	*30,986*	*29,822*
			(millions 1980 PPP dollars per year)				
Research expenditures[c]							
Research institutes	78.1	560.0	476.2	724.8	1,485.2	1,843.1	1,974.7
Universities	4.7	7.3	10.5	11.4	58.7	112.2	124.8
Total	*82.8*	*567.3*	*436.2*	*736.2*	*1,543.9*	*1,955.3*	*2,099.5*
	%	%	%	%	%	%	%
Agricultural research intensity[d]	.07	.58	.41	.36	.41	.39	.40

Source: Authors' calculations based on data reported in Fan and Pardey (1992).

Note: Here, as elsewhere in this paper, agriculture is interpreted in its broader sense to include crop, livestock, fisheries and forestry.

[a] Includes science and technology personnel who hold a university or higher level educational degree or are conferred with senior or intermediate academic titles.

[b] Includes personnel directly engaged in supporting the design and implementation of research.

[c] Current yuan data were first deflated to constant 1980 yuan using the national retail price index taken from *China's Statistical Yearbook 1991* (1991) then converted to purchasing power parity (PPP) dollars using the 1980 PPP over GDP conversion factor reported in Summers and Heston (1991).

[d] Agricultural research intensity ratios, as defined here, measure agricultural research expenditures as a percentage of AgGDP.

Table 7: *Production Function Estimates for Chinese Agriculture, 1965-89*

	Cobb-Douglas		Quasi-Translog	
Explanatory variable	(1)	(2)	(3)	(4)
Constant	-2.574 (22.92)[a]	-3.398 (23.56)	-2.822 (9.44)	-3.231 (11.01)
Labor	0.129 (3.69)	0.147 (4.48)	0.502 (7.233)	0.375 (7.06)
Land	0.235 (9.63)	0.230 (10.08)	0.206 (3.367)	0.295 (6.67)
Fertilizer	0.260 (9.86)	0.265 (10.77)	0.016 (0.418)	0.201 (4.54)
Power	0.097 (4.14)	0.064 (2.86)	0.087 (2.778)	0.039 (0.961)
Research		0.217 (8.33)		0.079 (1.42)
Irrigation	0.250 (9.34)	0.178 (6.71)	0.0629 (1.20)	0.069 (1.42)
Time	0.019 (4.47)	0.013 (4.14)	0.0558 (3.10)	0.024 (1.20)
Labor*t[b]			-0.0186 (4.71)	-0.013 (4.47)
Land*t			-0.0088 (2.53)	-0.011 (4.06)
Fertilizer*t			0.00755 (2.94)	0.005 (1.82)
Power*t			0.0155 (7.0)	0.014 (4.93)
Research*t				0.003 (0.90)
Irrigation*t			0.00354 (1.167)	0.005 (1.80)
Time squared			-0.0251 (0.459)	-0.00005 (0.113)
Institutional dummy[c]	0.130 (2.26)	0.087 (1.61)	-0.0251 (-4.6)	0.053 (0.97)
Degrees of freedom	473	472	467	465
Adjusted R^2	0.959	0.963	0.976	0.977

Note: For exposition purposes, the coefficients on the six regional dummies (normalized on the northeast) and six regional dummy-by-time interaction variables have been excluded.

[a] Numbers in parentheses are t-values.
[b] "Labor * t", for example, indicates labor-by-time period interaction variable.
[c] This estimate represents β_i in equation (1). The regional specific effects of these institutional reforms, as given by β_{Ig}, are not reported here.

Table 8: *Accounting for Growth in Agricultural Output, 1965-89*

	Northeast	North	Northwest	Central	Southeast	Southwest	South	National
	%	%	%	%	%	%	%	%
Conventional inputs	*44.1*	*43.2*	*29.1*	*37.9*	*34.4*	*45.9*	*38.2*	*38.9*
Labor	2.9	1.8	4.8	4.7	1.9	6.6	3.4	3.4
Land	- 0.5	- 1.0	- 0.9	- 1.5	- 0.8	- 0.8	- 0.2	- 0.9
Fertilizer	23.7	22.8	10.6	26.4	23.4	22.3	21.7	21.3
Power	7.0	12.6	13.3	8.8	7.5	15.3	13.3	11.8
Irrigation	11.0	7.0	1.3	- 0.5	2.4	2.5	0.03	3.3
Research	*30.2*	*8.6*	*14.4*	*19.8*	*35.2*	*23.3*	*19.6*	*19.8*
Additional sources	*25.4*	*48.1*	*56.6*	*42.3*	*30.4*	*30.9*	*41.9*	*41.9*
Institutional change	14.2	18.6	16.1	- 7.4	10.2	12.6	- 1.7	13.8
Residual[a]	11.2	29.5	40.5	49.7	20.2	18.3	43.6	27.6
Production growth[b]	100	100	100	100	100	100	100	100
	(4.7)	(5.7)	(4.1)	(4.3)	(5.2)	(4.3)	(4.8)	(4.9)

Note: Production elasticities for input i in year t from the quasi-translog specification are defined as $E_{it} = \partial lnY_t / \partial lnX_{it} = a_i + a_{it}$. The elasticities used in accounting for output growth are averages, i.e., $E_i = 1/2(E_{i1} + E_{iT})$, where E_{i1} and E_{iT} denote production elasticities of input i in the beginning and ending years of the sample respectively taken from model 4 in table 7.

[a] An accounting residual (equal to the third term in equation 3) derived by netting out the effects of conventional inputs, research, and institutional change from measured growth in output.

[b] Bracket figures represent annual rate of change of agricultural output.