EPTD DISCUSSION PAPER NO. 13

ROLE OF INPUTS, INSTITUTIONS, AND TECHNICAL INNOVATIONS IN STIMULATING GROWTH IN CHINESE AGRICULTURE

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September 1995

ABSTRACT

Recent attempts to quantify the sources of growth in Chinese agriculture have attributed an exceptionally large share of this growth to the contemporary institutional and 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 *direct* growth promoting consequence of institutional change and market reforms have been overstated by these earlier studies, even during the early stages of reforms that included the rapid introduction of the household production responsibility system. Research-induced technical change accounts for nearly 20% of the growth in aggregate agricultural output since 1965 although the share of growth attributable to technological innovation and changes in inputs and institutions varies considerably over time. Disaggregating the results within China also reveals substantial interregional variability in the sources of local growth, as would be expected in such a large and diverse country.

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ROLE OF INPUTS, INSTITUTIONS, AND TECHNICAL INNOVATIONS IN STIMULATING GROWTH IN CHINESE AGRICULTURE

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1. INTRODUCTION

The series of institutional and market reforms beginning at the end of the 1970s have had significant effects on agricultural output and productivity growth in Chinese agriculture. Much has been written on the relative contribution of these reforms to stimulating growth in agriculture [see McMillan, Whalley and Zhu (1989), Fan (1990, 1991), Lin (1992), and Wen (1993)]. But despite the significant (research-induced) technological changes that also occurred throughout this period, these previous studies simply subsumed any research and development (R&D) effects into a "residual" term along with a whole host of other productivity enhancing factors. In this paper we identify the direct effects of R&D on agricultural production growth and contrast that with the consequences of a changing pattern of conventional input use and an on-going series of institutional and market reforms. Our analysis suggests that a significant share of the rapid growth in agricultural output is attributable to investments in agricultural R&D. As a consequence, the growth-promoting effects *directly* attributable to institutional and market reforms, while certainly significant, appear substantially smaller than previously claimed.

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The views expressed here are those of the authors. The support of the Rockefeller Foundation in carrying out this work is gratefully acknowledged. This study was done 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-Friedhem, and two anonymous reviewers on earlier versions. Senior authorship is unassigned.

The paper is organized as follows. In the following section we review the evidence regarding the growth in agricultural output as well as changes in land and labor productivity. The next section sketches out the several phases of institutional change and market reforms that have most directly affected Chinese agriculture. Contemporary developments concerning China's agricultural research system are then briefly reviewed. The following section reports the conceptual framework and empirical analysis of the sources of growth in Chinese agriculture. We conclude the paper with a discussion of some policy implications.

2. AGRICULTURAL OUTPUT AND PRODUCTIVITY TRENDS

OUTPUT

The value of aggregate agricultural output in China grew at a compound rate of 4.7% a year from 1965 to 1993 (Table 1).[1] Until 1978 the annual rate was 3.3%. It jumped to 7.5% during the period 1979 to 1984 and thereafter declined to 5.2% per annum. Regional deviations from these national average patterns of growth were quite marked. In three regions, the north, northeast, and south, agricultural output increased at a faster rate than the national average.[2] By contrast the central region (one of the major agricultural areas in China) as well as the northwest and southwest regions had long-run rates of growth some 8% to 15% below the national average.

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[1] See the appendix for a description of the output and input variables constructed for this study and the sources used for these data.

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

China's grain production grew on average by 3.0% per annum over the past 43 years -- over one percent per annum faster than the growth in population over the corresponding period. Cash crop production (including cotton, oil crops, and fruits) achieved notable success, generally exceeding the increase in food grain production. 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 1993. 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 27% of the total value of agricultural output, more than double their share back in 1949. At 4.5% and 8.0%, respectively (in 1993), 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 that have followed

Table 1—Regional agricultural production growth indices, 1965 = 100[a]

	Region[b]							
Year	**Northeast**	**North**	**Northwest**	**Central**	**Southeast**	**Southwest**	**South**	**National**
1965	100	100	100	100	100	100	100	100
1970	135	123	107	115	119	107	113	118
1975	160	163	122	135	137	121	134	139
1978	167	163	123	148	152	140	152	152
1979	168	173	129	163	167	147	155	162
1980	180	176	129	153	161	156	167	164
1981	185	185	139	166	177	160	177	173
1982	193	203	153	186	200	179	204	192
1983	233	231	163	190	204	192	210	208
1984	251	261	184	212	235	210	226	232
1985	231	270	203	224	247	217	251	241
1986	251	269	208	234	260	227	264	250
1987	261	291	220	244	269	236	285	264
1988	279	304	241	243	279	244	299	274
1989	257	320	246	256	282	253	322	283
1990	319	340	283	268	292	266	345	304
1991	328	358	298	276	281	283	368	315
1992	351	370	313	293	317	292	401	335
1993	384	413	327	311	346	299	428	361
	Growth rate[c]							
1965-78	4.0	3.8	1.7	3.1	3.3	2.6	3.3	3.3
1979-84	8.4	8.6	7.4	5.5	7.0	7.4	7.8	7.5
1985-93	6.6	5.4	6.1	4.1	4.3	4.1	6.9	5.2
1965-93	4.9	5.2	4.3	4.1	4.5	4.0	5.3	4.7

Source: See appendix.

[a] Agricultural production is taken to be the gross deomestic production value (AgGPV) measured in constant 1980 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 prefectured-level units (including both prefectures and prefectural-level cities or municipalities) and 2,182 country-level units. For our purposes, the country is divided into seven regions according to agricultural characteristics: northeast Heilongiang, Liaoning, and Jilin provinces; north municipalities of Beijing and Tianjin, and Hebei, Henan, Shandong, Shanxi, and Shaanxi provinces; northwest autonomous regions of Nei Monggol, Ninexia, Xinjian, 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.

from the quite rapid growth in per capita income over the past several decades as well as China's increased level of participation in international agricultural commodity 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).

PRODUCTIVITY

Regional patterns of land and labor productivity growth are presented in Table 2. 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; Fan and Ruttan, 1992), a situation that is consistent with the country's exceptionally low land-to-labor ratio.[3] However, from 1965 to 1993 China's labor productivity grew substantially despite a tendency for land area per unit of labor to decrease. The growth rate was 3.3% a year from 1965 to 1993 -- 1.6% prior to the reforms that began to have impact in 1979, 5.7% from 1979 to 1984, declining to 3.9% per year from 1985 to 1993. For the country as a whole the rate of growth in land productivity averaged 4.7% per annum from 1965 to 1993 -- 3.1% prior to 1979, 8.1% from 1979 to 1984, and 5.1% over the following eight years. It is noteworthy that land productivity grew more rapidly than labor productivity, suggesting a general tendency to adopt land-saving and labor-using technologies throughout the country.

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[3] 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 $Q/L = (A/L)\,(Q/A)$.

Table 2—Rate of growth of regional land and labor productivity, 1965-93

Year	Northeast	North	Northwest	Central	Southeast	Southwest	South	National
	percentage							
Labor productivity[a]								
1965-78	2.1	2.9	0.3	0.7	1.3	0.5	1.4	1.6
1979-84	6.6	6.6	5.3	4.1	6.2	4.2	6.8	5.7
1985-93	4.8	3.99	4.8	3.0	4.1	2.2	6.0	3.9
1965-93	3.5	4.0	2.9	2.5	5.7	1.8	3.9	5.3
Land productivity[b]								
1965-78	3.3	4.2	2.2	2.4	3.1	2.0	2.1	3.1
1979-84	8.5	8.9	8.1	6.8	7.0	7.7	10.3	8.1
1985-93	6.8	5.3	7.8	4.0	5.0	2.5	5.7	5.1
1965-93	4.9	5.3	5.0	4.1	4.5	5.2	5.0	4.7

Source: See appendix.

[C] Labor productivity is measured as total agricultural production divided by total labor input measured in person-year equivalent terms.

[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).

These national trends mask considerable differences across regions both in the levels of these partial productivity measures and their paths over time. The highest measured output per hectare occurred 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. 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.

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 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.

3. INSTITUTIONAL CHANGES AND MARKET REFORMS IN CHINESE AGRICULTURE

Since the new Republic was formed, China has experienced a series of sometimes radical institutional reforms. The official raison d'źtre for these changes was to promote rapid economic development, a more equal distribution of wealth, attain national food security, and move forward socialist or communist "ideals" (MOA, 1989).

The mode of production has been the target of repeated government-sponsored change. Large-scale land reform was one of the first priorities of the newly formed Communist government. Until the 1949 Revolution there was a feudal system of land ownership with something in the order of 70% to 80% of the agricultural land being held by landlords who constituted only 10% of the rural population. Most farmers were landless peasants who rented land, commonly at exorbitant rates, from these landowners. Soon after 1949 land was confiscated by the government without compensation and redistributed to peasant farmers.

Beginning in 1952 some small-scale peasant farmers voluntarily pooled their land and other resources into a cooperative mode of operation. This was soon followed by government efforts to develop large, collective operations and by 1956 most of China's agricultural production was done on a collectivized basis. Under this system land ownership was vested in a collective that usually consisted of around 200 families. Within the collective an individual's income was tied to the number of work points accumulated throughout the year in line with the amount of time, effort, skill, and political attitude that was bought to one's collective work.[4] Home gardens on "private plots" -- constituting about 5% of all arable land at this time -- were also farmed by households, the produce from which could be sold on free markets.

This collective system of production remained in place until the late 1970s although the size of the basic collective unit did vary substantially over time. At the height of the Commune movement in 1958/59 the *average* communal unit had grown to 5,000 households covering 10,000 acres with food being allocated as much on the basis of need as on accumulated work points. Work on private plots was also prohibited at this time. But by 1962 the "production unit", a sub-unit of the Commune consisting of only 20-30 neighboring families, had become the basic unit of operation and accounting. Decisions regarding farm operations, including the adoption of new technologies, were primarily made by unit leaders. Market exchanges of land between different production units in the collective system were outlawed.

The agricultural sector reforms initiated in late 1978 have occurred in two, reasonably distinct phases. The first phase of reforms focused primarily on decentralizing the system of agricultural production while emphasis during the second stage was given to liberalizing factor and output markets.

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[4] Lin (1988) gives an analysis of the economics of communal production systems as practiced throughout China at this time.

THE FIRST PHASE OF REFORMS

At the outset the rural reforms initiated in late 1978 were seen primarily as a means of freeing up rural trade fairs or developing "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, a relaxation of regional self-sufficiency requirements, and moves to liberalize and decentralize many factor and product markets that included significant increases in the prices paid for state-purchased farm produce. These new policies sought to move away from a lopsided stress on grain production, by encouraging diversification of the rural economy as well as foster 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.

These institutional changes have demonstrably accelerated the rate of development of the Chinese agricultural sector. By 1984, more than 99% of production units had adopted the household production responsibility system. McMillan, Whalley, and Zhu's (1989) attributed about 78% of the farm productivity gains between 1978 and 1984 to changes in the incentive system away from collective management; the remaining 22% of the gains ostensibly flowed from the higher prices received by producers.

THE SECOND PHASE OF REFORMS

The second phase of reforms was designed primarily to liberalize the country's (agricultural) pricing and marketing systems. Prior to these reforms, virtually all commodities were subject to various government procurement and rationing programs.

In 1953 a number of production controls were introduced along with a series of demand management measures. These included a quantity rationing and administered pricing system coupled with a compulsory grain procurement program. In 1960 the procurement program was divided into a "basic quota" and an "above quota" component, wherein farm units made obligatory grain deliveries under both categories but a price premium was paid for above quota grain. The amount of basic quota purchased has remained essentially fixed since 1953 so most of the increase in procured grain over the years has been in the above quota category. On the heals of a bumper crop in 1984, this procurement system was changed from a mandatory to a voluntary contract system at the beginning of 1985, whereby procurement quantities for certain key commodities were determined by mutual agreement between individual farmers and the government. The procurement systems for secondary commodities were abolished.

In 1987 the government further reformed markets for vegetables, fruits, and fishery products. The number of commodities subject to government procurement programs declined from 38 in 1985 to 9 in 1991. In 1993, the grain market was further liberalized and the grain rationing system that had been in existence for 40 years was abolished. In 1993, more than 90% of all agricultural produce was sold at market determined prices, a graphic indication of the degree to which agriculture in China has been transformed from a command and control to a largely free-market sector.

4. AGRICULTURAL RESEARCH INVESTMENTS[5]

Since 1961 there has been an annual 7.3% rate of growth in research personnel and a corresponding 5.7% rate of growth in real research expenditures in China. Both these rates of growth accelerated over recent years so that by 1993 there were about 62,800 agricultural scientists and more than 32,000 technical support staff in the Chinese agricultural research system (Table 3). 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 early 1990s these percentages were 19.0% and 6.7%, respectively.

While the Chinese agricultural research system dwarfs all other public-sector systems -- in fact it is 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% to 6% of its researchers hold a postgraduate degree compared with 60% to 70% in national agricultural research systems in other less-developed Asian

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

Table 3—Quantitative development of agricultural research, 1953-93

	1953-57	1958-60	1961-65	1966-76	1977-85	1986-90	1991-93
	(full-time equivalents)						
Research personnel							
Scientists & engineers							
Research Institutes	-	-	6,966	11,118	27.207	45,589	51,477
Universities	193	363	504	503	3,051	8,009	9,819
Total	-	-	7,669	11,621	30,257	53,598	61,296
Technical support Staff[b]							
Research Institutes	-	-	4,644	7,411	17,921	29,591	312,447
Universities	-	-	66	82	400	939	946
Total	-	-	4,710	7,494	18,320	30,530	32,393
	(millions 1980 PPP dollars per year)						
Research expenditures[c]							
Research institutes	78.1	560.0	476.2	724.8	1,485.2	1,875.8	2,256.0
Universities	4.7	7.3	10.5	11.4	58.7	117.8	152.0
Total	82.8	567.3	436.2	736.2	1,543.9	1,993.6	2,408
	(percentages)						
Agricultural research intensity[d]	.07	.58	.41	.36	.41	.38	.40

Source: Authors' calculations based on data reported in Fan and Pardey (1992) and SSTC (1994).
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, 1994, 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.

countries. 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 1% in 1993 (SSTC, 1994), which is three times higher than the corresponding figure for agriculture. Those holding Msc degrees were 8% for all-sectors and only 4.2% for agriculture. This state of affairs is no doubt a legacy of the industrial-led development strategies of the 1950s and 1960s and the anti-intellectual climate of the Cultural Revolution years.

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 developing countries, particularly in Asia, whose ARIs rose over this same period. By the mid-1980's, the latest year for which comparative data are available, China spent slightly less than the developing country average on research and had an ARI ratio that was less than one-quarter the developed country average.

Much of China's agricultural research is crop related. In 1993 about half of its research personnel and expenditures were crop-production oriented. Around 7% of the research personnel work on fisheries problems, 12% on forestry, but only 8% on livestock production issues -- a subsector that accounts for around 27% of the value of agricultural output (SSTC 1994).

Agricultural research in China is also institutionally fragmented. In 1993 only 14% of the scientists and engineers (excluding university personnel) were based in national institutes. The overwhelming majority of researchers (i.e., 51%) work in institutes administered and often largely financed at the provincial level, while the remaining 35% work 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 institutes, the research institute, personnel, and expenditure shares for each region of the country are generally 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. Be that as it may, this spatial variability in research effort will be captured in the growth accounting analysis to follow.

5. SOURCES OF PRODUCTION GROWTH IN CHINESE AGRICULTURE

Statistically identifying and quantifying the sources of production growth for any economy is usually handicapped by the paucity of suitable data. This problem is no less serious in the case of China. There are 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.

DATA, MEASUREMENT, AND MODEL SPECIFICATION

The marked changes in the composition of agricultural output plus the substantial cross-commodity differences in the rate of growth noted earlier suggest 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,[6] 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, all denoted here by X_i, $i = 1, ..., 5$, and a research investment or stock-of-useable-knowledge variable, X_6. Also included were a set of regional dummy variables, D_g, $g = 2, ..., 7$, 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, time-specific dummies D_{I1} and D_{I2} capturing the effects of two phases 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:

$$lnY_{jt} = \alpha_0 + (\alpha_1 + \alpha_2 t)t + \sum_{i=1}^{6}(\beta_{1i} + \beta_{2i} t)\ln X_{ijt} + \beta_{I1} D_{I1} + \beta_{I2} D_{I2} + \sum_{g=2}^{7}(\beta_g + \beta_{I1g} D_{I1} + \beta_{I2g} D_{I2}) D_g + e_{jt}$$

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

where provinces are denoted by $j = 1, ..., 29$ (Hainan province is not separated from Guangdong in this study) and $t = 1, 6, 11, ..., 24$ denotes observations for the years 1965, 70, and 75, and annually thereafter for the years 1976 to 1993 to give a total of 609 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 in Chinese agriculture over this 28-year period, multicollinearity problems pose significant estimation difficulties in the translog case. But 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 above would cause factor shares to vary over time. Thus the quasi-translog specification represents a reasonably flexible alternative. This 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 through time 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.

Data details are given in an appendix. Output is measured as the value of (on-farm) agricultural production expressed in 1980 prices where agriculture is defined in a broad sense to include crop, livestock, forestry, fishery, and sideline 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 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 the total irrigated area in agriculture.

Developing plausible measures of the reforms initiated in late 1978 for inclusion in a growth accounting framework is problematic. While some 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 trade liberalization and exchange rate adjustments), and there are 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 program.

For all these reasons we opted for a straightforward, reduced-form approach to this aspect of the measurement and accounting problem. Several dummy variables were included in the model; one to capture the first phase of reforms from 1979 to

1984 and the second to reflect the series of market reforms that were largely implemented in the years after 1985.

Beginning with the work of Griliches (1964), a large number of studies have included R&D expenditures as explanatory variables in production or productivity functions. Research investments can lead to a change in productivity by changing the quality or price of conventional inputs and outputs (i.e., through a change in the technology used to produce those inputs and outputs) or by increasing the stock of knowledge or the use of the existing knowledge. The relationship between research investments and changes in the stock of useful knowledge is sometimes referred to as the *research production function* or a *knowledge production function*. Usually this stock cannot be observed directly, so the knowledge production function is more a part of the conceptual apparatus than an empirical tool. The empirically useful variant of the knowledge production function, and the one described by equation 1, is the function that relates output (or productivity) to lagged values of research investments.[7]

[7] Alston, Norton, and Pardey (1995) discuss in detail the conceptual, measurement, and interpretation problems of including R&D variables in agricultural production (cost, profit, and supply) functions.

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. There is some evidence that relatively short lags may be appropriate for much of the research done in 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. Because 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 effectively depreciated. With this in mind we included a research or stock-of-usable-knowledge variable that was a weighted sum of deflated past research expenditures, r_{t-i}, given by

$$X_{6t} = \sum_{i=1}^{7} w_{t-i}\, r_{t-i}$$

where the weights are normalized to sum to one and are defined as $w_{t-1} = w_{t-7} = 0.05$, $w_{t-2} = w_{t-6} = 0.1$, $w_{t-3} = w_{t-5} = 0.2$ and $w_{t-4} = 0.3$.[8] 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 represented by

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

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.

Because suitably disaggregated data were not available to enable appropriate Divisia aggregation procedures to be used as a way of systematically accounting for quality change in the conventional inputs, the temporal and spatial differences in input quality that arise for reasons other than R&D (as well as the productivity enhancing effects of investment in extension services and the like) are subsumed in the time and spatial 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. Moreover, 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.

PRODUCTION FUNCTION ESTIMATION

The ordinary least squares estimates of equation 1 are reported in table 4, which for comparative purposes includes estimates of the Cobb-Douglas version of the production function as well. Regressions (2) and (4) include regional dummies as independent variables while regressions (1) and (3), which omit these dummies, were included for comparative purposes. 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 0.909 for model (3) (evaluated at $t = 1$) to 0.942 for model (2), suggesting near constant returns to scale in the conventional variables. While this constant returns to scale feature of the quasi-translog specification persisted over time, individual production elasticities were quite variable. In particular, since 1965 the elasticities on traditional inputs such as land and labor declined at an average annual rate of 5.7% and 6.2%, respectively (regression 4 in Table 4). By contrast, modern inputs

Table 4—Production function estimates for Chinese agriculture, 1965-93

	Cobb-Douglas		Quasi-Translog	
Explanatory variable	(1)	(2)	(3)	(4)
Constant	-2.966 (18.14)	-3.018 (18.42)	-2.483 (8.03)	-2.469 (7.97)
Labor	0.117 (3.47)	0.106 (3.12)	0.402 (3.07)	0.405 (8.16)
Land	0.168 (6.31)	0.151 (7.89)	0.307 (3.34)	0.316 (6.65)
Fertilizer	0.203 (7.71)	0.210 (7.90)	0.059 (2.34)	0.061 (2.43)
Power	0.094 (2.98)	0.149 (5.74)	0.011 (.67)	0.013 (0.96)
Research	.080 (4.07)	0.094 (4.87)	.047 (1.95)	0.071 (1.42)
Irrigation	0.345 (14.11)	0.326 (13.69)	0.130 (3.30)	0.129 (3.27)
Time	0.01 (3.07)	0.013 (4.14)	0.002 (1.26)	0.002 (1.22)
Labor·t[b]			-0.014 (6.42)	-0.012 (6.44)
Land·t			-0.011 (2.53)	-0.009 (4.53)
Fertilizer·t			0.0071 (3.09)	0.007 (2.94)
Power·t			0.013 (4.79)	0.011 (2.16)
Research·t			.004 (1.95)	0.005 (2.15)
Irrigation·t			0.011 (1.167)	0.010 (4.85)
Time squared			-0.0001 (0.57)	-0.00004 (0.304)
Institutional dummy 1	.140 (2.42)	0.128 (2.32)	0.1266 (2.08)	0.110 (2.33)
Institutional dummy 2	.268 (6.49)	.155 (6.64)	0.197 (2.43)	.162 (6.63)
Degrees of freedom	593	571	586	564
Adjusted R^2	0.969	0.991	0.978	0.992

Note: Regressions (2) and (4) include regional dummies as independent variables, while regression (1) and (3) excluded them. For reasons of space, 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 + 1" for example, indicates a labor-by-time period interaction variable.

such as fertilizer, power, and irrigation services have a much larger marginal impact on output in more recent years than they did in the mid-1960s. Similarly the research coefficient grew by 4.1% per annum suggesting that the marginal returns from research (or, more correctly, the stock-of-knowledge variable) are now much higher than they were in earlier years. Our results also show that the coefficients of the institutional dummies are statistically significant and that the second phase of reforms had an even greater impact on stimulating agricultural production than the first phase.

SOURCES OF GROWTH

To account for the separate contribution of each input 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:

$$\partial \ln Y_t / \partial t = \sum_{i=1}^{6} \beta_{kt} \partial \ln X_{it} / \partial t + \sum_{i=1}^{6} \ln X_{it} \partial \beta_{kt} / \partial t$$
$$+ (\beta_{I1} + \beta_{I1g} D_g) \partial D_{I1} / \partial t + (\beta_{I2} + \beta_{I2g} D_g) \partial D_{I2} / \partial t + \partial A_t / \partial t$$

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

The first right-hand-side 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.[9] 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 and fourth terms reflect the region-specific effects of the first and the second phases of institutional reforms, respectively, 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 effects 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 input use, agricultural research, and institutional change on production growth, it is convenient to treat terms three and five as a "residual" effect. Dividing each of the terms in equation (3) by $\partial \ln Y_1 / \partial t$ 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 4 are summarized in Tables 5 and 6.

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[9] 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 deviation of extension services from this proportionality would be captured by the last term of equation 3.

We have grouped the data in Tables 5 and 6 in a way that readily identifies the share of overall growth in agricultural output coming from the increased use of conventional inputs, increases in the stock of usable knowledge arising from local

Table 5—Accounting for growth in agricultural output for different periods

	Period			
	1965-78	1979-84	1985-93	1965-93
	(percentages)			
Conventional Inputs	82.4	4.2	20.0	5.9
Labor	12.5	5.6	6.2	7.5
Land	-1.8	-0.8	0.1	0.1
Fertilizer	38.0	12.0	9.1	21.7
Power	24.7	7.8	5.5	12.9
Irrigation	9.0	-0.4	-0.9	3.7
Research	25.2	19.1	14.1	19.5
Institutional Changes	0.0	38.6	42.1	17.6
Residual[a]	-7.6	18.1	23.7	17.1
Production Growth[b]	100	100	100	100
	(3.3)	(8.1)	(5.2)	(4.7)

Note: Production elasticities for input i in year t from the quasi-translog specification are defined as $\partial \ln Y_t / \partial \ln X_{it} = \beta_{1i} + \beta_{2i} t.$ 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 4.

[a]An accounting residual (equal to the last 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.

Table 6—Accounting for growth in agricultural output by regions, 1965-1993

	Northeast	North	Northwest	Central	Southeast	Southwest	South	National
				(percentages)				
Conventional inputs	56.1	48.3	42.3	46.6	46.2	58.3	32.2	45.7
Labor	7.2	5.6	8.0	10.0	4.5	13.2	6.8	7.5
Land	0.1	-0.3	-2.0	0.0	-0.0	2.1	0.7	0.0
Fertilizer	25.4	23.7	23.9	23.3	20.6	27.2	13.1	21.7
Power	11.5	12.3	10.6	13.5	16.8	14.8	11.5	12.9
Irrigation	12.0	7.1	1.9	-0.2	3.3	3.0	0.12	3.7
Research	21.1	18.4	16.3	18.9	18.2	20.1	28.1	19.5
Institutional change	19.9	13.9	13.3	26.8	27.7	10.3	14.4	17.6
Residual	2.9	19.2	28.1	7.7	8.9	11.3	14.3	17.1
Production growth	100 (4.9)	100 (5.2)	100 (4.3)	100 (4.1)	100 (4.5)	100 (4.0)	100 (5.3)	100 (4.7)

Note: See notes to Table 5.

investments in agricultural research, institutional change, and an undifferentiated set of additional additional growth factors. The latter group captures the growth-promoting effects arising from improvements in rural infrastructure and extension services, unmeasured changes in the quality of the conventional inputs themselves, as well as factor-biased technical changes due to investments in research. Table 5 presents the results of growth accounting for the whole period and three different sub-periods -- the pre-reform period from 1965 to 1978, a first phase reform period from 1979 to 1984, and a second phase reform period from 1985 to 1993.

Agricultural output grew at an annual average rate of 4.7% over the 1965 to 1993 period. The measured use of conventional inputs accounted for about 46% of this growth, with manurial and, especially, chemical fertilizers alone accounting for 22% of the growth. The shift towards more capital- and energy-intensive production system that came with increased levels of mechanization throughout Chinese agriculture accounted for about 13% of the increased output. About 7.5% of the growth in output could be attributed to labor, while land made only negligible contributions to growth over this period. Our results also suggest that the expansion of irrigated area has not contributed to the growth in agricultural output to the degree that might have been expected. But 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 area per se. So part of this infrastructural effect of irrigation is likely to be captured by the power variable.

The direct effects of agricultural research accounted for almost 20% of the growth in Chinese agricultural output since 1965. These research effects are comparable magnitude to the improvements in technical and allocative efficiency stemming *directly* from the series of institutional and market reforms that got underway in the late 1970s. By our reckoning these institutional and market reforms accounted for about 18% of the nation's growth in agricultural output.

Growth accounting for different sub-periods suggests that the sources of production growth varied markedly over time. During the pre-reform period, the dominant source of production growth in Chinese agriculture was the increased use of conventional inputs. Fertilizer accounted for more than 38% of the total production growth, and power accounted for 25%. Increased use of labor input accounted for 13% of the growth, while a reduction in sown area led to a 1.8% contraction in agricultural production. About 25% of the total production growth during this period was attributed to the increased investment in agricultural research. It was during this period that China made moves to more effectively integrate research performed at the national and local levels. Compared with the relatively small size of the investment the payoff to research was extremely high.

Our results indicate that the introduction of the household production responsibility system accounted for about 39% of the total production increase from 1979 to 1984. Most significantly, however, the growth-promoting effects of the second phase of on-going market and institutional reforms appear at least as significant as the effects of the household production responsibility system; a transformation in the means of production that was all but completed within four years of its introduction. We estimated that these second phase reforms accounted for more than 42% of the growth in agricultural production after 1984.

While certainly not denying the significant growth-promoting impacts of these institutional changes and market reforms it seems that their direct effects (aside from their induced effects with regard to factor and technology use) may not constitute the dominant source of longer run growth as suggested by others who have empirically studied this issue. 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, research accounted for more than 19% of the growth in agricultural output during the first phase of reforms and 14% during the second phase.

Table 6 indicates there is also marked spatial variation in the sources of growth. Conventional inputs accounted for less than one third of the growth in agricultural output in the southern region but over one half of the growth in the northeast. Specific inputs played different roles in different regions. It is noteworthy that research accounted for more than 28% of the growth in the south, while accounting for only 16.3% in the northwest. The southwest and northwest regions constitute the most poorly developed regions in the country and gained the least from the institutional changes, while the southeast, one of the most developed regions, gained the most. Given data constraints we caution against overinterpretting these disaggregated results but they clearly point to substantial spatial differences in the sources of growth which have important policy implications that warrant further study.

6. CONCLUDING COMMENTS

This study has identified and quantified the effects of a number of growth factors that influenced Chinese agricultural performance since 1965. The importance of any one factor varied markedly over time and across regions. Over the longer run 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 more than 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," especially over the shorter term. However, for the somewhat longer time horizon included in this study, these influences are matched by the contributions of research.

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 length-of-run considerations to bear in mind when assessing the growth promoting impacts of institutional and technical change. While a significant share of the growth effects of the institutional 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.

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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 -- Agricultural output is measured as gross agricultural production value expressed in 1980 prices. For observations prior to 1980 we took the 1980 gross agricultural production figures for each province reported in the 1981 *China's Agricultural Yearbook* and backcast them using the corresponding agricultural production value index measured in "comparable" (i.e., constant) prices as reported in the 1990 edition of the *Historical Statistical Materials for Provinces, Autonomous Regions and Municipalities (1949-1989)*. Output data after 1979 were taken from various issues of *China's Agricultural Yearbook, China's Statistical Yearbook,* and *China's Rural Statistical Yearbook*. The measure of agricultural production value we use is net of the output of village (i.e., off-farm) industries. It is reported separately from *total* agricultural production after 1978. For the years prior to 1979, we calculated net agricultural production using a two-step procedure. We first estimated village industry values for each province by taking the national village industry values from 1971 to 1978 (*China's Statistical Yearbook* 1983) and prorating them to the provincial level using the provincial rural industry shares for 1979. We formed estimates for 1970 and 1965 by backcasting these figures with time trend variables. This is a reasonable approximation given that village industry production for these earlier years was negligible. These provincial estimates were then subtracted from the corresponding total to derive the agricultural production figure net of village industry value.

Labor -- Labor is measured in stock terms as the number of persons engaged in agricultural production at the end of each year. It is defined as the labor engaged in crop production, forestry, livestock, fishery, and sideline production. Labor engaged in rural industries is excluded from labor input in this study. For years prior to 1979 provincial estimates of agricultural labor for selected years are reported in the 1990 volume of *Historical Statistical Materials for Provinces, Autonomous Regions and Municipalities (1949-1989).* Missing observations were calculated using the following formula

$$L_{jt} = P_{jt} \_ \frac{r_{j,80}}{r_{n,80}} \_ r_{n,t}$$

where L_{jt} denotes the jth region's labor input in year t; P_{jt}, j region's agricultural population in year t; $r_{j,80}$, the jth region's ratio of agricultural labor to agricultural population for 1980; $r_{n,80}$, national ratio of agricultural labor to agricultural population in 1980, and $r_{n,\,t}$, is the national ratio of agricultural labor to agricultural population in year t. For years following 1979 the agricultural labor data were taken from various issues of *China's Agricultural Yearbook, China's Statistical Yearbook* and *China's Rural Statistical Yearbook.*

Land -- Land in agriculture is taken to be the sum of sown area and grassland. This measure was chosen for several reasons. First, it approximates a flow-type variable by capturing 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. 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). Finally, the accuracy of official statistics on arable (i.e., cultivated) land have commonly been called into question (*China's Statistical Yearbook 1991,* 1992, p. 314). The data for sown area prior to 1979 were taken from *National Agricultural Statistical Materials for 30 Years, 1949-1979*. Missing observations are estimated using the sum of total grain and cash crop areas obtained from the same source. The data for sown area for later years were taken from various issues of *China's Agricultural Yearbook, China's Statistical Yearbook* and *China's Rural Statistical Yearbook*.

Fertilizer -- Fertilizer is an aggregate of both chemical and manurial fertilizers, both measured in pure nutrient terms. The data for chemical fertilizer prior to 1979 are reported in *National Agricultural Statistical Materials for 30 Years, 1949-1979*. Missing observations were estimated using the national trend and provincial 1979 weights. The data after 1978 were taken from various issues of *China's Agricultural Yearbook, China's Statistical Yearbook* and *China's Rural Statistical Yearbook*. 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 fertilizer used per year was estimated as [(0.25 x Rural Population + 4 x Numbers of Livestock) x 0.022) x 0.75].

Power -- Power input is measured as the aggregate of machinery horsepower and draft animals. The data on machinery horsepower in 1965 and 1970-72 were interpolated based on tractor count data, while those after 1972 are reported in *National Agricultural Statistical Materials for 30 years, 1949-1979, Agricultural Yearbook* and *China's Statistical Yearbook*. The numbers of draft animals prior to 1980 were taken from *National Agricultural Statistical Materials for 30 Years, 1949-1979*, and those after 1979 were reported in various issues of *China's Agricultural Yearbook, China's Statistical Yearbook* and *China's Rural Statistical Yearbook*.

Irrigation -- Irrigation services used in agriculture are proxied by irrigated area. The data on irrigated area prior to 1979 are reported in *National Agricultural Statistical Materials for 30 Years, 1949-1979*. Missing observations were estimated using national trend and 1979 provincial weights. The data after 1978 are reported in the various issues of *China's Agricultural Yearbook, China's Statistical Yearbook* and *China's Rural Statistical Yearbook*.

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 for selected provinces were obtained from their provincial academies of agricultural sciences. The missing observations were estimated by econometrically extrapolating the provincial trends from 1993 to 1986 back to 1950 then recalibrating the extrapolated series for each province for each year 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 take from *China's Statistical Yearbook* (1991 and 1994).

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