Cross-Commodity Analysis of China's Grain Sector: Sources of Growth and Supply Response. By Hunter Colby, Xinshen Diao, and Agapi Somwaru, U.S. Department of Agriculture, Economic Research Service, Market and Trade Economics Division. Technical Bulletin No. 1884.

Abstract

We investigate sources of output growth and supply response in rice, wheat, corn, and soybeans, the four most important crops in China's grain sector, during 1978-97. Using a growth accounting methodology, we found large total factor productivity (TFP) contributions to growth in grain production immediately following China's rural economic reform (1978-85). In 1995-97, the TFP contribution dropped to only 16 percent of growth in grain production, as greater use of inputs increasingly drove growth. In the supply response analysis, the results of the econometrically estimated restricted profit function confirm a joint and nonseparable multiproduct technology for China's grain sector. Complementarity prevails in the grain sector among different outputs and inputs, meaning that an increase in the price of intermediate inputs/capital or wages would result not only in an absolute reduction in all outputs but also in a change in the composition of these outputs. The expansion (or scale) effects subsided during 1986-97, implying a relatively slow outward shift of the production frontier during this period. If the current government policy environment remains unchanged, China's grain production will become more costly, constraining its future growth and competitiveness in world markets.

Keywords: China agriculture, growth accounting, total factor productivity (TFP), multiproduct supply response.

Acknowledgments

The authors have benefited from discussions with Terry Roe and Eldon Ball. The authors are also grateful to M. Gopinath, Shenggen Fan, Terry Roe, Praveen Dixit, Joy Harwood, John Dyck, Steven Zahniser, Bill Kost, Scott Rozelle, and Francis Tuan for their critical comments and suggestions. An early version of the paper was presented at the International Agricultural Trade Research Consortium, "China's Agricultural Trade and Policy," San Francisco, CA, June 26, 1999. The authors are solely responsible for any remaining errors.

Washington, DC 20005-4788 May 2000

Contents

Executive Summary

This report analyzes the sources of output growth and supply response in rice, wheat, corn, and soybeans, the four most important crops in China's grain sector, during 1978-97. The study, using a growth accounting methodology, finds large total factor productivity contributions to growth in grain production immediately following China's rural economic reform (1978-85). These findings are reinforced by additional analysis using a multiproduct supply response approach.

Most of the growth in total factor productivity during 1978-85 was from efficiency gains due to institutional reforms. After 1985, when the efficiency gains had diminished, the growth rate of productivity fell sharply and contributed less than 20 percent of growth in grain production. In recent years (1995-97), increased use of inputs, especially intermediates/capital, became major sources of growth in China's grain sector.

Historically, there has been a decline in the ratio of labor relative to land used in China's grain production, though in recent years this decline has slowed significantly. The current land tenure system, which blocks scale economies by preventing land transfers, is a major factor constraining the development and expansion of labor-saving technology in China's grain sector. Given that increased input use, including labor, drove growth in China's grain sector in recent years, grain production will become more costly as wages and prices for intermediate/capital inputs rise. This could constrain growth in China's grain production and weaken its competitiveness in world grain markets. However, the gap between productivity growth in China's grain sector and overall productivity growth in developed countries such as the United States suggests that China can improve its grain production technology if the economic and policy environment encourages investment in agricultural research and development, water control systems, and land infrastructure.

This report also examines output and input adjustments in China's grain sector due to changes in prices following adoption of the Household Responsibility System and expansion of the system of rural free markets. The econometric analysis captures the relationships among outputs supplied and inputs demanded in a non-separable and joint production system characteristic of China's multiproduct grain farms. Multiple production activities are the dominant structure of technology in China. Grain outputs are jointly produced and inputs are jointly employed, an important factor underlying this study's finding of a strong complementarity among outputs and among inputs. Study results also find that grain output is highly responsive to changes in input prices. An increase in the price for intermediate inputs/capital or wages would result in absolute reductions in all grain production as well as changes in the composition of grain production.

Each grain's output is highly responsive to changes in that particular grain's price, but there is also a strong complementary supply/price relationship with other grains. That is, an increase in the output price for a particular grain would result in increased production of all grains. This result indirectly supports the finding from the growth accounting analysis that the current heavy dependence on intermediate input use for production growth could constrain growth in China's grain production should wages or the prices of inputs rise.

Future work in identifying and measuring the sources of growth in China's agriculture should focus on disaggregating to regions (or even provinces). National analysis may obscure some important regional differences in productivity because of differences in economic development and agricultural practices across regions.

Cross-Commodity Analysis of China's Grain Sector

Sources of Growth and Supply Response

Introduction

China's agricultural output grew at an astonishing rate over the last 20 years following the introduction of economic reforms in 1978. Grain output more than doubled, rising to 490 million tons in 1998. During that same period, China's agricultural trade also grew very rapidly (especially in the 1990's), but more erratically than agricultural output. Only in the 1990's did both output and trade move upward. China's agricultural imports rose from US $5.5 billion in 1990 to $10 billion in 1996. Exports also rose substantially, but mostly in the early 1990's as government policies discouraged grain exports after the mid-1990's.

China's changing role in world trade, both as an importer and exporter, has heightened the need to understand its production potential. Anticipating China's production growth and adoption of production technologies calls for an understanding of China's past production growth and output and input utilization choices. Especially important, for a whole host of political, social, and economic reasons, is to identify the sources of growth in China's grain sector and examine the structure of its grain production. Moreover, in an era of stronger market orientation, it is also important to understand the role of output and factor prices in generating supply or production response.

Growth Accounting Analysis—Sources of Output Growth

Previous Studies and Background

The existing literature on China's agricultural growth is insufficient to predict its potential. Most of these studies were conducted in the late 1980's and early 1990's, focusing on the period immediately following the introduction of rural reform. Moreover, with only a handful of very recent exceptions, these studies were based on the gross value of agricultural output (GVAO), with little information on joint production by China's household farms.

Most studies examining the early reform period (1978-85) are strongly influenced by the unusually high growth rate of China's agricultural production in that period. Even though many researchers recognized the importance of institutional changes in the early growth of China's agricultural production (see McMillan et al., 1989; Fan, 1991; Wen, 1993), they were unable to pinpoint contributions of these changes versus technological changes.

Lin (1992) attempted to identify the sources of total factor productivity (TFP) growth. TFP captures the growth in outputs not accounted for by the growth in production inputs (e.g., labor, capital, and fertilizer). In Lin's study, TFP was analyzed by breaking out the individual contributions of the introduction of the household responsibility system (HRS) during 1978-84, changes in government purchase prices, and the expansion in the system of rural free markets. However, because the study used aggregated agricultural data and covered only a few post-HRS years, it is difficult to accurately gauge the potential of China's future growth based on Lin's analysis.

Huang and Rozelle (1996) successfully separated the contribution of technological change in the growth of production from other factors (including institutional change). However, the study covered only rice production.

In this study, we apply a growth accounting method to disaggregated national data for rice, wheat, corn, and soybeans from 1978 to 1997, measuring the different sources of growth for these four grains. Data were compiled from provincial data and aggregated to a national level to indicate China's potential growth in grain production. Carter, Chen, and Chu (1999) provide a similarly disaggregated analysis of six crops and two livestock products, but for only one province (Jiangsu). Agricultural production structure and productivity growth vary greatly across regions (Fan, 1991), so it is hard to extrapolate national growth potential from their study.

Our growth accounting analysis is divided into three periods that correspond to major shifts in China's agricultural policy. The first period (1978-85) covers the transformation of the old commune system to the family-based HRS. In the second period (1986-94), the reforms shift from the rural to the urban economy. The provincial governor's grain responsibility system, which promotes grain production and self-sufficiency, marks the third period (1995-97). The growth rates of the four grains are observed to be quite different in these three periods, implying strong institutional and policy impacts.

Over the last two decades, China's grain production increased by nearly 200 million tons, led by rice, wheat, corn, and soybeans. These four grains accounted, on average, for 96 percent of the growth in total grain production. The share of these four grains' contribution to total grain output rose from 80 percent in the late 1970's to 86-87 percent in the late 1990's. Among these four grains, soybeans and wheat grew most rapidly, while wheat and rice had the largest contribution share (table 1).

The contribution share of each grain is defined as the ratio of the output growth rate for each grain over the growth rate for the four grains in total, weighted by the share of each crop in the value of the four grains' output. Between 1978 and 1997, wheat accounted for 27 percent of the value of the four-grain total, and contributed the most (38 percent) to total grain growth, while rice accounted for 46 percent of the value of the four-grain total and contributed less (30 percent) to total grain growth than wheat. The rapid growth in wheat output, 4.5 percent annually, made it the largest contributor to growth in grain output.

The growth rate of soybean output was 4.9 percent per year. Due to this rapid growth rate, soybeans contributed 12.5 percent of growth in total grains, though they accounted for only 8 percent of grain output in value terms. Corn accounted for 19.4 percent of total grain value and contributed a similar share (19.5 percent) to total growth, implying that corn's growth rate is similar to the growth for total grains.

We now turn to the growth accounting analysis to understand how and why the rates differed across time and among crops.

Method

The purpose of growth accounting analysis is to determine the sources of growth in output. However, the choice of output and input indices can strongly influence the accounting results. The traditional output index is usually measured in terms of constant output prices, while the input index is calculated using a fixed share to weight individual inputs. Consequently, the aggregated output and input indices, and hence the

Table 1—Growth rate and contribution of each crop

	1978-85		1986-95		1995-97		1978-97	
	Growth rate	Contribution	Growth rate	Contribution	Growth rate	Contribution	Growth rate	Contribution
	Annual average percent							
Four-crop total	4.0	100.0	2.0	100.0	4.8	100.0	3.2	100.0
Rice	3.0	36.9	0.5	11.5	4.5	38.9	2.0	30.3
Wheat	6.9	46.9	1.6	21.9	7.5	40.2	4.5	37.7
Corn	1.9	8.3	5.0	46.7	1.7	7.8	3.3	19.5
Soybeans	4.9	8.0	4.8	19.9	4.5	13.1	4.9	12.5

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98) data.

estimated TFP, are likely to be biased if such traditional measures are used (Fan, 1997). This method would be particularly problematic for the period we study because of China's institutional reforms and subsequent changes in production and input use structures.

To capture the effects of change in production or input combinations, we applied an index number procedure. Specifically, we computed a Tornqvist input index for each crop and a Tornqvist output index for aggregate grains. The Tornqvist index is an approximation of the Divisia index and can be derived from a flexible multiproduct structure of production constrained to constant returns to scale. This index measure accounts for changes in the share of an individual input in total production costs, and the share of an individual crop's output in total grain output, over time. These structural changes are often outcomes of technological innovations or institutional changes (see Diewert, 1976, and Caves et al., 1982, for additional explanations of the Divisia index approach). The input and output indices are defined as follows:

$$\ln V_{j,t} = \tfrac{1}{2}\sum_{f}(S_{f,j,t-1})\ln\left(\frac{X_{f,j,t}}{X_{f,j,t-1}}\right) \quad (1)$$

$$\ln V_{t} = \tfrac{1}{2}\sum_{f}(S_{f,t}+S_{f,t-1})\ln\left(\frac{X_{f,t}}{X_{f,t-1}}\right) \quad (2)$$

$$\ln Q_{t} = \tfrac{1}{2}\sum_{j}(S_{j,t}+S_{j,t-1})\ln\left(\frac{Y_{j,t}}{Y_{j,t-1}}\right) \quad (3)$$

where $S_{f,j,t} = (p_{f,t}X_{f,j,t})/(p_{j,t}Y_{j,t})$ is the share of the cost of input X_f (f are inputs, e.g., labor or land) in the revenue of crop Y_j (j are outputs) at time t. $S_{f,t} = (p_{f,t}X_{f,t})/S_j(p_{j,t}Y_{j,t})$ is the share of the cost of input X_f in the revenue of total grains (p_f and p_j are prices for inputs and outputs, respectively). $S_{j,t} = (p_{j,t}Y_{j,t})/S_i(p_{i,t}Y_{i,t})$ is the share of each crop in the revenue of total grains. $V_{j,t}$ and V_t are input indices for crop Y_j and aggregate grains, respectively. Q_t is an aggregate output index. Furthermore, the levels of output and inputs are normalized to 1 in a specific year and then accumulated over time. The TFP indices in logarithmic form can be expressed as:

$$G_{j,t} \equiv \ln\left(\frac{TFP_{j,t}}{TFP_{j,t-1}}\right) = \ln\left(\frac{Y_{j,t}}{Y_{j,t-1}}\right) - \ln V_{j,t} \quad (4)$$

for crop j, and

$$G_{t} \equiv \ln\left(\frac{TFP_{t}}{TFP_{t-1}}\right) = \ln Q_t - \ln V_t \quad (5)$$

for the whole grain sector.

The growth rate of output and the contributions of inputs and TFP to the growth in each crop and aggregate grains can be calculated from equations 1-5. For the whole grain sector, the output growth rate at time t is 100 • (Q_t - 1), the growth rate of TFP is 100 • [$EXP(G_t)$ - 1], and the contribution of TFP to output growth at time t roughly equals 100 • [$EXP(G_t)/Q_t$].

In growth accounting analysis, TFP is obtained by subtracting an input index, which captures labor or other physical inputs, from an output index (for example, total grain output). As a residual term, TFP captures all nonphysical input factors that affect output growth over time. Technological change, weather, policy change, institutional change, and other external shocks can all affect production efficiency (e.g., change in the output level given input levels).

Technological change is usually a sustainable source of TFP growth (i.e., it is a long-term effect). Similarly, changes in institutions or policy can provide a long-term impact. But most other sources of TFP growth—good weather, for example—provide only short-term boosts to productivity. The growth accounting method by itself cannot identify short- versus long-term sources of TFP growth. The influence of short-term effects on TFP growth can be moderately reduced by studying a longer period of time.

Data

Data for each crop's output and sown area, and price indices for the outputs and inputs were obtained from the *China Statistical Yearbook*, published by China's National Bureau of Statistics (NBS). The cost data, including person-day time of labor use, wages, and intermediate input costs by crop, were drawn from the annual household survey, "National Crop Production Cost and Labor Productivity Survey," published in the

China Rural Statistical Yearbook. The survey covers the costs of intermediate inputs (fertilizers, pesticides, seeds, plastic sheeting, irrigation, energy, draft animals, and capital depreciation, including small farming tools, agricultural machinery, and other capital). The intermediate input price index was obtained from the *China Statistical Yearbook* and the China Commerce Yearbook.

We aggregated inputs into three categories: land, labor, and intermediates/capital. Because only aggregate data for variable expenses (costs of intermediate inputs) and fixed expenses (capital depreciation) were published, we defined intermediate and capital inputs as a single input. The implicit quantity associated with this input category is calculated by dividing its expenditure by the price index.

For land, we used area sown to each grain instead of cultivated area because of the extensive multiple-cropping of grain in China. There were no data for land prices or returns to land. Thus, we assumed that net revenue from each grain's production—that is, gross revenue minus the cost of labor and intermediates/capital as well as tax payments—was the return to land.

China's official statistics under-report actual cultivated area (Crook, 1993). This problem may spill over to sown area statistics, since sown area is the number of times a piece of land is planted multiplied by the amount of cultivated area. The majority of the reporting error is believed to have occurred during the 1960's and early 1970's as a result of collectivization, the formation of communes, and the Cultural Revolution. Even though the under-reporting of land artificially inflates the level of yields, the yield growth rates analyzed in this study are largely unaffected because they reflect a more recent time period.

We measure labor as time spent (person-days) on each crop rather than the number of laborers in agriculture for two reasons. First, most households raise many different crops. Second, farmers generally spend only part of their time in agriculture because the small scale of household plots provides for opportunities in nonfarming sectors. The wage data from the survey were too low to accurately reflect the opportunity costs of rural nonfarm labor. Since land is farmed mainly by individual households rather than hired or nonfamily labor, the underestimated returns to labor would be captured in the returns to land. The indices for all these data are reported in tables A1-A2 (see appendix).

Growth Accounting Analysis—Contribution of TFP

On average, growth in TFP contributed more than 70 percent of the increase in total output of China's four major grains over the last two decades (table 2). The TFP contribution is defined as the ratio of the TFP growth rate over the growth rate of grain output. Growth in rice production can be explained by TFP growth alone, while TFP contributed 48-65 percent of output growth for soybeans, corn, and wheat.

Our study covers more of the post-reform contributions of TFP to the growth of China's grain sector than most. One recent exception, Carter et al. (1999), covers a similar time period (1978-96) and compares agricultural productivity growth in China at national and provincial (Jiangsu) levels. The study calculated TFP for six crops in Jiangsu province, while the national analysis is based on gross value of agricultural output. When the inputs were weighted, the TFP growth rates calculated for the four grains in Jiangsu (1.9, 2.6, 3.3, and 2.7 percent for rice, wheat, corn, and soybeans) are comparable with our rates except for corn, which is rarely produced in south China.

Many studies examine China's agricultural productivity during the 1980's. For example, using a parametric approach, Lin (1992) found that growth in TFP contributed about 50 percent of growth in total grain output in the periods 1978-84 and 1985-87. Based on Fan's (1997) growth accounting analysis, which also used Divisia input and output indices, TFP growth was found to contribute 77 and 70 percent of the growth in aggregate agricultural output (including livestock and other commodities) over the periods 1979-84 and 1985-95, respectively. These results are comparable with our 1978-97 estimates (table 2). However, our results show a much larger TFP contribution in the early period and a much smaller TFP contribution in more recent periods.

We also compared our results with studies of other countries' agricultural TFP. For example, using a similar index number method, Evenson et al. (1999) found that TFP growth contributed 55 percent of the growth in India's total crop production during 1956-87. In a

Table 2—Contribution of TFP to grain production growth

Years	Total 4	Rice	Wheat	Corn	Soybean
			Annual average percent		
Output growth rate:					
1978-97	3.2	2.0	4.5	3.3	4.9
1978-85	4.0	3.0	6.9	1.9	4.8
1986-94	2.1	0.5	1.6	5.0	4.5
1995-97	4.8	4.5	7.5	1.7	6.3
TFP growth rate:					
1978-97	2.3	2.3	2.9	1.7	2.3
1978-85	5.4	5.3	6.6	4.7	3.8
1986-94	0.4	-0.3	0.3	1.5	2.8
1995-97	0.8	3.0	2.6	-4.1	-2.3
TFP contribution:					
1978-97	73	112	65	52	48
1978-85	136	173	96	241	79
1986-94	19	-58	18	30	63
1995-97	16	67	36	-256	-39

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

study of the sources of sectoral growth in U.S. agriculture and using a similar index number method, Gopinath and Roe (1997) found that TFP explains all of the growth in U.S. agriculture over 1960-90, as input effects are negative.

For the aggregate grain category, the contribution of TFP to the growth in output fell over time with each subperiod (table 2). In 1978-85, the growth rate of TFP exceeded the growth rate of output for aggregate grain, rice, and corn. When output grows more rapidly than the use of production inputs, TFP contributes significantly to the growth in output. If use of production inputs falls while output increases, TFP's contribution to the growth in output exceeds 100 percent. On the other hand, if more inputs are used while output falls, TFP's contribution to the growth of output becomes negative.

TFP growth in the early period (1978-85) captures the efficiency gains from institutional changes. Before 1978, China's agricultural production was centrally planned and quite inefficient. In other words, China's production was well within its "production possibility frontier"—the set of efficient input combinations chosen by producers on the basis of profit maximization. This period (1978-85) saw a shift from the collective production system to the household responsibility system (HRS); less administrative intervention in agricultural production and reduced mandatory quotas for grain purchased by the government; increases in government procurement prices; and the blossoming of free-market activities.

Lin (1992) found that the introduction of the HRS contributed more than 90 percent to growth in agricultural productivity during the early period. In contrast, based on a parametric approach, Huang and Rozelle (1996) found that technological change was relatively more important. Using rice as an example, they found that nearly 40 percent of growth in rice output during 1978-84 was due to the rise in yields resulting from the adoption of new varieties. This finding, like our result, indicates the importance of TFP in the early period. In rice, we found that TFP accounted for 173 percent of the growth in rice production over 1978-85.

The efficiency gains from institutional reforms can occur at any given level of technology. Therefore, the impact on growth lasts only for a limited time. A slowdown in TFP growth after the first period (1978-85) indicates that when China's grain production moved to its production possibility frontier at the given level of technology, efficiency gains from further reform became smaller. Hence, additional growth in TFP would have to come from technological change.

Table 3—Grain prices normalized by an index for total agricultural products

Years	Rice	Wheat	Corn	Soybean	Total grains
	Price index for same period's total agricultural products is 100				
1978-97	107.5	98.4	106.3	157.5	120.0
1978-85	106.3	108.7	107.9	143.2	115.6
1986-94	105.0	87.2	97.5	106.5	98.5
1995-97	98.2	112.0	110.4	110.7	106.7

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

The growth rate of aggregate output fell to 2.1 percent in the second period (1985-94), and the growth rate of TFP fell to 0.4 percent (table 2). Thus, the contribution of TFP to output growth fell to 19 percent for all grains. And when rapid growth in rice production came to a sudden halt during the second period, the TFP growth rate for rice turned negative (table 2).

The slowdown in grain output growth may have been due to changes in relative agricultural prices. Markets for vegetables, fruits, and fishery products were further liberalized after 1985, and prices for these commodities rose relative to grains. The slowdown in TFP growth may be related to the reduced public investment in agricultural research and development and in infrastructure (irrigation, flood control, etc.) after the early reform period (Huang and Rozelle, 1996; Fan and Pardey, 1997).

The average growth rate of grain production rebounded dramatically during the third period (1995-97), reaching 4.8 percent (higher even than during the first period). Soybean and wheat growth was especially rapid, while the growth rate for corn was just 1.7 percent (table 2). TFP growth was only 0.8 percent per year in the third period, so the contribution of TFP to grain growth fell to 16 percent from 19 percent in the previous period.

We hypothesize that the rise in grain prices relative to other agricultural products (except for rice) boosted production growth in the third period (table 3). This is confirmed by the econometric analysis of supply response discussed in the next section. Higher grain prices were due not only to changes in market prices, but also to increases in government procurement prices. In addition, when the "governor's grain bag" policy was introduced in late 1994, provincial governments were required by the central government to ensure sufficient grain production. The provincial governments subsequently introduced various production subsidies, especially subsidies on agricultural inputs such as pesticides and fertilizer. In some provinces, governments reinstated administrative measures to stabilize grain prices and maintain the area sown to grain crops (Fang and Beghin, 1999). As the policy environment shifted toward supporting grain production, inputs into the grain sector grew while the contribution of TFP to growth actually fell.

In summary, the high TFP growth rate and its large contribution to grain production growth in the period immediately following China's rural economic reforms was largely due to efficiency gains arising from institutional change. After 1985, the annual growth rate of TFP fell sharply. Increased grain output in recent years was due more to rising grain prices than to improvements in production technology. A fall in the contribution of TFP implies, on the one hand, that the recent growth in the grain sector will be shortlived since it is largely due to increased input use. On the other hand, lower TFP growth also implies that the gap between TFP growth in China's grain sector and other countries' agricultural sectors (Evenson et al., 1999), especially developed countries (Gopinath and Roe, 1997), is quite large. If China's economic environment and government policy can encourage more investment in agricultural research and development, water control systems, and land infrastructure, China can further increase productivity in its grain sector.

Growth Accounting Analysis—Contribution of Intermediate Inputs and Capital

In this section, we analyze the contributions of labor and intermediate inputs/capital to grain production growth. The increase in production factors contributed 27 percent of growth in China's grain output during 1978-97. This contribution was primarily due to the increased use of intermediate inputs and capital. Land use was nearly constant and the use of labor fell by more than 3 percent annually (table 4). The use of intermediate inputs and capital in grain production increased in each sub-period over the last two decades. Moreover, the growth rate of intermediates/capital use rose over time, from 4.0 percent in 1978-85 to 5.1 percent in 1995-97. This indicates that grain production is becoming more intermediate/capital-intensive, as does the decreased use of labor and relatively stable use of land over the 1978-97 period. Sown area (land) and labor days (time spent working) used in production of the four grains fell by 0.6 and 9 percent in the first period (1978-85). In this period, rice and corn acreage fell 1.0 and 1.7 percent, while wheat and soybean acreage rose slightly (table 5). National sown area statistics indicate that the reductions in land use were due to changes in cropping intensity, as farmers moved from triple- and double-cropping to double- or even single-cropping (Weins, 1982). During 1978-85, total sown area for all crops fell by 0.63 percent, implying that grain area was not simply shifting to nongrain production (table 6).

Although labor-day statistics in the first period (1978-85) may be suspect, labor efficiency certainly rose due to the reforms. Before 1978, individual peasant income in China was calculated according to time spent in the collective field without reference to production outcome. This system strongly encouraged peasants to participate in collective work assignments but to put little effort into their actual work (or chu gong bu chu li in Chinese). The HRS encourages peasants to efficiently use labor time as incomes are determined solely by production output.

Labor's contribution to production growth differed significantly depending on whether it was based on labor-day (or time spent) of peasants or the number of persons engaged in grain production. For example, in Fan and Pardey (1997), with increasing **numbers** of laborers, the contribution of labor to production growth was 5.6 percent in 1979-84. However, when the labor contribution to growth is based on the labor days of peasants, as in our study, time spent on grain production declined 9 percent annually and the contribution of labor to growth was negative. Given that most farmers in China allocate their time among many different crops and livestock, as well as to nonagricultural work, we believe that **time** spent on grain production is the most accurate measure of labor's contribution to growth in grain production.

In the second period (1986-94), area sown to grains was quite stable (with a 0.36-percent annual increase) and nearly identical to the change in total sown area (table 6). Land sown to rice and wheat fell slightly (table 5), while land sown to corn and soybeans both rose by 2 percent. Labor used in production of the four grains fell 0.83 percent per year over this period (though rising slightly in production of corn and soybeans). This is not consistent with national statistics that show the number of agricultural laborers rising by

Table 4—Input contribution to grain production growth

Years	Total input contribution	Growth rate of		
		Land use	Labor use	Intermediates/ capital use
	Percent	*Annual average percent*		
1978-97	27	0.34	-3.58	4.35
1978-85	-36	-0.64	-9.08	4.03
1986-94	81	0.36	-1.44	4.35
1995-97	84	2.62	3.58	5.14

Note: A negative share implies input use fell and the growth rate of TFP was greater than the growth rate of output.
Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

Table 5—Growth in output and input use in grain production

Crop/ year	Output	Land use	Labor use	Intermediate/ capital use
		Annual average percent		
Rice:				
1978-97	2.03	-0.42	-4.04	2.72
1978-85	3.01	-1.01	-8.56	1.66
1986-94	0.48	-0.68	-2.46	4.27
1995-97	4.49	1.73	2.26	0.60
Wheat:				
1978-97	4.46	0.16	-4.29	5.76
1978-85	6.89	0.02	-9.25	7.22
1986-94	1.64	-0.09	-2.20	3.91
1995-97	7.48	1.22	1.58	8.01
Corn:				
1978-97	3.33	0.92	-2.58	5.26
1978-85	1.90	-1.71	-10.37	3.38
1986-94	5.03	2.00	0.81	6.33
1995-97	1.66	3.97	6.81	6.47
Soybeans:				
1978-97	4.89	2.38	-1.24	6.41
1978-85	4.79	1.11	-7.82	9.35
1986-94	4.50	2.00	1.39	0.96
1995-97	6.33	6.58	7.19	16.90

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

0.8 percent during 1986-94. However, in the national statistics, agricultural laborers were classified by their main production activities. That is, those engaged primarily (more than 50 percent of labor time) in agriculture were counted as agricultural laborers. Our conclusion, based on household survey data, is that peasants working primarily in agriculture spent less time on grain production than before.

In the final period (1995-97), land and labor returned to grain production, rising by 2.6 and 3.6 percent annually (table 6). Compared with the increase of 1.3 percent in total area sown, grains successfully competed for additional land at the expense of other crops. Moreover, 1995-97 was the only period in which changes in land and labor use move in the same direction (rising) across the four grain crops. These observations all suggest that the market and policy environment during this period favored grain production.

While increased input use contributed more than 80 percent of the growth in grain output in the second and third periods (table 4), different inputs played different roles in that growth. In 1986-94, increased intermediate input/capital use was nearly the sole source of growth, while in 1995-97, increased labor and land use together contributed more than intermediate inputs/capital to grain output growth.

Structural Change in Input Use—Rise in Capital/Land Ratio and Fall in Labor/Land Ratio

With rapid economic development, China's technological change should move toward less use of labor (as wages increase) and more use of intermediate inputs and capital. We calculated the ratios of labor and land as well as intermediates/capital and land in order to examine whether or not technological change affected the structure of input use. The ratio of intermediates/capital over land rose by 110 percent for total grain production over the last two decades. That is to say, if the ratio in 1978 is normalized to be 100, then by 1997 the ratio is more than 200, with an annual increase of 4 percent (table 7). On the other hand, the ratio of labor over land for total grain production fell by more than 50 percent, with an annual decline of 4 percent. The results suggest both a substitution effect and a bias in the direction of technological change, which is labor-saving and capital/intermediate input-using. The

Table 6—Growth in agricultural labor use and sown area

Years	Total sown acreage	Land in 4 grains	Agricultural labor	Labor in 4 grains
		Annual average percent		
1978-97	0.14	0.34	0.87	-3.57
1978-85	-0.63	-0.64	1.43	-9.08
1986-94	0.35	0.36	0.83	-1.44
1995-97	1.27	2.62	-0.26	3.58

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

Table 7—Change in ratio of labor use and intermediate/capital use per unit of land

Years	Labor/land		Intermediates and capital/land	
	Total change	Annual change	Total change	Annual change
			Percent	
1978-97	-53.1	-4.0	110.6	4.0
1978-85[1]	-46.3	-8.5	37.9	4.7
1986-97[2]	-12.6	-1.1	52.7	3.6

[1] The ratio in 1977 was set at 100. [2] The ratio in 1985 was set at 100.

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

substitution effect reflects the change in the opportunity cost of labor relative to that of capital and intermediate inputs. Whether technological bias is increasing the marginal productivity of capital/intermediate inputs more than that of labor is less certain. The rise in the opportunity cost of labor and the tendency to pull labor from the grains sector reflects the growing efficiency in the economy outside of primary agriculture.

In the subperiods 1978-85 and 1986-97, the capital/land ratio rose by 38 and 53 percent, with annual increases of 4.7 and 3.6 percent, respectively. The labor/land ratio fell by 46 percent in 1978-85 and 13 percent in 1986-97, or 8.5 percent and 1.1 percent per year (table 7). We performed statistical tests to formally identify structural change in input use during the 1978-97 period. The Van der Waerden (VW), the Kolmogorov-Smirnov (KS), and the Wilcoxon score tests are applied to both the labor/land and capital/land data series. The results indicate that the location parameters of labor and capital use per unit of land are statistically significant across the two time periods, 1978-85 and 1986-97. The calculated chi-square values for the VW, KS, and Wilcoxon tests are 12.62, 2.19, and 13.71. All three results suggest that there is structural change between these two subperiods.

We argue that the current land tenure system is a major constraint to additional declines in labor use per unit of land. In fact, the growth rate of labor use in grain production actually rose almost 3.6 percent in the 1995-97 period. Under the current system, agricultural land cannot be sold, and in many areas cannot even be rented legally. Incomplete property rights mean farmers are reluctant to invest in land improvements (Perkins, 1994, pp. 28-29). Moreover, this system constrains the ability of farms to increase in size and limits the adoption of labor-saving technology.

A more extensive study is needed to explain why the decline in the labor/land ratio in grain production slowed during the last decade. However, if the land tenure system is unchanged, it will likely continue to constrain the development and expansion of labor-saving technology in China's grain sector. With increases in wages and the opportunity costs of grain production, China's competitiveness in world grain markets may well weaken.

In summary, increased input use has driven growth in China's grain sector during the last decade. Increased use of intermediate inputs and capital was the largest contributor to growth in the grain sector. The recent policy bias toward grain production has stimulated input use rather than productivity growth in the grain sector. With a slowdown in the decline of labor use per unit of land, the cost of grain production will continue to rise, which will either curb China's competitiveness in world grain markets or else restrict further growth in grain production.

Analyzing Supply Response in the Grain Sector

In the previous section, we applied a growth accounting analysis to capture the sources of growth due to technological change, differences in production efficiency, or, in general, growth in outputs not accounted for by growth in inputs. In this section, we attempt to capture the product supply and input demand responsiveness of grain producers that result from changes in prices induced primarily by shifts in government policies. This econometric approach endeavors to estimate the sources of input and output growth associated with producers' response to changes in price regimes.

In the growth accounting analysis, we did not need to address functional representation of the underlying technology or structural assumptions—such as separability in output prices and nonjointness in inputs—that are associated with multiproduct technology in agricultural supply response studies. In this section, we capture all information relevant to China's grain production structure using a restricted profit function, and empirically estimate grain production technology. We also measure the substitution and expansion (scale) effects for both inputs and outputs and conduct tests to determine whether the data are consistent with separable and nonjoint technology.

The parametrical approach attempts to capture the adjustments of output and input utilization choices in China's grain sector due to changes in prices mainly induced by adoption of the HRS and the expansion of the rural free market system. We estimate a coherent set of interrelated supply functions and input demand functions for the four grains, approximate the technology within a multiproduct framework by a restricted profit function, and test various production decisions. The input indexes constructed for each grain subsector and for the aggregate sector are consistent with the economic principles linking aggregate and individual sector accounts without compromising the economic integrity of the accounts. The data used for the parametric analysis are the same as used in the previous section (see appendix tables 1-2). The supply response analysis helps to identify the economic behavior of farmers and their responsiveness within the properties of the multiproduct production specification. Together, the growth accounting and supply response approaches provide complementary perspectives on China's agricultural growth potential.

Separability of technology assumes that prices within a group satisfy the requirements for consistent aggregation, in our case, into a total grain sector (Berndt and Wood, 1975; Lau, 1978). That is, with separability, the prices of each individual grain subsector do not depend on prices of other production activities outside the grain sector as a whole. The grain subsectors can be combined into an aggregate grain sector, the price of which is then a function of output and input production activities (outside the grain sector) that always move in fixed proportions. On the other hand, the rejection of separability in output prices implies that the individual grain subsectors cannot consistently be aggregated across the system into one aggregate grain sector and the production of grains in this case can be characterized by a nonseparable technology.[1]

Nonjointness in inputs means that when a commodity is produced by a nonjoint technology, decisions about its production are independent of decisions about the other products in the group (Lau, 1978). Nonjointness in inputs implies that the supply of a grain subsector can be examined without regard to other product prices and that the level of each output is independent of the prices of competing outputs. This is a necessary implicit assumption made for single-commodity production studies. A single-output approach does not allow measurement of the interdependencies among outputs and the differential effects of various outputs on factor demand. The rejection of nonjointness in inputs of the grain subsectors, which is explored later in the study, implies that important interactions are present in the production of all grains in China.

Because of the potential interactions among grains induced by China's rural economic reforms, and the potential for nonjointness in particular, we estimated output supply and input demand elasticities by a system of equations derived from a restricted profit-maximization specification. In China, a season of winter wheat is often followed by a season of late rice in the south, while winter wheat is followed by a season of summer corn in the north. Soybeans are often intercropped with other crops in both the south and the north. These multiproduct farming systems within households strongly suggest that the production supply response of each grain cannot be estimated independently and, thus, that the system is likely to be characterized by joint production. This means that the production level of each grain can be affected by the prices of other competing grains.

The grain sector's technology is assumed to relate two variable inputs (labor and intermediates/ capital), a fixed input (land), and four outputs (the four grains). Let $Y = (Y_1,\dots,Y_6)$ be the vector of output and variable inputs. When $Y_i > 0$, i=1,…,4, it represents an output, when $Y_i < 0$, i=5,6, it represents a variable input, and X is a fixed input (land). In addition, tech-

[1] In the growth accounting analysis, we constructed individual indexes for total outputs and inputs and for each grain subsector. The estimates of productivity growth do not require that outputs and inputs be separable (see Ball, 1985).

nology is assumed to exhibit constant returns to scale. Let $P = (P_1,\ldots,P_6)$ denote a vector of prices for outputs and inputs. Then the restricted profit, $p(P;X)$, is approximated by the translog function with arguments, P and t, where t indexes the time:

$$\ln \pi = \alpha_0 + \sum_{t=1}^{6} \alpha_i \ln P_i + \tfrac{1}{2} \sum_{i=1}^{6} \sum_{j=1}^{6} \beta_{ij} \ln P_i \cdot \ln P_j + \sum_{i=1}^{6} \rho_i \ln P_i \ln X + \sum_{i=1}^{6} \gamma_i \ln P_i \cdot t + \Theta t + \tfrac{1}{2} \vartheta t^2 \qquad (6)$$

with the following restrictions:

$$\beta_{ij} = \beta_{ji}; \sum_{i=1}^{6} \alpha_i = 1; \sum_{i=1}^{6} \beta_{ij} = \sum_{i=1}^{6} \rho_i = \sum_{i=1}^{6} \gamma_i = 0$$

Using Hotelling's lemma,

$$\frac{\partial \ln \pi}{\partial \ln P_i} = \frac{P_i Y_i}{\pi} = S_i$$

on equation 6 yields the share equations (S_i) that are linear in normalized prices:

$$S_i = \alpha_i + \sum_{j=1}^{6} \beta_{ij} \ln P_j + \rho_i \ln X + \gamma_i t,\; i = 1,\ldots,6 \qquad (7)$$

Equation 7, representing the maintained or unconstrained model, is used to estimate product supply and input demand relations and to test the hypotheses of nonjoint and separable technology. The input data used to estimate equation 7 can be found in appendix table A3. In estimating equation 7, we used a maximum-likelihood approach, taking into account convexity restrictions, meaning that the Hessian matrix of the restricted-profit function is positive semidefinite (Lau, 1978; Ball, 1988). The imposition of the constraints does not affect the Cramer-Rao lower bound for the variance of the estimator (Rothenberg, 1974). The system is estimated using the General Algebraic Modeling System.

Product Supply and Input Demand

Estimates of the parameters of the six supply-demand equations are reported in appendix table A4. The estimated parameters provide new evidence about the structure of production on China's grain farms during 1978-97. All own-price coefficients have the expected sign, which is consistent with expectations, and all are significantly different from zero at the 5-percent level. In other words, the output supply and factor demand equations possess properties that are consistent with underlying profit maximation theory. The parameter estimates satisfy the homogeneity and symmetry conditions and the estimated model was constrained to give a positive semidefinite Hessian matrix in prices. This implies that the output-supply equations have the expected own-price elasticity signs.

Consistent with the disaggregated estimates, rice and wheat are product substitutes with each other, and with corn and soybeans, since the estimated parameters are negative (see appendix table A4). On the other hand, the estimated positive parameters for corn and soybeans indicate a complementary or joint production technology.

After we incorporated into the maintained model the appropriate restrictions that are associated with weak separability in output prices, we estimated this restricted model. Then, we performed a maximum likelihood test for the restricted and the maintained model based on the hypothesis that the production technology exhibits weak separability in output prices. Our test rejected the null hypothesis at the 1-percent level of statistical significance (see appendix table A5), meaning that the system is nonseparable. This implies that we cannot aggregate the grain subsectors into one grain sector. Also, a third model was specified and estimated to account for nonjointness in inputs by incorporating the appropriate restrictions into the maintained model. When we performed the maximum-likelihood test comparing the nonjointed technology model with the maintained model, we rejected the hypothesis that the technology of grains exhibits nonjointness in inputs at the 1-percent level of statistical significance (see appendix table A5). Thus, we conclude that China's grain system follows a joint technology.

The results of these tests on the structure of grain technology are consistent with the observation that multiple production activities are the dominant cropping style in China, where the production or input requirements relate multiple outputs and multiple inputs. This also implies that the supply response of each grain should not be estimated independently as the production of grains is interrelated and depends upon the decisions regarding other grains. In short, aggre-

Table 8—Output supply and input demand elasticities

Commodity	Price of Rice (1)	Wheat (2)	Corn (3)	Soybean (4)	Labor (5)	Intermediates and capital (6)
Part 1, 1978-85:						
(1) Rice	1.48	0.96	0.46	0.04	-1.51	-1.43
(2) Wheat	1.75	0.96	0.40	0.02	-1.69	-1.45
(3) Corn	1.29	0.61	1.03	0.46	-0.84	-2.55
(4) Soybean	0.32	0.10	1.29	3.72	-0.79	-4.65
(5) Labor	2.30	1.41	0.46	0.15	-2.53	-1.79
(6) Intermediates and capital	1.61	0.89	1.01	0.65	-1.32	-2.85
Part 2, 1986-97:						
(1) Rice	1.01	0.58	0.20	-0.03	-1.09	-0.67
(2) Wheat	0.98	0.96	0.15	-0.03	-1.32	-0.74
(3) Corn	0.47	0.21	1.17	0.53	-0.25	-2.12
(4) Soybean	-0.14	-0.09	1.11	3.25	-0.37	-3.77
(5) Labor	1.76	1.25	0.18	0.12	-2.13	-1.18
(6) Intermediates and capital	0.74	0.48	1.01	0.86	-0.81	-2.29

Source: Estimated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

gation across grain subsectors is not consistent with the structure of grain technology in China.

Estimates of Supply and Demand Elasticities

The elasticities of output supply and input demand from the maintained model are presented in table 8. These elasticities are derived from the estimated equations that satisfy the homogeneity, symmetry, and convexity restrictions. In most studies, the calculated elasticities are obtained by evaluating the parameter estimates either at the sample mean values of the variable involved or at the point of approximation of the functional form. In this study, we computed the elasticities using the average factor shares for two periods, 1978-85 and 1986-97.

An important advantage in estimating a multiproduct production system is that no endogenous variables need to be used as explanatory variables in estimating it. That is, the profit function approach (in contrast with a cost or revenue function approach) avoids inconsistencies in the econometric estimates due to simultaneous equation problems in the variables involved. However, the profit function provides the gross elasticities (Marshallian elasticities) but not the structural input substitution (along an isoquant) and output expansion trade-offs (along a production possibility frontier). In this study, we separated substitution and expansion effects (see Sakai, 1974; and Nagatani, 1973, for discussions of substitution and expansion effects in production theory), and followed Lopez (1984) to obtain the same information from the profit function as from direct approaches like the cost function or revenue function specifications. A change in an output price causes the relative prices of the four grains to change. This induces technical substitution among the grains produced along the existing isoquant frontier (the substitution effect). Furthermore, relative price changes induce changes in input demand. With increases in the use of all variable inputs, output will change along the new expansion path by shifting the production possibility frontier outward (the expansion or scale effect). The substitution effect usually causes output of other grains to decline when the price for a specific grain rises and hence output of this grain increases. The expansion effect, on the other hand, can result in increases in all grains' output.

The estimated results confirm the hypotheses that grain outputs are jointly produced and that inputs are jointly employed (table 8; columns 1-4 and rows 1-4, the supply elasticities with respect to the prices of outputs; columns 5-6 and rows 1-4, the supply elasticities with respect to the prices of inputs; columns 1-4 and rows 5-6, the demand elasticities with respect to the prices of outputs; and columns 5-6 and rows 5-6, the demand elasticities with respect to the prices of inputs). Input usage varies across grain subsectors. The labor and capital elasticities (table 8, columns 1-4 and rows 5-6) capture the effects of output prices on the marginal cost of each grain subsector's production. As the elasticities for rice and wheat are very elastic, any increase in labor or capital cost would affect the production of these crops much more than the production of the other grains. The supply elasticity of each grain's production to its own price is generally greater than unity and more elastic than to prices for the other grains, which implies the dominance of own effects over cross effects (Sakai, 1974). Own-price elasticities range from 0.96 for wheat to 3.72 for soybeans in the period 1978-85 (table 8, part 1, columns 1-4 and rows 1-4). Since the own-price elasticities of soybeans, corn, and rice are greater than unity, while that of wheat is less than unity, the supply response and consequently planting options for soybeans, corn, and rice producers are greater than for wheat producers. The cross-elasticities are positive, suggesting that an increase in the output price for a particular grain would result in increased production of all grains' outputs (the scale effect). However, the cross-elasticities for all grains are not price elastic.

When the 1986-97 period is compared with 1978-85, the own-price elasticity of rice and soybeans decreased by 32 and 13 percent respectively, the own price elasticity of corn increased by 3 percent, and the own price elasticity for wheat remained the same. Also during the latter period, a competitive relationship is observed for soybeans and rice as well as soybeans and wheat (the substitution effect). In general, the magnitude of all elasticities, own and cross, decreased in this period, implying both smaller substitution and scale effects. This might have been the consequence of changes in relative agricultural prices as prices for non-grain crops started to increase relative to that of grains. This finding complements the conclusions of the growth accounting analysis, which indicated that growth rate of aggregate output slowed significantly during 1986-97, especially for rice and wheat.

The large magnitude of the labor and intermediates/capital elasticities in the 1978-85 period indicates that the increase in input usage for rice and wheat production might have resulted in the shift of the product transformation frontier outwards (the expansion effect, see table 8, part 1, columns 1-4 and rows 5-6). This shift consequently allowed increased production in all outputs (gross complementarity of outputs) in this period. During the 1986-97 period, however, the labor and intermediates/capital elasticities declined compared with that of the early period (table 8, part 2, columns 1-4 and rows 5-6). The results in table 8 indicate that the rice and wheat subsectors are more sensitive to increases in labor costs than the corn and soybean subsectors, since their responses to change in wages are very elastic (1.76 and 1.25 respectively). This also implies that as the opportunities for farm labor employment in the non-agricultural sector increase, due to the overall economic development of China, the cost of rice and wheat production might also increase considerably. On the other hand, the elasticity of capital in soybean production increased compared with that in the early period by 32 percent, implying that the soybean subsector became more sensitive to the cost of intermediate inputs and capital.

The supply response elasticities to factor prices are negative and elastic during the first period (table 8, columns 5-6 and rows 1-4), as are the own-price elasticities of the input demand functions (table 8, columns 5-6 and rows 5-6). This is consistent with economic theory, which indicates that the marginal revenue of an input increases when quantities of other inputs increase or when output prices increase (Sakai, 1974). During the 1986-97 period, however, the own elasticities of labor and intermediate inputs slightly declined. At the same time, labor demand became more inelastic to changes in corn and soybean prices while it remained elastic to changes in rice and wheat prices. Regarding intermediate inputs/capital, the changes are more drastic as the demand became inelastic with respect to rice and wheat production while remaining elastic to corn and soybean prices. This result might shed some light regarding the structural changes in input usage and input intensity, as indicated by the growth accounting method. However, further indepth analysis is needed on this issue in order to make concrete inferences.

The estimates of the factor demand elasticities suggest that returns to labor and intermediates/capital may decrease quite drastically as a consequence of increasing wages or intermediate/capital costs. Moreover, an increase in the price of intermediates/capital or wages would not only constrain the expansion of outputs, it would also change the composition of outputs because the elasticities are different across commodities. For example, an increase in wages would affect rice and wheat production more than corn and soybeans. On the other hand, changes in intermediate/capital costs would affect mostly corn and soybean production. This reinforces the findings of the role of intermediate inputs and capital in the growth accounting analysis—that increased input use has been the driving force behind China's growth in grain production.

In sum, complementarity prevails among the inputs used and the outputs produced and an increase in the price of intermediates/capital or wages would result in absolute reductions in all outputs as well as changes in the composition of outputs as the elasticities are different across commodities. In other words, higher labor costs would affect rice and wheat costs of production significantly, with a smaller effect on corn and soybean production. On the other hand, higher intermediate inputs/capital costs would affect corn and soybean production significantly, with a smaller effect on rice and wheat production. This indicates the dependency of grain production on labor and intermediate inputs/capital costs.

Technological Change

The estimated coefficient of time trend, t, captures the systematic bias in technological change (also called the constant rate of bias) for the estimation period (appendix table A4). The negative t for rice, corn, and soybeans implies that the growth rate of technological change for these three grains is below the average growth rate in the grain sector, while the opposite is true for wheat with a positive t. This is consistent with the finding from the growth accounting analysis that wheat, on average, had a higher annual TFP growth rate than the other grains (table 2).

The sign of t for inputs (labor and capital) is positive, and the value for capital is greater than that for labor (table A4). This implies the presence of a positive technological change and that such change is more capital biased. This result supports the finding that technological change resulted in higher intermediates/capital use per unit of land.

Summary and Conclusions

We used a growth accounting method to analyze the sources of output growth in rice, wheat, corn and soybeans, the four most important crops in China's grain sector, during 1978-97. We found TFP contributed greatly to growth in grain production in the period immediately after China's rural economic reform (1978-85). Most of this growth was from efficiency gains due to institutional reforms. After 1985, when efficiency gains had diminished, the growth rate of TFP fell sharply and contributed less than 20 percent to growth in grain production. In recent years (1995-97), increased use of inputs, especially intermediates/capital, became major sources of growth in China's grain sector. These results imply that recent growth in grain output may fall as wages and prices for intermediate inputs increase. The gap between TFP growth in China's grain sector and TFP growth in developed countries suggests that China can improve its grain production technology if the economic and policy environment encourages investment in agricultural research and development, water control systems, and land infrastructure.

The changes in the labor-land ratio and the intermediates/capital-land ratio over the last two decades in China are consistent with economic theory. That is, with economic growth, technological change induces less use of labor and more use of capital. However, the decline in China's labor-land ratio slowed significantly in recent years. The current land tenure system is a major factor constraining the development and expansion of labor-saving technology in China's grain sector. Given that increased input use, including labor, drove growth in China's grain sector in recent years, grain production will become more and more costly as wages and opportunity costs rise. This will likely constrain growth in China's grain production and weaken its competitiveness in world grain markets.

We also estimated the supply response for the four grains using a multiproduct framework. The parametric approach confirms the hypothesis of a nonseparable and joint production system in China's grain sector.

We separated substitution and expansion effects to obtain the same information from the restricted profit function as from direct approaches. We accounted for both the substitution and the expansion effects. The expansion effects subsided in the more recent period, implying a relatively slow outward shift in the production frontier. This result indirectly supports our finding from the growth accounting analysis that TFP grew much more slowly in recent years than immediately following rural economic reform.

Own-price elasticities of soybeans, corn, and rice are greater than unity while wheat's elasticity is less than unity. Hence, the supply response and consequently planting options for soybean, corn, and rice producers are greater than for wheat producers. Since the input use elasticities for rice and wheat are very elastic, any increase in labor or capital costs will affect the supply of these crops much more than the production of other grains.

The own- and cross-supply elasticities decreased in the 1986-97 period. This finding supports the conclusions of the growth accounting analysis, which indicates that growth in TFP slowed significantly during 1986-97, especially for rice and wheat. As labor and intermediates/capital elasticities declined in this period compared with the early period, changes in input use would not affect the composition of grain production as much as in the first period. Rice and wheat production would be affected more by increases in wages than corn and soybean production, while soybean production is overall most sensitive to the costs of intermediate inputs and capital. In general, complementarity prevails among the inputs used and the outputs produced. In addition, an increase in the price of intermediates/capital or wages would result in absolute reductions in all outputs as well as changes in the composition of outputs.

The input demand functions are price elastic, which has important implications for grain production. The estimates suggest that returns to labor and intermediates/capital may decrease quite drastically as a consequence of increasing wages or intermediate/capital costs. Changes in intermediate/capital costs would affect mostly corn and soybean production while changes in wages would affect mostly rice and wheat production. This reinforces the findings of the role of intermediate inputs and capital in the growth accounting analysis and implies that the cost of intermediate inputs and capital as well as wages might become very important in determining the grain sector's production dynamics.

Future work in identifying and measuring the sources of growth in China's agriculture should focus on disaggregating to regions (or even provinces). National analysis may obscure some important regional differences in productivity because of differences in economic development and agricultural practices across regions. In addition, future work should quantify the sources of TFP growth in China's grain sector. Sustainable TFP growth is a key factor in maintaining growth in China's agriculture. Although we point out that TFP growth slowed after 1985 due to the diminishing effect of institutional changes, a parametric approach is needed to quantitatively analyze the different sources of TFP growth.

References

Ball, V.E. (1985) "Output, Input, and Productivity Measurement in U.S. Agriculture, 1948-79," *American Journal of Agricultural Economics*, 67(3): 475-486.

Ball, V.E. (1988) "Modeling Supply Response in a Multiproduct Framework," *American Journal of Agricultural Economics*, 70(4): 813-825.

Berndt, E.R., and D. O. Wood (1975) "Technology, Prices and the Derived Demand For Energy," *Review of Economic and Statistics*, 57(1): 259-268.

Carter, C.A., J. Chen, and B. Chu (1999) "Agricultural Productivity Growth in China: Farm Level versus National Measurement." Paper presented at the 1999 Trade Policy Research and Analysis Symposium of the IATRC, San Francisco, CA.

Caves, D.W., L.R. Christensen, and W.E. Diewert (1982) "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity," *Econometrica*, 50(6): 1393-1414.

China's Ministry of Internal Trade (1988-1997) *China Commerce Yearbook*, Beijing, China: China Commerce Yearbook Publishing House.

China's National Statistical Bureau (1978-98) *China Rural Statistical Yearbook*, Beijing, China: China Statistical Publishing House.

China's National Statistical Bureau (1978-98) *China Statistical Yearbook*, Beijing, China: China Statistical Publishing House.

Crook, Frederick (1993) "Underreporting of China's Cultivated Land Area: Implications for World Agricultural Trade," *China Agriculture and Trade Report*, USDA, Economic Research Service: 33-39.

Diewert, W.E. (1976) "Exact and Superlative Index Numbers," *Journal of Econometrics*, 4: 115-145.

Evenson, R., C.E. Pray, and M.W. Rosegrant (1999) *Agricultural Research and Productivity Growth in India*, Research Report 109, International Food Policy Research Institute (IFPRI), Washington, DC.

Fan, S. (1997) "Production and Productivity Growth in Chinese Agriculture: New Measurement and Evidence," *Food Policy*, 22(3): 213-228.

Fan, S. (1991) "Effects of Technological Change and Institutional Reform on Production Growth in Chinese Agriculture," *American Journal of Agricultural Economics*, 73(2): 266-275.

Fan, S., and P.G. Pardey (1997) "Research, Productivity, and Output Growth in Chinese Agriculture," *Journal of Development Economics*, 53: 115-137.

Fang, C., and J. Beghin (1999) "Self-Sufficiency, Comparative Advantage, and Agricultural Trade: A Policy Analysis Matrix for Chinese Agriculture." Paper presented at the 1999 Trade Policy Research and Analysis Symposium of the IATRC, San Francisco, CA.

Gopinath, M., and T.L. Roe (1997) "Sources of Sectoral Growth in an Economy Wide Context: the Case of U.S. Agriculture," *Journal of Productivity Analysis*, 8: 293-310.

Hayami, Y., and V.W. Ruttan (1971/1985) *Agricultural Development: An International Perspective*, Baltimore: The Johns Hopkins University Press.

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

Lau, L.J. (1978) "Testing and Imposing Monotonicity, Convexity, and Quasi-Convexity Constraints," in D. McFadden and M. Fuss (eds.) *Production Economics: A Dual Approach to Theory and Applications*, Amsterdam, North Holland Publishing Co.

Lin, J.Y. (1992) "Rural Reforms and Agricultural Growth in China," *The American Economic Review*, 82(1): 34-51.

Lopez, R. (1984) "Estimating Substitution and Expansion Effects Using a Profit Function Framework," *American Journal of Agricultural Economics*, 66(3): 358-67.

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

Nagatani, K. (1978) "Substitution and Scale Effects in Factor Demand," *Canadian Journal of Economics*, 11(3): 521-27.

Perkins, D. (1994) "Completing China's Move to the Market," *Journal of Economic Perspectives*, 8(2): 23-46.

Rothenberg, T.J. (1974) *Efficient Estimation With A Priori Information*, New Haven, CT, Yale University Press.

Sakai, Y. (1974) "Substitution and Expansion Effects on Production Theory: The Case of Joint Production," *Journal of Economic Theory*, 9: 255-274.

Weins, T. (1982) "The Limits to Agricultural Intensification: the Suzhou Experience," in *China Under the Four Modernizations*, Part I, U.S. Government Printing Office, 462-474.

Wen, G.J. (1993) "Total Factor Productivity Change in China's Farming Sector: 1952-1989," *Economic Development and Cultural Change* 42: 1-41.

Appendix

Formulas used to calculate supply and input demand elasticities:

Elasticity with respect to own price:

$$\eta_{ii} = \frac{\beta_{ii}}{S_i} + S_i - 1$$

Elasticity with respect to prices of other commodities/ factors of production:

$$\eta_{ij} = \frac{\beta_{ij}}{S_i} + S_j$$

Values of b_{ij} are displayed in appendix table 1, while S_i is the dependent variable in equation 7. The average shares of S_i for the two periods 1978-85 and 1986-97 are used in computing the elasticities.

Appendix table 1—Quantity indices of grain outputs and inputs

	Wheat				Rice			
		---Input---				---Input---		
	Output	Land	Labor	Capital[1]	Output	Land	Labor	Capital[1]
1978	0.795	1.067	1.883	0.845	0.598	0.904	1.202	0.454
1979	0.835	1.050	1.572	0.906	0.697	0.910	1.125	0.649
1980	0.812	1.050	1.541	0.911	0.613	0.894	1.066	0.657
1981	0.836	1.032	1.320	0.894	0.662	0.877	0.904	0.663
1982	0.938	1.025	1.184	0.886	0.760	0.866	0.756	0.673
1983	0.981	0.900	1.009	0.848	0.904	0.900	0.676	0.733
1984	1.035	0.917	0.962	0.891	0.975	0.917	0.670	0.738
1985	0.979	0.994	1.007	0.948	0.953	0.906	0.609	0.739
1986	1.000	1.000	1.000	1.000	1.000	0.918	0.583	0.792
1987	1.012	0.998	0.971	1.062	0.954	0.893	0.558	0.796
1988	0.982	0.991	0.970	1.181	0.949	0.892	0.556	0.794
1989	1.046	1.013	0.984	1.286	1.009	0.925	0.580	0.793
1990	1.099	1.025	0.979	1.386	1.091	0.953	0.618	0.873
1991	1.067	1.010	0.938	1.360	1.066	0.959	0.575	0.988
1992	1.081	0.995	0.888	1.212	1.128	0.945	0.533	1.033
1993	1.031	0.941	0.836	1.119	1.182	0.937	0.564	1.003
1994	1.022	0.935	0.805	1.381	1.103	0.898	0.499	1.043
1995	1.076	0.953	0.839	1.357	1.135	0.894	0.525	0.991
1996	1.133	0.973	0.856	1.376	1.228	0.918	0.527	1.154
1997	1.166	0.984	0.861	1.406	1.369	0.932	0.523	1.314

	Corn				Soybean			
		---Input---				---Input---		
	Output	Land	Labor	Capital	Output	Land	Labor	Capital
1978	0.790	0.619	0.891	0.302	0.652	0.221	0.228	0.076
1979	0.847	0.625	0.735	0.398	0.642	0.225	0.198	0.079
1980	0.883	0.631	0.727	0.405	0.684	0.223	0.196	0.084
1981	0.836	0.602	0.605	0.386	0.803	0.249	0.184	0.102
1982	0.855	0.575	0.503	0.381	0.778	0.261	0.165	0.113
1983	0.963	0.583	0.495	0.404	0.840	0.235	0.140	0.110
1984	1.036	0.575	0.448	0.411	0.835	0.226	0.126	0.101
1985	0.901	0.548	0.414	0.381	0.904	0.239	0.129	0.142
1986	1.000	0.593	0.447	0.438	1.000	0.257	0.137	0.118
1987	1.118	0.626	0.472	0.506	1.049	0.262	0.141	0.121
1988	1.092	0.610	0.467	0.499	0.999	0.252	0.135	0.125
1989	1.114	0.631	0.491	0.547	0.881	0.249	0.131	0.124
1990	1.366	0.663	0.501	0.614	0.947	0.234	0.131	0.118
1991	1.394	0.669	0.452	0.609	0.836	0.218	0.105	0.105
1992	1.346	0.652	0.493	0.589	0.887	0.224	0.111	0.113
1993	1.449	0.641	0.453	0.545	1.317	0.293	0.152	0.162
1994	1.401	0.656	0.445	0.662	1.343	0.286	0.146	0.155
1995	1.580	0.706	0.525	0.749	1.162	0.252	0.124	0.139
1996	1.799	0.759	0.562	0.814	1.542	0.327	0.174	0.208
1997	1.472	0.737	0.542	0.799	1.615	0.346	0.179	0.247

[1] Intermediates/capital and the same for the following tables.

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

Appendix table 2—Price indices of grain outputs and inputs

	Output				Input		
	Wheat	Rice	Corn	Soybean	Land	Labor	Capital
1978	0.562	0.560	0.504	0.327	0.074	0.323	0.804
1979	0.732	0.734	0.655	0.405	0.194	0.533	0.808
1980	0.790	0.791	0.706	0.448	0.249	0.533	0.812
1981	0.831	0.833	0.743	0.707	0.371	0.667	0.826
1982	0.837	0.864	0.771	0.735	0.663	0.667	0.841
1983	0.922	0.952	0.849	0.809	1.121	0.667	0.867
1984	0.922	0.958	0.849	0.809	1.000	1.000	0.944
1985	0.941	0.959	0.865	0.832	0.801	1.000	0.989
1986	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1987	1.132	1.034	1.041	1.034	0.820	1.333	1.070
1988	1.357	1.191	1.090	1.128	0.799	1.467	1.243
1989	1.773	1.452	1.436	1.385	1.103	1.733	1.478
1990	1.642	1.336	1.402	1.363	0.870	1.833	1.560
1991	1.574	1.259	1.236	1.361	0.456	1.933	1.605
1992	1.533	1.386	1.338	1.626	0.741	2.267	1.664
1993	1.911	1.460	1.595	1.995	0.952	2.733	1.899
1994	2.942	2.222	2.413	2.286	1.510	3.967	2.309
1995	3.554	2.958	3.400	2.585	2.609	4.860	2.942
1996	3.703	3.230	3.244	3.314	2.358	6.467	3.189
1997	3.266	2.875	3.056	3.318	1.263	6.467	3.173

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

Appendix table 3—Share of value of output value of each grain and input value in total grain net revenue ($S_j S_j = 1$)

Year	Rice (S_1)	Wheat(S_2)	Corn(S_3)	Soybean(S_4)	Labor(S_5)	Capital(S_6)
1978	4.856	2.419	1.700	0.499	-3.470	-5.005
1979	2.914	1.622	1.041	0.268	-2.169	-2.676
1980	2.451	1.233	0.937	0.252	-1.691	-2.183
1981	1.837	0.971	0.646	0.324	-1.249	-1.528
1982	1.297	0.722	0.428	0.204	-0.675	-0.976
1983	0.941	0.596	0.335	0.153	-0.378	-0.646
1984	1.112	0.724	0.403	0.170	-0.604	-0.805
1985	1.239	0.818	0.413	0.218	-0.683	-1.006
1986	1.039	0.691	0.409	0.224	-0.529	-0.834
1987	1.254	0.719	0.502	0.256	-0.735	-0.996
1988	1.393	0.787	0.490	0.254	-0.768	-1.156
1989	1.287	0.676	0.437	0.183	-0.618	-0.965
1990	1.442	0.775	0.602	0.223	-0.768	-1.274
1991	1.921	1.021	0.776	0.281	-1.076	-1.922
1992	1.724	1.082	0.737	0.324	-1.123	-1.745
1993	1.341	0.782	0.620	0.386	-0.878	-1.252
1994	1.305	0.708	0.578	0.288	-0.767	-1.111
1995	1.171	0.685	0.648	0.199	-0.705	-0.998
1996	1.337	0.841	0.732	0.351	-1.027	-1.235
1997	1.844	1.268	0.857	0.560	-1.550	-1.979

Source: Calculated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

Appendix table 4—Parameter estimates for the translog restricted profit function

Parameter	Estimated value (Standard error)	Parameter	Estimated value (Standard error)	Parameter	Estimated value (Standard error)
$\alpha1$	1.491 (0.161)	$\beta23$	-0.388 (0.792)	$\beta66$	-0.001 (0.436)
$\alpha2$	1.118 (0.083)	$\beta24$	-0.271 (0.228)	$\tau1$	-0.039 (0.295)
$\alpha3$	0.840 (0.062)	$\beta25$	-0.367 (0.382)	$\tau2$	0.006 (0.234)
$\alpha4$	0.948 (0.421)	$\beta26$	0.458 (0.281)	$\tau3$	-0.047 (0.026)
$\alpha5$	-1.079 (0.161)	$\beta33$	0.956 (0.598)	$\tau4$	-0.056 (0.019)
$\alpha6$	-2.318 (0.539)	$\beta34$	0.145 (0.172)	$\tau5$	0.028 (0.032)
$\beta11$	0.836 (1.128)	$\beta35$	0.384 (0.289)	$\tau6$	0.108 (0.031)
$\beta12$	-0.371 (0.577)	$\beta36$	-0.511 (0.211)		
$\beta13$	-0.586 (0.436)	$\beta44$	1.164 (0.116)		
$\beta14$	-0.459 (0.446)	$\beta45$	0.150 (0.194)		
$\beta15$	-0.295 (0.747)	$\beta46$	-0.729 (0.142)		
$\beta16$	0.875 (0.548)	$\beta55$	0.220 (0.741)		
$\beta22$	0.939 (0.839)	$\beta56$	-0.092 (0.543)		

Note: 1 is rice, 2 wheat, 3 corn, 4 soybean, 5 labor, and 6 intermediates/capital.
Source: Estimated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.

Appendix table 5—Chi-square statistics for hypothesis tests

Hypothesis	Calculated value	Degree of freedom	Critical value 0.05	Critical value 0.01
Output separability	36.59	12	21.03	26.22
Input nonjointness	41.67	6	12.59	16.81

Source: Estimated by ERS from *China Statistical Yearbook* (1978-98), *China Rural Statistical Yearbook* (1985-98), and *China Commerce Yearbook* (1987-97) data.