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SOURCES OF GROWTH AND SUPPLY RESPONSE: A CROSS-COMMODITY ANALYSIS OF CHINA'S GRAIN SECTOR

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Abstract

A growth accounting method is used to analyze the sources of growth in China's rice, wheat, corn and soybeans, the four most important crops in China's grain sector, during 1978-97. A large TFP contribution to growth in grain production is found in the period immediately following China's rural economic reform (1978-85). In recent years the growth rate of TFP falls sharply, contributing less than 20 percent of growth in grain production, as increased use of inputs became the major engine of growth. If the current government policy environment remains unchanged, China's grain production will become increasingly costly and constrain future growth and competitiveness in world grain markets. The supply response of the four grains is estimated using a multiproduct framework. The parametric approach shows a joint production system in China's grain sector and gross complementarity in the effect of a price change on the supply of outputs and demand for inputs.

Key Words: Supply Response, Economic Growth, Productivity, China

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1. Introduction

China's agricultural output grew at an astonishing rate over the last 20 years following the introduction of economic reforms in 1978. For example, since 1978 grain output more than doubled, rising to 490 million tons in 1998. During that same period, but particularly during the 1990s, China's agricultural trade also grew very rapidly. Compared to agricultural output, however, agricultural trade was quite volatile. Nevertheless, during the 1990s, agricultural imports almost doubled, rising from US $5.5 billion in 1990 to $10 billion in 1996. Agricultural exports also rose substantially, but the majority of export growth occurred in the early part of the 1990s as government policies discouraged grain exports after the middle 1990s.

China's growing role in world trade, both as an importer and exporter, has increased the need to understand and foresee its future production growth. In order to presage China's potential in production growth, understanding China's past growth is essential, as a historical analysis can serve to spotlight the road that China has traveled in the past 20 years and the crossroads at which China currently stands. One of the key issues for historical analysis is to identify the sources of growth in China's agricultural output, especially in major crops, such as grains. For a whole host of political, social and economic reasons, the grain sector will continue to captivate the attention of the government.

The existing literature on China's past growth in agriculture is not sufficient to evaluate China's potential growth. Most of these studies were conducted in the late 1980s and early 1990s, 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 individual crops.

Most of the results from the studies examining the early reform period 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 (McMillan, et. al., 1989; Fan, 1990; Wen, 1993), precisely measuring the different contributions of institutional changes and technological changes to growth in agricultural production is a challenge.

One creative study by Lin (1992) attempted to identify the sources of total factor productivity (TFP) growth by breaking out the individual contributions of the household responsibility system (HRS), changes in government purchase prices, and the expansion in the system of rural free markets. However, because the study used aggregated agricultural data and only covered a few post-HRS years, it is difficult to accurately gauge the potential of China's future growth based on Lin's analysis.

Using a different strategy, Huang and Rozelle (1996) examined the contribution of technological change in the growth of production and successfully separated the contribution of technological change from other factors (including institutional change). However, the study only covered rice production.
In this study we use a growth accounting method on disaggregated national data for rice, wheat, corn, and soybeans from 1978 to 1997 to identify and measure the different sources of growth in these four

grains. This may provide insight on China's potential in grain production growth. A very recent study by Carter, Chen, and Chu (1999) provides a similar disaggregated analysis of six crops and two livestock products, but only for one province (Jiangsu). Given sharp differences in agricultural production structure and productivity growth across regions (Fan, 1991), it is problematic to extrapolate from their study and assess national output growth potential.

Our study also parametrically estimates supply response for these four grains in a multiproduct framework. The supply response analysis can help to identify the economic behavior of farmers. Taken together, the growth accounting and supply response approaches provide complementary perspectives of China's agricultural growth potential.

The paper is organized as follows. A growth accounting analysis is conducted in the next section. We divided the 19 years (1978-97) into three periods that correspond to major shifts in agriculture policy. The first period (1978-85) was characterized mainly by the transformation of the old commune system to the family-based HRS, while in the second period (1986-94) the focus of the reforms shifted from the rural to the urban economy. The provincial governor's grain responsibility system, implemented in 1994, was a defining agricultural policy change for the third period (1994-97). This new policy tends to promote grain production and self-sufficiency. The growth rates of the four grains are observed to be quite different in these three periods, implying strong institutional and policy impacts on China's grain production. Section three focuses on parametric estimation of supply response of the four grains based on the same data. The final section concludes.

2. Growth accounting analysis -- Sources of output growth

Over the last two decades, China's grain production increased by nearly 200 million tons, mainly due to the increase in output of rice, wheat, corn and soybeans. These four grains contributed, on average, 96 percent of growth in total grain production. The share of these four grains in total grain output rose from 80 percent in the late 1970s to 86-87 percent in the late 1990s.

Table 1. Contribution of each crop to grain growth (annual average percent)

	1978-85		1986-94		1995-97		1978-97	
	Growth rate	Contribution rate	Growth rate	Contribution Rate	Growth rate	Contribution rate	Growth rate	Contribution Rate
Total 4 grains	4.0	100	2.0	100	4.8	100	3.2	100
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

Table 1 displays growth rates for the output of these four grains. Average growth rates are calculated for the entire period (1978-97) and for the three sub-periods, 1978-85, 1986-94, and 1995-97. Table 1 also shows the contribution of each crop to growth in total grain output. The contribution share of each grain is roughly equal to the ratio of the output growth rate for each grain over the output growth rate for the grain sector, weighted by the share of this crop in the value of total grain output.

On average, wheat contributed the most (38 percent) to grain growth over the last two decades, and rice ranked second, contributing 30 percent (table 1, final column). By comparison, in value terms wheat accounted for 27 percent of the value of total grains, while rice accounted for 46 percent. The rapid growth in wheat output, 4.5 percent annually, made it the largest contributor to growth in grain output.

The output growth rate of soybeans was 5 percent per year. Due to this rapid growth rate, soybeans contributed 13 percent of growth in the total grains, though it only accounted for 8 percent of grain output in value terms. Corn accounted for 19.4 percent of the value of total grain output in average and contributed a similar share (19.5 percent) to the total growth, which implies corn's growth rate is similar to the growth of total grains.

Table 1 also shows that the growth rate varied cross the sub-periods. The growth accounting analysis conducted in this section can help to understand how and why the growth rates differed across sub-periods and different crops.

2.1 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 estimated TFP, are likely to be biased (Fan, 1997). This traditional method would be particularly problematic for the period we study because of the significant changes in production and input use structures due to China's institutional reforms and economic development over the last two decades.

In order to capture the effects of change in production or input combinations, we developed a Divisia input index for each crop and a Divisia output index for the aggregate grains (see Diewert, 1976 and Caves, et al., 1982 for discussions of the advantages of the Divisia index approach). Specifically, the input and output indices are defined as follows:

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

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

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

where $S_{f,j,t} = (p_{f,t}X_{f,j,t})/(p_{j,t}Y_{j,t})$ is the share of cost of input X_f in the revenue of crop Y_j. $S_{f,t} = (p_{f,t}X_{f,t})/\sum_j(p_{j,t}Y_{j,t})$ is the share of cost X_f in the revenue of total grains. p_f and p_j are prices for input and output, respectively. $S_{j,t} = (p_{j,t}Y_{j,t})/\sum_i(p_{i,t}Y_{i,t})$ 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 grain, respectively. Q_t is an aggregate output index. Furthermore, the levels of output and inputs are normalized to one in a specific year (1986) and then accumulate over time. The *TFP* indices in logarithmic form can be expressed as:

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

for the crop j, and

$$(5)\qquad G_{t} \equiv \ln\left(\frac{TFP_{t}}{TFP_{t-1}}\right) = \ln Q_{t} - \ln V_{t}$$

for the whole grain sector.

Growth rate of output and contributions of inputs and *TFP* to the growth in each crop and the aggregate grain can be calculated from (1) - (5). Taking the growth accounting of the grain sector as an example, the output growth rate at time t is $100 \cdot (Q_t - 1)$, the growth rate of *TFP* is $100 \cdot [EXP(G_t) - 1]$, and the contribution of *TFP* to the output growth at t is approximately equal to $100 \cdot [EXP(G_t)/Q_t]$.

In growth accounting analysis, TFP is obtained by subtracting an input index from an output index. As a residual term, TFP captures all non-physical input factors that affect output growth over time. In addition to technological change, weather, policy change, institutional change and other external shocks can affect production efficiency, i.e., change the output level with given inputs. However, technological change is usually a sustainable source of TFP growth (i.e., it is a long-term effect). Other sources of TFP growth generally only provide relatively temporary, short-term boosts to productivity. The growth accounting method by itself cannot identify the two types of sources of TFP growth (short and long term). However, the influence of short-term effects on TFP growth can be reduced by studying a longer period of time and by using a rolling average instead of a single year's rate in the analysis.

2.2 Data

The data for the quantity of each crop's output, sown area, and price indices for the outputs and inputs were obtained from the *China Statistical Yearbook*, published by China's National Statistical Bureau. The cost data, including person-day time of labor use, wages and intermediate input costs by crops, were drawn from the annual household survey, "National Crop Production Cost and Labor Productivity Survey," published in *China Rural Statistical Yearbook*. The survey covers the costs of intermediate inputs and capital depreciation, which for intermediate inputs includes fertilizers, pesticides, seeds, plastic sheeting, irrigation, energy, and draft animals, and for depreciation includes small farming tools, agricultural machinery and other capital. The intermediate input price index was obtained from the *China Statistical Yearbook* and *China Commerce Yearbook*.

We aggregated inputs into three categories: land, labor, and intermediates/capital. Because only aggregate data for costs of intermediate inputs and capital depreciation were published, we defined intermediate and capital input as a single input. The quantity of intermediates/capital is calculated by divided their expenditure by the price index.

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

It is now recognized that China's official cultivated land statistics underreport actual cultivated area (Crook, 1993). This problem may spill over to sown area statistics, since sown area is calculated as the number of times a piece of land is planted multiplied by the amount of cultivated area. It is believed that the majority of the error crept in during 196s and 1970s as a result of many rural campaigns in China (such as collectivization, the formation of communes and the Cultural Revolution). Therefore, even though the under reporting of land artificially inflates the level of yields, there is little effect on yield growth rate.

We chose to use time spent (person-days) on each crop rather than the number of laborers in agriculture as the measure for labor. There are two reasons for this decision. One is that most households raise many different crops. The second is that farmers generally only spend part of their time in agriculture because of the small size of the land cultivated by each household and because of increased opportunity in rural or urban non-farming sectors. We noted that the wage data from the survey was too low to accurately reflect the opportunity costs of rural non-farm labor. However, as the vast majority of China's land was cultivated by individual households and the incidence of hired or non-family member labor was extremely small, the underestimated returns to labor would be captured in the returns to land.

2.3 Growth accounting analysis -- contributions of TFP

On average, growth in TFP contributed more than 70 percent of the increase in the total output of the four grains over the last two decades. Growth in rice production can be exclusively explained by TFP growth, while TFP contributed 48-65 percent of output growth for soybean, corn and wheat (table 2, row 9).

Our study covers more of the post-reform contributions of TFP to the growth of China's grain sector than most other studies. One recent exception is Carter et al. (1999) which 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 for the national level the growth accounting analysis is based on gross value of agricultural output. When the inputs were weighted, the TFP growth rates calculated by Carter et al. for the four grains in Jiangsu are roughly comparable with what we calculated at the national level. (Carter et al. reports annual growth rates of TFP of 1.9, 2.6, 3.3, and 2.7 percent for rice, wheat, corn and soybeans, respectively).

Table 2. Contribution to grain production growth (annual average percent)

Output growth rate	Total 4	Rice	Wheat	Corn	Soybean
1978-97	3.2	2.0	4.5	3.3	4.9
1978-85	4.0	3.0	6.9	1.9	4.9
1986-94	2.1	0.5	1.6	5.0	4.8
1995-97	4.8	4.5	7.5	1.7	4.5
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

Many studies examine China's agricultural productivity during the 1980s. For example, Lin (1992) found that growth in TFP contributed about 50 percent of growth in total crop output in the periods 1978-84 and 1984-87. Based on Fan's (1997) growth accounting analysis, which also used Divisia input and output indices, TFP growth was found to contribute approximately 77 and 70 percent of the growth in aggregate agricultural output over the periods 1979-84 and 1985-95, respectively. These results are comparable with what we obtained in our study for the entire period of 1978-97 (table 2, column 1 row 9). For the sub-periods, however, compared to other studies our results show a much larger TFP contribution in the early period and a much smaller TFP contribution in the recent period.

We also compared our results with studies of other countries' agricultural TFP. For example, Evenson et al. (1999) found that TFP growth contributed 55 percent of growth in India's total crop production during 1956-87. In a study about sources of sectoral growth in U.S. agriculture, Gopinath and Roe (1997) found that TFP explains all of the growth in U.S. agriculture as input effects are negative.

2.4. Contribution of TFP to output growth fell over time

The contribution of TFP to the growth in grain output in each sub-period generally falls over time (table 2, column 2 and rows 10-12) although it varies by crop. In the first period (1978-85), growth in TFP exceeds growth in output for aggregate grain, rice and corn. Thus the contribution of inputs to the growth is negative. In the case of wheat and soybeans, however, TFP contributed 96 and 79 percent, respectively, of output growth for wheat and soybeans (table 2, columns 3-5 and rows 10-12).

Many studies point out that TFP growth in the early period (1978-85) also captures the efficiency gains arising from the institutional changes that occurred during that period. Under the centrally planned production system in place prior to 1978, China's agricultural production was terribly inefficient. In other words, China's production was well within its "production possibility frontier" -- a set of efficient input combinations chosen by producers on the basis of profit maximization. The most important institutional changes during this period include a shift from the collective production system to the household responsibility system (HRS); decreases in administrative intervention in agricultural production and cutting back mandatory quotas for grain purchased by the government; increases in government procurement prices; and the introduction and increase in free market activities.

Lin (1992) found that the introduction of the HRS or household-based farming system contributed more than 90 percent of growth in agricultural productivity during the early period. In contrast, Huang and Rozelle (1996) found that technological change (i.e., new varieties of rice) contributed nearly 40 percent of growth in rice yields for the 1978-84 period. However, in terms of rice, this finding is also comparable with our study given the magnitude of the calculated contribution of TFP to the growth in rice production (173 percent in 1978-85).

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

The growth rate of aggregate output fell to 2 percent in the second period (1985-94), and the growth rate of TFP fell to 0.4 percent (table 2, column 1). Thus, the contribution of TFP to the growth fell to 19 percent for all grains. And as rapid growth in rice production came to a sudden halt during this period, the TFP growth rate for rice turned negative (table 2, column 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 reduction in public investment in agricultural research and development and water control infrastructure after the early reform period (Huang and Rozelle, 1996; Fan and Pardey, 1997).

The average growth rate of grain production re-bounded dramatically during the third period (1994-97) as it reached 4.8 percent (higher even than during the first period). A rapid growth rate is observed for rice and wheat production. The growth rate of wheat output is especially rapid at 7.5 percent per year, while the growth rate of corn is quite low at only 1.7 percent.

In contrast with output growth, the TFP growth rate was only 0.8 percent per year in the third period. With a high output growth rate but a low TFP growth rate, the contribution of TFP to grain growth fell to 16 percent from 19 percent in the previous period.

The rise in grain prices relative to other agricultural products was a major force in stimulating grain production growth in the third period (table 3). 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 to take the major responsibility for ensuring sufficient grain production. Provincial governments, therefore, increased their public expenditures on agriculture by introducing various production subsidies, especially subsidies on agricultural inputs such as chemical fertilizer. In some provinces, governments returned to the use of administrative measures to stabilize grain prices and maintain the area sown to grain crops (Fang and Beghin, 1999). As the policy environment became more and more biased towards supporting grain production, inputs shifted into the grain sector at the same time as the contribution of TFP to growth actually fell.

Table 3. Change in the four grains' prices
(normalized by price index for total agricultural products)

	Rice	Wheat	Corn	Soybean	Total grains
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

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 is largely due to efficiency gains arising from institutional change. After 1985, the annual growth rate of TFP falls sharply. Increased grain output in recent years is due more to rising grain prices than to improvements in production technology. A fall in the growth contribution of TFP implies, on the one hand, that the recent growth in the grain sector will be short-lasted since it is largely due to increased input use. On the other hand, the low TFP growth also implies that the gap between TFP growth in China's grain sector and in other countries' agricultural sectors (Evenson et al.), especially developed countries (Gopinath and Roe), is quite large. If China's economic environment and government policy can encourage higher levels of investment in agricultural research and development, development better water control systems (irrigation, flood control, etc.) and improvements in land, China clearly has the potential to further increase productivity in its grain sector.

2.5 Growth accounting analysis -- Contribution of intermediate inputs and capital

In total, the increase in production factors contributed 30 percent of growth in aggregate grain output in the last two decades. The 30 percent contribution to the growth of outputs 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 three percent annually (table 4).

Table 4. Change in input use in total grain production

	Contribution of total input to growth	Change in land	Change in labor	Change in Intermediates/capital
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

Table 4 shows that 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 growth trend indicates that grain production technology was becoming more intermediate/capital intensive. Decreased use of labor and relatively stable use of land (table 4) provides further evidence.

Sown area (land) and labor days (time spent working) used in production of the four grains fell by 0.6 and 9 percent, respectively, in the first period (1978-85). The fall in acreage is observed for rice and corn production (-1.0 and -1.7 percent, respectively, table 5), while wheat and soybean acreage rose slightly (0.02 and 1.1 percent, respectively). Comparing these adjustments with national total sown area statistics, it appears 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 this period, total sown area for all crops fell by a similar percentage (0.63 percent, table 6), implying the shift in land use from grain production to non-grain crops was not the major cause in the decline in grain acreage.

Although there may be problems in the labor-day statistics in the first period (1978-85), it is nonetheless certain that labor efficiency rose significantly due to the reforms. Before the reforms, individual peasant income in China was calculated according to his (her) time (man-day) spent in the collective field without reference to the production outcome of the time spent. 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). After the HRS reform, peasant incomes were determined by their production output (and not by the number of hours or days spent in the field). Thus, the current system encouraged peasants to efficiently use labor time while producing more output.

Table 5. Change in input use in each grain crop's production

Rice	Output	Change in land	Change in labor	Change in Intermediates/capital
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	Output	Change in land	Change in labor	Change in Intermediates/capital
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	Output	Change in land	Change in labor	Change in Intermediates/capital
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	Output	Change in land	Change in labor	Change in Intermediates/capital
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

Labor's contribution to growth was observed to differ significantly depending on the calculation method selected, i.e., whether it was based on the labor day (or time spent) of peasants or the number of persons engaged in grain production. For example, in Fan and Pardey (1997), labor was calculated as the number of persons engaged in agricultural production. 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, there is a 9 percent annual decline in time spent working on grain production and the contribution of labor to growth is negative. Given that the vast majority of farmers in China allocate their time among many different crops and livestock activities, as well as to nonagricultural work activities, we believe that using 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 grain was quite stable (0.36 percent annual increase, table 6). This is consistent with the change in total sown area (a 0.35 percent of annual increase). Among the four grain crops, land sown to rice and wheat fell slightly (-0.7 and -0.09 percent respectively, table 5), while land sown to corn and soybeans rose 2 and 1.1 percent, respectively. Labor used in production of the four grains fell 1.4 percent per year over this period (though rising slightly in production of corn and soybeans). The fall in use of labor in grain production is not consistent with national statistics that show the number of agricultural laborers rose by 0.8 percent. However, in the national statistics, agricultural laborers were classified by their main production activities. That is, those engaged primarily (more than 50 percent) in agriculture were counted as agricultural laborers. Our conclusion, based on the household survey data, is that peasants working primarily in agriculture spent less time on grain production.

In the final period, 1995-97, land and labor returned to grain production, rising by 2.6 and 3.6 percent annually, respectively (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 among the four grain crops (rising). These observations all suggest that the market and policy environment during this period favored grain production.

Table 6. Change in number of agricultural laborers and sown area (average annual percent)

	Total sown acreage	Land in 4 grains	Agricultural labor	Labor in 4 grains
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

While increased input use contributed more than 80 percent of the growth in grain output in the second and third periods (table 4, column 1), different inputs played different roles in that growth. In 1986-94, increased intermediate input/capital use was a major source of growth, while in 1995-97, increased labor and land use together contributed roughly the same amount as intermediate inputs/capital to grain output growth.

2.6 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 be characterized by movement towards less use of labor and more use of intermediate inputs and capital as rapid growth in wages make labor relatively more expensive. We calculated the ratio of labor and land as well as intermediates/capital and land in order to examine whether or not technological change affected the structure of production in terms of input use per unit of land. We found that the ratio of intermediates/capital over land rose by 100 percent for total grain production over the last two decades. Normalizing the ratio for 1978 at 100, by 1997 the ratio was more than 200, with an annual rate of 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 or an annual decline of 4 percent. These changes are consistent with the theoretical expectations for the character of technological change in developing countries (Hayami and Ruttan, 1971 and 1985).

We also examined these two ratios in two sub-periods, 1978-85 and 1986-97, and found that the capital/land ratio rose by 38 and 53 percent, respectively. The annual increases were 4.7 and 3.6 percent, respectively. However, the labor/land ratio fell by 46 percent in the first period (1978-85) and 13 percent in the second (1986-97). The annual decline in the ratio is 8.5 percent in the first period versus 1.1 percent in the second (table 7).

Table 7. Change in input use per unit of land (percent)

	Labor/Land		Intermediates and capital/Land	
	Total change	Annual change	Total change	Annual change
1978-97	-53.1	-4.0	110.6	4.0
1978-85	-46.3	-8.5	37.9	4.7
1986-97	-12.6(1)	-1.1	52.7(1)	3.6

(1) The ratio in 1985 was set at 100.

We argue that the current land tenure system is a major constraint to additional declines in labor use per unit of land. Under the current system, agricultural land is not allowed to be sold, and in many areas cannot even be rented legally. The land tenure system constrains the ability of farms to increase in size. Thus, even though there has been rapid expansion of rural nonagricultural industry and large-scale rural-to-urban migration in recent years, labor use in the grain sector, as measured by time spent, did not fall.

A more extensive study on this issue may find more explanations for why the decline in the labor/land ratio in grain production slowed during the last decade. This question, however, is beyond the scope of the current study. If the land tenure system remains unchanged, it will likely continue to constrain the development and expansion of labor saving technology in China's grain sector. With increases in the wages and opportunity costs of grain production, the labor costs and total costs of grain production will rise, negatively affecting China's competitiveness in world grain markets.

In summary, increased input use has been a dominant source of growth in China's grain sector during the last decade. While increased use of intermediate inputs and capital was the largest contributor to growth in the grain sector, labor and land use did not fall in the last three years. 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.

3. Analyzing supply response in the grain sector

In this section, we employ a parametric approach to examine the structure of China's grain sector and analyze the effects of prices on production decisions (i.e., supply response). In the previous growth accounting analysis, problems regarding the choice of production function structure are ignored since the calculation of growth contributions by inputs and TFP are based on the index number procedure. In parametric analysis, we capture the *total* effects of changes in prices of outputs or inputs on the supply of all outputs and demand for all inputs.

As in the earlier analysis, we focus on the output of China's four major grains--wheat, rice, corn, and soybeans. Because of the potential interactions between the grains, we specify a restricted profit function to estimate output supply and input demand elasticities by a system of equations derived from the profit-maximization specification. The method is derived from Ball (1988).

Double cropping or inter-cropping is prevalent in China. For example, 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 inter-cropped with other crops in both the South and the North. Multiproduct farming systems within households strongly suggests the production supply response of each grain cannot be estimated independently. As grain production is not separable in terms of outputs and input uses, the production level of each grain can be affected by the prices of other grains.

The grain sector's technology is assumed to relate two variable inputs (labor and intermediates/ capital), one fixed input (land), and four outputs (the four grains). Let $Y = (Y_1,\ldots,Y_6)$ be the vector of output and variable inputs, and when Yi > 0, i=1,…,4, then it represents an output, and when Yi < 0, i= 5,6, it represents an input. In addition, technology is assumed to exhibit constant returns to scale. Let $P = (P_1,\ldots,P_6)$ denote a vector of prices for output and inputs. Then the restricted profit, $\pi(P)$, can be approximated by the translog function with arguments, P and t, where time t indexes the time:

(6) $$\ln p = a_0 + \sum_{i=1}^{6} a_i \ln P_i + \tfrac{1}{2}\sum_{i=1}^{6}\sum_{j=1}^{6} b_{ij} \ln P_i \cdot \ln P_j + \sum_{i=1}^{6} g_i \ln P_i \cdot t + q\, t + \tfrac{1}{2} J\, t^2,$$

with the following restrictions:

$$b_{ij} = b_{ji};\ \sum_{i=1}^{6} a_{i} = 1;\ \sum_{i=1}^{6} b_{ij} = \sum_{i=1}^{6} r_{i} = \sum_{i=1}^{6} g_{i} = 0.$$

Using Hotelling's lemma,

$$\frac{\partial \ln p}{\partial \ln P_i} = \frac{P_i Y_i}{p} = S_i,$$

on equation (6) yields:

$$(7) \qquad S_i = a_i + \sum_{j=1}^{6} b_{ij} \ln P_j + g_i t, \quad i = 1,\ldots,6.$$

Equation (7), representing the maintained model, is estimated and used to test whether output separability and input nonjointness prevail. In estimating (7), using the maximum likelihood approach, and taking into account the convexity restrictions, 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 (GAMS, 1988).

The parameter estimates and the associated standard errors are reported in table A1 (see Appendix). The hypotheses that the production technology exhibits weak separability in output prices and nonjointness in inputs are both rejected at the 1% level of statistical significance. The statistics for the hypothesis tests are reported in table A2. The result of the test on the structure of production is consistent with the observation that multiple production activities are the dominant cropping style in China. This implies that the supply response of each grain production should not be estimated independently.

The elasticities of output supply and input demand obtained from the maintained model are in table 8.[1] Besides the elasticities at the point of approximation reported in table A3, we calculate the average elasticities for the two periods, 1978-85 and 1986-97. The estimated results show that grain outputs are jointly produced and the inputs are jointly employed. In general, gross complementarity prevails among the inputs used and the outputs produced.

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

[1] The way to calculate the supply and input demand elasticities can be found in the Appendix.

(Sakai, 1974). A gross complement relationship is observed (i.e., 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 (table 8, columns 1-4 and rows 1-4). However, with few exceptions, the cross-elasticities for all grains are not price elastic.

The gross complementarity among inputs and among outputs captures the *total effect* of price variation, which can be decomposed into a *substitution effect* and an *expansion effect*. 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 (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 outward (expansion 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 expansion effect is usually ignored by conventional supply response analysis in which estimation is conducted independently for each grain.

The magnitude of the positive elasticities of input demands with respect to output prices (table 8, columns 1-4 and rows 5-6) provides further support for the existence of a gross complement relationship among the outputs.

Table 8. Output supply and input demand elasticities

	Elasticity with Respect to Price of					
Commodity	Rice (1)	Wheat (2)	Corn (3)	Soybean (4)	Labor (5)	Intermediates and capital (6)
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
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

The competitive relationship is only observed for soybeans and rice, and soybeans and wheat for the second period (1986-97). Moreover, the magnitude of all elasticities, own and cross, falls in this period. This finding supports one of the conclusions of the growth accounting analysis – that growth in TFP slowed significantly during the second period.

The supply response to factor prices is negative and price elastic, which is consistent with economic theory (table 8, columns 5-6 and rows 1-4). Moreover, an increase in the price for intermediates/capital or wages would result in absolute reductions in all outputs as well as changes in the composition of outputs because the elasticities are different across commodities.

The input demand functions are also generally price elastic (table 8, columns 5-6 and rows 5-6), which is consistent with supply response to changes in factor prices. The gross complementarity of the inputs (i.e., the cross-elasticities of input demand are all negative) suggests that an increase in output would be accompanied by increases in the demand for all factors of production. We also observe from table 8 that the supply and input demand elasticities fall in the second period of 1986-97 comparing with those in 1978-85.

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. The negative t for rice, corn, and soybeans implies that the growth rate of technological change in production of these three grains is below the average growth rate of technological change in the grain sector, while the opposite is true for wheat with a positive t. This result is consistent with the findings from the growth accounting analysis in the previous section, i.e., that wheat on average had a higher annual TFP- growth rate than the other grains (table 2).

The sign of t for the inputs (labor and capital) is positive, and the value of it for capital is greater than that for labor. This implies the presence of a positive technological change and that such change is more capital biased. This result further supports the findings in the previous section, i.e., that technological change resulted in more intermediates/capital usage per unit of land.

4. 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 a large contribution of TFP to growth in grain production in the period immediately after China's rural economic reform (1978-85). Most of this growth can be explained as the efficiency gains due to the institutional changes of the reform. After 1985, the growth rate of TFP 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. 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 has the potential to improve its grain production technology if the economic and government policy environment encourages investment in agricultural research and development, developing better water control systems and supporting land improvements.

The changes in the labor-land ratio and the intermediates/capital-land ratio over the last two decades in China fall within the predictions of economic theory, i.e., that with economic growth, technological change is induced towards 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 the fact that increased input use, including labor, was a dominant source of 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 constrain future growth in China's grain production and its competitiveness in world grain markets.

We also estimate the supply response for the four grains using a multiproduct framework. The parametric approach shows a joint production system in China's grain sector. The estimated results are consistent with economic theory for a joint production system. Once the expansion effect is taken into account in the systematic estimation, the total effect of a price change on the supply of all outputs and demand for all inputs is found to exhibit gross complementarity. The complement effects became smaller in the more recent period, implying a relatively slow outward shift of the production frontier. This result indirectly supports our findings from the growth accounting analysis that TFP grew much more slowly in recent years than during the early period immediately following rural economic reform.

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Appendix

Formulas used to calculate supply and input demand elasticities:

Elasticity with respect to own price:

$$h_{ii} = \frac{b_{ii}}{S_i} + S_i - 1.$$

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

$$h_{ij} = \frac{b_{ij}}{S_i} + S_j .$$

Values of b_{ij} are displayed in Table A1, while S_i is the dependent variable is Equation (2). The average shares of S_i for the two periods of 1978-85 and 1986-97 are used in computing the elasticities.

Table A1. Parameter estimates for the translog restricted profit function

Parameter	Estimated Value & (Standard error)	Parameter	Estimated Value & (Standard error)	Parameter	Estimated Value & (Standard error)
α_1	1.491 (0.161)	β_{23}	-0.388 (0.792)	β_{66}	-0.001 (0.436)
α_2	1.118 (0.083)	β_{24}	-0.271 (0.228)	τ_1	-0.039 (0.295)
α_3	0.840 (0.062)	β_{25}	-0.367 (0.382)	τ_2	0.006 (0.234)
α_4	0.948 (0.421)	β_{26}	0.458 (0.281)	τ_3	-0.047 (0.026)
α_5	-1.079 (0.161)	β_{33}	0.956 (0.598)	τ_4	-0.056 (0.019)
α_6	-2.318 (0.539)	β_{34}	0.145 (0.172)	τ_5	0.028 (0.032)
β_{11}	0.836 (1.128)	β_{35}	0.384 (0.289)	τ_6	0.108 (0.031)
β_{12}	-0.371 (0.577)	β_{36}	-0.511 (0.211)		
β_{13}	-0.586 (0.436)	β_{44}	1.164 (0.116)		
β_{14}	-0.459 (0.446)	β_{45}	0.150 (0.194)		
β_{15}	-0.295 (0.747)	β_{46}	-0.729 (0.142)		
β_{16}	0.875 (0.548)	β_{55}	0.220 (0.741)		
β_{22}	0.939 (0.839)	β_{56}	-0.092 (0.543)		

Note: 1 is rice, 2 is wheat, 3 is corn, 4 is soybean, 5 is labor, and 6 is intermediates/capital.

Table A2. Chi-square statistics for hypothesis tests

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

Table A3. Output supply and input demand elasticities at the point of approximation

	Elasticity with Respect to Price of					
Commodity	Rice (1)	Wheat (2)	Corn (3)	Soybean (4)	Labor (5)	Intermediates and capital (6)
1978-85						
(1) Rice	1.052	0.869	0.447	0.640	-1.277	-1.731
(2) Wheat	1.159	0.958	0.493	0.706	-1.407	-1.908
(3) Corn	0.793	0.656	0.978	1.121	-0.622	-2.926
(4) Soybean	1.007	0.832	0.993	1.176	-0.921	-3.087
(5) Labor	1.764	1.458	0.484	0.809	-2.283	-2.233
(6) Intermediates and capital	1.114	0.920	1.060	1.262	-1.039	-3.318

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