Recent Trends in China's Agricultural Productivity Growth at Province Level: 1985-2007[1]

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Abstract

In this study, we estimate the total factor productivity (TFP) growth for twenty-five contiguous China provinces for the 1985-2007 period. The estimates are based on a multilateral spatial linked measurement approach. The sources of aggregate output growth for each province were decomposed into TFP growth and input growth, where input growth was further decomposed into contributions from growth of labor, capital, land, and intermediate goods. Over the study period, productivity growth contributed 2.7 percentage points to output growth annually, which was slightly higher than the input growth contribution of 2.4 percentage points per annum. Coastal provinces tended to have higher productivity growth rates than others. On average, the annual rate of productivity growth peaked during 1996-2000, at 5.1 percent. It slowed in 2000-2005 to a rate of 3.2% per annum and declined in the most recent years (2005-2007) to -3.7 percent.

Key words: China agricultural productivity, Total factor productivity (TFP), Törnqvist-Thiel (TT) index, China agricultural policy, multilateral comparison

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1. Introduction

Since late 1978 China has implemented a series of market-oriented reforms including deregulating market, commercializing production, facilitating agricultural trade, and much more. As a result, China's growth in real gross domestic product (GDP) averaged around 10% per annum from 1978 to 2007, the highest in the world. Reforms also led to rapid transformation in rural China. The expansion of China's agricultural output since 1979 is remarkable. China's grain output increased from 305 million metric tons in 1978 to over 500 mmt in 2007, an annual growth rate of 2.5 percent. Such growth is much faster than its population growth rate of one percent per annum. The value added in agriculture rose at an even higher annual rate of 4.8 percent due to the increased diversification and specialization in agricultural production over time. This growth formed the basis for China's broader macroeconomic growth during the ensuing decades. However, the gains from past reforms seem to be distributed unequally among regions (Fan and Zhang, 2002).

Many studies have assessed the impact of reform on China's agricultural productivity growth for the post-1978 era (McMillan, Whalley, and Zhu, 1989; Fan, 1997; Mao and Koo, 1997; Fan and Zhang, 2002, Lin, 1992; Wen, 1993; Jin et al., 2002, among others). However, most of these studies only evaluate the productivity growth for years up to 1990s. No matter which method was in use economists have reached a similar conclusion that agricultural productivity growth during the immediate post-1978 period was high. As to the source of growth, McMillan, Whalley, and Zhu (1989) suggested that between 1978 to 1984, 78 percent of the increase in agricultural productivity in China can be attributed to the incentive effects of institutional change, the new Household Responsibility System introduced in late 1978. Lin (1992) also indicated that “decollectivization” was important in improving productivity growth. It accounted for half of output growth during 1978-1984. Zhang and Carter (1997) suggested a lower but still significant impact from economic reforms. They asserted that the institutional impact of economic reform expanded about 38% of production growth from 1980 to 1985. Besides the impact of institutional changes on productivity growth, Stone (1998) indicated that increased input use such as fertilizer and other inputs also contributed to farm output. On the other hand, Brown (1994) pointed out the limitation of contribution from input growth in agricultural production and suggested that continuing productivity growth was crucial in maintaining sustainable agriculture production in China. While Fan and Pardey, 1997; Fan, 2000; Huang, Hu, and Rozelle, 2002; Rozelle, Huang, and Otsuka, 2005; and Hu et al., 2007 among others, showed a high return and important role of public research investment in China’s agricultural productivity growth we are unable to identify the impact of China’s serial reforms or science policy in the long-run due to lack of information on China’s agricultural productivity growth for more recent years.

Among China’s agricultural productivity studies, most were based on commodity-specific measurement or data from either a single region or the entire national agricultural sector in aggregate, often together with data from other countries for international comparison purpose (Nin-Pratt, Yu, and Fan , 2010; Coelli and Rao, 2003; Fuglie, 2008, among others). For example, Colby, Diao, and Somwaru (2000) analyzed four crops’ source of growth during 1978-97. They found large total factor productivity contributions to growth in grain productivity immediately flowing China’s rural economic reform (1978-1985). In 1995-97, TFP’s contribution to output growth dropped as inputs’ contribution grew. Carter, Chen and Chu (2003) use farm level data, aggregate data for Jiangsu province, as well as aggregate national data to measure agricultural TFP growth. Their results show that TFP growth was strong during the immediate post-reform 1978-1987 period. However, using the farm level data, productivity slowed from 1988 to 1996. On the other hand, productivity continued to grow based on national data during the same period. Rae et al. (2006) employ a stochastic frontier approach to estimate TFP for four major livestock products in China. They found that TFP growth across five geographic regions was on average slightly slower in the 1990s than in the 1980s. On the other hand, Jin, Huang, and Rozelle (2010) measure China's agricultural productivity growth using stochastic frontier approach for 23 commodities. They found that productivity growth varied from commodity to commodity. Their results show that, in general, the productivity growth for the 1995 to 2004 period was faster than for the 1985 to 1994 period. Based on national data Nin-Pratt, Yu, and Fan (2010) found faster productivity growth in the post-reform period. However, it seems besides agreeing on a high productivity growth during the immediate years after 1978's reform there is no consistent answer for an overall China's agricultural productivity growth over a longer period. Also, with a few exception (Fan and Zhang, 2002), Tong, Fulginiti, and Sesmero (2012) there is little comparative information on agricultural productivity at the provincial level.

Among a few provincial level studies, Fan and Zhang (2002) employed the Törnqvist-Theil index methodology to measure regional as well as national productivity growth for China agricultural sector. Using regional estimates they identified the growth patterns among regions and stated that the less-developed areas may have benefited less from reforms than was previously thought. Their results show a much faster productivity growth during the 1979-1997 period compared with the pre-reform period (1952-1978). Yet, their estimates only cover up to the year 1997. Using data from more recent years Tong, Fulginiti, and Sememo (2012) employ

Malmquist index and stochastic production frontier approaches to measure provincial level productivity growth during the 1993-2005 period. They found that agricultural productivity growth in China was higher in the mid-1990s than in the late 1990s, with a trend reversal around 1998; growth in productivity picked up again during the 2000s. However, their aggregate output is measured in constant 1993 prices. Fan and Zhang (2002) pointed out that constant prices may not be the appropriate weights in aggregating total output because the growth rates calculated from these constant prices may be seriously biased, especially when relative prices have changed. In addition, neither of these studies showed how the relative productivity levels varied from province to province nor did they show how output and input composition shifted through years and across regions.

To have a better understanding on how China's agricultural productivity evolved across regions and over time after 1985 and how productivity level varied among regions, this study first develops new estimates of China's agricultural productivity growth based on provincial data for 1985 to 2007 period. We utilize a broad measure of major crops and livestock outputs, and land, labor, capital, and intermediate goods inputs (including fertilizer, pesticide, energy, feed, seed, irrigation, and other materials) at the provincial level. Second, we apply multilateral comparison techniques not used in previous China studies to construct a spatial-linked TFP panel for twenty-five adjacent Chinese provinces to understand the variations in relative productivity level among regions over the study period. These measures can be used to evaluate the impact of China's reforms or policies on agricultural productivity growth regionally.

This study provides a new assessment of China's agricultural productivity growth based on provincial data from 1985-2007, a longer time series that includes the early years following reforms as well as more recent decades that were not available in earlier studies. The study includes broader coverage of outputs and inputs than previous studies which often focused on grains or a limited scope of commodities. This study provides geographic perspective by utilizing provincial data. China is a large, geographically diverse country. Regions differ in their resource endowments and access to capital and technology. We apply multilateral comparison techniques to construct a longitudinal spatially-linked total factor productivity (TFP) panel. Our estimates indicate that livestock output grew faster than crops and input composition shifted over time with intermediate goods accounting for most of the input growth. Unfortunately, the provinces with the lowest productivity level in 1985 still remained on the bottom indicating an unequal distribution of productivity gains across regions.

The paper is organized as follows. In the next section we briefly present China's agricultural policies to understand the forces that may shape the country's agricultural sector. In section 3 we introduce the methodologies used in measuring aggregate outputs, aggregate inputs, and multilateral TFP indices among regions. We also describe how we measure individual inputs and their corresponding data sources. Sections 4 and 5 present the estimates of output growth, input growth, and total factor productivity growth at China's provincial level as well as the sources of aggregate output growth. Section 6 discusses formal tests for the potential impact of policies on TFP growth and section 7 summarizes the results and conclusions.

2. Brief Review of China's Agricultural Policies

During the first half of the 20th century, China was a nation composed largely of poorly performing agricultural sector with little surplus to withstand years of floods, droughts, pest infestations, or wars. An ill-fated push for *collectivized* agriculture during 1958-60 resulted in what was probably the worst famine in China's history. In the 1960s and 70s China's agriculture grew marginally during years of political upheaval. In the late 1970s China began dismantling the collective agricultural system by adopting the "household responsibility system (HRS)" that allocated land production rights to individual households and subsequently established a more market oriented agriculture. The new system has created more incentive for farmers to improve their productivity and increase their production. The government then gradually liberalized prices and allowed partial privatization of agricultural markets in the 1980's. This series of rural reforms has motivated farmers to adopt cost reducing practices and new technologies (Colby, Diao, and Somwaru, 2000; Lohmar et al., 2009).

In the mid-1990's China abandoned its food rationing system, and adopted a "governors' grain-bag responsibility system" that required each province to maintain an overall balance of grain supply and demand to ensure food security while it regulated local markets. In the late 1990s the government also encouraged farmers to produce high value-added agricultural products that could bring higher returns per unit of land, such as vegetables, fruits, livestock, aquatic products, medicinal herbs, and flowers.

China's joining the World Trade Organization in 2001 brought reduction in protection policies and increased imports of a few commodities—notably soybeans and cotton (Huang, Rozelle, and Chang. 2004). In 2004, to elevate farmers' incentives for grain cultivation, China's government reversed a historical policy which taxed agricultural production. The new policy provided funds in the form of direct payments to grain producers, and subsidies for purchased inputs. In brief, after several years of experimentation, China began a nationwide push to phase out agricultural taxes in 2004 and the taxes on farmer households were totally eliminated in 2006. All these policies implemented in recent years were continuously aimed to increase

Chinese farmers' income as well as to provide incentives for food security especially food grains (Lohmar et al., 2009).

3. Measures of Output, Input, Total Factor Productivity, and Data Sources

Total Factor Productivity

A total factor productivity (TFP) index takes account of the use of all inputs to the production process. Among the measurements, the Törnqvist-Theil (TT) index is usually used to approximate the Divisia index. The quantity estimate using a TT index is based on the rolling weights that can accommodate any substantial changes in relative prices over time. Based on the growth of aggregated output and input, the total factor productivity (TFP) growth between two subsequent periods of time can be expressed as the difference between these two indexes:

$$ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i \frac{1}{2} * \left(R_{i,t} + R_{i,t-1}\right) * \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j \frac{1}{2} * \left(W_{n,t} + W_{n,t-1}\right) * \ln\left(\frac{X_{n,t}}{X_{n,t-1}}\right) \quad (1)$$

where *lnTFP* is the log of the TFP index; R_i's are the shares of output *i* in total revenue and W_n's are the shares of input n in total cost at time *t* and *t-1*, respectively; Y_i's and X_n's are the quantities of output *i* and input *n* at time *t* and *t- 1*, respectively.

Caves, Christensen, and Diewert (1982) proposed a methodology of multilateral comparisons on outputs, inputs, and productivity using superlative index numbers. They defined an output comparison so that transitive results are obtained in the multilateral setting. The translog multilateral output index between region *k* and region *l*, δ^*_{kl}, is defined as the geometric mean of the bilateral output comparisons (δ_{ks}, δ_{ls}) between regions *k, l* and each of other regions *s*, shown as equations (2) and (3) below:

$$\overline{\ln \delta_k} = \frac{1}{S}\sum_{s}^{S} \ln \delta_{ks} \qquad (2)$$

$$\overline{\ln \delta_l} = \frac{1}{S}\sum_{s}^{S} \ln \delta_{ls} \qquad (3)$$

Caves, Christensen and Diewert (1982) have shown that the multilateral output index can be expressed as follows:

$$\ln \delta_{kl}^{*} = \overline{\ln \delta_k} - \overline{\ln \delta_l} = \frac{1}{2}\sum_{i}(R_i^k + \overline{R}_i)(\ln Y_i^k - \overline{\ln Y_i}) - \frac{1}{2}\sum_{i}(R_i^l + \overline{R}_i)(\ln Y_i^l - \overline{\ln Y_i}) \qquad (4)$$

$\overline{R_i}$ are arithmetic means of revenue shares for output i; $\overline{\ln X_n}$ are geometric means of input n among regions.

Following the same concept, the translog multilateral input index between region *k* and region *l*, ρ_{kl}^{*}, can be expressed as follows:

$$\ln \rho_{kl}^{*} = \overline{\ln \rho_k} - \overline{\ln \rho_l} = \frac{1}{2}\sum_{i}(W_n^k + \overline{W}_n)(\ln X_n^k - \overline{\ln X_n}) - \frac{1}{2}\sum_{n}(W_n^l + \overline{W}_n)(\ln X_n^l - \overline{\ln X_n}) \qquad (5)$$

Where $\overline{\ln \rho_k}$, $\overline{\ln \rho_l}$ are the relative inputs of regions *k, l,* to all s regions:

$$\overline{\ln \rho_k} = \frac{1}{S}\sum_{s}^{S} \ln \rho_{ks} \qquad (6)$$

$$\overline{\ln \rho_l} = \frac{1}{S}\sum_{s}^{S} \ln \rho_{ls} \qquad (7)$$

$\overline{W_n}$ are arithmetic means of cost shares for input n; $\overline{\ln X_n}$ are geometric means of input n among regions. The multilateral total factor productivity (TFP) index based on a flexible translog functional form for region *k* and region *l* can then be expressed as the following equation:

$$\ln \lambda_{kl}^{*} = \overline{\ln \lambda_k} - \overline{\ln \lambda_l} = \frac{1}{2}\sum_i (R_i^k + \overline{R}_i)(\ln Y_i^k - \overline{\ln Y_i}) - \frac{1}{2}\sum_i (R_i^l + \overline{R}_i)(\ln Y_i^l - \overline{\ln Y_i}) -$$

$$\frac{1}{2}\sum_n (W_n^k + \overline{W}_n)(\ln X_n^k - \overline{\ln X_n}) - \frac{1}{2}\sum_n (W_n^l + \overline{W}_n)(\ln X_n^l - \overline{\ln X_n}) \quad (8)$$

Where $\overline{\ln \lambda_k}$, $\overline{\ln \lambda_l}$ are the relative productivities of regions *k, l,* to all s regions:

$$\overline{\ln \lambda_k} = \frac{1}{S}\sum_s^S \ln \rho_{ks} \quad (9)$$

$$\overline{\ln \lambda_k} = \frac{1}{S}\sum_s^S \ln \rho_{ks} \quad (10)$$

Under these settings the translog multilateral output, input, and productivity indices are all transitive.

$$\ln \delta_{kl}^{*} = \ln \delta_{km}^{*} - \ln \delta_{lm}^{*} \quad (11)$$

$$\ln \rho_{kl}^{*} = \ln \rho_{km}^{*} - \ln \rho_{lm}^{*} \quad (12)$$

$$\ln \lambda_{kl}^{*} = \ln \lambda_{km}^{*} - \ln \lambda_{lm}^{*} \quad (13)$$

Therefore, using a base region *l*, we can construct normalized multilateral TFP index among regions. The expression of the TFP index among regions can also be expressed as follows:

$$\ln(\frac{TFP_k}{TFP_l}) = \frac{1}{2}\sum_i (R_i^k + \overline{R}_i) * \ln(\frac{Y_i^k}{\tilde{Y}_i}) - \frac{1}{2}\sum_i (R_i^l + \overline{R}_i) * \ln(\frac{Y_i^l}{\tilde{Y}_i}) - \frac{1}{2}\sum_n (W_n^k + \overline{W}_n) * \ln(\frac{X_n^k}{\tilde{X}_n}) - \frac{1}{2}\sum_n (W_n^l + \overline{W}_n) * \ln(\frac{X_n^l}{\tilde{X}_n}) \quad (14)$$

where a bar indicates the arithmetic mean and a tilde indicates the geometric mean. In this study we construct the multilateral input, output, and TFP index for twenty-five contiguous provinces in China using Anhui province as the base province for the period 1985 through 2007.

Output, Input, and Data Sources

We compiled annual data on agricultural output and input for twenty-five contiguous provinces and autonomous regions in China (we use the term “provinces” for all of the provinces and regions hereafter), including Anhui, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hebei, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Ningxia, Qinghai, Shaanxi, Shandong, Shanxi, Sichuan (Chongqing city is combined with Sichuan), Xinjiang, Yunnan, and Zhejiang. We excluded three province-level municipalities (Beijing, Tianjin, and Shanghai), one island province (Hainan) and one autonomous region (Tibet) due to their small size in agricultural production and lack of consistent and accurate data. The time period for this research begins in 1985 since that was the first year that some critical data needed for the study were available.

Output

We use prices from major crops including corn, cotton, peanut, rice, soybeans, and wheat, and major livestock including milk, pork, beef, mutton, chicken, and eggs to construct multilateral price indices using 1994 as the base year and Anhui as the base province. The estimates will not be affected by which base year or base province was chosen as the results are transitive across provinces and over years. Aggregate output is then measured as a longitudinal implicit quantity panel deflated by the multilateral price indices. We exclude fishery production from our estimates due to lack of detailed information on its output and inputs. Data for the value of aggregate output and output of individual products are from the China Rural Statistical Yearbook (various years). Individual crop prices are from the National Agricultural Product Cost and Revenue Survey data books. Individual livestock prices are from the China Animal Husbandry Yearbook.

Intermediate goods

We construct the price index for intermediate goods based on the Törnqvist index method using the prices and cost shares for fertilizer, pesticide, energy, seed, and feed. The total values of intermediate goods as well as quantities of fertilizer, pesticide, and energy are drawn from China Rural Statistical Yearbooks. Since Yearbooks only report the price index for those inputs, we use the published cost information for some specific years[3] from the China Rural Statistical Yearbooks to impute the average prices by dividing the cost with quantities for those specific years. We then chain link the prices with the price indices reported in the China Statistical Yearbooks to develop the fertilizer, pesticide, and energy price series.

For some specific years, the average seed prices can be measured using the seed cost[4] divided by the sown area as a proxy. We then chain linked these prices with constructed crop price indices from each province to get the seed price series for each province. The seed costs are measured by the multiplication of seed prices and sown area. Feed prices use the feed crop price as a proxy. The implicit quantities of feed are calculated based on a percentage of the implicit quantity of livestock.

[3] The data are only available for some specific years.
[4] The cost of seed, feed, and other inputs are reported for some specific years but not every year.

Land

In China, there is no private ownership of land and therefore no reported land value. Following Fan and Zhang (2002) we use the residual of total revenue to impute rental costs. The rental rate is the total rental cost divided by the arable land area. The official data on arable land were believed to underestimate the total area in the past. Since we are unable to justify this under-reporting land area, we use the official land data reported in China Statistical Yearbooks (various issues) in our estimates. The number after 1996 is based on 1996 China land census data. The 1996 land census data has shown discontinuity between 1995 and 1996 for many provinces. As Lin and Ho (2003) indicate, "the 1996 land survey revealed a total cultivated land area of 130 million hectares, nearly 40 percent more than what was reported by local cadres to the State Statistical Bureau. Much of the "discovered" farmland was located in the hilly and mountainous regions where the quality of land is low". In our study, to avoid the bias in TFP measurement due to the sudden increase of land use in 1996 we exclude the TFP growth rate of 1996 in our reported average annual TFP growth rate as the dramatic increase in land area could cause a sudden drop in TFP in 1996.

Capital

In this study we apply the perpetual inventory method (PIM) to measure the capital stocks. The quantities and prices of capital input are the rental rates and the service flow based on the capital stocks we construct for each province. We classify the capital input by three types of assets: structures, equipment, and draft animals. The PIM cumulates investment data measured in constant prices into a measure of capital stocks. The measurement can be shown as the following equation:

$$K_t = \sum_{\tau=0}^{\infty} d_\tau I_{t-\tau} \quad (15)$$

where K_t is the capital stock at the end of time t, d_τ is the relative efficiencies of capital goods at age τ, $I_{t-\tau}$ is the investment at time t-τ. There are three kinds of relative efficiency patterns: the declining balance pattern, the one-hoss shay, and the straight line pattern. In this study we adopt a declining balance pattern with geometrically declining efficiency for the investment. Therefore, equation (15) can be expressed as the following equation in discrete time:

$$K_t = K_{t-1} + I_t - \delta K_{t-1} \quad (16)$$

where δ is the depreciation rate and is equal to the rate of replacement. In this case we need data on capital stock benchmark, capital investment, investment price deflator, and the depreciation rate for each type of capital.

Since there is no reported agricultural capital stock benchmark data at the provincial level to our knowledge, we estimated a steady state capital benchmark for 1984 (the year before our study period following Harberger's (1978) method. This method has been applied often in the literature (Sun, Fulginiti, and Peterson, 2007 among others) when the capital benchmark is unavailable. We first assume a steady-state relation between the steady-state investment (I^*) and the steady-state capital stock (K^*):

$$I^* = (g + \delta) K^* \qquad (17)$$

where g is the growth rate of real investment and δ is the depreciation rate. The initial capital stock can be retrieved with the following equation

$$K^* = I^* / (g + \delta) \qquad (18)$$

Then by adding investment during the previous period and deducting depreciation we can rebuild the capital stock series. The capital expenditure is mainly drawn from China Rural Statistics Yearbook. The data is allocated to three categories—buildings, machinery, and draft animals based on the composition of the agricultural assets from each province.

Under the geometric efficiency decline pattern, the depreciation rate is equal to the rate of replacement. Following Sun and Ren (2008) we apply 8% depreciation rates for structures and 17% depreciation rate for equipment and draft animals. For the special case $d_\tau=\delta(1-\delta)^{\tau-1}$ (Jorgenson, 1963, 1973, Ball et al., 2008), the rental rate can be shown as

$$c=w(r+\delta) \qquad (19)$$

where d_τ is the relative efficiency of the capital goods at time period τ, c is the rental price of capital service, w is the purchase price (new investment) of the asset, and r is the real rate of return of this investment (opportunity cost of this investment) calculated as the nominal rate of loans to state and industries less the inflation rate measured with the GDP deflator in China. The rates of loans and GDP deflators are drawn from the IMF database.

4. Sources of China's Agricultural Output Growth and Input Growth

Over the 1985 to 2007 period, China's agricultural output growth averaged 5.1-percent per annum. This was much faster than other developed countries over the same period. According to the estimates (see table 1), the 5.1-percent annual output growth can be decomposed into 2.4 percent of input growth and 2.7 percent of total factor productivity growth. The roughly equal contributions of inputs and TFP contrasts with the recent experience of developed countries. It shows that while industrialized countries, such as the U.S. and many EU countries, exhibit declining or negative input growth, leaving TFP growth as the major driver of their agricultural output growth (Ball et al., 2010), China's input growth still played an important role over the last two decades. Among the four input categories, labor and land have experienced negative growth and contribute negatively to input's contribution of output growth, reflecting the crowding-out effect from competing uses of labor and land in other sector along with fast economic growth. The decline in agricultural labor also reflects the release of surplus labor to rural industry and urban employment and increasing efficiency in agricultural production. The use of intermediate goods (such as agricultural chemicals), beginning from a low base, grew at a 6.43-percent rapid annual rate, (see table 2) offsetting the decline in labor and land and contributed 2.5 percentage points annually to output growth (see table 1). Capital growth, with a 3.5-percent annual growth rate (see table 2), only contribute 0.2 percentage points annually to output growth (see table 1) as capital's cost share is still much smaller than other inputs. Capital growth could be higher after our study period as the government subsidized agricultural machinery heavily beginning in 2008 (Lohmar et al., 2009). Notwithstanding, productivity growth still accounted for more than half of output growth.

(Insert table 1, table 2 here)

Among the twenty-five provinces, the differences are noticeable. Some provinces relied more on input growth while others attributed most of their output growth to TFP growth. For example, input growth in Zhejiang, Guangdong, and Qinghai are either negative or smaller than 1% and therefore their output growths were due almost entirely to productivity growth. In general, most of Northeast and North provinces relied more on input growth whereas most East and South provinces (many of them near the east or south coast) depended more on productivity growth. Overall, coastal provinces were usually more industrialized or commercialized and therefore had much stronger economic growth, along with China's fast-growing economy, in the past two decades compared with provinces located in the interior of China. Although the growing economy has pulled production resources away from the farm sector into non-farm industrialized sectors of the economy, the development of non-farm sectors has benefited in turn the farm sector especially in provinces with more intensive public infrastructure. Also opening trade has enhanced local agricultural productivity growth through international technology spill-in transfers and increased market access.

Table 2 shows growth in the use of individual inputs among provinces. Among the twenty-five provinces, ten provinces experienced negative growth in labor including all six East provinces and five out of seven coastal provinces. It seems that the higher opportunity cost of labor in the richer regions on the east coast, may have forced farmers to use other technical embodied chemicals and machineries to replace labor (noticeably in harvesting and in transporting). Negative growth also reflects the shedding of surplus farm labor. Almost every province had negative growth in land use except Heilongjiang, Inner Mongolia, Xinjiang, and Qinghai, which are all located in the very inner regions of China. On the other hand, capital growth is around 3~5% in general, except for Heilongjiang at a 12-percent annual growth rate. High capital input growth in Heilongjiang may have reflected higher capital intensity in state-owned farms within that region (Woodward, 1982).

The emergence of a commercial livestock sector (Fuller, Tuan, and Wailes, 2002) was an important contributor to increased productivity. From table 3 we can find that, during the 1985-2007 period, livestock output grew at an average rate of 5.45% per annum, compared with crops' 4.53%. The growth in livestock also exceeded crops' growth in 17 out of 25 provinces, implying that China's agricultural output growth reflects a change in product mix toward higher-valued products along with its fast economic growth. Among the provinces, Jilin had the highest livestock growth rate at 16.24% per annum (because it is the corn belt of China) while Fujian had the highest crops growth rate at 7.08% per annum. The lowest livestock growth is in Zhejiang, with an average annual growth rate of 6.89% as Zhejiang began contracting with Jilin hog producers for supplying pork since early 2000's. Still, this number surpasses the growth rate of crops, on average. It implies that the economic growth in China may have driven the fast increase in the production of livestock as income growth led to increased consumption.

5. Trends and Multilateral Comparison of China's Regional TFP Growth

According to table 1 the increased input use explains only part of China's agricultural output growth. TFP growth played a significant role in promoting high output growth in China's agricultural sector. Table 4 presents the TFP annual growth rate for each of the twenty-five provinces in five sub-periods. The TFP growth rate between 1995 and 1996 was excluded as the 1996 China land survey revealed that nearly 40 percent more land was cultivated than what was reported in the past (Lin and Ho, 2003). The dramatic increase in land area led to a distinct decrease in TFP estimates for that year. We assume the actual land area change rate was consistent with the reported data in the pre-survey period even though the land area may be underestimated. In general, the average annual TFP growth rate from 1985 to 2007 (excluding the 1995-1996 period) was 2.7% which was higher than the U.S. farm sector's productivity growth rate of 1.31% during this same period (ERS-USDA, 2012) as well as TFP growth in other developed countries (Ball et al., 2010). Yet, these estimates are close to the results estimated by Fan and Zhang (2002) in the overlapping periods 1985-1995. The weighted average annual TFP growth rate for 1985-1990 and 1990-1995 periods in this study are 1.5% and 3.7% respectively while the average of Fan and Zhang's (2002) two estimated national series during that two periods are 1.7% and 3.7% respectively. As a newly opened economy, the fast productivity growth in the China's agricultural sector can be taken as a catch-up effect from relative low productivity levels in the early 1980s.

From table 4, the weighted annual TFP growth rates show an accelerating trend for the earlier three subsequent periods, 1985-1990, 1990-1995, and 1996-2000, at rates 1.5%, 3.7%, and 5.1%. ITFP growth slowed in the 2000-2005 period, however, at a still impressive high growth rate of 3.2% per annum. The continuing productivity growth during our study period implies that China's agricultural policies, including encouraging crop specialization and regionalization, such as cotton and oilseeds, production of high value products, such as fruits and vegetables, and seed quality improvement, such as rice and wheat, may have enhanced productivity advancement during those periods (Lohmar et al., 2009). The possible technical catch-up effect as well as the efficiency improvement effect through the relocation of surplus inputs from the agricultural sector to non-farm sector may also have played an important role in China's agricultural productivity growth. However, during the 2005-2007 period, 22 out of 25 provinces experienced negative productivity growth. This may reflect a disease-related decrease in pork production in 2007.

(Insert table 4 here)

Table 5 shows the rankings of TFP growth among provinces. We find that five out of the seven top TFP growth provinces are located in the coastal area (see figure 1), including Zhejiang, Hebei, Guangdong, Guangxi, and Fujian. However, in contrast the top two TFP growth provinces, Qinghai and Ningxia, are poor provinces in western China. Those two provinces also ranked twenty-third and last among the twenty-five provinces in the multilateral TFP level in 1985 (see table 6). It implies a productivity catch-up effect for these two provinces while other coastal provinces may be benefited more from intensive public infrastructure investment and spill-in effects from trade openness, as discussed in the previous section.

(insert table 5 here)

(insert figure 1 here)

One unique contribution of this study is the multilateral comparison of the TFP levels among regions. We construct a spatial-linked TFP index for twenty-five contiguous provinces following the methodology proposed by Caves, Christiansen, and Diwert (1882). Table 6 presents the TFP rankings for the years 1985 and 2007. The top five provinces in 1985 were Guangdong, Hunan, Guangxi, Sichuan, and Zhejiang, in order. Those five provinces are still the top-five in 2007 while Zhejiang took Sichuan's place and became the fourth highest province in TFP level. Unfortunately, the last six provinces with the lowest TFP level in 1985 remained the lowest six provinces in 2007 although the rankings were changed. The six provinces are Shanxi, Shaanxi, Xinjiang, Qinghai, Gansu and Ningxia. All are located in the Northwest or North regions (see figure 2). While Qinghai and Ningxia have experienced the fastest TFP growth in the post-reform period, it's still hard for them to catch-up with other provinces. Shanxi and Gansu were two provinces with both low TFP levels and TFP growth in the study period. It seems that the inability to acquire new technology for these poorer provinces has hindered their ability to keep up with other provinces.

Among other provinces, Fujian, Hebei, and Yunnan have moved up by three or four places. They all demonstrated high TFP growth with rates higher than 2.8% per annum (see table 5 and 6); where Fujian and Hebei are both located in the coastal area.

(insert table 6 here)

(insert figure 2 here)

While input growth accounts for most of output growth for private business sectors (Jorgenson, Gollop, and Fraumeni, 1987), Ball et al. (2010) showed that agriculture is one of the few exceptions in a study of U.S. and EU agricultural productivity. Our study shows that for a developing country, China, which has experienced tremendous economic growth after its 1978's economic reform, both input growth and productivity growth have played important roles in agricultural output growth. Still, TFP growth contributed slightly more than input growth to agriculture output growth at a rate of 2.7% to 2.4% during the study period.

6. Summary and Conclusions

In this study, we decompose agricultural output growth into total factor productivity growth and input growth, where input growth is further decomposed into growths in labor, land, capital, and intermediate goods, for twenty-five contiguous China provinces for the 1985-2007 period. Most studies that analyze China's agricultural production either used Malmqvist index analysis without reflecting changes revenue shares or cost shares among output and inputs over time, or focus on a single commodity, such as crop production, or a partial productivity measure, such as yield, or a single province or area. This study devotes significant effort constructing the multilateral price indices and implicit quantities for crops, livestock, labor, intermediate goods, capital service flow, and land to capture the nature of changing shares in cost or revenue through time for individual inputs and outputs. We also constructed multilateral TFP levels as well as TFP growth rates among twenty-five provinces.

For the 1985-2007 period the average annual productivity growth rate was 2.7% for the twenty-five provinces. Our analysis shows that TFP growth and input growth both played significant roles in China’s agricultural output growth, with TFP growth contributing slightly more than input growth. Coastal provinces tended to have higher productivity growth than others. Average productivity growth accelerated in the 1990-1995, and 1996-2000 periods after gentle TFP growth in 1985-1990. It slackened during 2000-2005 and became negative in 2005-2007. The early years’ high TFP growth may reflect a catch-up effect that slowed eventually when TFP grew to a higher level. Whether there is a systematic productivity slowdown in China’s farm sector or not needs to be monitored in future research. The shift in input and output composition among regions and the shrinking labor input in many provinces indicate that the nonfarm economic growth absorbed surplus labor, and urban growth created demand for high-value crops and livestock. In addition, the fast growth in output and productivity in China’s farm sector may be a result of agricultural policy reforms that facilitated diversification, specialization, and regionalization of agricultural production. Yet, a more thorough evaluation is needed if we want to address the policy effect issue and can be an extension of this research.

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Table 1 Sources of output growth

Region	Province	Output growth	Sources of output growth		Input growth decomposition			
			TFP growth	Input growth	labor growth	capital growth	land growth	Intermediate goods growth
Northeast	Heilongjiang	5.3%	1.9%	3.5%	0.4%	0.2%	0.1%	2.7%
	Jilin	5.2%	2.4%	2.8%	0.2%	0.2%	-0.1%	2.4%
	Liaoning*	6.0%	2.5%	3.5%	0.1%	0.2%	-0.1%	3.3%
North	Hebei	6.8%	3.5%	3.3%	0.0%	0.2%	-0.1%	3.2%
	Inner Mongolia	5.6%	2.4%	3.2%	0.1%	0.2%	0.2%	2.7%
	Shanxi	2.7%	0.5%	2.3%	0.1%	0.2%	0.0%	2.0%
Middle	Henan	5.8%	2.3%	3.4%	0.2%	0.2%	-0.1%	3.1%
	Hubei*	4.3%	2.5%	1.8%	-0.3%	0.1%	-0.2%	2.2%
	Hunan	4.7%	2.3%	2.4%	0.0%	0.1%	0.0%	2.3%
East	Anhui	3.6%	1.5%	2.1%	-0.1%	0.1%	-0.1%	2.2%
	Fujian*	5.6%	3.3%	2.3%	0.1%	0.1%	-0.2%	2.3%
	Jiangsu*	4.1%	2.8%	1.3%	-0.7%	0.1%	-0.2%	2.0%
	Jiangxi	4.6%	2.6%	2.0%	-0.2%	0.2%	-0.1%	2.1%
	Shandong*	5.3%	2.0%	3.3%	-0.2%	0.5%	-0.1%	3.1%
	Zhejiang	3.2%	3.7%	-0.5%	-1.8%	0.2%	-0.3%	1.3%
South	Guangdong*	4.0%	3.5%	0.6%	-0.2%	0.1%	-0.6%	1.3%
	Guangxi*	6.0%	3.3%	2.7%	0.1%	0.1%	0.0%	2.5%
Southwest	Guizhou	3.7%	1.6%	2.2%	0.3%	0.1%	0.0%	1.8%
	Sichuan	6.0%	3.4%	2.6%	0.1%	0.0%	0.0%	2.5%
	Yunnan	5.8%	2.8%	3.0%	0.7%	0.1%	0.0%	2.3%
Northwest	Gansu	5.2%	1.9%	3.4%	0.5%	0.1%	-0.1%	2.8%
	Ningxia	6.0%	3.8%	2.2%	0.4%	-0.5%	0.0%	2.3%
	Qinghai	4.1%	4.0%	0.1%	0.1%	-1.5%	0.0%	1.5%
	Shaanxi	5.4%	2.9%	2.5%	0.1%	0.2%	-0.3%	2.5%
	Xinjiang	6.6%	2.6%	4.0%	0.2%	0.2%	0.1%	3.5%
National average		5.1%	2.7%	2.4%	-0.1%	0.2%	-0.1%	2.5%

Note 1: '*' indicates the coastal province.
Note 2: National average is the weighted average of provincial estimates using revenue shares from each province as the weights.

Table 2. Inputs growth among regions

Region	Province	Labor	Capital	Land	Intermediate goods
Northeast	Heilongjiang	2.12%	12.07%	0.15%	6.62%
	Jilin	1.02%	6.64%	-0.17%	6.69%
	Liaoning*	0.53%	4.80%	-0.43%	7.19%
North	Hebei	-0.22%	3.14%	-0.47%	8.43%
	Inner Mongolia	0.61%	3.62%	0.45%	7.77%
	Shanxi	0.54%	5.72%	-0.68%	5.00%
Middle	Henan	0.60%	3.00%	-0.45%	7.88%
	Hubei*	-1.03%	0.45%	-0.70%	6.19%
	Hunan	0.01%	1.25%	-0.04%	6.63%
East	Anhui	-0.30%	2.30%	-0.56%	5.41%
	Fujian*	-0.38%	2.97%	-0.47%	6.20%
	Jiangsu*	-2.83%	1.48%	-0.50%	4.51%
	Jiangxi	-0.53%	4.65%	-0.39%	5.66%
	Shandong*	-0.87%	4.36%	-0.62%	7.32%
	Zhejiang	-5.07%	2.87%	-0.91%	3.72%
South	Guangdong*	-0.51%	2.00%	-2.92%	4.59%
	Guangxi*	0.13%	4.55%	-0.02%	7.45%
Southwest	Guizhou	0.60%	4.45%	-0.34%	4.94%
	Sichuan	-0.78%	3.69%	-0.77%	6.46%
	Yunnan	1.16%	4.92%	-0.25%	7.24%
Northwest	Gansu	1.20%	2.93%	-0.47%	6.74%
	Ningxia	1.05%	1.90%	-0.08%	7.47%
	Qinghai	0.35%	-2.65%	0.12%	4.57%
	Shaanxi	0.23%	3.71%	-1.51%	5.75%
	Xinjiang	1.43%	5.00%	0.20%	9.02%
National average		-0.40%	3.50%	-0.60%	6.43%

Note 1: '*' indicates the coastal province.
Note 2: National average is the weighted average of provincial estimates using revenue share from each province as the weight.

Table 3. Outputs growth among regions

Region	Province	Crops	Livestock
Northeast	Heilongjiang	4.61%	6.78%
	Jilin	3.83%	7.91%
	Liaoning*	4.86%	7.09%
North	Hebei	6.11%	8.09%
	Inner Mongolia	5.82%	6.48%
	Shanxi	2.72%	3.80%
Middle	Henan	5.09%	7.43%
	Hubei*	3.90%	4.59%
	Hunan	4.48%	4.96%
East	Anhui	3.20%	4.00%
	Fujian*	5.54%	4.36%
	Jiangsu*	3.84%	3.26%
	Jiangxi	3.84%	5.34%
	Shandong*	4.66%	5.83%
	Zhejiang	3.35%	2.09%
South	Guangdong*	4.22%	3.13%
	Guangxi*	6.40%	5.53%
Southwest	Guizhou	3.99%	3.58%
	Sichuan	3.43%	6.87%
	Yunnan	5.07%	5.62%
Northwest	Gansu	5.75%	3.81%
	Ningxia	5.58%	6.73%
	Qinghai	4.07%	4.21%
	Shaanxi	4.96%	6.10%
	Xinjiang	6.88%	5.76%
National average		4.53%	5.45%

Note 1: '*' indicates the coastal province.
Note 2: National average is the weighted average of provincial estimates using revenue share from each province as the weight.

Table 4. Total Factor Productivity Growth among Regions

Region	Province	1985-1990	1990-1995	1995-2000	2000-2005	2005-2007	1985-2007
Northeast	Heilongjiang	2.8%	1.8%	-0.1%	5.9%	-6.4%	1.9%
	Jilin	3.9%	0.6%	5.5%	4.7%	-8.8%	2.4%
	Liaoning*	2.2%	3.8%	4.0%	4.3%	-7.3%	2.5%
North	Hebei	3.4%	3.8%	5.7%	4.5%	-3.3%	3.5%
	Inner Mongolia	2.6%	-0.5%	7.1%	5.7%	-8.5%	2.4%
	Shanxi	2.6%	0.6%	1.6%	1.5%	-10.1%	0.5%
Middle	Henan	2.8%	3.8%	3.0%	3.2%	-6.1%	2.3%
	Hubei*	2.3%	4.8%	2.4%	1.6%	-0.4%	2.5%
	Hunan	-1.4%	4.6%	4.5%	4.4%	-3.9%	2.3%
East	Anhui	0.8%	2.5%	4.7%	0.6%	-3.4%	1.5%
	Fujian*	-0.4%	6.7%	8.7%	1.4%	-2.6%	3.3%
	Jiangsu*	-0.1%	6.3%	3.1%	3.4%	-0.8%	2.8%
	Jiangxi	2.2%	1.3%	7.2%	2.6%	-2.1%	2.6%
	Shandong*	1.6%	3.7%	4.3%	0.8%	-3.1%	2.0%
	Zhejiang	-1.2%	5.0%	9.0%	5.8%	-2.5%	3.8%
South	Guangdong*	-0.5%	4.5%	5.4%	4.5%	4.4%	3.5%
	Guangxi*	4.4%	2.7%	8.0%	2.3%	-5.3%	3.3%
Southwest	Guizhou	-1.2%	2.4%	7.6%	2.3%	-8.2%	1.5%
	Sichuan	-0.2%	3.4%	8.7%	5.3%	-7.4%	3.0%
	Yunnan	3.3%	-1.6%	11.5%	2.4%	-3.9%	2.8%
Northwest	Gansu	3.2%	2.9%	4.2%	0.5%	-5.1%	1.9%
	Ningxia	6.4%	1.0%	7.0%	3.1%	-0.4%	3.8%
	Qinghai	7.9%	2.3%	5.3%	5.9%	-8.7%	4.0%
	Shaanxi	1.6%	2.4%	7.3%	2.5%	0.1%	2.9%
	Xinjiang	4.4%	12.0%	-6.4%	-0.7%	0.7%	2.6%
National average		1.5%	3.7%	5.1%	3.2%	-3.7%	2.6%

Note 1: '*' indicates the coastal province.
Note 2: We exclude the estimate of 1996 from the estimate of period '85-07'.
Note 3: National average is the weighted average of provincial estimates using revenue share from each province as the weight.

Table 5. Rankings of Annual TFP Growth Among Provinces

Province	Annual growth rate	Ranking
Qinghai	4.0%	1
Ningxia	3.8%	2
Zhejiang*	3.8%	3
Hebei*	3.5%	4
Guangdong*	3.5%	5
Guangxi*	3.3%	6
Fujian*	3.3%	7
Sichuan	3.0%	8
Shaanxi	2.9%	9
Yunnan	2.8%	10
Jiangsu*	2.8%	11
Jiangxi	2.6%	12
Xinjiang	2.6%	13
Liaoning*	2.5%	14
Hubei	2.5%	15
Inner Mongolia	2.4%	16
Jilin	2.4%	17
Henan	2.3%	18
Hunan	2.3%	19
Shandong*	2.0%	20
Gansu	1.9%	21
Heilongjiang	1.9%	22
Guizhou	1.5%	23
Anhui	1.5%	24
Shanxi	0.5%	25

Note 1: The average annual growth rate does not include the year 1996.
Note 2: '*' indicates provinces that are along the coast.

Table 6. Rankings of TFP Level Among Provinces

Province	Ranking_1985	Ranking_2007	Ranking Changes[1]
Guangdong*	1	1	0
Hunan	2	2	0
Guangxi*	3	3	0
Sichuan	4	5	-1
Zhejiang*	5	4	1
Hubei	6	7	-1
Jilin	7	6	1
Shandong*	8	9	-1
Anhui	9	14	-5
Henan	10	10	0
Fujian*	11	8	3
Guizhou	12	17	-5
Jiangsu*	13	12	1
Liaoning*	14	15	-1
Hebei*	15	11	4
Heilongjiang	16	19	-3
Yunnan	17	13	4
Jiangxi	18	16	2
Inner Mongolia	19	18	1
Shanxi	20	23	-3
Shaanxi	21	20	1
Xinjiang	22	22	0
Qinghai	23	21	2
Gansu	24	24	0
Ningxia	25	25	0

Note 1: The negative numbers in ranking changes indicate deterioration in the ranking.

Figure 1. Top ten provinces in agricultural TFP growth in China

Sources: See table 2.

Notes: ■ indicates the top ten provinces with the highest TFP annual growth rate during the 1985 to 2007 period. ■ indicates provinces, which are not covered in our estimates.

Figure 2 Provinces with highest or lowest TFP level

Sources: See table 6.

Notes: ■ indicates provinces with the highest TFP levels in both 1985 and 2007. :

■ indicates provinces with the lowest TFP levels in both 1985 and 2007.

■ indicates provinces not covered in our estimates.