An Analysis of Total Factor Productivity Growth in China's Agricultural Sector

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Abstract

A panel data of 27 provinces in China is used to analyze the productivity growth in China's agricultural sector over the period 1984-1999. We first compute the output-orientated Malmquist productivity indexes and its decompositions using non-parametric DEA (Data Envelopment Analysis) approach. Tobit regressions are then used to identify the major determinants of TFP growth and its components. Results showed that the overall TFP growth remains sluggish in China's agricultural sector. Government tax policies and investments on R&D have not yet been very effective in promoting productivity, efficiency and technical progress. On the other hand, regional factor seems to be a very important determinant on efficiency improvement and technical innovation. Regional disparities also warrant further investigations on other socio-economic and geographic characteristics of provincial agricultural production.

Key words: total factor productivity, agriculture, China, Malmquist productivity indexes

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1. Introduction

China is one of the most populous countries in the world. There is considerable speculation regarding the productivity performance of its agricultural sector. Estimates of China's agricultural productivity have been controversial. Differences in the estimation methods and reliability in the statistics created many debates on the trend of China's agricultural productivity. McMillan, Whalley and Zhu (1989), Wen (1993), and Lin and Wen (1995) provide comprehensive reviews on the total factor productivity (TFP) growth in China's farm sector during the reform era. They show that the rapid TFP growth partly contributes to the rural China's miracle growth in the early 1980's. However, others argue that TFP growth has stagnated after 1985 in spite of the fact that output has continued to grow at over 5 percent per year.

Productivity is generally defined in terms of the efficiency improvement and technical change with which inputs are transformed into outputs in the production process. Indexes of productivity, therefore, are simply the ratios of an aggregate output index to an index for total factor use. The most popular form for estimating TFP growth in the past is the Törnqvist index. The Törnqvist index calculates TFP growth based on information concerning prices, and uses cost/revenue shares as weights to aggregate inputs/outputs. However, when calculating the Törnqvist index, observed output is assumed to be equivalent to frontier output. Consequently, decomposition of the TFP growth into the movements towards (efficiency improvement) and shifts in the production frontier (technical change) is not possible.

On the other hand, the Malmquist index has gained considerable popularity in recent years since Färe et al. (1994) apply the linear-programming approach to calculate the distance functions that make up the Malmquist index. There are three reasons for this increasing popularity. First of all, since the data envelopment type of analysis can be directly applied to calculate the index, the Malmquist index has the advantage of computational ease. Second, calculation of the Malmquist index does not require information on cost or revenue shares to aggregate inputs or outputs. Consequently, the Malmquist index is less data-demanding than the Törnqvist index. Finally, the Malmquist productivity-change index is more general in that it allows for further decomposition of TFP growth into changes in efficiency and changes in technology. This further decomposition is important for facilitating a multilateral comparison that may help explain and characterize the differences and similarities in growth patterns for different regions in China.

The purpose of this study is twofold. First, we intend to use the Malmquist index to calculate TFP growth in China's agricultural sector. A panel data of 27 provinces is collected over the period 1984-1999. Since the method constructs a best-practice frontier from the sample, the results not only allow us to compare the pattern of productivity growth and its components, but also to identify those provinces shifting the frontier over time (i.e., the "innovators"). Next, Tobit regression analysis will be conducted to identify the major determinants of TFP growth and its components. Specifically, the role of government policies, investment in infrastructure, and education in the process of TFP growth will be investigated.

The remaining of the paper is organized as follows. The next section briefly describes the methodology of measurement of efficiency and productivity. Section 3 describes the dataset. Section 4 measures TFP growth using the Malmquist index approach. Regression results on the major determinants are also presented. Summary and concluding remarks are presented in the last section.

2. Malmquist TFP Index Approach

The Malmquist productivity index (MPI), as proposed by Caves, Christensen and Diewert (1982), allows one to describe multi-input, multi-output production without involving explicit price data and behavioral assumptions. The MPI identifies TFP growth with respect to two time periods through a quantitative ratio of distance functions (Malmquist 1953). Distance functions can be classified into input distance functions and output distance functions. Input distance functions look for a minimal proportional contraction of an input vector, given an output vector, while output distance functions look for maximal proportional expansion of an output vector, given an input vector. By using distance functions, the MPI can measure TFP growth without cost data, only with quantity data from multi-input and multi-output representations of technology. In this study, we use output distance functions.

Before formulating MPI, we need some basic concepts and definitions. Assuming that for each time period *t*= 1, 2, …, T, $x_i \in R_+^N$ and $y_i \in R_+^M$ denote, respectively, an $N \times 1$ input vector and an $M \times 1$ output vector for period *t* (*t*=1,2,…, T). The set of production possibilities is given by the closed set,

$$S_t = \{(x_t, y_t) : x_t \quad can \quad produce \quad y_t\}, \tag{1}$$

where the technology is assumed to have the standard properties, such as convexity and strong disposability, as described in Färe et al (1994). The output sets are defined in terms of S_t as:

$$P_t(x_t) = \{y_t : (x_t, y_t) \in S_t\}. \tag{2}$$

According to Shephard (1970), the output distance function in *t* for any productivity unit would be:

$$d_o^t(x_t, y_t) = \inf\{\theta : (y_t/\theta) \in P_t(x_t)\}, \tag{3}$$

where the subscript "o" stands for "output oriented". Färe and Lovell (1978) showed that the distance function was the Farrell's reciprocal measurement (Farrell, 1957).

This distance function represents the smallest factor, θ, by which an output vector y_t is deflated so that it can be produced with a given input vector x_t under period *t*'s technology. That is to say, $d_o^t(x_t, y_t)$ provides a standardized average of distance of a unit in the period t to frontier t of production set when inputs are constant.

The productivity change using technology of period *t* as reference is as follows:

$$M_o^t(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_o^t(x_{t+1}, y_{t+1})}{d_o^t(x_t, y_t)}\right]. \tag{4}$$

Similarly, we can measure the MPI with period *t+1* technology as references as follows:

$$M_o^{t+1}(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_o^{t+1}(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_t, y_t)}\right]. \tag{5}$$

In order to avoid choosing an arbitrary period as reference, Färe et al (1994) specifies the MPI as the geometric mean of the two indices above:

$$M_o(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_o^t(x_{t+1}, y_{t+1})}{d_o^t(x_t, y_t)} \frac{d_o^{t+1}(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_t, y_t)}\right]^{1/2}. \tag{6}$$

The MPI formula in index (6) can be equivalently rewritten and decomposed into the following two components:

$$\text{EFFCH} = \frac{d_o^{t+1}(x_{t+1}, y_{t+1})}{d_o^t(x_t, y_t)} \tag{7}$$

, and

$$\text{TECHCH} = \left[\frac{d_o^t(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_{t+1}, y_{t+1})} \times \frac{d_o^t(x_t, y_t)}{d_o^{t+1}(x_t, y_t)}\right]^{1/2}. \tag{8}$$

The EFFCH is the efficiency change index and measures the output-oriented shift in technology between the two periods. When it is greater (or less) than one, there exists some improvement (or deterioration) in the relative efficiency of this unit. The term TECHCH is the geometric average of both components and measures technical change between period *s* and *t*. The first component in TECHCH measures the position of unit *t+1* with respect to the technologies in both periods. The second component also estimates this for unit *t*. If the TECHCH is greater (or less) than one, then technological progress (or regress) exists.

Unfortunately, it is impossible to observe the set of production possibilities S_t. Therefore, the indices mentioned above must be estimated. Various methodologies have been used (Hjalmarsson, Kumbhakar and Heshmati, 1996). Färe et al (1994) use Data Envelopment Analysis (DEA) methods to estimate and decompose the MPI. The DEA method is a non-parametric approach in which the envelopment of decision-making units (DMU) can be estimated through linear programming methods to identify the "best practice" for each DMU. The efficient units are located in the frontier and the inefficient ones are enveloped by it.

Four linear programs (LPs) must be solved for each DMU to obtain the distances defined in equation (3) and they are:

$$\left[d_o^t\left(x_{i,t}, y_{i,t}\right)\right]^{-1} = \max_{\phi,\lambda} \phi,$$

$$\text{st} \quad -\phi y_{i,t} + Y_t \lambda \geq 0,$$

$$x_{i,t} - X_t \lambda \geq 0,$$

$$\lambda \geq 0, \tag{9}$$

$$\left[d_o^{t+1}\left(x_{i,t+1}, y_{i,t+1}\right)\right]^{-1} = \max_{\phi,\lambda} \phi,$$

$$\text{st} \quad -\phi y_{i,t+1} + Y_{t+1}\lambda \geq 0,$$

$$x_{i,t+1} - X_{t+1}\lambda \geq 0,$$

$$\lambda \geq 0, \tag{10}$$

$$\left[d_o^{t}\left(x_{i,t+1}, y_{i,t+1}\right)\right]^{-1} = \max_{\phi,\lambda} \phi,$$

$$\text{st} \quad -\phi y_{i,t+1} + Y_t\lambda \geq 0,$$

$$x_{i,t+1} - X_t\lambda \geq 0,$$

$$\lambda \geq 0, \tag{11}$$

$$\left[d_o^{t+1}\left(x_{i,t}, y_{i,t}\right)\right]^{-1} = \max_{\phi,\lambda} \phi,$$

$$\text{st} \quad -\phi y_{i,t} + Y_{t+1}\lambda \geq 0,$$

$$x_{i,t} - X_{t+1}\lambda \geq 0,$$

$$\lambda \geq 0, \tag{12}$$

Here, *K, N, M* and T represent, respectively, the total number of firms, inputs, outputs and time periods in the sample, ϕ denotes a scalar, which represents the proportional expansion of output vector, given the input vector, $\lambda = \left[\lambda_1, \lambda_2, \cdots, \lambda_K\right]$ denotes the $K \times 1$ vector of constants, which represent peer weights of a firm, $y_{i,t}$ and $x_{i,t}$ represent the $M \times 1$ output vector and the $N \times 1$ input vector, respectively, of firm *i* in period *t,* Y_t and X_t represent, respectively, the $M \times K$ output matrix and $N \times K$ input matrix, containing the data for all firms in period *t*. The notations for period *t+1* are defined in a similar fashion.

Equations (9) and (10) measure the technical efficiency of the i^{th} firm in period *t* and *t+1*, respectively. In equations (11) and (12), the i^{th} observation from period *t+1* is compared to the technology constructed using the period *t+1* data, and vice versa.

3. Data

This subsection offers more details on the definition of inputs and outputs and the dataset used in this paper. Due to the data limitation, our empirical study is based on a panel of aggregated data. The source of data comes from the *Rural Statistical Yearbook of China*. Because data of Shanghai, Hainan, Chongqing and Tibet are not available until year 1984, the panel contains 27 agricultural producing provinces over the period 1984-2000**.**

In the empirical analysis the following output and inputs are used to model the production technology. The output variable used in our TFP analysis is the total gross output value of farming, forestry, animal husbandry and fishery. There are five input variables: number of rural labor, irrigated area, machinery, chemical fertilizer, and electricity consumption. Sample means of these variables are presented in Table 1. The outputs are measured in 100 million RMB of gross values deflated by agricultural price index. The numbers of rural labor are measured in

10000 persons. Irrigated area is measured in 1000 hectares. Agricultural machinery is measured in 10000 kilowatt. Chemical fertilizer is measured in 10000 tons, while electricity consumption is measured in 100 million kilowatt-hour.

Table 1. Sample Means

	1984-1992	1993-2000	1984-2000
Output (100 million RMB)	119.17	198.48	156.50
Inputs:			
Labor (10000 persons)	1103.53	1104.24	1103.86
Power (10000 kw)	885.93	1390.34	1123.30
Irrigated (1000 hectares)	1568.91	1785.52	1670.84
Electricity (100 million kwh)	25.39	62.16	42.69
Fertilizer (10000 tons)	77.41	128.63	101.51
Affected areas (1000 hectares)	772.25	894.33	829.70

For further consideration of the effect of natural disaster on the productivity of China's agriculture, areas affected by natural disaster, measured in 1000 hectares, is also included in this study. It is expected that the influence of areas affected by natural disaster is negatively related to the productivity. We can include this variable as a non-discretionary input by imposing a restriction of the following form:

$$z_{it} - Z\lambda \geq 0\,, \tag{13}$$

where z_{it} denote total areas affected by natural disaster of the i^{th} province/region for period t and matrix Z denotes the affected areas of the full sample. Since this input variable has a negative effect on productivity, we can also invert the measure as an output by the following form:

$$- z_{it} + Z\lambda \geq 0 . \tag{14}$$

Since the method constructs a best-practice frontier from the sample, the results not only allow us to compare the pattern of productivity growth and its components, but also to identify provinces shifting the frontier over time (i.e., the "innovators"). Next, a regression analysis will be conducted to identify the sources of TFP growth. Specifically, the role of government policies, investment in infrastructure, and education in the TFP growth process will be investigated.

In the second stage of our analysis, we will identify the factors influencing the productivity and efficiency performance. The Tobit regression is used to regress the indexes calculated in the first stage on some categories factors. Due to data limitations, pooled data of 135 observations from 27 provinces during the period 1995-1999 are used in the second stage. Table 2 lists variables used in the Tobit regression model and their definitions. Most of the variables are obtained from *China Statistical Yearbook*. Exceptions include machinery-plough area ratios, which come from the *China Agriculture Yearbook.*

Table 2. Variable definitions of the Tobit regression model

Symbol	Definitions	Mean	Min.	Max.
ALWR	agriculture labor wage / total labor wage	70.50	49.04	90.12
EATR	agriculture and animal husbandry taxes and tax on the use of cultivated land / gross output value of farming, forestry, animal husbandry and fishery	0.01	0.01	0.07
EDU	expenditure for operating expenses of departments of culture, education / population	120.42	56.88	865.17
FVSHARE	gross output value of farming / gross output value of all agriculture sector	58.51	42.06	78.15
R&D	total funds and total expenditures of state-owned research and development institutions / population	70.14	5.61	1440.70
MACHINE	total machinery-plough area / cultivated land area	13.12	0.14	67.92
TECL	TECL=1 for advanced-technology region, 0 for low-technology region	–	–	–

4. Empirical Results

4.1 Comparison of Productivity Growth

Instead of presenting the results for each year, a summary description of average productivity growth of each province over the entire sample period 1984-2000 and two sub-periods 1984-1992, 1993-2000 are presented. Table 3 provides descriptive statistics of the results, which indicate that there are slight variations in productivity change across the provinces/regions. Recall that the value greater than one indicates increasing productivity and less than one implies diminishing productivity from period t to period $t+1$. The mean values of TFP change range from 0.902 to 1.062, from 0.902 to 1.042 and from 0.913 to 1.062 for the whole period, sub-period 1 and sub-period 2, respectively. The average TFP growth over the whole period was -0.1 percent per annum. The mean value for the 1st sub-period is 0.995 and 1.003 for the 2nd sub-period respectively, implying that overall TFP growth is improving over the two periods. This is most likely due to the "cooperation of equity share" adopted by the state-owned farms after 1993 and the construction of a rural market system after 1992.

We also note that, the TFP growths in most of the eastern regions (e.g., Beijing, Tianjin, Hebei, Liaoning, Jilin Jiangsu, Zhejiang, Fujian, Shandong, Hubei, Guangdong, Ningxia, Xinjiang) are greater than one, and on average, slightly higher than those in the other regions. This could be due primarily to the differences in soil quality, irrigation and climatic conditions. Most of the western regions are not irrigated, while most areas in the central and eastern regions are irrigated. Beijing, the capital city of China, outperforms all the other provinces by a large margin, followed by the Hebei province. However, if we divide the timeperiod into two sub-periods, Beijing's TFP growth has been caught up by Hebei during the 2nd period. Fujian and Ningxia also show great improvements in TFP growth during the 2nd period. On the other hand, Gansu, Guizhou, Jiangxi, Tianjin, and Xinjiang show significant deteriorations over time.

(Table 3 here)

4.2 Sources of Productivity Growth

The TFP growth can be decomposed into two components, efficiency change and technical progress. The first component, efficiency change (or efficiency improvement), measures the relative deviation of each province from its corresponding frontier. The second component, technical progress, captures the movement of the frontiers over the sample period. The decomposition results are illustrated in Tables 4 and 5 respectively. We can use the decomposition to investigate sources of productivity growth.

From Table 4 and Table 5, we observe that the average efficiency and technical change over the whole period was 1.001 and 0.998, respectively. This tells us that from the national perspective efficiency progresses by only 0.1 percent without any significant progress in technology during the sample period. From the regional perspective, we find that Hebei province shows 2 percent improvement in efficiency while Shanxi province deteriorates by 2 percent in catching up with the frontier. Most of the other provinces do not show significant progress or regress in efficiency.

As for the technical progress, the national average over the sample period is 0.998, which indicates a slight regress. In comparison to the 0.1 percent efficiency progress, the main contributor to the productivity growth in China's agricultural sector seems to be coming from efficiency progress. However, if we examine the regional results, Beijing shows a significant progress by 7.6 percent, followed by the 2.3 percent in Fujian province. The regional discrepancies in technical progress are obviously much larger than those in efficiency improvement. It turns out that at the regional TFP growth is largely determined by the technical progress.

Table 4 and Table 5 also show that at the national level the two components are almost identical over the two sub-periods. However, at the regional level half of the provinces experience progresses while the other half are either unchanged or show regressive performance. Therefore, the regional disparities in both efficiency and technical progress are enlarged over time.

(Table 4, 5 here)

In the case of temporal comparisons we are also interested in combining annual changes in TFP into a measure over a given period. The index constructed is known as a chain index. The chained indexes of TFP, efficiency and technical changes for the whole sample period are shown in Figure 1. The efficiency change tends to be opposite against technical change in the first sub-period, but then move in the same direction as the technical change in the second sub-period. TFP change always undergoes the same tendency with technical change. This, again, indicates that technical change should be the main driving force behind TFP growth in China's agriculture sector.

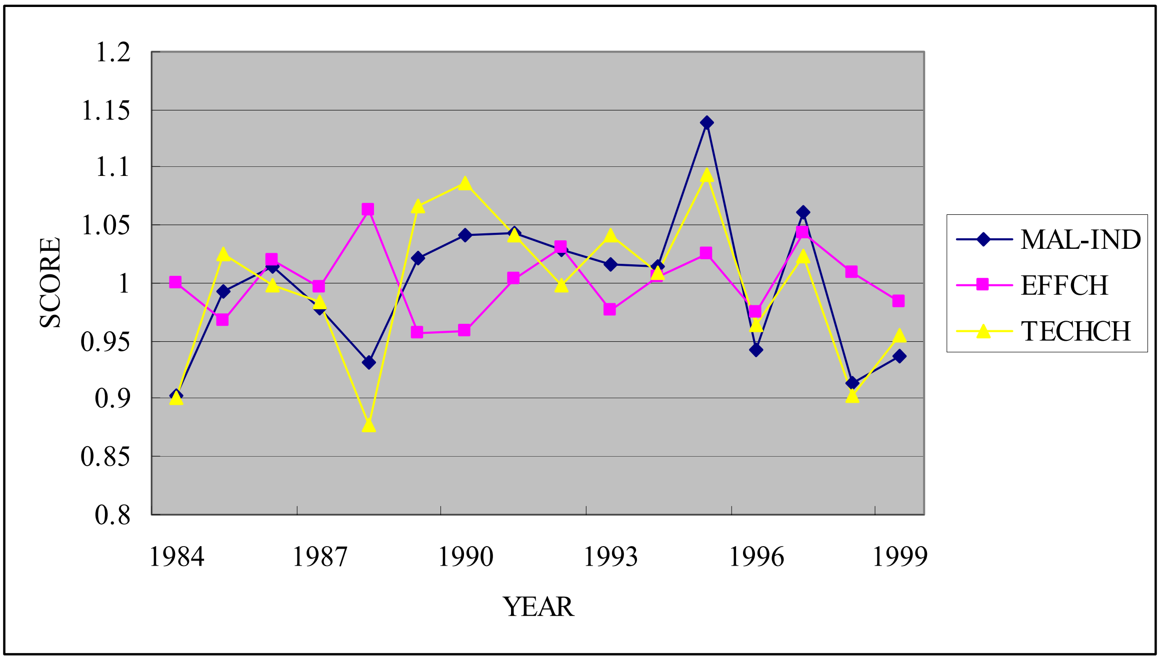

Figure 1. Cumulative Indexes of Malmquist Index, Efficiency Change and Technical Change in China's Agriculture, 1984-1999.

To conclude, three empirical findings can be drawn from the analysis. First, China's TFP growth in agriculture comes mainly from technical progress rather than from efficiency improvement. Second, TFP growth rate in the eastern region outperforms the other parts of China. Third, regional disparities seem to be worsened over time. Differences in soil quality, irrigation and climatic conditions could be the main reasons. A regression analysis will follow so that the reasons behind these findings can be investigated.

4.3 Regression Analysis

To further investigate the determinants of productivity growth in China's agriculture, we hypothesize a set of influential factors based on previous literature. In our regression models, the dependent variables are the scores of TFP change, efficiency change and technical change, respectively. As for the explanatory variables, proxies for effective tax rate (EATR) are used to investigate the impacts of agricultural tax policy by dividing provincial government agricultural tax revenues with their corresponding nominal gross agricultural products. Per capita expenditures on research and development (R&D) in provincial level is used to represent the effort of R&D investments, while per capita expenditure on operating costs of cultural and education departments (EDU) is used to represent human capital investments. Agriculture labor wage relative to total labor wage (ALWR) is used to examine whether changes in labor productivity will affect TFP growth, while the share of farming in total agriculture output value (FVSHARE) intends to capture the importance of specialization in productivity change. Since regional difference in technical change has a significant impact on overall TFP change (Mao and Koo, 1997), we also add a dummy variable (TECL) in each regression equation. This dummy variable represents different level of technologies adopted in agricultural production.

A value of one indicates a higher endowment of advanced technologies and zero otherwise. The Tobit estimates of productivity change, efficiency change and technical change equations are reported in Table 6.

Table 6. Tobit Regression Results for Factors Affecting TFP, Efficiency and Technical Change Based on the Panel of 27 Provinces, 1995-1999.

	TFP Change	Efficiency Change	Technical Change
Intercept	1.9592	10.8590	2.9150
	(2.5921)***	(8.8206)***	(3.8383)***
ALWR	0.0223	0.0003	0.0330
	(2.3162)**	(0.0265)	(3.4083)***
EATR	1.6726	2.4046	4.0259
	(0.1667)	(0.2396)	(0.4011)
EDU	0.0001	-0.0001	0.0003
	(0.0948)	(-0.0599)	(0.2321)
FVSHARE	0.0159	-0.0043	0.0212
	(1.6529)**	(-0.4135)	(2.2003)**
R&D	0.0006	-0.0001	0.0010
	(1.1517)	(-0.2204)	(1.815)**
MACHINE	-0.0143	-0.0020	-0.0212
	(-1.7355)**	(-0.2359)	(-2.5625)***
TECL	0.3203	-0.0672	0.4771
	(1.5945)*	(-0.3243)	(2.3634)***

Notes: Numbers in parentheses are one-tailed-*t* statistics.
Asterisks ***, **, * indicate significant at 1%, 5%, and 10% level, respectively.

Table 6 shows that TFP growth is positively related to ALWR (significant at 1% level), FVSHARE (significant at 5% level) and TECL (significant at 10% level). EATR, EDU and R&D, though positively related to productivity growth, are not significant. The negative sign on MACHINE is unexpected. These results imply that the main determinants of TFP growth in China's agriculture are relative labor productivity and level of specialization and initial technology endowment. Investments on R&D, human capital and machineries have not yet shown any significant influence.

Results for the efficiency change are also given in column 2 of Table 6. The results show that all seven factors cannot explain efficiency change in China's agricultural production. Again, expenditures on education, R&D and machineries fail to improve efficiency.

Results for technical change model are given in column 3 of Table 6. The results show that ALWR and TECL (significant at 1% level), FVSHARE and R&D (significant at 5% level) are positively related to technical change. The coefficients on EATR, EDU are not significant. The negative sign of MACHINE is again unexpected. Many researchers have confirmed that there exists a huge surplus labor in rural China which calls for an urgent policy implementation. Therefore, excess labor on land may deter machinery from improving farmers' efficiency and productivity

The results also show a number of interesting points. Higher agriculture labor wage relative to overall wage level may also induce technology progress.

Specialization and technological endowment have positive contributions on TFP growth and technical progress, but not on efficiency. In other words, provinces with higher farm wage bill and rely more on farming outputs appear to foster the adoption of technological innovation. This is not surprising, given that those provinces located in more advanced-technology region also exhibit more technical progresses. Such a pattern hints at agglomeration economies in advanced-technology.

Higher education spending will not necessarily lead to higher TFP growth, while provinces with larger expenditures on R&D tend to have more technical progress than others. Therefore, spending on education is less effective at fostering agricultural innovations than spending on R&D. Machinery-plough area ratio (MACHINE) appears to be negatively related to productivity, efficiency and technical change. This result may arise from adopting the "double-index" method in the rural area. The outcome of this method is inefficiency in using cultivated area to produce unsuitable grain crops. Higher density in land use may induce a higher machinery-plough area ratio, but it may fail to improve productivity and efficiency simultaneously. Effective agricultural tax rate (EATR) is positively related to TFP, efficiency and technical change, though not significantly so. The possibility that relatively high effective agricultural tax revenues are the outcomes of TFP growth rather than the results warrants further investigation.

5. Conclusions

This study provides empirical evidence about the productivity of agriculture sector in China over the period 1984-1999. The two-stage estimation procedure is applied. In the first stage, we compute the output-orientated Malmquist productivity indexes and its decompositions using non-parametric DEA approach. In the second stage, Tobit regressions are used to identify the major determinants of TFP growth and its components. A panel of 27 provinces is used in our estimation.

The results indicate that national TFP remains unchanged over the entire period, but some progresses in the latter period is observed. Regional results suggest that the major source of growth comes from technical progress. Further attentions should be paid to the regional discrepancies in TFP growth and why there is very little improvement on efficiency given the fact that market system has been introduced into the agricultural sector.

In the second stage, we investigate the influence of government policies and investment in R&D and education on efficiency improvement, technical change, and productivity growth. Results show that the productivity changes were positively related to the ratio of agriculture labor wage to total labor wage, ratio of gross output value of farming to total agriculture gross output value, and a dummy variable of provinces placed in advanced-technology region. Effects on TFP growth of agriculture tax and expenditures on education and R&D are positive but not significant. The negative sign on machinery-plough area ratio is also unexpected, but may be explained by the surplus labor problem in the rural area and the adoption of the “double index” strategy by the Chinese agricultural authorities.

The analyses in this study showed that the overall TFP growth remains sluggish in China’s agricultural sector. Government tax policies and investments on R&D have not yet been very effective in promoting productivity, efficiency and technical progress. On the other hand, regional factor seems to be a very important determinant on efficiency improvement and technical innovation. Regional disparities also warrant further investigations on other socio-economic and geographic characteristics of provincial agricultural production.

Our results echo those provided by Mao and Koo (1997) on productivity growth in Chinese agriculture after rural economic reforms, which conclude that advanced-technology provinces had higher productivity and technology growths than low-technology provinces in agricultural production. Besides the initial technology endowment, relative wage bill and specialization are also crucial to TFP growth.

Table 3. Estimates of Malmquist TFP Change in China's Agriculture, 1984-1999, by Province/Region

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	1984-99	1984-92	1993-99
Anhui	0.970	0.964	0.982	0.898	0.961	0.972	0.797	1.114	1.091	0.969	1.017	1.107	0.938	1.082	0.859	0.932	0.978	0.972	0.986
Beijing	1.359	1.585	1.210	0.669	0.607	1.153	1.119	1.345	0.997	0.973	0.974	0.820	0.939	1.720	0.819	0.932	1.076	1.116	1.025
Fujian	0.808	0.899	1.008	1.009	1.032	0.998	1.139	1.064	1.084	1.112	1.117	1.086	1.057	1.040	0.946	0.975	1.023	1.005	1.048
Gansu	1.037	0.981	1.011	1.028	0.878	0.961	1.084	1.033	1.003	0.970	0.955	1.002	0.955	1.035	0.934	0.952	0.989	1.002	0.972
Guangdong	1.013	1.020	1.024	1.003	1.014	1.039	1.070	1.087	0.924	1.021	1.054	1.062	1.040	1.079	0.943	0.933	1.020	1.022	1.019
Guangxi	0.961	0.949	0.985	0.961	1.021	0.967	1.020	1.078	1.004	1.006	1.066	1.013	1.088	0.943	0.891	0.960	0.995	0.994	0.995
Guizhou	0.797	1.050	0.910	0.989	0.886	0.962	1.252	0.864	1.026	0.920	0.931	0.993	0.901	1.180	0.653	0.950	0.954	0.971	0.933
Hebei	0.787	0.926	1.005	1.013	0.971	0.998	1.040	0.988	0.942	1.035	1.102	2.395	0.399	1.047	0.964	0.944	1.035	0.963	1.127
Heilongjiang	0.849	1.079	0.927	1.060	0.861	1.049	1.064	1.075	0.963	1.188	1.042	1.018	0.952	0.857	0.869	0.954	0.988	0.992	0.983
Henan	0.861	0.893	1.164	0.913	0.990	1.007	0.976	0.969	1.042	0.977	1.118	1.051	1.015	1.008	0.936	0.947	0.992	0.979	1.007
Hubei	0.892	0.979	0.975	0.880	1.060	1.042	0.997	1.052	1.058	1.043	1.130	1.047	1.068	0.925	0.922	0.939	1.001	0.993	1.011
Hunan	0.886	0.953	1.016	0.935	0.986	0.987	1.069	1.001	1.015	0.994	1.009	1.059	1.032	0.957	0.908	0.986	0.987	0.983	0.992
InnerMongolia	0.970	0.884	0.966	1.056	0.890	1.054	1.023	0.982	0.966	1.018	0.890	1.076	0.878	1.072	0.938	0.989	0.978	0.977	0.980
Jiangsu	0.728	1.024	0.977	1.003	0.961	1.053	0.991	1.115	1.104	1.088	1.117	1.048	0.937	1.021	1.188	0.775	1.008	0.995	1.025
Jiangxi	0.916	0.962	0.976	0.958	0.984	1.044	1.146	1.050	1.052	1.040	0.994	1.044	0.999	0.939	0.928	0.898	0.996	1.010	0.977
Jilin	0.795	0.970	1.108	1.002	0.834	1.188	1.099	1.015	1.085	1.096	1.004	1.134	0.907	1.069	0.955	0.894	1.010	1.011	1.008
Liaoning	0.655	1.014	0.994	1.110	0.889	1.022	1.119	1.072	1.129	1.001	1.096	1.145	0.993	1.055	0.916	0.995	1.013	1.000	1.029
Ningxia	0.988	0.962	0.838	1.058	1.316	0.694	0.800	0.977	1.068	0.899	0.911	2.382	0.696	1.210	0.624	0.812	1.015	0.967	1.076
Qinghai	1.097	0.949	1.154	0.978	0.529	0.864	0.988	1.234	0.853	0.874	0.954	1.030	0.715	1.221	0.925	0.945	0.957	0.961	0.952
Shaanxi	0.894	1.031	1.003	0.983	0.968	0.971	1.022	1.024	1.112	0.962	0.985	1.114	0.964	1.018	0.893	0.946	0.993	1.001	0.983
Shandong	0.846	0.954	1.027	0.979	0.954	1.011	1.209	0.991	1.017	1.226	1.024	1.042	1.000	0.952	0.936	0.976	1.009	0.999	1.022
Shanxi	0.635	0.899	0.955	1.061	0.996	0.972	0.883	1.080	1.048	1.005	0.966	1.086	0.928	1.081	0.936	0.947	0.967	0.948	0.993
Sichuan	0.902	0.981	1.009	0.984	0.973	0.993	1.160	1.009	0.984	0.990	1.024	1.017	0.985	0.934	0.942	0.948	0.990	0.999	0.977
Tianjin	0.940	1.055	1.114	0.898	0.756	1.511	1.020	0.918	1.082	0.997	0.921	0.954	1.055	1.026	0.878	0.929	1.003	1.033	0.966
Xinjiang	1.120	0.965	1.035	1.024	0.944	1.062	0.994	1.079	1.003	1.040	0.999	0.991	1.003	1.069	0.891	0.994	1.013	1.025	0.998
Yunnan	0.941	0.898	1.057	1.030	0.915	1.008	0.978	0.925	0.965	0.974	0.979	0.963	0.995	1.035	1.112	0.836	0.976	0.969	0.985
Zhejiang	0.713	0.994	0.980	0.955	0.986	1.004	1.077	1.045	1.164	1.025	1.012	1.058	1.013	1.101	0.936	1.024	1.005	0.991	1.024
Annual Average	0.902	0.993	1.015	0.979	0.932	1.022	1.042	1.044	1.029	1.016	1.014	1.138	0.943	1.062	0.913	0.937	0.999	0.995	1.003

Table 4. Estimates of Efficiency Change in China's Agriculture, 1984-1999, by Province/Region

	1984	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**1984-99**	**1984-92**	**1993-99**
Anhui	1.090	0.960	1.033	0.908	1.020	0.925	0.710	1.098	1.101	0.908	0.992	1.028	0.963	1.195	0.967	0.992	0.993	0.983	1.006
Beijing	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Fujian	0.990	0.921	0.933	1.004	1.152	0.913	1.039	1.021	1.049	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.002	1.000
Gansu	1.175	1.012	1.043	1.108	0.964	0.937	1.017	1.038	1.024	0.952	0.937	0.948	0.946	1.125	1.013	0.959	1.012	1.035	0.983
Guangdong	1.205	1.041	0.981	0.986	1.052	1.000	0.950	1.052	0.896	0.942	1.018	0.984	1.010	1.066	1.013	0.939	1.008	1.018	0.996
Guangxi	1.074	0.926	1.049	0.951	1.145	0.974	0.877	1.092	1.017	0.978	1.025	0.965	1.123	1.002	0.927	1.033	1.010	1.012	1.008
Guizhou	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.998	1.000	0.964	1.037	1.000	1.000	1.000
Hebei	0.922	0.883	1.095	1.022	1.099	0.926	0.995	0.992	0.985	0.987	1.082	1.657	0.560	1.122	1.025	0.938	1.018	0.991	1.053
Heilongjiang	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.977	0.987	0.998	1.000	0.995
Henan	0.970	0.882	1.213	0.908	1.078	0.936	0.875	0.925	1.062	0.931	1.062	0.992	1.035	1.117	1.004	0.966	0.997	0.983	1.015
Hubei	1.000	1.000	1.000	0.907	1.103	0.978	0.881	0.995	1.011	0.958	1.120	0.956	1.068	0.924	0.993	1.058	0.997	0.986	1.011
Hunan	0.978	0.961	1.060	0.956	1.037	0.962	0.948	0.987	1.063	0.957	0.970	0.992	1.014	1.081	0.996	1.005	0.998	0.995	1.002
InnerMongolia	1.000	0.923	1.010	1.072	1.000	1.000	1.000	1.000	1.000	1.000	0.940	1.015	0.870	1.204	1.000	1.000	1.002	1.001	1.004
Jiangsu	0.919	1.035	0.959	0.982	1.090	0.933	0.896	1.070	1.033	0.986	1.091	0.940	0.937	0.996	1.216	0.826	0.994	0.991	0.999
Jiangxi	1.017	0.986	1.003	0.985	1.013	1.013	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.002	1.000
Jilin	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.973	1.028	1.000	1.000	1.000	1.000	1.000
Liaoning	0.863	0.913	1.119	1.054	0.964	0.985	1.018	1.006	1.104	0.920	1.032	1.052	0.995	1.005	1.000	1.000	1.002	1.003	1.001
Ningxia	1.019	0.992	0.793	1.035	1.700	0.658	0.923	0.864	1.135	0.897	1.092	1.297	0.888	0.928	0.927	1.023	1.011	1.013	1.007
Qinghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shaanxi	1.044	1.029	1.022	0.985	1.046	0.921	0.917	0.976	1.072	0.913	0.952	1.047	0.940	1.040	0.947	0.994	0.990	1.001	0.976
Shandong	0.954	0.926	1.078	0.963	1.049	0.911	1.098	0.950	1.027	1.149	0.962	0.973	1.024	1.026	1.002	0.991	1.005	0.995	1.018
Shanxi	0.722	0.857	1.051	1.071	1.144	0.910	0.834	1.072	1.100	0.962	0.943	1.036	0.918	1.147	1.007	0.946	0.983	0.973	0.994
Sichuan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.938	1.038	1.007	0.999	1.000	0.998
Tianjin	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Xinjiang	1.059	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.921	1.043	1.041	1.000	1.000	1.004	1.007	1.001
Yunnan	1.036	0.926	1.063	1.044	0.972	1.024	0.932	0.918	1.044	0.938	0.933	0.899	0.990	1.168	1.216	0.847	0.997	0.995	0.999
Zhejiang	0.939	0.970	1.008	0.941	1.072	0.945	0.992	1.022	1.127	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.002	1.000
Annual Average	0.999	0.968	1.019	0.996	1.063	0.957	0.959	1.003	1.031	0.977	1.006	1.026	0.974	1.043	1.009	0.983	1.001	1.000	1.002

Table 5. Estimates of Technical Change in China's Agriculture, 1984-1999, by Province/Region

	1984	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**1984-99**	**1984-92**	**1993-99**
Anhui	0.890	1.004	0.951	0.989	0.943	1.050	1.122	1.015	0.990	1.067	1.025	1.077	0.974	0.906	0.888	0.939	0.989	0.995	0.982
Beijing	1.359	1.585	1.210	0.669	0.607	1.153	1.119	1.345	0.997	0.973	0.974	0.820	0.939	1.720	0.819	0.932	1.076	1.116	1.025
Fujian	0.816	0.977	1.080	1.005	0.896	1.093	1.095	1.041	1.034	1.112	1.117	1.086	1.057	1.040	0.946	0.975	1.023	1.004	1.048
Gansu	0.883	0.970	0.969	0.927	0.910	1.025	1.066	0.995	0.980	1.019	1.020	1.057	1.010	0.920	0.923	0.993	0.979	0.969	0.992
Guangdong	0.841	0.980	1.044	1.017	0.964	1.039	1.126	1.033	1.031	1.083	1.036	1.079	1.031	1.012	0.931	0.994	1.015	1.008	1.024
Guangxi	0.895	1.025	0.939	1.010	0.892	0.993	1.163	0.987	0.986	1.029	1.040	1.049	0.968	0.942	0.961	0.929	0.988	0.988	0.988
Guizhou	0.797	1.050	0.910	0.989	0.886	0.962	1.252	0.864	1.026	0.920	0.931	0.993	0.903	1.180	0.677	0.916	0.954	0.971	0.931
Hebei	0.854	1.049	0.918	0.992	0.883	1.078	1.044	0.996	0.957	1.049	1.018	1.445	0.712	0.933	0.940	1.006	0.992	0.975	1.015
Heilongjiang	0.849	1.079	0.927	1.060	0.861	1.049	1.064	1.075	0.963	1.188	1.042	1.018	0.952	0.857	0.890	0.966	0.990	0.992	0.988
Henan	0.887	1.012	0.959	1.005	0.918	1.077	1.116	1.048	0.981	1.050	1.053	1.060	0.981	0.903	0.932	0.981	0.998	1.000	0.994
Hubei	0.892	0.979	0.975	0.970	0.961	1.066	1.131	1.057	1.047	1.089	1.009	1.095	1.000	1.002	0.928	0.888	1.006	1.009	1.002
Hunan	0.906	0.992	0.959	0.978	0.951	1.026	1.127	1.015	0.955	1.038	1.040	1.068	1.018	0.885	0.911	0.981	0.991	0.990	0.992
InnerMongolia	0.970	0.958	0.957	0.985	0.890	1.054	1.023	0.982	0.966	1.018	0.947	1.060	1.010	0.890	0.938	0.989	0.977	0.976	0.979
Jiangsu	0.793	0.989	1.019	1.022	0.881	1.129	1.106	1.041	1.068	1.103	1.024	1.115	1.000	1.026	0.977	0.939	1.015	1.005	1.026
Jiangxi	0.902	0.975	0.973	0.973	0.972	1.030	1.146	1.050	1.052	1.040	0.994	1.044	0.999	0.939	0.928	0.898	0.995	1.008	0.977
Jilin	0.795	0.970	1.108	1.002	0.834	1.188	1.099	1.015	1.085	1.096	1.004	1.134	0.933	1.040	0.955	0.894	1.010	1.011	1.008
Liaoning	0.758	1.110	0.888	1.053	0.922	1.037	1.099	1.066	1.022	1.088	1.061	1.088	0.998	1.050	0.916	0.995	1.009	0.995	1.028
Ningxia	0.970	0.969	1.056	1.022	0.774	1.055	0.867	1.131	0.941	1.002	0.834	1.836	0.784	1.304	0.673	0.794	1.001	0.976	1.032
Qinghai	1.097	0.949	1.154	0.978	0.529	0.864	0.988	1.234	0.853	0.874	0.954	1.030	0.715	1.221	0.925	0.945	0.957	0.961	0.952
Shaanxi	0.856	1.002	0.981	0.998	0.926	1.054	1.115	1.050	1.037	1.054	1.035	1.063	1.025	0.978	0.943	0.953	1.004	1.002	1.007
Shandong	0.886	1.031	0.953	1.017	0.909	1.110	1.101	1.042	0.990	1.067	1.064	1.071	0.976	0.928	0.934	0.985	1.004	1.004	1.004
Shanxi	0.880	1.048	0.909	0.990	0.871	1.068	1.058	1.007	0.953	1.045	1.025	1.049	1.011	0.943	0.929	1.001	0.987	0.976	1.000
Sichuan	0.902	0.981	1.009	0.984	0.973	0.993	1.160	1.009	0.984	0.990	1.024	1.017	0.985	0.995	0.908	0.941	0.991	0.999	0.980
Tianjin	0.940	1.055	1.114	0.898	0.756	1.511	1.020	0.918	1.082	0.997	0.921	0.954	1.055	1.026	0.878	0.929	1.003	1.033	0.966
Xinjiang	1.058	0.965	1.035	1.024	0.944	1.062	0.994	1.079	1.003	1.040	0.999	1.077	0.962	1.027	0.891	0.994	1.010	1.018	0.999
Yunnan	0.909	0.970	0.995	0.987	0.942	0.985	1.049	1.008	0.924	1.039	1.049	1.070	1.006	0.886	0.915	0.988	0.983	0.974	0.993
Zhejiang	0.760	1.025	0.972	1.015	0.919	1.062	1.086	1.023	1.033	1.025	1.012	1.058	1.013	1.101	0.936	1.024	1.004	0.988	1.024
Annual Average	0.902	1.026	0.999	0.984	0.878	1.067	1.087	1.042	0.998	1.041	1.009	1.093	0.964	1.024	0.903	0.954	0.998	0.998	0.998

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