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DISCUSSION PAPER

Leibniz Institute of Agricultural Development
in Central and Eastern Europe

RECENT EVIDENCE ON AGRICULTURAL EFFICIENCY AND PRODUCTIVITY IN CHINA: A METAFRONTIER APPROACH

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DISCUSSION PAPER NO. 104
2007

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ABSTRACT

Economic reform in China helped transform the structure and volume of agricultural production and resulted in significant changes in efficiency and productivity. This paper measures agricultural technical efficiency (TE) and total factor productivity (TFP) in China by allowing producers operating under their own technologies. A metafrontier function approach is applied using a panel data set on 28 provinces during 1991-2005. The provinces are categorized into advanced-technology and low-technology provinces. Based on the metafrontier estimation, TFP growth is decomposed into TE change (TEC), technical change (TC) and scale efficiency change (SEC). This information is useful for policy makers to design suitable policies in enhancing agricultural TE and TFP growth in China. Our major findings indicate that TC was mostly attributed to Chinese agricultural TFP growth throughout the period of study. SEC and TEC exhibited negative effects to TFP growth for the advance- and low-technology provinces, respectively. Most of the advanced-technology provinces exhibited higher TE than the low-technology provinces. The comparatively low TE scores in the low-technology provinces imply that the low-technology provinces were operating far from the metafrontier. The fluctuation of TE measured with respect to the metafrontier function indicates it is possible that Chinese agricultural TFP growth can be improved through the improvement of TE. The results also show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFP growth.

JEL: Q16, Q18, P27

Keywords: Metafrontier, Agriculture, China, Technical Efficiency, Total Factor Productivity.

ZUSAMMENFASSUNG

NEUE ANHALTSPUNKTE FÜR EFFIZIENZ UND PRODUKTIVITÄT IN DER CHINESISCHEN AGRARPRODUKTION: EINE METAFRONTIER UNTERSUCHUNG

Chinas wirtschaftliche Reformen halfen der Landwirtschaft, die Struktur und dem Umfang der landwirtschaftlichen Produktion umzubauen. Signifikante Erhöhungen der Effizienz und der Produktivität waren die Folge. Die vorliegende Arbeit misst technische Effizienz (TE) und total factor productivity (TFP) in China unter der Annahme individueller Technologien der Landwirte. Mit Hilfe eines Paneldatensatzes für 28 Provinzen über den Zeitraum 1991-2005 wird ein metafrontier Ansatz angewandt. Die Provinzen werden in technologisch fortschrittliche und weniger entwickelte Regionen eingeteilt. Auf der Basis des metafrontier Ansatzes wird das TFP Wachstum in Änderung der technischen Effizienz (TEC), technischen Fortschritt (TC) und Änderung der Skaleneffizienz (SEC) zerlegt. Daraus abgeleitete Informationen sind für die Entwicklung angepasster Politiken zur Förderung technischen Fortschritts und TFP-Wachstums in der chinesischen Landwirtschaft erforderlich. Zentrale Ergebnisse der Analyse zeigen, dass das Wachstum der TFP hauptsächlich durch den technischen Fortschritt erklärt wird. Dagegen weisen SEC und TEC negative Effekte auf das Wachstum der TFP in beiden Provinz-Untergruppen auf. Die Mehrzahl der technisch weiterentwickelten Provinzen weisen eine höhere technische Effizienz als die weniger entwickelten Regionen auf. Die vergleichsweise niedrigen TE-Werte der letzteren deuten auf die weiter entfernte Lage dieser Provinzen von der Metafrontier hin. Die Ergebnisse zeigen, dass Chinas TFP-Wachstum durch eine Steigerung der TE erhöht werden kann. Des Weiteren leisten die Faktoren Arbeit und Düngemittel einen wichtigen Beitrag zur Produktion. Somit sind zusätzlich die Ausbildung der Landwirte und die Bereitstellung moderner Produktionsmittel für die Steigerung der TFP von Bedeutung.

JEL: Q16, Q18, P27

Schlüsselwörter: Metafrontier, Landwirtschaft, Stochastic Frontier Schätzung, China, Technische Effizienz, Technischer Fortschritt, Skaleneffizienz, Total Factor Productivity.

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1 INTRODUCTION

Given the important role of agriculture in the economy and trade, the pursuit of efficiency and productivity in agricultural production with better access to food security has posed major issues for the Chinese policy makers and WTO accession negotiation. The impressive growth of agricultural production in 1978-1984 acknowledged to the successful reform from the collective system to household responsibility system (HRS). Subsequently, an unexpected stagnation of grain yield and a drop in agricultural production occurred in the later 1980s. Though the market-oriented reform through 1990s has been a start-and-stop affair (BRUEMMER et al., 2006), the direction of policy implication is to explore the potential TE, increase the capital improvement and expand the new technology in production (HUANG et al., 2002; HUANG et al., 2002; LIU and WANG, 2005). By the end of 1990s, it is witnessed that China's leader decided to make another push at grain marketing reform with the goal of increasing the efficiency of farming and allowing farmers to pursue activities in which they have a comparative advantage. At the same time, the government actively promoted the shift of farmers into non-grain crops, such as cash crops, fruit and vegetables. After fifteen years of negotiations, China ratified an agreement committing itself to one of the most liberalized international trade regimes in the world. Further, the nation has adopted numerous trade-policy-oriented measures in preparation. Tariffs had been lowered from more than 60 % in 1990s to around 20 % in 2000. From 2002, the government began to subsidize the grain producers instead of collecting agricultural tax. Subsidies, although just beginning, are mostly though to be decoupled (SONNTAG et al., 2005).

Much public attention has been paid to production and its enormous potential for higher efficiencies evolved in those undergoing sustained agricultural growth. Evaluating both the efficiency and productivity in Chinese agricultural production keeps pace with the evolvement of the frontier methodology. A bulk of conclusions has surrounded the arbitrary selection and merits of a specific methodology, and the availability of the data sources. Efficiency measurements draw the supports from frontier functions using two approaches: Parametric and nonparametric approaches. Initially, a parametric estimation on the efficiency and productivity of Chinese agricultural production date back to a study by FAN (1991). Using the aggregated provincial data, FAN (1991) showed that the gaps of TE across regions inlay in the development of local economy and technology expansion. Moreover, 63 % of productivity growth could be devoted to the improvement of TE obtained from the unique impact of institutional reform over 1965-85. Following a time-varying TE model proposed by CORNWELL et al. (1990), WU (1995) assumed TE consists of linear and quadratic time-trend and province-specific components. The main finding of his study is that TFP growth differs largely among regions through the regional variation of TE. With a more flexible form of the varying coefficients frontier function model, KALIRAJAN et al. (1996) revealed that TE improved greatly after the reform but turned to negative during the stagnation of yield in 1984-987.

In order to identify the determinants of TE scores, the studies turn to apply frontier models to farm household-level datasets. Vesting in a profit frontier functions, WANG et al. (1996) defined a shadow-price profit frontier model to examine production efficiency of Chinese rural households. Their study showed that the profit efficiency score in agriculture production ranges from 0.06 to 0.93, with the average of 0.62. Factors such as educational level, family size and net income are positively related to production efficiency. TIAN and WAN (2000) employed deterministic frontiers into one-sided components of stochastic variation estimated by the traditional stochastic frontier functions. TE scores for several crops were evaluated and decomposed. They found that TE is responsive to crop varieties and planting system, which is under the influence of technology improvement. Recently, BRUEMMER et al. (2006) estimated a multiple-output distance functions for individual households data attained from Zhejiang province. Their study showed that the difference in productivity prior to and post-1990s resulted from the difference in TE in the two periods, which could owe to the land policy and the frequent adjustment of market policies. CHEN et al. (2006) applied the traditional stochastic frontier analysis (SFA) model proposed by BATTESE and COELLI (1992) and used the same fixed-point survey data sources as BRUEMMER et al. (2006). They concluded that TE is determined by the farm size and the village intrinsic characteristics.

The implicit assumption of the parametric estimation on TE is the frontier function can be estimated under functional form specification. Without specifying an ex-ante functional form and assuming the behavior of producers, some studies seek to a nonparametric method using index accounting approaches. MAO and KOO (1997) applied a data envelopment analysis (DEA) model to decompose Malmquist index into TC and TEC indices. They identified that TE did not perform identically among provinces and potential for the further improvement of TE is still great, even for the important agricultural provinces.

All the above-mentioned studies followed the frontier production function approach initiated by FARRELL (1957). The foundation for the measurement of TE using a parametric approach is a stochastic frontier model originally proposed by AIGNER et al. (1977). This approach has been expanded by various models of measuring and computing production functions and TE (KUMBHAKAR and LOVELL, 2000). These models assume that all producers in different groups of a given industry have access to the same technology, and thereby facing the same best practice frontier. However, each producer may choose to operate on a different part of its technology due to the geographic influences, resources endowment and policy implication on technology. When the resource is endowed differently in the regions, the empirical evaluation without considering the location specific factors of production and TC can not provide useful policy application. To take account of the technology variation, BETTESE et al. (2002) recently presented a metafrontier function model using the parametric estimation to allow measuring the TE for each producer operating under different production frontiers.

This paper extends the empirical analysis on TE of Chinese agricultural production in several dimensions. First, the parametric estimation of the metafrontier function model is applied to investigate TE of the provinces in China. The provinces are categorized into two groups due to distinctive levels of economic development and production technologies. Secondly, a more recent panel data set of 28 provinces covering the time period of 1991 to 2005 is used in this paper. Since the start of China's WTO agricultural commitments and subsidizing the grain producers in 2002 promoted structural changes in subsequent years, the analysis in this paper will reflect a period of more rapid market-oriented reform and structure changes of agricultural production in China. Thirdly, TFP growth is measured using the defined metafrontier function and TFP growth is decomposed into associated components. This information is useful for policy makers to design suitable policies in enhancing agricultural TE and TFP growth in China. To our knowledge, it is the initial application of this technique into the empirical application.

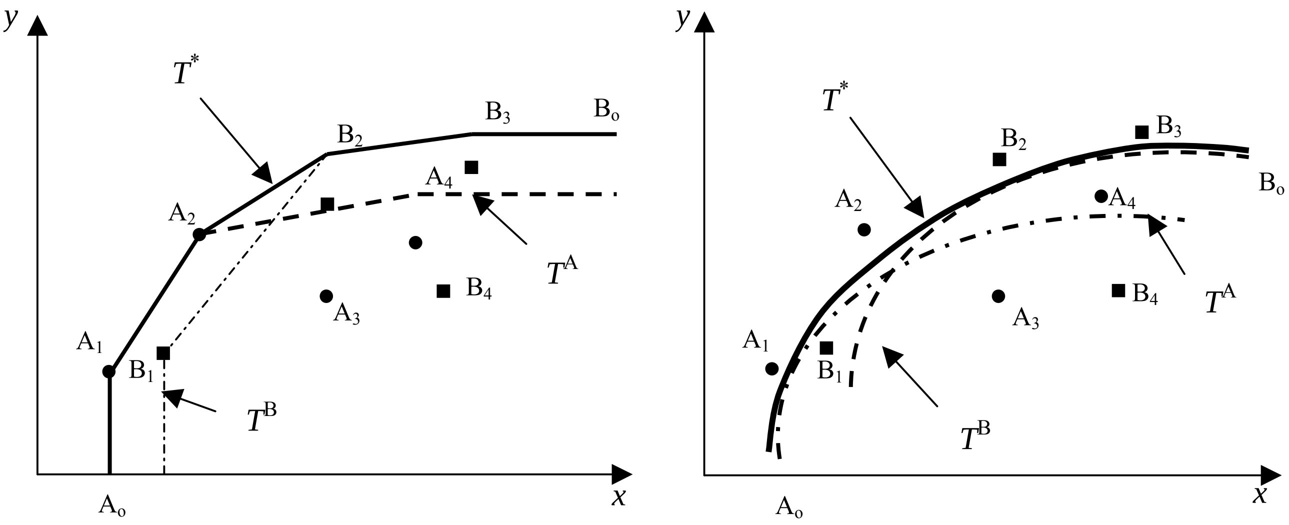
The remainder of this paper is organized as follows. The next section presents a theoretical concept of a metafrontier approach, followed by a discussion of the empirical techniques used to estimate efficiency and productivity using the metafrontier analysis. Then, we describe the data set and the definitions of all variables. The empirical results are presented and discussed, and the final section summarizes our main conclusions.

2 MODEL SPECIFICATION

When all producers in different groups of a given industry have a potential access to the same technology but each producer may choose to operate on a different part of their technologies depending on circumstances such as the natural endowments, relative prices of inputs and the economic environment, then the assessment of producer's efficiency and productivity can be measured using a metafrontier concept. HAYAMI and RUTTAN (1970) initially proposed a metaproduction function which is defined as the envelope of commonly conceived neoclassical production functions. Thus, it is a common underlying production function that is used to represent the input-output relationship of a given industry.

The metafrontier function can be measuring using both nonparametric and parametric approaches. The nonparametric approach is known as DEA and the parametric approach is known as SFA. Figure 1 (a) and (b) illustrate how the metafrontier function is constructed using the DEA and SFA approaches, respectively. Consider there are two different groups of technologies, namely A and B. Let points A_1, A_2, A_3 and A_4 indicate the input-output bundles of four producers in group A. These points are used to construct a frontier for production technology in group A or T^A. Similarly, points B_1, B_2, B_3 and B_4 show the input-output bundles of four producers in group B. These points are used to construct a frontier for production technology in group or T^B. If each group of producers has potential access to the same technology, the grand frontier which envelops the two group-specific frontiers can be represented by line $A_oA_1A_2B_2B_3B_o$. This line is referred as a metafrontier function or T^*. The metafrontier function using DEA constructs piece-wise linear convex production technology by enveloping all observed data from each group-specific technology. It does not require specified functional form for each group-specific technology. On the other hand, the metafrontier function using SFA constructs a smooth production technology by tangenting a specified functional form of production functions from each group-specific technology. The metafrontier using SFA is a smooth function and not a segmented envelope of each group-specific technology.

Figure 1: Group-specific frontier and metafrontier



(a) Using DEA

(b) Using SFA

2.1 Define group-specific technology and metatechnology

Consider the case where all producers are categorized into K groups and producers in each group operate under a group-specific technology T^k where $k = 1,...,K$ denotes the index of producer groups. For a data set of each group *k* consisting of a vector of inputs and outputs for each of the *i*-th producer where $i = 1,...,I^k$ denotes a producer index. Let the input and output vectors for the *i*-th producer in the *k*-th group be denoted $x_i^k = \left(x_{i1}^k,...,x_{iN}^k\right) \in R_+^N$ and $y_i^k = \left(y_{i1}^k,...,y_{iM}^k\right) \in R_+^M$, respectively. For any input vector of all producers in the *k*-th group $x^k \in R_+^N$ and any output vector of all producers in the *k*-th group $y^k \in R_+^M$, an input vector x^k is transformed into net outputs y^k by a production technology T^k. The technology set for the *k*-th group technology T^k which satisfies the axioms presented in FÄRE et al. (1985) is defined as

$$T^k = \{(x^k, y^k) : x^k \text{ can produce } y^k\}. \tag{1}$$

Now, consider any input and output vectors of all producers in all groups are given by $x = \left(x^1 \cup ... \cup x^K\right) \in R_+^N$ and $y = \left(y^1 \cup ... \cup y^K\right) \in R_+^M$, respectively. If a particular output $y \in R_+^M$ can be produced using a given input vector $x \in R_+^N$ in any one of the producer group, a pair (x, y) is belong to a metatechnology T^*. The T^* is defined as the grand technology which envelops all group-specific technologies, $T^1,...,T^K$. The technology set for the metatechnology (T^*) is defined as[1]

$$T^* = \{(x, y) : x \text{ can produce } y \text{ in at least one group-specific technology}\}, \tag{2}$$

where the boundary of the metatechnology set indicates the metafrontier.

A measure of TE defined in FARRELL (1957) can be analyzed using a distance function. The distance function is defined as a rescaling of the length of an input or output vector with the production frontier as a reference. Because either inputs or outputs can be scaled, the distance function can have an input or output orientation. The output distance function of an observed data (x^k, y^k) relative to the group-specific technology T^k is defined as

$$D_o^k(x, y) = \min\{\mu^k : y^k / \mu^k \in T^k\}. \tag{3}$$

$D_o^k(x, y)$ is equal to output-orientated TE, $TE_o^k(x, y)$, of the observed data (x^k, y^k) with respect to T^k, so that $0 \le TE_o^k(x, y) = D_o^k(x, y) \le 1$. Similarly, the relationship between the output-orientated TE and output distance function of the observed data (x, y) relative to T^* is defined as $0 \le TE_o^*(x, y) = D_o^*(x, y) \le 1$ where $D_o^*(x, y) = \min\{\mu^* : y / \mu^* \in T^*\}$.

2.2 Decomposition technical efficiency under metatechnology

Figure 2 shows a decomposition of TE under metatechnology. The metatechnology (T^*) which is constructed from the two production technologies, T^A and T^B, is represented by line $A_oA_1A_2B_2B_3B_{oo}$. The boundary of the metaechnology represents a metafrontier. Consider the production technology T^A where point A_1, A_2 and A_4 lie on the frontier but point A_3 lies below

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[1] This metatechnology `T^* satisfies all the production axioms in FÄRE et al. (1985) except the convexity axiom. In order to ensure the convexity property, the metatechnology is defined as the convex hull of the union of each group-specific technology as T^* = Convex Hull {T^1 U T^2 U … U T^K}.

the frontier. TE_o^A of the point A_1, A_2 and A_4 corresponding to its own frontier is equal to one whereas TE_o^A of the point A_3 is equal to the ratio of $A_3^*A_3$ to $A_3^*A_3^{***}$. When the metafrontier (T^*) is considered, TE_o^* of the point A_1, A_2 is still equal to one whereas TE_o^* of the point A_3 is equal to the ratio of $A_3^*A_3$ to $A_3^*A_3^{**}$ and TE_o^* of the point A_4 is equal to the ratio of $A_4^*A_4$ to $A_4^*A_4^{**}$. Similarly, consider the production technology T^B where point B_1, B_2 and B_3 lie on the frontier but point B_3 lies below the frontier. TE_o^B of the point B_1, B_2 and B_3 corresponding to its own frontier is equal to one whereas TE_o^B of the point B_4 is equal to the ratio of $B_4^*B_4$ to $B_4^*B_4^{**}$. When the metafrontier (T^*) is considered, TE_o^* of the point B_2, B_3 and B_4 is still the same as TE_o^B whereas TE_o^* of the point B_1 is equal to the ratio of B_oB_1 to $B_oB_1^{**}$. When the TE_o is measured relative to the group-specific technology and metatechnology, it can occur a gap between the two technologies used as a reference. This gap is called a technology gap which is defined as the ratio of the distance function using an observed data based on the metotechnology T^* to the group-specific technology T^k.

Using the output orientation, the technology gap ratio (TGR) can be defined as

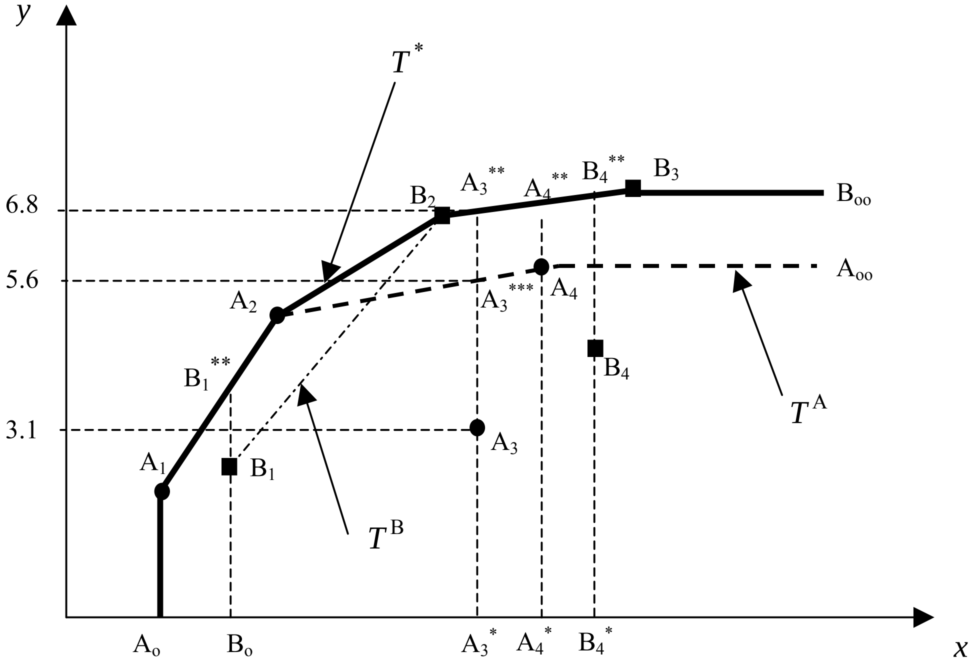
$$TGR_o^k(x,y) = \frac{D_o^*(x,y)}{D_o^k(x,y)} = \frac{TE_o^*(x,y)}{TE_o^k(x,y)}, \tag{4}$$

or it can be written as

$$TE_o^*(x,y) = TE_o^k(x,y) \times TGR_o^k(x,y). \tag{5}$$

Equation (5) shows that TE measured with respect to the metafrontier (T^*) can be decomposed into the product of the TE measured with respect to the *k*-th group technology (T^k) and the technology gap ratio. Note that the value of $TGR_o^k(x,y)$ will be between zero and one so that $TE_o^*(x,y) \le TE_o^k(x,y)$. For example, consider point A_3 in Figure 2, TE with respect to T^A can be measured by the ratio of the distances between $A_3^*A_3$ to $A_3^*A_3^{***}$. The $TE_o^A(x_{A3}, y_{A3}) = 3.1/5.6 = 0.554$ implying that all outputs could be possibly produced by 45 % more from the given inputs by using T^A as a reference. The TE with respect to T^* can be measured by the ratio of the distances between $A_3^*A_3$ to $A_3^*A_3^{**}$. The $TE_o^*(x_{A3}, y_{A3}) = 3.1/6.8 = 0.456$ implying that all outputs could be possibly produced by 54 % more from the given inputs by using T^* as a reference. Therefore, $TGR_o^k(x,y) = 0.456/0.554 = 0.823$ implying that the possible output for the T^A is 82.3 percent of that represented by the metafrontier (T^*).

Figure 2: Decomposition of technical efficiency under the metafrontier



2.3 SFA approach to metafrontier

When suitable panel data for each producer in each group during the time period, $t = 1,...,T$ are available, the metafrontier estimation using the SFA can be achieved using a two-step procedure. First, the stochastic production frontier for each group is estimated and compared with that for all producers. Then, a statistical test is performed to examine whether all producers in different groups have potential access to the same technology.

If the group *k* consists of data on I^k producers, the stochastic production frontier model for the *i*-th producer at time period *t* based on the group-specific data and the pooled data is given as follows.

$$\ln Y_{it}^c = \ln f(X_{it}^c, t; \beta^c) + v_{it}^c - u_{it}^c, \tag{6}$$

where superscript *c* refers to a choice of the stochastic production frontier model [If $c = k$, equation (6) refers to the stochastic group-specific production frontier model when the data for the *i*-th producer in the *k*-th group at the *t*-th time period are used, and if $c = p$, equation (6) refers to the stochastic pooled production frontier model when the data for all producers in all groups for all time periods are used]; Y_{it}^c denotes the output quantity for the *i*-th producer at the *t*-th time period; X_{it}^c denotes the input quantity for the *i*-th producer at the *t*-th time period; β^c s are unknown parameters associated with the X -variables to be estimated; v_{it}^c s are a two-sided random-noise component assumed to be i.i.d. $N(0, \sigma_v^{2c})$ and u_{it}^c s are a non-negative technical inefficiency component. The v_{it}^c and u_{it}^c are distributed independently of each other, and of the regressors. The non-negative technical inefficiency component, u_{it}^c, is assumed to follow a half normal distribution, $u_{it}^{c} \sim$ i.i.d $N^{+}\left(0,\sigma_{u}^{2c}\right)$, and is defined by some appropriate inefficiency model [see, BATTESE and COELLI (1992, 1995)][2].

Following BATTESE and COELLI (1992), the stochastic group-specific and pooled production frontier models, taking the log-quadratic translog functional form under a non-neutral TC assumption can be written as follows.

$$\begin{aligned}\ln Y_{it}^{c} &= \beta_{0}^{c} + \sum_{n=1}^{N} \beta_{n}^{c} \ln X_{nit}^{c} + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm}^{c} \ln X_{nit}^{c} \ln X_{mit}^{c} \\ &\quad + \sum_{n=1}^{N} \beta_{nt}^{c} \ln X_{nit}^{c} \cdot t + \beta_{t}^{c} t + \frac{1}{2}\beta_{t}^{c} t^{2} + v_{it}^{c} - u_{it}^{c},\end{aligned} \tag{7}$$

where $m,n = 1,...,N$ index of input quantities and $u_{it}^{c} = \{\exp[-\eta(t-T)]\}u_{i}^{c}$ where ηs are parameters to be estimated and u_{i}^{c}s are non-negative random variables which are assumed to account for technical inefficiency in production and are assumed to be i.i.d. as truncations at zero of the $N^{+}\left(0,\sigma_{u}^{2c}\right)$ distribution. Young's theorem requires that the symmetry restriction is imposed so that $\beta_{nm} = \beta_{mn}$ for all $m,n = 1,2,3$.

An estimate of output-orientated TE for the *i*-th producer at the *t*-th time period is given by

$$TE_{oit}^{c} = \exp\{-u_{it}^{c}\}. \tag{8}$$

If the stochastic frontiers across groups do not differ, then the stochastic pooled frontier function can be used as a grand technology for each group. However, if the stochastic frontiers across groups do differ, the metafrontier function will be used as a grand technology for each group. The second step will involve estimating the metafrontier function. The metafrontier function using SFA does not fall below the deterministic functions for the stochastic group-specific frontier model as shown in Figure 2. In order to obtain estimated parameters of the metafrontier function, we need to ensure that the estimated function best envelops the deterministic components of the estimated stochastic frontiers for the different groups. BATTESE et al. (2004) proposed a method so called the minimum sum of absolute deviations to identify the best envelope. The parameter estimates of the metafrontier function are estimated by solving the following LP problem.

$$\text{Min} \sum_{i=1}^{I}\sum_{t=1}^{T}\left|(x_{it}\beta^{*} - x_{it}\hat{\beta}^{k})\right| \equiv \bar{x}\beta^{*} \tag{9}$$

such that $x_{it}\beta^{*} \geq x_{it}\hat{\beta}^{k}$,

where $\bar{x}$ denotes the row vector of mean of the elements of the x_{it} vector for all observations in the data set; x_{it} is the logarithm form of the input quantity for the *i*-th producer in the *t*-th time period; $\hat{\beta}^{k}$s are the estimated coefficients obtained from the stochastic group-specific frontiers obtained from equation (7) and β^{*}s are parameters of the metafrontier function to be estimated.

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[2] We follow the suggestion of BATTESE and CORRA (1977), and replace the two variance parameters with the two new parameters $\sigma^{2} = \sigma_{v}^{2} + \sigma_{u}^{2}$ and $\gamma = \sigma_{u}^{2} / \sigma^{2}$. By doing this we can search the parameter space of γ between 0 and 1, to provide good starting values for the iterative maximization routine which is used to calculate the maximum likelihood parameter estimates.

Once the β^* parameters of the metafrontier function in equation (9) are estimated, the decomposition of TE under the metafrontier can be calculated. The technology gap for the *i*-th producer in the *k*-th group at the *t*-th time period can be obtained by

$$TGR_{oit}^{k}(x,y)=\frac{e^{x_{it}\beta^{k}}}{e^{x_{it}\beta^{*}}}. \tag{10}$$

Then, a measure of the output-oriented TE relative to the metafrontier, $TE_o^*(x,y)$, can be obtained using equation (5).

2.4 Decomposition of total factor productivity change

TFP growth is generally defined as the residual growth in outputs not explained by the growth in input use. TFP growth can be measured and decomposed into associated components attributing to the TFP growth after the metafrontier function in equation (9) is estimated. This information is useful for policy makers to design suitable policies in enhancing the productivity growth in the industry.

Following OREA (2002), a measure of TFP change (TFPC) for each firm between any two time periods can be calculated by using the estimates of the coefficients of the metafrontier and the firm-level sample data. The logarithmic form of the TFPC between period t and $t+1$ for the *i*-th firm is defined as

$$\begin{aligned}\ln\left(\frac{TFP_{it+1}}{TFP_t}\right)&=\ln\left(\frac{TE_{oit+1}^{*}}{TE_{oit}^{*}}\right)+\frac{1}{2}\left[\frac{\partial\ln y_{it+1}}{\partial t}+\frac{\partial\ln y_{it}}{\partial t}\right]\\&+\frac{1}{2}\sum_{n=1}^{N}\left[\left(SF_{it+1}\cdot E_{nit+1}\right)+\left(SF_{it}\cdot E_{nit}\right)\right]\left(\frac{\ln x_{nit+1}}{\ln x_{nit}}\right),\end{aligned} \tag{11}$$

where the three terms on the right-hand-side of equation (11) represents the output-oriented TEC, TC and SEC, respectively.

The output-orientated TE measure, $\left(TE_o^*\right)$, in equation (11) is the output-orientated TE prediction of the *i*-th firm in the *t*-th time period, and is calculated from equation (5). The TC measure, $\left(TC_{itt+1}\right)$, is the mean of the TC measures evaluated at the period t and period $t+1$ data points. The SEC measure, $\left(SEC_{itt+1}\right)$, relates to the change in scale efficiency, which requires calculation of the scale factor $\left(SF\right)$ and input elasticity $\left(E_n\right)$ evaluated at the period t and period $t+1$ data points. The SF of the *i*-th firm in the *t*-th time period $\left(SF_{it}\right)=(E_{it}-1)/E_{it}$ where $E_{it}=\sum_{n=1}^{N}E_{nit}$ represents the scale elasticity and $E_{nit}=\partial\ln y_{it}/\partial\ln x_{nit}$ is production elasticity for the *n*-th input.

3 DATA SOURCE AND DESCRIPTIONS

A balanced panel data set of 28 provinces covering the time period of 1991 to 2005 is used in the empirical analysis. Figure 3 illustrates the location of all provinces in China. Provinces selected for analysis include all provinces in China excluding Hainan and Tibet due to the missing information[3]. Considering regional disparities, all provinces are ranked by using GDP per capita at 2001 according to the definition presented in KOO and MAO (1997)[4]. Provinces are divided into two groups of technologies: Advanced-technology and low-technology provinces. Each group consists of 14 provinces. A list of the provinces in each group is summarized in Figure 3.

Figure 3: The location of advanced- and low-technology provinces

Advanced-technology provinces	*Low-technology provinces*
1. Beijing	1. Shanxi
2. Tianjin	2. Inner-Mongolia
3. Hebei	3. Anhui
4. Liaoning	4. Jiangxi
5. Jilin	5. Henan
6. Helongjiang	6. Hunan
7. Shanghai	7. Guangxi
8. Jiangsu	8. Sichuan
9. Zhejiang	9. Guizhou
10. Fujian	10. Yunnan
11. Shandong	11. Shaanxi
12. Hubei	12. Gansu
13. Guangdong	13. Qinghai
14. Xinjiang	14. Ningxia

Note: a. Tibet, Hainan, Macao, Hong Kong and Taiwan are not included in this study;
b. The data of Chongqing is aggregated into the data of Sichuan provinces.

The primary data on agricultural production were extracted from the official data sources – *China Statistical Yearbook* and *Chinese Agricultural Statistical Yearbook*. The data used in this study contains the measurements of agricultural output and input quantities. In this study, the production technology is represented by one output and six inputs. The definitions of these variables are summarized as follows:

Dependent variable: The gross output value of farming at 1990 constant prices in billions of yuan (y) is chosen as the dependent variable. The gross output value of farming aggregates physical output from seven grain crops and twelve economic crops. However, it excludes the value of forestry, animal husbandry, handicraft products for self-consumption or for sales as sideline occupations and the total value of industries run by villages and cooperative organizations under villages.

Independent variable: Following the existing literatures, independent variables include six important physical inputs such as capital, labor, chemical fertilizer, pesticide, plastic film and irrigation (LIN, 1992; WU, 1995; LIU and WANG, 2005).

Capital input (x_1) denotes farm machinery in the unit of millions of KW, mainly including the big tractor and walking tractors. Other inputs such as draft animals are excluded in this study due to the unavailable information in the provincial statistics.

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[3] Although Chongqing is separated from Sichuan as a municipal administrative city, data series of Chongqing were added together with those of Sichuan due to the unavailability of its data before 1998. In addition, Macao, Hong Kong and Taiwan are not included in this study.

[4] <http://www.demographia.com/db-china-reggdp-2001.htm>.

Labor force denotes the number of total rural labors directly engaged in production of agriculture, forestry, animal husbandry and fishery annually. To measure the labor input in farming sector (x_2), we followed the calculation by LIN (1992) to weight the labor input in agriculture by the value share of farming output in total agricultural output.

Chemical fertilizer (x_3) refers to the pure-content quantity of chemical fertilizers applied in yearly agricultural production in tons. The pure-content gross quantity of chemical fertilizer is calculated to convert the gross weight into weight containing 100 percent of effective components.

Pesticide (x_4) is the quantity of chemical pesticides applied in agriculture reported in tons annually.

Plastic film (x_5) includes those for coving young plants and seeds listed in tons annually.

Irrigation is one of the very important factors in agricultural production. An effectively irrigated area including not only the full sets of technological irrigation facilities but also adequate water sources for the normally agricultural irrigation can be used as an irrigation variable[5]. The irrigation variable (x_6) used in this study is defined as the ratio of effectively irrigated area to total cultivated area. Total cultivated land area refers to land that is plowed constantly for growing crops excluding the land of tea plantations, orchards, nurseries of young plants, forest land, natural and man-made grassland.

Table 1 presents the descriptive statistics of the variables used in the study summarized by the two groups of technology defined above. The advance-technology provinces show higher mean for each variable than the low-technology provinces expect for the labor input. However, the low-technology provinces exhibit lower standard deviation for each variable than the advance-technology provinces expect for the capital and labor inputs.

Table 1: Descriptive statistics of variables, 1991-2002

Variables	*Unit*	*Advanced-technology provinces*	*Low-technology provinces*	*All provinces*
Dependent variable				
Output	Billion Yuan	27.678	22.505	25.092
		(19.520)	(17.094)	(18.507)
Independent variables				
Capital	Thousand KW	4615.148	4160.390	4387.769
		(4453.458)	(5604.301)	(5060.772)
Labor	Thousand Person	4752.045	7967.061	6359.553
		(3724.526)	(5698.546)	(5070.276)
Fertilizer	Million KG	1451.905	1305.492	1378.699
		(1127.808)	(1033.238)	(1082.749)
Pesticide	Million KG	48.823	33.195	41.009
		(40.953)	(31.282)	(37.228)
Plastic	Million KG	51.025	34.573	42.799
		(52.847)	(28.218)	(43.106)
Irrigation	%	64.290	43.490	53.891
		(24.070)	(18.510)	(23.837)

Notes: Means are calculated. Standard deviations are presented in parentheses.

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[5] The increased quantity of irrigation power may be used as a better proxy of the increasing and improving irrigated technique and project rather than the expended irrigated area. However, this variable can not been found in official statistical yearbooks, and thus can not be included in the specified models.

4 RESULTS

4.1 Discussions of parameter estimates and production structure

The data described in section 3 were used in the estimation of the stochastic group-specific and pooled production functions shown in equation (7). The stochastic group-specific production functions are estimated using the data of the advanced- and low-technology provinces separately whereas the stochastic pooled production function is estimated using the data of all provinces. The data variables used in the model estimation were normalized by their respective geometric means. This transformation does not alter the performance measures obtained, but does allow one to interpret the estimated first-order parameters as elasticities, evaluated at the sample means. The estimated coefficients for each model are presented in Table 2. The estimation results from each model are similar and all first-order coefficients have the expected signs except for the estimated parameters, β_{x4} of the low-technology provinces model.

The likelihood ratio (LR) test statistic for the null hypothesis that the group-specific frontiers are identical is 106.44. The LR test statistic follows a chi-square distribution with 39 degrees of freedom. The null hypothesis was rejected with a p-value less than 0.001. This result implies that the group-specific frontiers are not the same. Therefore, the metafrontier function described in section 2.3 needs to be estimated. Table 2 also presents the estimated coefficients of the stochastic metafrontier function. All first-order coefficients have the expected signs and can also be interpreted as shadow shares. The estimates of the input elasticities under the stochastic metafrontier function model are 0.0413, 0.2446, 0.4341, 0.0530, 0.0690 and 0.5285 for capital, labor, fertilizer, pesticide, plastic and irrigation, respectively. The sum of the input elasticities provides information about scale economies and is 1.3705, indicating that the technology exhibits moderately increasing returns to scale at the sample mean. The first order coefficients of the time trend variable provide estimates of the average annual rate in TC. The stochastic metafrontier function model suggest that the technology is improving at a rate of 2.71 % per annum,

Table 2: Estimated parameters of stochastic group-specific frontier and metafrontier models

Para-meters[a]	Stochastic frontier						Metafrontier[b]	
	Advanced-technology provinces		Low-technology provinces		All provinces			
β_0	2.6686	(0.0465)	2.5797	(0.0537)	2.5495	(0.0433)	2.6293	(0.0150)
β_{x1}	0.0420	(0.0317)	0.0184	(0.0289)	0.0439	(0.0164)	0.0413	(0.0085)
β_{x2}	0.3646	(0.0614)	0.3304	(0.1202)	0.2947	(0.0356)	0.2446	(0.0060)
β_{x3}	0.2906	(0.0727)	0.5293	(0.1149)	0.3859	(0.0552)	0.4341	(0.0167)
β_{x4}	0.0051	(0.0519)	-0.0140	(0.0658)	0.0358	(0.0312)	0.0530	(0.0113)
β_{x5}	0.0678	(0.0392)	0.0255	(0.0309)	0.0203	(0.0177)	0.0690	(0.0064)
β_{x6}	0.5520	(0.1193)	0.8039	(0.2364)	0.4799	(0.0748)	0.5285	(0.0310)
β_t	0.0421	(0.0059)	0.0207	(0.0078)	0.0365	(0.0033)	0.0271	(0.0010)
β_{x11}	0.0211	(0.0355)	-0.0295	(0.0267)	-0.0067	(0.0204)	-0.0027	(0.0110)
β_{x12}	-0.2059	(0.0510)	0.0128	(0.0575)	-0.0776	(0.0274)	-0.1603	(0.0126)
β_{x13}	0.1199	(0.0520)	-0.0125	(0.0660)	0.0672	(0.0398)	0.0946	(0.0250)

β_{x14}	0.0374	(0.0442)	-0.0420	(0.0339)	-0.0314	(0.0228)	0.0230	(0.0123)
β_{x15}	0.0408	(0.0359)	0.0009	(0.0218)	0.0176	(0.0159)	0.0825	(0.0116)
β_{x16}	-0.1707	(0.0775)	0.1570	(0.1130)	-0.0315	(0.0663)	-0.2160	(0.0231)
β_{x22}	0.3070	(0.1112)	-0.2944	(0.2748)	0.1332	(0.0685)	0.0839	(0.0289)
β_{x23}	-0.0850	(0.1230)	0.1517	(0.3298)	-0.1045	(0.0962)	-0.1217	(0.0589)
β_{x24}	-0.1129	(0.0713)	0.0083	(0.1219)	-0.0074	(0.0420)	0.0834	(0.0308)
β_{x25}	-0.0272	(0.0570)	0.0230	(0.0633)	-0.0007	(0.0282)	0.0424	(0.0130)
β_{x26}	0.7263	(0.1500)	-0.5272	(0.4302)	0.6944	(0.1135)	0.5261	(0.0411)
β_{x33}	-0.1962	(0.2384)	-0.0540	(0.5815)	0.2132	(0.1840)	0.5670	(0.1326)
β_{x34}	0.1590	(0.0900)	0.0428	(0.1775)	-0.0047	(0.0648)	-0.2128	(0.0448)
β_{x35}	0.1951	(0.1022)	-0.1470	(0.1087)	-0.0728	(0.0577)	-0.1915	(0.0198)
β_{x36}	-0.4919	(0.2330)	1.0752	(0.6946)	-0.3362	(0.1899)	-0.3234	(0.0722)
β_{x44}	-0.0311	(0.0210)	-0.1430	(0.1051)	-0.0005	(0.0192)	0.0379	(0.0107)
β_{x45}	-0.0691	(0.0408)	0.0990	(0.0506)	0.0330	(0.0258)	0.0380	(0.0131)
β_{x46}	-0.0037	(0.1043)	0.1337	(0.3230)	-0.0659	(0.0922)	-0.0456	(0.0623)
β_{x55}	-0.1638	(0.0637)	-0.0084	(0.0264)	0.0120	(0.0194)	0.0029	(0.0064)
β_{x56}	0.0586	(0.0959)	-0.3459	(0.1728)	-0.1349	(0.0819)	-0.0458	(0.0607)
β_{x66}	0.4344	(0.5484)	-2.6276	(0.9912)	1.1428	(0.4167)	0.3150	(0.1620)
β_{x1t}	-0.0213	(0.0048)	0.0039	(0.0055)	-0.0050	(0.0027)	-0.0212	(0.0014)
β_{x2t}	0.0324	(0.0085)	-0.0061	(0.0149)	0.0164	(0.0047)	0.0007	(0.0028)
β_{x3t}	-0.0369	(0.0103)	0.0174	(0.0164)	-0.0185	(0.0071)	-0.0024	(0.0023)
β_{x4t}	0.0115	(0.0058)	-0.0033	(0.0100)	0.0074	(0.0038)	0.0109	(0.0031)
β_{x5t}	0.0093	(0.0047)	0.0005	(0.0065)	-0.0003	(0.0033)	0.0087	(0.0022)
β_{x6t}	0.0501	(0.0122)	-0.0318	(0.0369)	0.0546	(0.0106)	0.0448	(0.0057)
β_{tt}	0.0004	(0.0011)	0.0006	(0.0019)	0.0016	(0.0008)	0.0004	(0.0005)
σ^2	0.0146	(0.0019)	0.0122	(0.0016)	0.3107	(0.4543)		
γ	0.7200	(0.0633)	0.6612	(0.0568)	0.9830	(0.0249)		
η	-0.0075	(0.0120)	0.0136	(0.0089)	-0.0082	(0.0056)		
Log-likelihood	256.1712		235.9472		438.8973			

Note: Numbers in parentheses are standard errors.

[a] Subscripts on β_x coefficients refer to inputs: 1 = capital; 2 = labor; 3 = fertilizer; 4 = pesticide; 5 = plastic and 6 = irrigation.

[b] Standard deviations of the metafrontier estimates are calculated using parametric bootstrapping as presented in BATTESE, RAO and O'DONNELL (2004).

Table 3 provides annual average production elasticities of inputs – capital, labor, fertilizer, pesticide, plastic and irrigation – for the year 1991-2005. The production elasticity for capital decreases over the period 1991-2005 by 7.42 % per anuum. The production elasticity for labor increases during 1991-1993 and decreases during 1994-2005 leading to a decrease by 2.40 % per anuum. The production elasticity for fertilizer decreases over the period 1991-2002 and increases during the period 2003-2005 leading to an increase by 0.44 % per anuum. The production elasticities for pesticide and plastic increase throughout the period by 12.79 % and 7.84 % per anuum, respectively. The production elasticity for irrigation increases during 1991-2002 and decreases during 2003-2005 leading to an increase by 2.11 % per anuum. The results indicate that the annual rates of increase of production elasticities for fertilizer, pesticide, plastic and irrigation are greater than the rates of decrease for capital and labor. The results also show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFP growth.

Table 3: Annual average production elasticities for different inputs, 1991-2005

Year	Capital	Labor	Fertilizer	Pesticide	Plastic	Irrigation
1991-1993	0.081	0.297	0.434	0.029	0.053	0.471
1994-1996	0.075	0.306	0.426	0.032	0.054	0.489
1997-1999	0.054	0.299	0.412	0.053	0.071	0.537
2000-2002	0.036	0.278	0.399	0.076	0.072	0.650
2003-2005	0.029	0.215	0.453	0.101	0.114	0.589
1991-2005	**0.041**	**0.245**	**0.434**	**0.053**	**0.069**	**0.529**

4.2 Discussions of decomposition technical efficiency under metafrontier

Table 4 provides average TE scores relative to the stochastic group-specific frontier and metafrontier technologies as well as TGR scores for each group of provinces during 1991-2005. Moreover, Table A1 in Appendix reports TE scores relative to the stochastic group-specific frontier and metafrontier technologies as well as TGR score for all 28 provinces over the period 1991 to 2005. TE scores relative to the group-specific technology for the advanced-technology provinces range from 0.688 by Hebei to 0.978 by Guangdong with an average of 0.806. TE scores relative to the group-specific technology for the advanced-technology provinces were decreasing over time. Based on the metafrontier technology as a reference, TE scores for the advanced-technology provinces range from 0.661 by Hebei to 0.940 by Guangdong with an average of 0.764. The average TE score implies that the advanced-technology provinces in this study were, on average, producing 80.6 % of the outputs that could be potentially produced from the given inputs by using their own technologies as a reference and 76.4 % using the metafrontier technology as a reference. The estimates of TGR for the advanced-technology province range from 0.847 by Shanghai to 0.980 by Helongjian with an average of 0.948. This result implies that the possible outputs for the advanced-technology provinces based on their groups-specific technology is, on average, 94.8 % of that represented by the metafrontier technology. Hebei and Tianjin are the two lowest ranked TE scores relative to both group-specific and metafrontier technologies whereas Guangdong and Liaoning are the two highest ranked TE scores relative to both technologies. The ranking of the TE scores from other provinces is not much different relative to both technologies except for Shanghai. Shanghai is the third highest ranked TE score relative to its group-specific technology while it is the fifth lowest ranked TE scores relative to the metafrontier technology.

Turning to the low-technology provinces, TE score relative to their own technology range from 0.581 by Ningxia to 0.979 by Sichuan with an average of 0.732. TE scores relative to the group-specific technology for the low-technology provinces were increasing over time. Based on the metafrontier technology as a reference, TE scores for the low-technology provinces range from 0.443 by Ningxia to 0.842 by Inner-Mongolia with an average of 0.644. The average TE score implies that the low-technology provinces in this study, on average, could be potentially produced 27 % more outputs from the given inputs by using their own technologies as a reference and 36 % more outputs using the metafrontier technology as a reference. The estimates of TGR for the low-technology provinces range from 0.764 by Ningxia to 0.975 by Gansu with an average of 0.882. This result implies that the possible outputs for the low-technology provinces based on their group-specific technology is, on average, 88.2 % of that represented by the metafrontier technology. Ningxia and Anhui are the two lowest ranked TE scores relative to the group-specific technology while Ningxia is still the lowest ranked TE scores relative to the metafrontier technology and Anhui is the is the forth lowest ranked TE scores relative to the metafrontier technology. Sichuan and Inner-Mongolia are the two highest ranked TE scores relative to both technologies. The ranking of the TE scores from other provinces is quite different relative to both technologies.

The empirical findings show that the advanced-technology provinces had average province TE higher than the low-technology provinces. The advanced-technology provinces generally led in terms of TGR and had smaller variation of TGR than the low-technology provinces. The comparatively low TE scores in the low-technology provinces imply that the low-technology provinces were operating far from the metafrontier. The fluctuation of TE measured with respect to the metafrontier function indicates it is possible that Chinese agricultural TFP growth can be improved through the improvement of TE.

Table 4: TE Scores by the group-specific and metafrontier technologies and TGR for each group, 1991-2005

Year	**Advanced-technology provinces**			**Low-technology provinces**		
	TE^k	**TGR**	**TE^***	**TE^k**	**TGR**	**TE^***
1991	0.815 (0.075)	0.911 (0.055)	0.744 (0.096)	0.710 (0.142)	0.904 (0.113)	0.636 (0.115)
1992	0.814 (0.076)	0.916 (0.042)	0.746 (0.078)	0.714 (0.140)	0.907 (0.076)	0.645 (0.119)
1993	0.813 (0.076)	0.957 (0.042)	0.778 (0.078)	0.717 (0.139)	0.904 (0.073)	0.646 (0.126)
1994	0.811 (0.077)	0.966 (0.029)	0.784 (0.083)	0.720 (0.138)	0.909 (0.071)	0.653 (0.126)
1995	0.810 (0.077)	0.977 (0.022)	0.791 (0.079)	0.723 (0.136)	0.901 (0.066)	0.649 (0.116)
1996	0.809 (0.078)	0.979 (0.014)	0.792 (0.077)	0.726 (0.135)	0.899 (0.067)	0.651 (0.123)
1997	0.808 (0.078)	0.973 (0.036)	0.785 (0.077)	0.729 (0.133)	0.885 (0.072)	0.643 (0.113)
1998	0.806 (0.079)	0.946 (0.088)	0.761 (0.092)	0.732 (0.132)	0.871 (0.089)	0.636 (0.117)
1999	0.805 (0.079)	0.959 (0.055)	0.771 (0.084)	0.735 (0.131)	0.869 (0.098)	0.637 (0.122)
2000	0.804 (0.080)	0.963 (0.055)	0.773 (0.083)	0.738 (0.129)	0.817 (0.140)	0.599 (0.131)
2001	0.802 (0.080)	0.956 (0.053)	0.766 (0.074)	0.741 (0.128)	0.886 (0.079)	0.655 (0.123)
2002	0.801 (0.081)	0.936 (0.066)	0.749 (0.086)	0.743 (0.127)	0.881 (0.076)	0.656 (0.129)
2003	0.800 (0.081)	0.940 (0.064)	0.751 (0.089)	0.746 (0.125)	0.869 (0.087)	0.648 (0.124)
2004	0.799 (0.082)	0.925 (0.075)	0.739 (0.101)	0.749 (0.124)	0.869 (0.090)	0.650 (0.120)
2005	0.797 (0.082)	0.919 (0.080)	0.732 (0.102)	0.752 (0.123)	0.868 (0.098)	0.652 (0.124)
1991-2005	**0.806** **(0.076)**	**0.948** **(0.058)**	**0.764** **(0.086)**	**0.732** **(0.128)**	**0.883** **(0.089)**	**0.644** **(0.119)**

4.3 Discussions of TFP decomposition

Table 5 presents weighted growth rate of TFP decomposition by the group of the provinces during 1991-2005. TFP growth by all provinces increases by 62.45 % over the sample period with a weighted average of about 3.234 % per annum. TEC is nearly negligible; it decreases by `0.43 % over the sample period (average of about 0.029 % per annum). SEC is less important; it increases by 1.46 % over the sample period (average of 0.097 % per annum). Overall, TC explains most of the TFP growth. It increases by 60.79 % with a weighted average of 3.166 % per annum. The major findings show that TFP change in China agriculture over the study period was mainly driven by technological progress. These aggregate figures dissimulate the diversity of effects across the two groups of provinces, although TC changes are dominant in both of two groups.

The advance-technology provinces show TFP growth of 65.6 % over the sample period (average of about 3.362 % per annum). TC increases by 66.3 % (average of about 3.391 % per annum) and the technical progress with the highest rate occurred during 2000-2002. TEC increases by 0.57 % with a weighted average incline of about 0.038 % per annum even though it indicates a decline after the period 1997. SEC decreases by 0.99 % with a weighted average decrease of about 0.066 % per annum although the entire decline is due to the negative SEC during 1997-2005. TC explains most of the TFP growth throughout the period. There is an impressive technical progress during 2000-2002. TEC is a major contribution to TFP growth together with TC during 1991-1996 and 2000-2005. However, TEC is negligible relative to TC and SEC during 1997-1999. SEC is negligible relative to TC and SEC throughout the period.

The low-technology provinces countries experience a TFP increase of 58.92 % over the sample period (average of about 3.088 % per annum). TC and SEC increase by 54.26 % (average of about 2.890 % per annum) and 4.57 % (average of about 0.298 % per annum). There is a major deteriorate in SEC during 2000-2002. TEC slightly decreases by 1.48 % over the sample period with a weighted average decline of about 0.099 % per annum. TC explained most of the TFP growth for the entire period. There is an impressive technical progress during 2000-2002. TEC is negligible relative to TC and SEC throughout the period except the period of 1997-1999. SEC is a major contribution to TFP growth together with TC during 2000-2002.

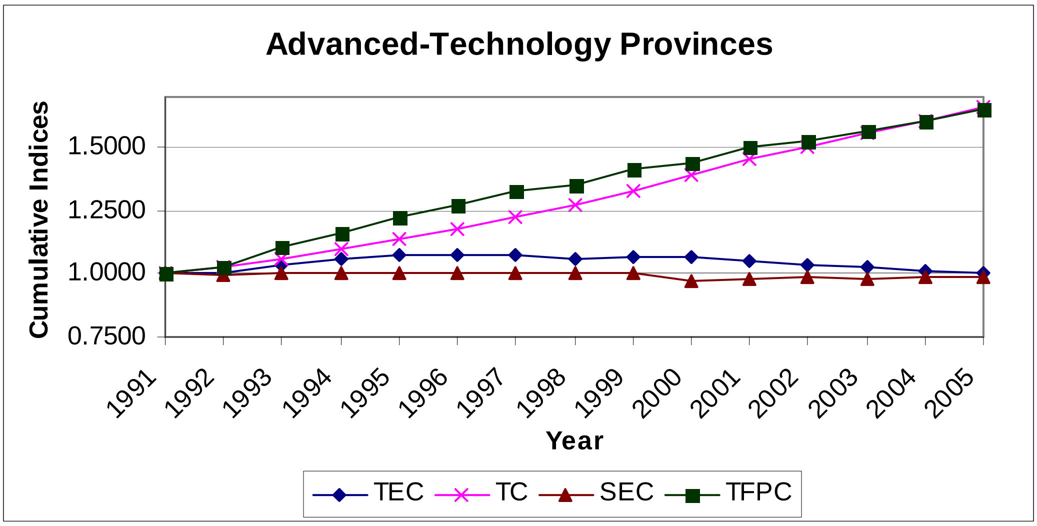
Table 5: Weighted annual growth rates of decomposed TFPC by provinces group (%)

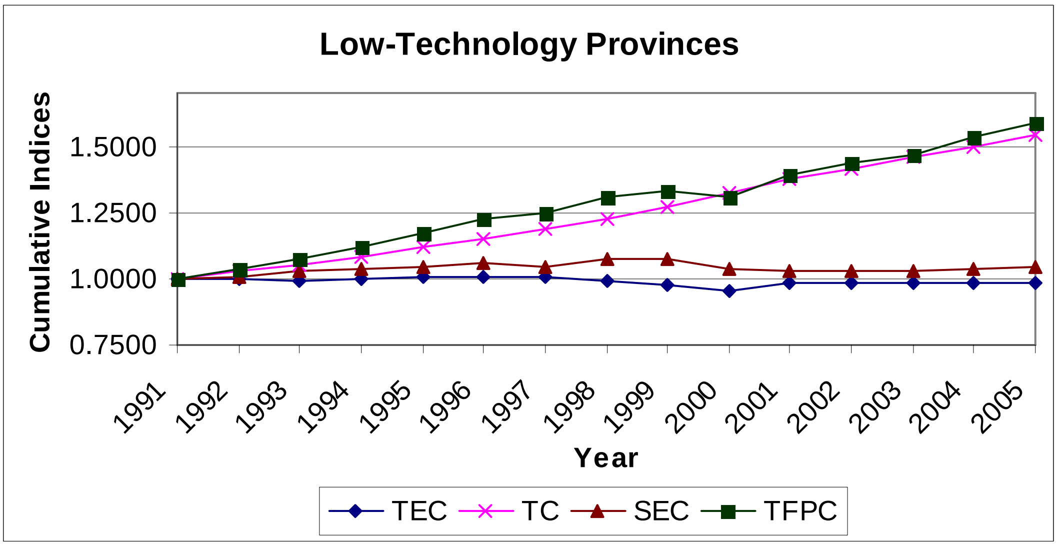
Period	*TEC*	*TC*	*SEC*	*TFPC*
			Advanced-technology provinces	
1991-1993	1.267	1.938	0.158	3.363
1994-1996	1.100	3.612	0.003	4.714
1997-1999	-0.283	3.829	-0.032	3.514
2000-2002	-1.056	4.238	-0.667	2.515
2003-2005	-0.840	3.338	0.206	2.703
1991-2005	**0.038**	**3.391**	**-0.066**	**3.362**
			Low-technology provinces	
1991-1993	-0.335	1.730	0.958	2.354
1994-1996	0.512	2.957	0.901	4.371
1997-1999	-0.853	3.215	0.463	2.825
2000-2002	0.219	3.671	-1.419	2.471
2003-2005	-0.041	2.875	0.587	3.420
1991-2005	**-0.099**	**2.890**	**0.298**	**3.088**
			All provinces	
1991-1993	0.529	1.842	0.525	2.897
1994-1996	0.838	3.320	0.403	4.561
1997-1999	-0.537	3.555	0.184	3.202
2000-2002	-0.493	3.983	-1.005	2.484
2003-2005	-0.480	3.132	0.377	3.028
1991-2005	**-0.029**	**3.166**	**0.097**	**3.234**

Figure 4 contains a set of the cumulative index plots of the TFP growth and its associated components by the group of the advanced- and low-technology provinces over the entire 1991-2005 period. The plot of the advanced-technology provinces shows that there was TFP progress over time and mainly driven by TC. The advanced-technology provinces showed a decline in TFP growth during 1991-1993 and 2000-2005 which was resulted from a decline in TEC. There was a significant increase in TEC in 1993 and a major decrease in SEC in 2000. The plot of the advanced-technology provinces shows that TFP change was closely driven by TC throughout the period. The TFP and TC changes were steadily improved while TEC and SEC was steadily stable leading to an increase of TFP growth for the entire periods. Overall, TC explains most of the TFP growth. However, the TEC was attributed to TFP growth more than the SEC throughout the period.

The plot of the low-technology provinces shows that TFP change was closely driven by TC. TFPC change was steadily improved throughout the period expect in 2000. A decrease in TEC led to a decrease in TFPC in 2000. TC change was steadily improved throughout the period. TEC was steadily stable and showed a small decrease during 1999-2000. SEC was steadily stable and showed an increase during 1993-1999. Overall, TC explains most of the TFP growth and the SEC was attributed to TFP growth more than the TEC throughout the period.

Figure 4: Cumulative indices of TEC, TC, SEC and TFPC by groups of the provinces, 1991 to 2005





The proportional growth of the average TEC, TC and SEC components constituting the average TFP growth for all provinces in each group over the time period of 1992 to 2002 are also reported in Table A1 in Appendix. All provinces can be divided into different categories according to their TFP growth and what sources are attributed to their TFP growth. All advanced-technology provinces except Helongjiang indicated TPF progress over the time period. TFP regress for Helongjiang was driven by a decline of TC and SEC. Hebei is the only province which TFP progress was driven by an increase in TEC, TC and SEC. TFP progress for Beijing, Zhejiang, Fujian and Guangdong was driven by an increase in TEC and TC with a decrease in SEC. TFP progress for Tianjin, Shanghai, Jiangsu, Hubei was mainly attributed by technical progress with a decline in TEC and SEC. Liaoning, Jilin, Shandong and Xijiang showed an increase in TC and SEC but a decrease in TEC attributing to their TFP progress.

Similarly, all low-technology provinces except Inner-Mongolia indicated TPF progress over the time period. TFP regress for Inner-Mongolia was driven by a decline of TEC and TC. TFP progress for all provinces except Qinghai and Ningxia was mainly driven by technical progress. Shanxi, Henan, Guizhou, Yunnan, Shaanxi, Gansu showed an increase in TEC, TC and SEC attributing to their TFP progress. TFP progress for Anhui and Guangxi Guangdong was driven by an increase in TC and SEC but a decrease in TEC. TFP progress for Jiangxi, Hunan and Sichuan was mainly attributed by technical progress with a decline in TEC and SEC.

The results of TFP growth decomposition by selected provinces are discussed here. The provinces are selected as a representation to explain agricultural productivity for each group of provinces. We select four provinces – two provinces with highest output shares and two provinces with lowest output shares – from each group. Two provinces with the highest output shares for the advanced-technology provinces are Shandong and Jiangsu, respectively, and two provinces with the lowest output shares are Shanghai and Tianjin, respectively. For the low-technology provinces, two provinces with the highest output shares are Sichuan and Henan, respectively, and two provinces with the lowest output shares are Qinghai and Ningxia, respectively.

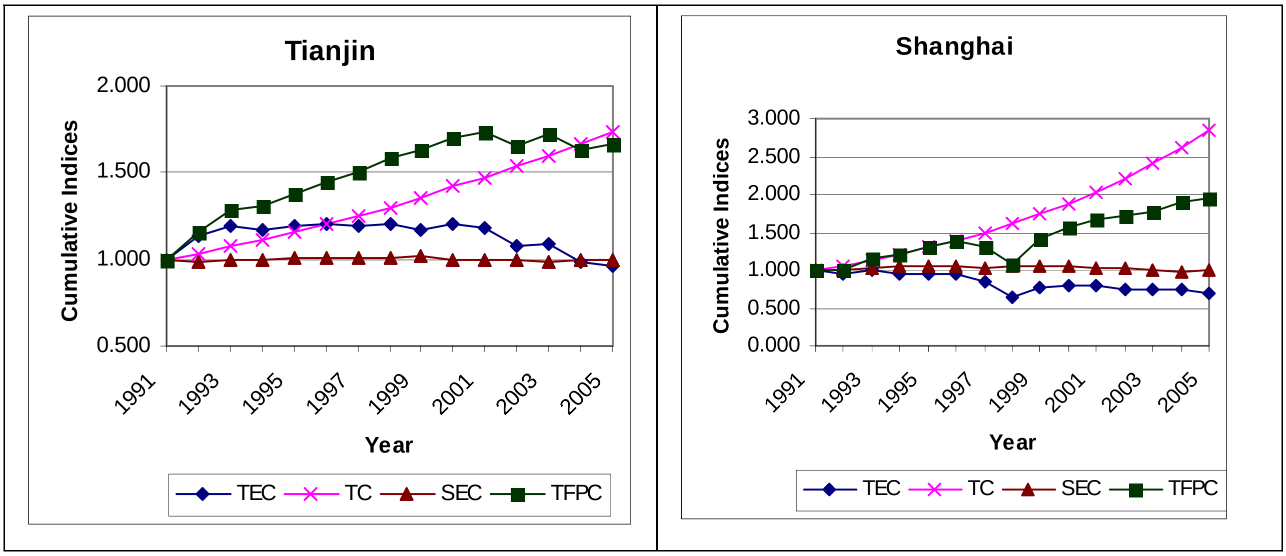
The unweighted TFP growth and its associated components over the sample period for each province are reported in Table A1 in Appendix. The unweighted TFP growth for the advanced-technology provinces over the sample period was 3.585 percent by Shandong, 3.327 percent by Jiangsu, 4.484 percent by Shanghai and 3.384 percent by Tianjin. Shandong showed its agricultural productivity progress driven by TC and SEC whereas Jiangsu, Shanghai and Tianjin showed their productivity progress mainly driven by technology progress with a decline in the TEC and SEC effects.

Figure 5 contains a set of the cumulative index plots of the TFP growth and its associated components by Tianjin, Shanghai, Jiangsu and Shandong over the entire 1991-2005 period. Tianjin showed agricultural productivity progress throughout the period except in 2002 and 2004. TEC was a major contribution to TFP progress during 1991-1996 whereas TC was a major contribution to TFP progress during 1997-2005. A decrease in TEC led to TFP regress in 2002 and 2004. TC was steadily improved throughout the period while SEC was steadily stable. Shanghai exhibited agricultural productivity progress over the sample period except in 1999 due to a decline of TEC in this period. TC was steadily improved throughout the period while SEC was steadily stable. Jiangsu and Shandong showed that TFP change was closely driven by TC throughout the period. The TFP and TC changes were steadily improved while TEC and SEC was steadily stable leading to an increase of TFP growth for the entire periods. Overall, TC explains most of the TFP growth. However, the TEC was attributed to TFP growth more than the SEC during 1991-2001.

Turning to the TFP growth decomposition for the low-technology provinces, the unweighted TFP growth over the sample period reported in Table A1 in Appendix was 3.774 percent by Sichuan, 3.054 percent by Henan, 1.980 percent by Qinghai and 1.523 percent by Ningxia. The high output share provinces such as Sichuan and Henan showed that technical progress led to their agricultural productivity progress. The low output share provinces such as Qinghai and Ningxia showed technical regress over time and an increase in TEC and SEC was led to their agricultural productivity progress.

Figure 6 contains a set of the cumulative index plots of the TFP growth and its associated components by Henan, Sichuan, Qinghai and Ningxia over the entire 1991-2005 period. Henan exhibited agricultural productivity progress over the sample period. All TEC, TC and SEC effects were major contributions to its TFP progress during 1991-1999 and 2003-2005. During 2000-2002, TEC was declining and TC and SEC were major contributions to its TFP progress during these periods. Sichuan showed that TFP change was closely driven by TC throughout the period. The TFP and TC changes were steadily improved while TEC and SEC was steadily stable leading to an increase of TFP growth for the entire periods. Qinghai showed agricultural productivity progress during 1991-1999 and a significant TFP regress in 2000 following with TFP regress during 2002-2005. TEC was a major contribution to TFP growth throughout the period. TC changes were steadily decreased for the entire periods. SEC was steadily stable throughout the period except a significant increase in 2000. Ningxia showed agricultural productivity progress throughout the period except in 1998, 2000 and 2002-2003. A decrease in TEC resulted in TFP regress. SEC was major contributions to its TFP progress for the entire periods. TC changes were steadily decreased for the entire periods.

Figure 5: Cumulative indices of TEC, TC, SEC and TFPC by the advanced-technology groups, 1991 to 2005



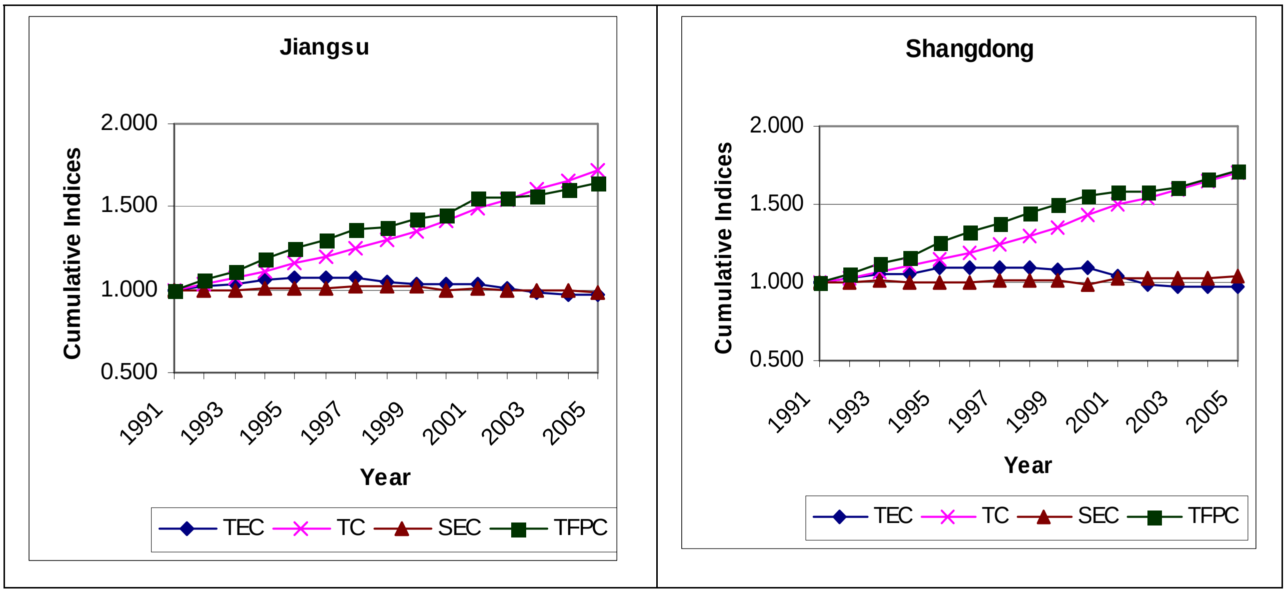
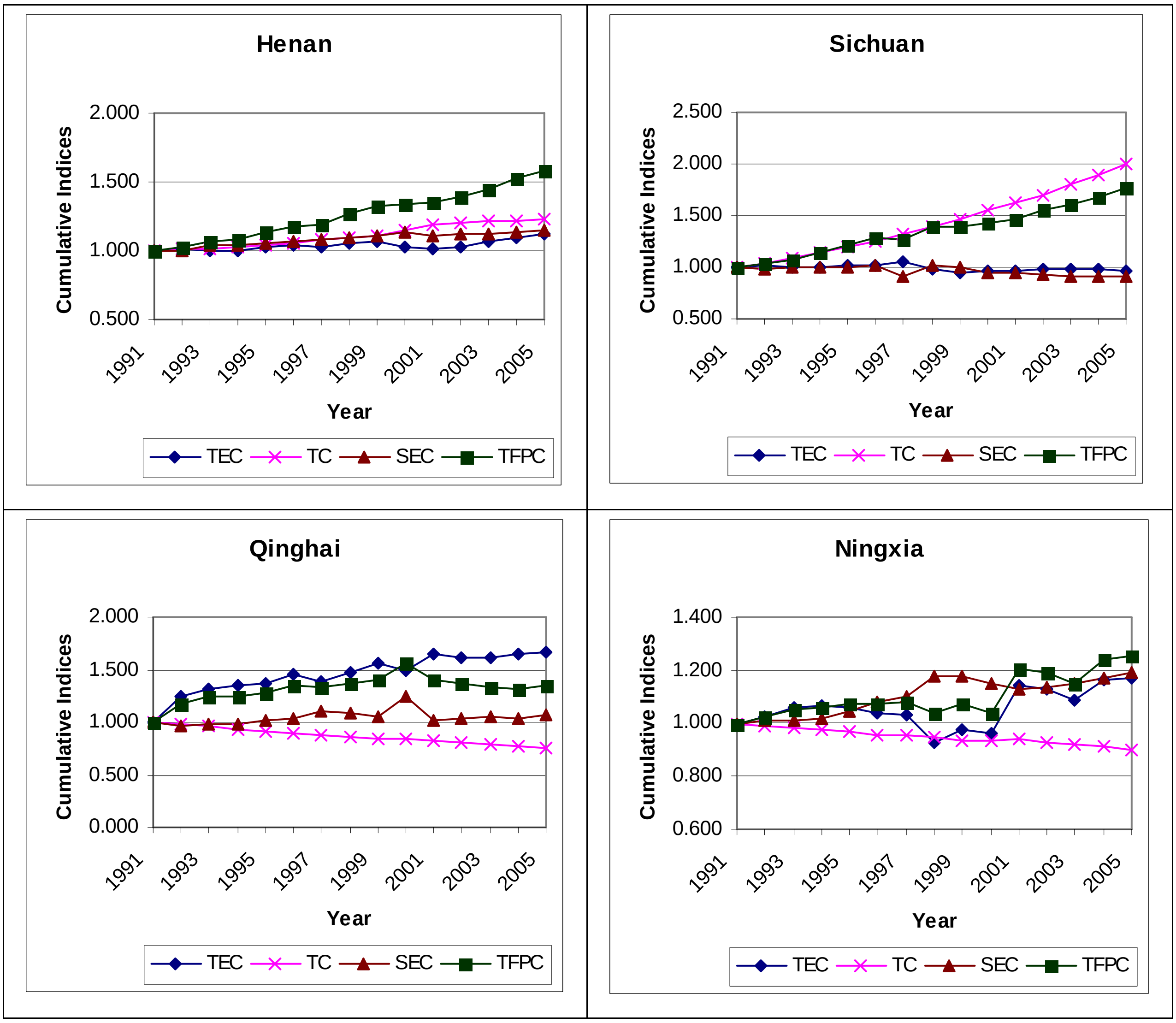


Figure 6: Cumulative indices of TEC, TC, SEC and TFPC by the low-technology groups, 1991 to 2005



5 CONCLUSIONS

With nearly one quarter of the potential agricultural resources and one-fifth of the world's population, China has the potential to supply a substantial share of the expected growth in food demand forecast for the first half of this century. This study utilizes a parametric metafrontier function approach presented in BETTESE et al. (2002, 2004) to measure and decompose Chinese agricultural TE and TFP growth in 28 provinces over the period from 1991-2005. The provinces are categorized into advanced- and low-technology provinces due to distinctive levels of economic development and production technologies. The metafrontier approach allows to investigate whether all producers in different regions have potential access to the same technology or they may choose to operate on a different part of their own technologies.

The empirical findings indicate that the weighted average TFP growth in the Chinese agriculture over the study period grew at 3.234 % per annum, which was driven primarily by a 3.166 % increase in TC. SEC exhibited a positive effect to TFP growth whereas TEC showed positive in early years, then negative starting in 1997. TC was a major contribution to TFP growth in both advanced- and low-technology provinces. SEC and TEC exhibited negative effects to TFP growth for the advance- and low-technology provinces, respectively. Most of the advanced-technology provinces exhibited higher TE than the low-technology provinces. The comparatively low TE scores in low-technology provinces were found to be related to the TE measured with respect to its own-group technology and the technology gap ratio. As researchers and policy makers discuss the "pros and cons" of China's WTO commitments in agriculture, the analysis in this study suggests that there may be benefits through the improvement of TE. The empirical results also show that labor and fertilizer still make important contributions to output, and thus improving the quality of farmers and applying modern physical inputs is also crucial to TFP growth.

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Appendix

Table A1: Average TE, TGR and the TFP decomposition by province

Provinces	TE^k	***TGR***	TE^*	***TEC***	***TC***	***SEC***	***TFPC***
Advanced-technology provinces				(in percentage)			
Beijing	0.820	0.948	0.778	0.180	4.190	-0.173	4.197
Tianjin	0.740	0.938	0.694	-0.286	3.693	-0.024	3.384
Hebei	0.688	0.960	0.661	0.499	2.049	0.534	3.082
Liaoning	0.948	0.948	0.898	-0.239	3.076	0.143	2.979
Jilin	0.784	0.969	0.760	-0.392	0.705	0.325	0.638
Helongjiang	0.839	0.980	0.822	0.012	-0.410	-0.344	-0.741
Shanghai	0.840	0.847	0.712	-2.439	6.957	-0.034	4.484
Jiangsu	0.793	0.960	0.761	-0.221	3.636	-0.088	3.327
Zhejiang	0.742	0.958	0.710	0.909	4.974	-0.914	4.969
Fujian	0.771	0.943	0.728	0.708	5.556	-0.257	6.007
Shandong	0.797	0.951	0.758	-0.198	3.559	0.225	3.585
Hubei	0.742	0.950	0.705	-0.037	4.486	-0.067	4.382
Guangdong	0.978	0.962	0.940	0.613	4.662	-0.786	4.489
Xijiang	0.806	0.958	0.772	-0.715	2.788	0.359	2.431
Average	**0.806**	**0.948**	**0.764**	**-0.115**	**3.566**	**-0.079**	**3.372**
Low-technology provinces							
Shanxi	0.615	0.903	0.554	0.277	1.188	0.534	2.000
Inner-Mongolia	0.976	0.863	0.842	-1.092	-0.602	1.285	-0.408
Anhui	0.596	0.938	0.558	-0.306	2.435	0.446	2.575
Jiangxi	0.694	0.844	0.584	-1.698	6.440	-0.770	3.972
Henan	0.726	0.858	0.623	0.743	1.378	0.934	3.054
Hunan	0.699	0.789	0.551	-0.895	6.074	-0.724	4.455
Guangxi	0.720	0.934	0.672	-0.588	2.393	0.547	2.351
Sichuan	0.980	0.842	0.825	-0.184	4.642	-0.683	3.774
Guizhou	0.731	0.888	0.650	0.577	3.082	0.043	3.702
Yunnan	0.711	0.941	0.669	0.214	2.231	0.942	3.387
Shaanxi	0.649	0.966	0.627	0.549	0.668	1.160	2.378
Gansu	0.649	0.975	0.633	0.135	0.977	1.401	2.512
Qinghai	0.917	0.851	0.781	3.423	-1.893	0.449	1.980
Ningxia	0.581	0.764	0.443	1.048	-0.692	1.167	1.523
Average	**0.732**	**0.883**	**0.644**	**0.157**	**2.023**	**0.481**	**2.661**

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