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## Analysis of regional productivity growth in China: A generalized metafrontier MPI approach

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## ABSTRACT

This paper analyzes the dynamics of China's productivity for the period 1996–2004 with a newly developed methodology – generalized metafrontier Malmquist productivity index (gMMPI). Implementing the gMMPI, this paper reviews the inequality of the coastal and non-coastal provinces, as well as the latent impact of scale efficiency change (SEC) for China. Using provincial data for the years 1996–2004, the empirical results are as follows. On average, China demonstrates an annual 3.191% productivity change, which is lower than 4.729% for the conventional MPI and accounts for about 26.508% of output growth over the period 1996–2004. Most of this change is propelled by technical progress, while a fraction is driven by the adjustment in production scale, and the efficiency change has an adverse effect. Furthermore, regional inequality is also found in this empirical work, and the productivity change of the coastal region is actually stronger than that of the non-coastal region. This paper also casts some focus on the China Western Development policy. Indeed, we do not find any outstanding achievement from the policy in the sample period, except that the west region sustained its rate of productivity change after 2000. Moreover, the SEC is found to be trivial in the advanced coastal region, but plays an important role in the relatively laggard non-coastal region. The implication of the positive SEC in the non-coastal region means that China's Western Development policy will improve the scale efficiency and the TFP growth of the west region.

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### 1. Introduction

Ever since the initiative of an “open door policy” in the late 1970s, China has witnessed continuously spectacular economic growth, at an average rate of 9.8% over the past three decades. While the change in state policy on international investment and trade has been widely recognized to contribute to the economic growth,<sup>1</sup> technological progress is alternatively regarded as the critical ingredient for sustained economic growth and catching up. Is China's remarkable growth driven principally by factor accumulation? Is there nothing miraculous about its growth, as in Young's (1995) critique on East Asian growth? These issues have inspired a boom of empirical studies to assess productivity growth in China.

One line of research pays attention to examining economy-wide productivity growth in China by adopting total factor productivity (TFP) as a measure of technological change.<sup>2</sup> Using the growth accounting approach, Borensztein and Ostry (1996),

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<sup>1</sup> Please see Yao (2006) for a comprehensive survey.

<sup>2</sup> Another line of research focuses on examining sector-wide productivity growth. Of these studies, a common conclusion is that there is a considerable high rate of agricultural productivity growth in the 1980s, while the conclusion on productivity growth of the manufacturing sector is mixed. For example, see McMillan, Whalley, and Zhu (1989), Wu (1995), Young (2003), and Szirmai, Ren, and Bai (2005).

Hu and Khan (1997), Fleisher and Chen (1997), Ezaki and Sun (1999), Wang and Yao (2003), and Islam, Dai, and Sakamoto (2006) provided assessments of TFP growth in the post-reform period and found that there was a considerable TFP growth rate in China, between 2.41% and 3.90%, during the post-reform period of 1980 to 1995.<sup>3</sup> The accuracy and reliability of the growth accounting approach depend heavily on accurate data and on a complicated calculation process regarding the factor price, while Young (2003) and Islam et al. (2006) strongly warned of the problems in China's national income accounts data.

In contrast to the growth accounting approach, a branch of studies is emerging that uses the frontier production approach with a more flexible assumption to production behavior to measure TFP growth in China. Wu (2000) first applied the Malmquist index of TFP growth to examine whether China's economic growth is sustainable and found an increasing trend of TFP growth over the period from 1987 to 1995. Chen (2001) found positive average TFP growth during the period from 1992 to 1999, because technology improvement was found to be a larger component for TFP growth. Zheng and Hu (2006) presented considerable average productivity growth for most of the data periods during 1979 to 2001. In their estimate, the TFP growth figure was 5.34% during the 1980s and 2.60% in the 1990s. However, TFP growth slowed significantly between 1995 and 2001, and the weighted average TFP growth rate during that time was only 1.11%. Shiu and Heshmati (2006) used the panel econometrics estimation approach for measuring provinces' TFP growth during 1993 to 2003. They found a spectacular TFP growth rate of nearly 9% across provinces, but they also identified a general trend for TFP growth decline.

When using the MPI approach to analyze China's TFP growth, there is nevertheless a serious limitation to a rigorous study – that is, for a long time the regional inequality between the coastal and non-coastal regions has persistently been a problem inside China's economy,<sup>4</sup> which implies that the coastal and non-coastal regions have different production frontiers. In light of this discrepancy, we should estimate separate production frontiers for these different regions. Indeed, production units in different regions face different production opportunities that force them to make choices from different sets of feasible input–output combinations. This difference can be attributed to the available stocks of physical, human, and financial capital, economic infrastructure, resource endowments, and any other characteristics of the physical, social, and economic environment in which production takes place (O'Donnell, Rao, & Battese, 2008). Hence, when using the conventional MPI to estimate the frontiers of the two regions separately to obtain the productivity change, the direct cross-sets comparison is restrained, but it requires a construction of some common function that defines the existing technologies. Fortunately for meeting the requirement, in view of the assumption that all producers in different groups (countries, regions, etc.) have potential access to the same technology, Battese, Rao, and O'Donnell (2004) had proposed a framework of metafrontier production function model. The advantage of this framework is that the cross-sets comparison of production efficiencies measured under different frontiers can be conducted on a common basis of potential technology. O'Donnell et al. (2008) subsequently formally utilized distance functions to define and illustrate the framework of the metafrontier production function, while extending the concept of the metafrontier to the domain measuring the total factor productivity; i.e., the metafrontier Malmquist productivity index (MMPI). Therefore the adoption of the MMPI should have more of a methodological advantage than the conventional MPI for investigating China's TFP growth, since the strong assumption regarding all provinces operating under the same frontier and the limitation in cross-sets comparison could be relaxed.

Nonetheless, it is also worth noting that the MMPI is still an incomplete measure in nature, since the potential impact of scale efficiency change (SEC) is not taken into account. From the perspective of industrial economics, the technological frontier of a production unit comprises three fractions: increasing return to scale (IRS), constant return to scale (CRS), and decreasing return to scale (DRS). As long as the used technology has variable return to scale, regardless of IRS or DRS, it invariably implies that there is room to improve the average product (productivity) through adjusting the operating scale. As Ray (1998) argued, even a fully efficient production unit operating on the frontier might not necessarily imply an optimal scale of production. Only the input–output combinations of the CRS level can harmonize the point of maximum average product.<sup>5</sup> Frisch (1965) termed the operating scale corresponding to the CRS as the technically optimal productive scale (TOPS). Therefore, from a static viewpoint, the scale efficiency refers to a ratio of the potential productivity of the current scale on the frontier (i.e., the productivity level without loss of technical efficiency) to the productivity level of the TOPS. Then, from a dynamic viewpoint, the scale efficiency change can be defined as a cross-period adjustment in scale efficiency toward the TOPS (Coelli, Rao, O'Donnell, & Battese, 2005).

Indeed, the problem of a productivity index measure ignoring the effect of SEC has been discussed in the literature. Under the conventional MPI framework, the issue is systematically addressed in both non-parametric and parametric contexts.<sup>6</sup> Since the MMPI is a productivity measure extended from the MPI that takes the metafrontier as its basis, it should be noted that the imperfection of MPI by ignoring the effect of the SEC, as criticized in the literature, should also be embedded in the MMPI. This study adopts a generalized MMPI framework (gMMPI), therefore further taking into account the effect of SEC in the MMPI.

The main purpose of this article is to provide new empirical evidence on China's regional productivity growth. It attempts to contribute in line with the existing empirical literature by providing the following three distinct types of empirical evidence. First, this study develops a generalized MMPI framework (gMMPI), which further takes into account the effect of SEC in the MMPI to reassess China's regional productivity growth during 1996–2004. Second, the study discusses the extent of productivity change

<sup>3</sup> Islam et al.'s (2006) study claimed that the average TFP growth was 2.95% for the longer period from 1978–2002.

<sup>4</sup> There is an abundance amount of studies showing that there is a growing regional imbalance in China – for example, Chen and Fleisher (1996), Yao and Zhang (2001), and Kanbur and Zhang (2005).

<sup>5</sup> The VRS correspond to a figure of scale elasticity deviating from unity and the CRS correspond to a figure of scale elasticity equal to unity. Banker (1984) also characterized the operating scale with scale elasticity equal to unity as the most productive scale size (MPSS).

<sup>6</sup> See Fare, Grosskopf, Norris, and Zhang (1994) and Grifell-Tatje and Lovell (1999) for the non-parametric context. Concerning the parametric context, please refer to Balk (2001) and Orea (2002).

contributing to economic growth as well as the components determining the productivity change. In particular, we assess the contribution of SEC in our model to regional economic growth as an attempt to shed light on regional development policy. Third, the regional (coastal and non-coastal) inequality is widely known as a challenge to the Chinese economy. From the viewpoint of productivity change, we assess whether or not the gap has been harmonized in the past decade. By combining analyses of productivity change on both coastal and non-coastal regions, our results may help to explain the regional disparity between the two regions in China and provide policy implications for regional development. In addition, the article also reviews the attainment of the China Western Development policy in terms of change in productivity and its components.

After the introduction, the rest of this paper is organized as follows. Section 2 provides a brief illustration of O'Donnell et al.'s (2008) MMPI, while the gMMPI framework is introduced under the parametric context, further taking into account the effect of adjustment in scale efficiency. Section 3 illustrates the data arrangement and model specifications. Section 4 reports on the empirical analyses, including the estimation of production frontiers and the calculations of the gMMPI. Section 5 then provides a brief review of the China Western Development policy. The final section summarizes concluding remarks and policy implications.

## 2. Methodology

### 2.1. Metafrontier Malmquist productivity index

The MMPI framework is illustrated in terms of a distance function in this section. First let  $x_t \in R^{+M}$  and  $y_t \in R^{+L}$  denote the input and output vectors in time  $t$ , and  $t = 1, 2, \dots, T$ , while the production technology is defined as capability of transforming inputs into outputs. Suppose that there are  $K$  technology possibility sets (groups) in total, and  $k = 1, 2, \dots, K$ . The technologically feasible input–output combinations can be categorized into an identical output oriented technology set  $P^k(x)$ :

$$P_t^k(x) = \{y_t^k \text{ is obtainable from } x_t^k\} \tag{1}$$

The upper boundary of the restricted technology set for the  $k$ th group refers to the group frontier (O'Donnell et al., 2008).<sup>7</sup> Then, the output-oriented distance function for this group  $k$  is defined as in Shephard (1970):

$$D_t^k(x_t^k, y_t^k) = \inf_{\delta} \left\{ \delta > 0 : \left( \frac{y_t^k}{\delta} \right) \in P_t^k(x_t^k) \right\} \tag{2}$$

According to Fare et al. (1994), the Malmquist productivity index (MPI) for capturing the cross period change in productivity on the basis of Caves, Christensen, and Diewert (1982) can be specified as:

$$MPI_{t,t+1}^k(x_t, y_t, x_{t+1}, y_{t+1}) = \frac{D_{t+1}^k(x_{t+1}, y_{t+1})}{D_t^k(x_t, y_t)} \times \left[ \frac{D_t^k(x_{t+1}, y_{t+1})}{D_{t+1}^k(x_{t+1}, y_{t+1})} \times \frac{D_t^k(x_t, y_t)}{D_{t+1}^k(x_t, y_t)} \right]^{\frac{1}{2}} \tag{3}$$

In Eq. (3) the first term on the right-hand side of the equal sign is technical efficiency change (TEC). The second term is technical change (TC), which is expressed by a geometric mean of the shift in the frontier measured by using the points of input–output combinations of periods  $t$  and  $t + 1$  as a reference. Due to using Eq. (3) as a group frontier-based measure, O'Donnell et al. (2008) dubbed it as the group Malmquist productivity index (GMPI). The simplified expression is thus:

$$GMPI_{t,t+1}^k = TEC_{t,t+1}^k \times TC_{t,t+1}^k \tag{3a}$$

Referring to Battese et al. (2004) and O'Donnell et al. (2008), we further assume that all of these  $K$  technology sets are subsets of a common technologically unrestricted output set  $P^*(x)$ , that is:

$$P_t^* = \{P_t^1 \cup P_t^2 \cup \dots \cup P_t^k\} \tag{4}$$

$$P_t^*(x_t) = \{y_t \text{ is potentially obtainable from } x_t\} \tag{5}$$

Under the fundamental assumption that all producers have potential access to the same technology (Battese & Rao, 2002; Battese et al., 2004), the upper boundary of this unrestricted technology set refers to the 'metafrontier' of all the groups. O'Donnell et al. (2008, p.232) had indicated that the cause of the differences among the technologies presented by the metafrontier and the group frontiers could be attributed to the deficiencies or discrepancies of economic infrastructure and/or other characteristics of the production environment. In this paper, we regard the coastal and noncoastal regions in China as belonging to different technology sets and operating under distinct group frontiers but facing a common potential metafrontier. The main reason is due to

<sup>7</sup> The output set is assumed to conform to the fundamental properties discussed in Fare and Primont (1995).

the fact that the economic infrastructure (e.g., transportation construction or available stocks of physical, human and financial capital) and the characteristics of the production environment (e.g., the developmental focus of public policy was heavily skewed toward the coastal regions in the past three decades) in the two regions are widely recognized as heteroskedastic. Nonetheless, from a more long-term perspective, it is possible that the technology gaps might be lessened through designing programs to improve quality, to ameliorate the economic infrastructure and/or to refine the characteristics of the production environment. In recent literature, [Fleisher, Li, and Zhao \(2009\)](#) investigate the income disparity in output and TFP growth. They conduct a series of econometric inspections to show how regional growth patterns in China depend on the economic conditions in terms of human capital and infrastructure capital, as well as foreign direct investment (FDI). A set of cost–benefit analyses is also conducted in the study to derive policy suggestions. The empirical results clearly profile the discrepancies in the intensities of the economic conditions in different development phases and regions. FDI had a significant effect on TFP growth before 1994, and then the effect becomes weaker after that year. The diminished influence of FDI is attributed to the fact that the acceleration of market reforms reduced the relative importance of FDI on technology transmission. Furthermore, both investments in labor factor quality and in physical infrastructure have contributed positively to TFP growth. Nonetheless, investing in human capital would generate higher returns in less-developed regions, while investing in infrastructure would generate higher returns in developed regions. We thus conclude that except for the existing program, China’s regional gap could be harmonized by further focusing on and designing suitable schemes of human capital investment in less-developed areas. Thus, the metafrontier conceptually implies a boundary whereby the obstacles of technological development are eliminated and the technological difference among the groups is transcended. Here the metafrontier output-oriented distance function can be expressed as:

$$D_t^*(x_t, y_t) = \inf_{\delta} \left\{ \delta > 0 : \left( \frac{y_t}{\delta} \right) \in P_t^*(x_t) \right\} \tag{6}$$

The metafrontier-based MPI measure (MMPI) defined in [Rao \(2006\)](#) and [O'Donnell et al. \(2008\)](#) is therefore:

$$MMPI_{t,t+1}(x_t, y_t, x_{t+1}, y_{t+1}) = \frac{D_{t+1}^*(x_{t+1}, y_{t+1})}{D_t^*(x_t, y_t)} \times \left[ \frac{D_t^*(x_{t+1}, y_{t+1})}{D_{t+1}^*(x_{t+1}, y_{t+1})} \times \frac{D_t^*(x_t, y_t)}{D_{t+1}^*(x_t, y_t)} \right]^{\frac{1}{2}} \tag{7}$$

The simplified expression is hence:

$$MMPI_{t,t+1} = TEC_{t,t+1}^* \times TC_{t,t+1}^* \tag{8}$$

Here,  $TEC^*$  and  $TC^*$  correspond to the technical efficiency change and technical change measured on the basis of the metafrontier.

### 2.2. Generalized metafrontier Malmquist productivity index

Until now, we have learned that the MMPI is constructed using a distance function and is comprised of two terms,  $TEC^*$  and  $TC^*$ . Nonetheless, as introduced in the preceding section, the MMPI is theoretically an incomplete measure for a more completely constructed index, since the potential impact of scale efficiency change (SEC) is not taken into account. This subsection thus introduces a generalized MMPI framework that further accounts for the effect of SEC in the MMPI.

Assume the production technology is a twice differentiable distance function in input vector  $x_t \in R^{+M}$ , output vector  $y_t \in R^{+L}$ , and time variable  $t$ . Applying [Diewert's \(1976\)](#) Quadratic Identity Lemma, the cross-period change in the distance function can be written in logarithmic form as:

$$\begin{aligned} & \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t) - \ln D_t^*(y_t^l, x_t^m, t) \\ &= \frac{1}{2} \sum_{l=1}^L \left[ \frac{\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial \ln y^l} + \frac{\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial \ln y^l} \right] \times (\ln y_{t+1}^l - \ln y_t^l) \\ &+ \frac{1}{2} \sum_{m=1}^M \left[ \frac{\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial \ln x^m} + \frac{\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial \ln x^m} \right] \times (\ln x_{t+1}^m - \ln x_t^m) \\ &+ \frac{1}{2} \left[ \frac{\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial t} + \frac{\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial t} \right] \end{aligned} \tag{9}$$

The MMPI can be presented as a ratio of the cross-period change in outputs weighted by output distance elasticity to the change in inputs weighted by input distance elasticity. Thus, the MMPI in a logarithmic form is:

$$\begin{aligned} & \ln\text{MMPI}_{t,t+1}(y_{t+1}^l, y_t^l, x_{t+1}^m, x_t^m) \\ &= \frac{1}{2} \sum_{l=1}^L \left[ \frac{\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial \ln y^l} + \frac{\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial \ln y^l} \right] \times (\ln y_{t+1}^l - \ln y_t^l) \\ & \quad - \frac{1}{2} \sum_{m=1}^M \left[ \frac{-\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial \ln x^m} + \frac{-\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial \ln x^m} \right] \times (\ln x_{t+1}^m - \ln x_t^m) \end{aligned} \tag{10}$$

Incorporating Eq. (9) into Eq. (10), we have:

$$\begin{aligned} \ln\text{MMPI}_{t,t+1}(y_{t+1}^l, y_t^l, x_{t+1}^m, x_t^m) &= [\ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t) - \ln D_t^*(y_t^l, x_t^m, t)] \\ & \quad - \frac{1}{2} \left[ \frac{\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial t} + \frac{\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial t} \right] \end{aligned} \tag{11}$$

The two terms on the right-hand side of the equals sign in Eq. (11) refer to  $\text{TEC}^*$  and  $\text{TC}^*$  in logarithmic form.

Here, when checking in details, the Eq. (10) indicates that the productivity index would be VRS in nature. This is due to the fact that the second fraction to the right of the equals sign in the Eq. (10) involves a term of weighted average change rate of inputs, where using the summary average input distance elasticities of the two periods as the weight. Once the weight is not equal to one, the characteristic of VRS is then implied. However, it is a general consensus among researchers that for a well-constructed productivity index, there are four desirable properties: identity, monotonicity, separability, and proportionality (Orea, 2002). It is well-recognized that the MMPI shown as Eq. (10) has the first three properties. Nonetheless, the proportionality indicates a homogeneous condition of degree 1. Such a condition would not be satisfied under the VRS, since the summary of the input weights is unequal to unity. In order to rectify the imperfection, we use the distance elasticity shares of inputs to replace the distance elasticity of inputs in Eq. (10) as the weights for the change in inputs.<sup>8</sup> Theoretically, the advantages of such an operation are that it can sustain the ranking and proportion of distance elasticities of inputs and simultaneously ensure the satisfaction of the proportionality property of a well-constructed productivity index. Hence, the MMPI represented as Eq. (10) is now rewritten as:

$$\begin{aligned} & \ln\text{gMMPI}_{t,t+1}(y_{t+1}^l, y_t^l, x_{t+1}^m, x_t^m) \\ &= \frac{1}{2} \sum_{l=1}^L \left[ \frac{\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial \ln y^l} + \frac{\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial \ln y^l} \right] \times (\ln y_{t+1}^l - \ln y_t^l) \\ & \quad - \frac{1}{2} \sum_{m=1}^M \left[ \frac{\frac{-\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial \ln x^m}}{\sum_{m=1}^M \frac{-\partial \ln D_{t+1}^*(y_{t+1}^l, x_{t+1}^m, t)}{\partial \ln x^m}} + \frac{\frac{-\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial \ln x^m}}{\sum_{m=1}^M \frac{-\partial \ln D_t^*(y_t^l, x_t^m, t)}{\partial \ln x^m}} \right] \times (\ln x_{t+1}^m - \ln x_t^m) \end{aligned} \tag{12}$$

<sup>8</sup> Similar processes were adopted by Denny, Fuss, and Waverman (1981) and Orea (2002). In Denny et al. (1981), a multi-output multi-input cost function model was estimated to measure productivity growth. In Orea (2002), a MPI framework was also developed under a non-metafontier framework.

This is where the gMMPI denotes a generalized MMPI. Hence, using Eqs. (9) and (12), the gMMPI can be constructed as:

$$\begin{aligned}
 \ln gMMPI_{t,t+1} &= \ln D_{t+1}^* (y_{t+1}^l, x_{t+1}^m, t) - \ln D_t^* (y_t^l, x_t^m, t) \\
 &= \left[ \ln D_{t+1}^* (y_{t+1}^l, x_{t+1}^m, t) - \ln D_t^* (y_t^l, x_t^m, t) \right] \\
 &\quad - \frac{1}{2} \left[ \frac{\partial \ln D_{t+1}^* (y_{t+1}^l, x_{t+1}^m, t)}{\partial t} + \frac{\partial \ln D_t^* (y_t^l, x_t^m, t)}{\partial t} \right] \\
 &\quad + \frac{1}{2} \sum_{m=1}^M \left[ \frac{\left( -\sum_{m=1}^M \xi_{t+1}^{*m} - 1 \right) \xi_{t+1}^{*m}}{\sum_{m=1}^M \xi_{t+1}^{*m}} + \frac{\left( -\sum_{m=1}^M \xi_t^{*m} - 1 \right) \xi_t^{*m}}{\sum_{m=1}^M \xi_t^{*m}} \right] \\
 &\quad \times (\ln x_{t+1}^m - \ln x_t^m)
 \end{aligned} \tag{13}$$

where:  $\xi_{t+1}^{*m} = \frac{\partial \ln D_{t+1}^* (y_{t+1}^l, x_{t+1}^m, t)}{\partial \ln x_{t+1}^m}$ ;  $\xi_t^{*m} = \frac{\partial \ln D_t^* (y_t^l, x_t^m, t)}{\partial \ln x_t^m}$

In this equation, the first two terms on the right-hand side of the equals sign refer to  $TEC^*$  and  $TC^*$ , which is similar to Eq. (11). The difference is that the third term captures  $SEC^*$ , which is dominated by two elements: the scale elasticity and the change in factor inputs. The scale elasticity is usually defined as a proportion of output change that would be induced by one percent additional factor input change (Ray, 1998). Meanwhile, the change in factor inputs indicates a cross-period adjustment in the volume of factor use. When the scale elasticity is larger than one, this implies that the production is increasing return to scale. Accordingly, increasing the volume of factor input use would result in an increase in the proportion of output change being larger than the proportion of input change, and vice versa.

We know that when scale elasticity deviates from unity (i.e., VRS technology), this term reflects the change in productivity influenced by the cross-period adjustment of the input scale. More specifically, when the used technology exhibits IRS (DRS), the productivity can be improved by enhancing (lowering) the input scale, and then the value of the  $SEC^*$  is larger than unity, and vice versa. Thus, the exponential form of Eq. (13) can be expressed by a simplified form as:

$$gMMPI_{t,t+1} = TEC_{t,t+1}^* \times TC_{t,t+1}^* \times SEC_{t,t+1}^* \tag{13a}$$

Therefore, we can understand from this subsection that the framework of gMMPI developed in this paper is extended from the framework of MMPI of O'Donnell et al. (2008). The extensions are that: i) the gMMPI imposes the regular properties of a well-constructed productivity index, which gives the MMPI the advantage of being a more theoretically complete construction, and ii) the gMMPI further accounts for the effect of scale efficiency change in its measure, where the effect of scale efficiency change is argued as one non-negligible component of a productivity index in the related literature at least since Fare et al. (1994), Ray and Desli (1997), Ray (1998), Grifell-Tatje and Lovell (1999), Balk (2001), and Orea (2002).

### 3. Model specifications, data, and variable constructions

#### 3.1. Model specifications

The group frontier in this study is constructed by using the stochastic frontier analysis (SFA) model. Applying the original specification of Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977) with a translog form, along with the panel data setting of Battese and Coelli (1992), the group frontier can be specified as:<sup>9</sup>

$$\begin{aligned}
 \ln Y_{it}^g &= \alpha_0^g + \beta_1^g (\ln L_{it}^g) + \beta_2^g (\ln K_{it}^g) + \beta_3^g (T) + \frac{1}{2} \beta_4^g (\ln L_{it}^g)^2 + \frac{1}{2} \beta_5^g (\ln K_{it}^g)^2 + \frac{1}{2} \beta_6^g (T)^2 \\
 &\quad + \frac{1}{2} \beta_7^g (\ln L_{it}^g \ln K_{it}^g) + \beta_8^g (\ln L_{it}^g T) + \beta_9^g (\ln K_{it}^g T) - U_{it}^g + V_{it}^g
 \end{aligned} \tag{14}$$

Here,  $i$  denotes the  $i$ th province;  $t$  represents the time period; and  $Y$ ,  $L$ , and  $K$  are output, labor input, and capital stock, respectively.  $T$  denotes the time variable; and  $\alpha$  and  $\beta$  are unknown technological parameters. Moreover,  $V_{it}$  is a stochastic variable and assumed to be iid  $N(0, \sigma_v^2)$ . Referring to Battese and Coelli (1992),  $U_{it} = \{U_i \exp[-\eta(t - T)]\}$ , which is independent of  $V_{it}$  and assumed to be a non-negative random variable and truncated at zero of iid  $N(\mu, \sigma_u^2)$  in order to represent technical inefficiency,

<sup>9</sup> Under a single-output context, the technology presented by the distance function is equivalent to the frontier production function.

Table 1

MLE estimations of the stochastic frontiers.

Variables	Coastal region	Non-coastal region	Pooling <sup>a</sup>
Intercept	−6.042*** (0.981)	−4.941* (2.682)	−4.804*** (0.976)
lnL	0.381 (0.448)	1.216* (0.722)	1.097*** (0.299)
lnK	1.909*** (0.468)	0.527 (0.376)	0.656*** (0.262)
T	−0.069 (0.045)	−0.002 (0.064)	0.025 (0.041)
lnL <sup>2</sup>	0.082 (0.081)	0.128 (0.120)	0.117*** (0.056)
lnK <sup>2</sup>	−0.131 (0.086)	0.310*** (0.136)	0.183*** (0.039)
T <sup>2</sup>	−0.006*** (0.003)	0.010*** (0.004)	−0.004** (0.002)
lnL × lnK	−0.122 (0.136)	−0.502*** (0.215)	−0.378*** (0.082)
lnL × T	−0.019*** (0.007)	0.035*** (0.016)	−0.004 (0.005)
lnK × T	0.040*** (0.009)	−0.044*** (0.021)	0.010* (0.006)
σ <sup>2</sup>	0.018*** (0.003)	0.043*** (0.010)	0.039*** (0.005)
γ	0.907*** (0.033)	0.962*** (0.011)	0.937*** (0.011)
μ	0.259*** (0.104)	0.347*** (0.059)	0.383*** (0.054)
η	0.007 (0.011)	−0.010 (0.010)	0.008 (0.006)
Observations	108	171	279
L-LR $\chi^2_{(0.05, 10)} = 18.31$	130.142***	256.620***	320.249***
L-LR $\chi^2_{(0.05, 28)} = 23.68$		133.027***	

Notes: \*\*\*, \*\*, and \* denote coefficient significance at 1%, 5%, and 10%, respectively. Figures in the parentheses are standard errors.

The LR statistic is defined by  $\lambda = -2\{\ln[L(H_0)] - \ln[L(H_1)]\}$ . Here, the  $\ln[L(H_0)]$  is the value of the log likelihood function for the frontier estimated by pooling all the provinces, while the  $\ln[L(H_1)]$  is the sum of the values of the log likelihood functions for the two groups' frontiers.

<sup>a</sup> All the provinces are used to estimate the stochastic frontier regardless of the regional segmentation.

<sup>b</sup> Likelihood ratio test;  $H_0$ : all the  $\beta = 0$ ;  $H_1$ : at least one of the  $\beta$  is not 0.

<sup>c</sup> Likelihood ratio test;  $H_0$ : the frontiers of the different province groups are identical;  $H_1$ : the frontiers of the different provinces groups are distinct.

while  $\eta$  is a cross-period adjustment factor.<sup>10</sup> Furthermore, superscript  $g$  denotes that the frontier and technological parameters are for  $g$ th groups. Thus, the technologically feasible output levels on the group frontier are:

$$\ln Y_{it}^g = \alpha_0^g + \beta_1^g(\ln L_{it}^g) + \beta_2^g(\ln K_{it}^g) + \beta_3^g(T) + \frac{1}{2}\beta_4^g(\ln L_{it}^g)^2 + \frac{1}{2}\beta_5^g(\ln K_{it}^g)^2 + \frac{1}{2}\beta_6^g(T)^2 + \frac{1}{2}\beta_7^g(\ln L_{it}^g \ln K_{it}^g) + \beta_8^g(\ln L_{it}^g T) + \beta_9^g(\ln K_{it}^g T) \quad (15)$$

The metafrontier production function model is specified as:

$$\ln Y_{it}^* = \alpha_0^* + \beta_1^*(\ln L_{it}) + \beta_2^*(\ln K_{it}) + \beta_3^*(T) + \frac{1}{2}\beta_4^*(\ln L_{it})^2 + \frac{1}{2}\beta_5^*(\ln K_{it})^2 + \frac{1}{2}\beta_6^*(T)^2 + \frac{1}{2}\beta_7^*(\ln L_{it} \ln K_{it}) + \beta_8^*(\ln L_{it} T) + \beta_9^*(\ln K_{it} T) \quad (16)$$

The superscript \* denotes that the frontier and technological parameters are all for the metafrontier. According to Battese et al. (2004), the following condition must hold to ensure the metafrontier is an envelopment curve:

$$\ln Y_{it}^* \geq \ln Y_{it}^g \quad (17)$$

Eq. (17) implies that the metafrontier production function is a deterministic parametric function, which ensures that the potential maximum output level on the metafrontier cannot be lower than that on the group frontiers. Operationally, according to Battese et al. (2004), the parameters of the metafrontier production function can be obtained by minimizing the difference between Eqs. (15) and (16) with linear programming (LP) or quadratic programming (QP), subject to Eq. (17).<sup>11</sup> The operations can be expressed as:

$$LP : \text{Min} |Y_{it}^* - Y_{it}^{g'}|; \text{ s.t. } : Y_{it}^* \geq Y_{it}^{g'} \quad (18)$$

$$QP : \text{Min} (Y_{it}^* - Y_{it}^{g'})^2; \text{ s.t. } : Y_{it}^* \geq Y_{it}^{g'} \quad (19)$$

### 3.2. Data source and variable constructions

The data used in this study includes 31 provinces in China over the 1996–2004 period, yielding 279 observations. We use this sample period due to the following two reasons. First, most existing studies concerning China's regional productivity growth utilize

<sup>10</sup> Refer to Battese and Coelli (1992) for more details.

<sup>11</sup> Refer to Battese et al. (2004) for details.

data before 2000. This study allows us to observe the recent trend of productivity growth. Second, in order to upgrade its economy towards technology-intensive and capital-intensive industries, China created High-Technology Development Zones (HTDZs) in 1995. This indicates that innovative activity has played a role of emerging importance for the Chinese economy since the mid-1990s. Whether or not the emphasis on innovative activity drives China to keep sustainable productivity growth is an important and topical issue. Therefore, it is more relevant to reexamine the issue of regional productivity growth using a data period since the mid-1990s. The data used in this study are mainly sourced from the various issues of *China Statistical Yearbook*. According to the geographical feature of whether a province is adjacent to the ocean, this study classifies the following twelve provinces into the coastal region: Liaoning, Shandong, Hebei, Beijing, Tianjin, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, and Hainan. Table 3 describes the measures of variables and data sources.

In Eq. (16), the dependent variable is the gross domestic product (GDP) of region  $i$  in year  $t$ . As for the input factors, the capital stock ( $K_t$ ) is calculated using the flows of capital investment according to the perpetual inventory method:  $K_t = (1 - \delta)K_{t-1} + I_t$ .

To simplify the calculation, we assume the initial capital stock is very small in the infinite time span and assume investment grows annually at a constant rate  $g$

$$K_t = I_t + (1 - \delta)I_{t-1} + (1 - \delta)^2 I_{t-2} + \dots = \sum_t I_{-t}(1 - \delta)^t = I_t \sum_t \left[ \frac{1 - \delta}{1 + g} \right]^t = \frac{I_t}{g + \delta} \tag{20}$$

where  $I$  is investment,  $\delta$  denotes the depreciation rate of capital stock, and  $g$  is the growth rate of capital investment. To calculate the capital stock, it is necessary to know the average depreciation rate and growth rate of capital. Both of these two values are unknown, and so it requires some reasonable assumptions before calculating capital stocks. Following the specification in Yao (2006), the depreciation rate is assumed to be 7.5%. This implies that the average life of capital equipment is 13.3 years, which is similar to the lifespan recommended by the government. The second assumption is that the growth rate of capital is 15%. This rate is calculated from the average growth rate of capital for the whole economy during the sample period of 1996 to 2004. Additionally, the labor input ( $L_t$ ) is the amount of labor employed by thousands of people.

#### 4. Empirical analysis

##### 4.1. Estimations of group frontiers and metafrontier

This subsection constructs the production frontiers. On the basis of Eq. (16), we consider two sets of hypothetical arrangements. One is that all the provinces use the same technology and face an identical frontier. The estimations are then displayed in the regression ‘pooling’ of Table 1. The other is that the coastal and non-coastal provinces in China use different technologies and operate under distinct frontiers. Table 1 respectively reports the estimations of the two regional groups in the regressions ‘coastal region’ and ‘non-coastal region’.

**Table 2**  
Estimation of metafrontier – linear programming approach.

Variables	Metafrontier coefficient	Bootstrapping approach		
		Mean	Std. dev.	Skewness
<i>Panel A. Linear programming estimates</i>				
Intercept	-4.3395	-4.6239	0.3916	-0.6301
lnL	0.2524	0.3388	0.1151	-0.0077
lnK	1.6788	1.6329	0.0952	0.0617
T	-0.0872	-0.0710	0.0222	-0.4775
lnL <sup>2</sup>	0.0863	0.0768	0.0145	-4.3547
lnK <sup>2</sup>	-0.1153	-0.1097	0.0117	-2.4490
T <sup>2</sup>	-0.0061	-0.0060	0.0004	6.5479
lnL × lnK	-0.1038	-0.1018	0.0154	19.2310
lnL × T	-0.0181	-0.0184	0.0016	1.3015
lnK × T	0.0408	0.0391	0.0021	-4.1183
<i>Panel B. Quadratic programming estimates</i>				
Intercept	-5.6397	-5.6979	0.5494	0.5467
lnL	0.6748	0.7054	0.2005	-0.0035
lnK	1.4734	1.4364	0.1439	-0.2999
T	-0.0902	-0.0736	0.0287	0.6316
lnL <sup>2</sup>	0.0981	0.1015	0.0213	-2.9863
lnK <sup>2</sup>	0.0100	0.0267	0.0500	0.2777
T <sup>2</sup>	-0.0040	-0.0046	0.0013	0.2834
lnL × lnK	-0.2503	-0.2669	0.0569	0.5572
lnL × T	-0.0088	-0.0079	0.0051	1.4138
lnK × T	0.0281	0.0253	0.0072	-2.3636

Note: Refer to Battese et al. (2004) for a basic concept of estimations.

**Table 3**

Estimations of the Malmquist productivity index: 1996–2004 (coastal and non-coastal regions in China).

Period	All region	Coastal region	Non-coastal region
<i>Panel A. Average changes in productivity and its decompositions<sup>a</sup></i>			
1996–1997	5.783***	6.102***	5.581***
1997–1998	5.496***	5.742***	5.341***
1998–1999	5.147***	5.382***	4.999***
1999–2000	4.857***	4.947***	4.799***
2000–2001	4.588***	4.697***	4.519***
2001–2002	4.257***	4.316***	4.220***
2002–2003	4.014***	4.110***	3.954***
2003–2004	3.687***	3.614***	3.732***
Average	4.729***	4.864***	4.643***
<i>Panel B. Mean difference test<sup>b</sup></i>			
Coastal region vs. noncoastal region <sup>c</sup>		0.221***	

<sup>a</sup>In Panel A, \*\*\* denotes significance of the parameter deviating from 0 at the 1% statistical level.<sup>b</sup>In Panel B, the difference test employed is the one way ANOVA test with *F*-statistics, while \*\*\*, \*\*, and \* denote coefficient significance at 1%, 5% and 10%, respectively.<sup>c</sup>The positive sign signifies that the figure of the coastal region is larger than the non-coastal region.

As observed from the table, we can see that the intercept of the pooling frontier (i.e., the conventional frontier regarding all of the provinces sharing the same technology) is higher than the two groups' frontiers. Roughly half of the estimated coefficients are significant. This indicates that a certain functional relationship actually exists among the dependent and explanatory variables that is in line with our fundamental theoretical expectation. Moreover, in the three regressions, the estimated parameters  $\gamma$  are all above 0.9. This reflects the fact that much (at least 90%) of the variation in the composite error term is due to the inefficiency component (Coelli et al., 2005), which implies that most of the deviation from the output level on the frontier could be attributed to controllable cause.

The log-likelihood ratios (LR) of the regressions are also reported in the bottom of Table 1. This is helpful for determining whether all the provinces in China share the same technology or if the coastal and non-coastal regions use distinct technologies. A

**Table 4**

Decomposition of the generalized metafrontier Malmquist productivity index: 1996–2004 (coastal and non-coastal regions in China).

Region	Period	gMMPI	TEC*	TC*	SEC*	
<i>Panel A. Average changes in productivity and its decompositions<sup>a</sup></i>						
All regions	1996–1997	3.912***	−0.171	3.850***	0.254	
	1997–1998	3.392***	−0.782***	3.710***	0.497**	
	1998–1999	3.994***	0.086	3.517***	0.400*	
	1999–2000	3.206***	−0.297	3.241***	0.289	
	2000–2001	3.257***	−0.507	3.109***	0.682**	
	2001–2002	3.124***	−0.479	3.065***	0.564**	
	2002–2003	2.282***	−1.323**	3.178***	0.492*	
	2003–2004	2.358***	−1.083***	3.493***	0.017	
	Average	3.191***	−0.569***	3.395***	0.399***	
	Coastal region	1996–1997	6.446***	0.375***	6.517***	−0.435***
		1997–1998	6.372***	0.388***	6.203***	−0.215
		1998–1999	6.089***	0.326**	5.879***	−0.114
		1999–2000	4.995***	0.239**	5.428***	−0.633**
2000–2001		5.233***	0.246*	5.090***	−0.092	
2001–2002		4.806***	0.127	4.925***	−0.219	
2002–2003		4.676***	0.056	4.935***	−0.269	
2003–2004		3.804***	−0.368	5.268***	−0.999*	
Average		5.303***	0.174***	5.531***	−0.372***	
Non-coastal region		1996–1997	2.312***	−0.616	2.165***	0.688**
		1997–1998	1.510***	−1.521***	2.135***	0.946***
		1998–1999	2.671***	−0.066	2.025***	0.725**
		1999–2000	2.076***	−0.635	1.860***	0.871**
	2000–2001	2.009***	−0.982*	1.858***	1.171***	
	2001–2002	2.061***	−0.859	1.890***	1.058***	
	2002–2003	0.770	−2.193***	2.069***	0.973***	
	2003–2004	1.445***	−1.535***	2.372***	0.659**	
	Average	1.857***	−1.038***	2.047***	0.886***	
	<i>Panel B. Mean difference test<sup>b</sup></i>					
	Coastal vs. noncoastal region <sup>c</sup>		3.446***	1.212***	3.484***	−1.258***

<sup>a</sup> In Panel A, \*\*\*, \*\*, and \* denote significance of the parameter deviating from 0 at 1%, 5%, and 10% level, respectively.<sup>b</sup> In Panel B, the difference test employed is the one way ANOVA test with *F*-statistics, while \*\*\*, \*\*, and \* denote coefficient significance at 1%, 5% and 10%, respectively.<sup>c</sup> The positive sign signifies that the figure of the coastal region is larger than the non-coastal region and vice versa.

LR test is then conducted referring to the operation in Battese et al. (2004). The calculated LR statistic is 133.027, which is significant at the 1% statistical level. This result strongly suggests that the provinces in the two regions indeed operate under different frontiers. Thus, the preferred model should be the one separately estimating the frontiers by segmenting the data from the coastal and non-coastal regions. As for the metafrontier, on the basis of Eqs. (15) and (16), Table 2 demonstrates the estimations using linear and quadratic programming. According to the original study of Battese et al. (2004), both the linear programming and quadratic programming are suggested as feasible approaches to estimate the metafrontier. In this paper, the linear programming approach is used, while the results obtained by the quadratic programming approach are listed for reference. Also in reference to Battese et al. (2004), the standard errors for the estimators of the metafrontier parameters can be obtained using bootstrapping methods. The results of bootstrapping methods are also provided in Table 2.<sup>12</sup>

#### 4.2. Calculations of generalized metafrontier Malmquist productivity index

Using the construction of frontiers in the last subsection of Section 2, the productivity index is calculated and can then be discussed. First, panel A of Table 3 reports the dynamics and components of conventional MPI. The table reveals that all provinces experienced an annual productivity growth of 4.729% on average over the 1996–2004 period. When distinguishing the provinces into two groups, the coastal region demonstrates a 4.864% and the non-coastal region has a 4.643% productivity change, respectively. Panel B then reports the mean difference of the two regions' productivity change at about 0.221.

It is worth noting that the results in Table 3 should be viewed with a degree of skepticism. For a long time, the regional inequality of the coastal and non-coastal regions in China has been intuitively regarded as an accomplished fact that is commonly known *a priori*. Theoretically, as O'Donnell et al. (2008) have indicated, when production units operate under different conditions of economic infrastructure and/or other characteristics of the production environment, then distinct technological frontiers are implied. An input–output combination that is technologically feasible in one group might not be the case in the other group. As discussed in Section 2.1, we treat the coastal and non-coastal regions in China as belonging to different technology sets and operating under distinct group frontiers due to the fact that the economic infrastructure and the characteristics of the production environment in the two regions are widely recognized as heteroskedastic. A similar volume of production input might not imply the same volume of output across regions. A similar magnitude and pattern of the values of the two regions are found here in the table despite the significance of the difference test. Based on the diagnosis process of Table 1, the suspicion of different technology sets should be attributed to the fact that Table 3 refers to results calculated under the conventional setting, which strongly assumes that all of the provinces share the same technology. Thus, as Orea and Kumbhakar (2003) have argued, when production units use different technologies and face different frontiers, estimating an identical frontier function encompassing every unit induces specification bias.

Table 4 further demonstrates the estimations of the gMMPI induced in the preceding section of this study. From the table, it is shown that the productivity growth in the sample period is about 3.191% on average. Comparing with Table 3, it is easy to find that the overall average change of gMMPI is lower than the 4.729% of conventional MPI. When checking further, this decline could be attributed to disentangling the strong assumption of an identical frontier. Now compared with Table 3, the average productivity change in the coastal region improves from 4.864% to 5.303%, while the average productivity change in the non-coastal region substantially declines from 4.643% to 1.857%. To interpret the reason that causes the variation more intuitively, we use two figures as illustrations. First, in Fig. 1, assume that there are two groups of production points, groups 1 and 2. In period  $t$ , the groups' frontiers are constructed using the production points of each group respectively, while the pooling frontier is constructed using all the production points together. Here, as estimated in Table 1, the intercept of the pooling frontier is higher than the intercepts of the group frontiers. Moreover, the metafrontier is depicted as an envelopment curve of the group frontiers.

Using Fig. 1 as the benchmark, we now assume that all the production points shift upward in period  $t + 1$ , and the margin of the shift in the points of group 1 is larger than that of group 2. Fig. 2 further profiles the production points, group frontiers, pooling frontier, and metafrontier in the period. Fig. 2 shows that the margin of upward shift in the group frontiers and metafrontier is similar to that of the two groups' production points, because the group frontiers may be estimated separately. However, for the pooling frontier, subject to the assumption of identical technology, the shape of the frontier for the two groups' fractions is the same reciprocally. The margin of upward shift tends to be underestimated in the fraction of group 1's points and overestimated in the fraction of group 2's points. Accordingly, this study finds that the average productivity changes under the metafrontier framework in the coastal region (non-coastal region) are higher (lower) than the conventional approach.

Using the metafrontier as the basis, several points can be derived from Table 4. The table clearly shows that China sustains a positive productivity growth during 1996 to 2004. The 3.191% average growth rate implies that there is about 26.508% of economic growth driven by gains in productivity.<sup>13</sup> To a certain extent, this result supports the viewpoint in the literature that TFP growth plays an important role in the post-reform growth of China (Islam et al., 2006). Prior to the sample period, Islam et al. (2006) indicated that the TFP growth rate was about 2.95% for 1978 to 2002. Ezaki and Sun (1999) reported the growth rate was 3% to 4% for 1981 to 1995, which contributes 40% of overall growth. Moreover, checking year-to-year productivity change as shown in Table 4, we clearly see that the TFP change dynamics over the sample period demonstrate a slight slowdown tendency. The change decelerated from 3.912% in 1996 to 2.358% in 2004. While the literature in the past had different views regarding the question of

<sup>12</sup> Please refer to Battese et al. (2004) for the details of metafrontier production function.

<sup>13</sup> The output growth rate in the same period is about 12.037% on average.

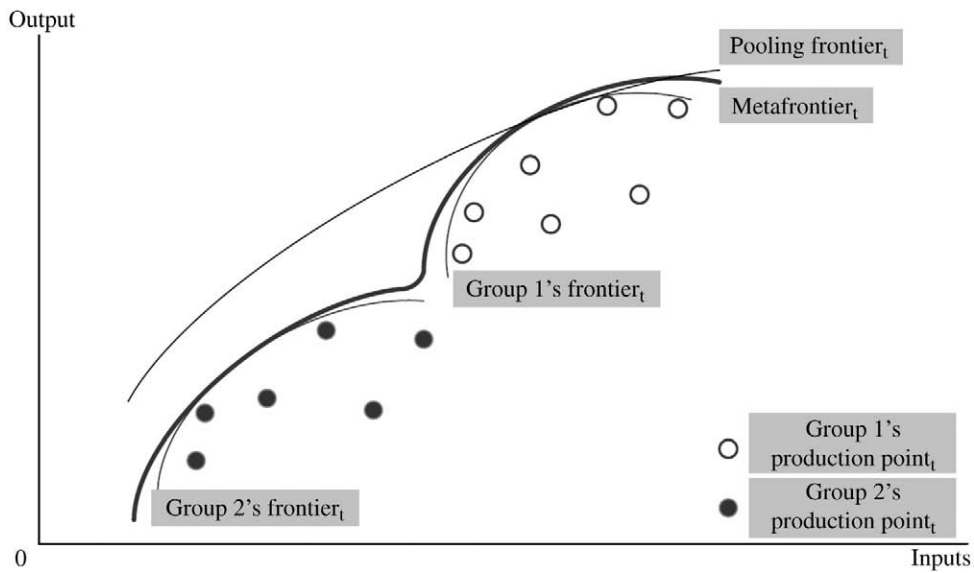


Fig. 1. Group frontiers, pooling frontier, and metafrontier.

whether China's TFP is accelerating or decelerating, our finding is consistent with the views of Zheng and Hu (2006) and Shiu and Heshmati (2006) that TFP growth in China has slowed since the mid-1990s.

Most studies were conducted based on data before 1995. Some of them achieved the decelerating result (e.g., Wu, 2000; Young, 2003), but others supported the accelerating viewpoint (e.g., Hu and Khan, 1997; Ezaki and Sun, 1999). Nonetheless, even though the deceleration trend is demonstrated in this study, the productivity growth rate of China was spectacular and much higher than in numerous countries in the world. For example, Fare, Grosskopf, and Margaritis (2006) reported that productivity growth in European Union countries from 1965 to 1998 ranges from 2.744% to  $-0.205\%$  and the overall average growth is about 0.6360%. China's

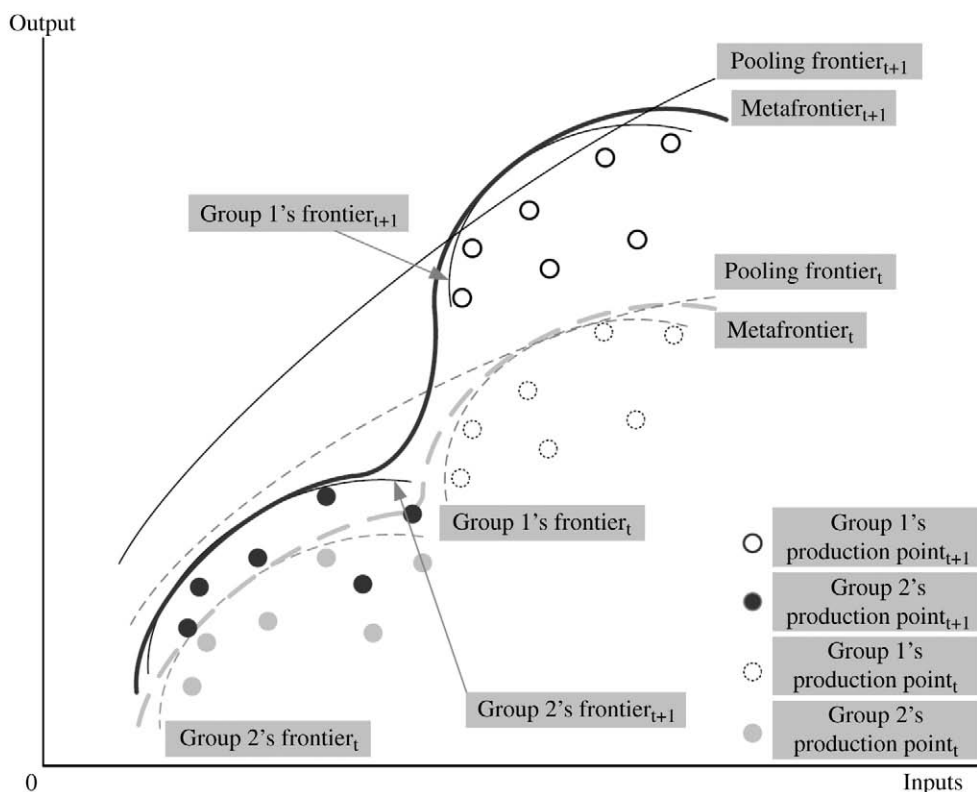


Fig. 2. Cross period shifts in the group frontiers, pooling frontier, and metafrontier.

performance is also much better than its East Asian counterparts that on average witnessed a negative productivity growth during 1985 to 2003 (Huang, Chen, & Wang, 2008).

Segmenting provinces into coastal and non-coastal regions, the regional inequality in productivity change can now be shown. It can be seen from Table 4 that both regions' TFP growths demonstrate a slower trend. The growth in the coastal region is about 5.303%, contributing 42.655% of output growth. On the other hand, the growth in the non-coastal region is about 1.857%, accounting for only 15.948% of the output change.<sup>14</sup> The estimations continue the results of Fleisher and Chen (1997) that China's non-coastal provinces experienced inferior productivity gains from 1978 to 1993 when compared with the coastal provinces. From the table, it is also noteworthy that the Severe Acute Respiratory Syndrome (SARS) epidemic broke out in the later sample years of this study. It is found that SARS impacted on the non-coastal region more heavily, and the productivity change of the non-coastal region demonstrates a substantial decline in that period.

Shifting focus to the composition of productivity growth, one can observe from Table 4 that the technical efficiency change demonstrates a weak magnitude and slight downturn in China during the sample period. Table 4 shows that the average change rate is about  $-0.569\%$  annually, while the yearly change of technical efficiency in the coastal region is about  $0.174\%$ , which is better than the  $1.038\%$  of degeneracy in the non-coastal region. On the other hand, the technical change serves as a dominating factor to the TFP change. For all provinces, the technical change rate is fairly high, ranging from  $3.850\%$  to  $3.065\%$  with an average of about  $3.395\%$ . One interesting finding is that the technical change in the coastal region is about  $5.531\%$ , which is more than twice as high as the  $2.047\%$  change in the non-coastal region.<sup>15</sup> This disparity on technical change might arise from the open policy of the Sixth (1983–1986) and Seventh (1986–1991) Plan that gives preferential treatment to coastal cities to promote growth in coastal regions.

#### 4.3. Discussions of scale efficiency change

The scale efficiency change addressed in this study demonstrates a slight rise. While the change rate is about  $0.399\%$  on average, the annual change in the coastal region is  $-0.372\%$ , and in the non-coastal region it is about  $0.886\%$ . Visually, these figures seem somewhat different from the previous literature.<sup>16</sup> Li et al. (2008) adopt the typical stochastic frontier analysis model to investigate the productivity growth in China during 1986 to 2000. They showed that the overall change rate of scale efficiency change for 1997 to 2000 is about  $0.858\%$ , while the average change rates for the eastern and the other regions are about  $0.600\%$  and  $0.512\%$ , respectively. We think the discrepancy noted herein should be a matter of course. The major reason is due to the fact that our study further considers the potential problem of distinct frontiers for the coastal and non-coastal regions. In addition, large parts of the data periods adopted in the two papers are also not the same.

Returning to the empirical results of this paper, the cause of inverse results between the rates of scale efficiency change in the two regions could presumably be attributed to the different types of scale elasticity and changes in input use. More specifically, the inputs used in the two regions increased in the sample period. However, most provinces in the coastal region are in a phase of decreasing return to scale (DRS), and most provinces in the non-coastal regions are in a constant return to scale (CRS) phase. Hence, an increasing input used in the DRS phase further results in the production scale deviating from the TOPS and inducing a negative scale efficiency change. In contrast, an increasing input used in a CRS phase results in the production scale getting closer to the TOPS, which induces a positive scale efficiency change.

From the viewpoint of regional development, the scale efficiency change decomposed in this study suggests some significant implications. First, the term plays diverse roles in the coastal and non-coastal regions of China. In the coastal region, the contribution of the scale efficiency change is adverse. Because the absolute figure is not large, the volume entirely offsets the positive effect on the productivity growth sourcing from the technical efficiency change. In contrast, the contribution of scale efficiency change in the non-coastal region is positive, which just makes up the inverse impact introduced from the downturn of technical efficiency change on productivity growth. In addition, as in the previous discussion, the TFP growth is almost dominated by the technical change in the coastal region, while the contributions of technical and scale efficiency change are relatively trivial. This situation is not necessarily the case in the non-coastal region. For the non-coastal region, about  $47.735\%$  of productivity growth is possessed by the scale efficiency change term despite technical change still having a similar role.

Such a result again reminds us to face the risk that might arise when we ignore the potential effect of scale efficiency change on the issue of productivity growth. Additionally, there might be some economic implications behind the results. An attempt is made to infer that for the relatively well-developed region, the contribution of scale efficiency change may not be significant as compared with the technical and technical efficiency changes. For the initial development stage of the lagging region, however, the effect of the scale adjustment would be one dominant factor that is non-negligible and directly manifested.

The inference on scale efficiency prompts our interest in observing the attainment of the recent China Western Development plan in terms of productivity growth. In the next subsection, a segmentation of the provinces in China is conducted to detect further economic implications.

Before reviewing the attainment of the recent China Western Development plan, we briefly summarize the productivity growth and its inclusions in China from a general perspective. Does the Chinese economy sustained by productivity change? Our empirical analysis shows that on the surface of output growth there is indeed the ingredient of productivity gains supporting China's striking economic performance. The TFP growth is about  $3.191\%$ , which accounts for about  $26.508\%$  of output growth annually over the period

<sup>14</sup> The output growth rate in the same period is about  $12.432\%$  in the coastal region and about  $11.642\%$  in the non-coastal region on average.

<sup>15</sup> Panel B shows a significant difference between the technical change in coastal and non-coastal region.

<sup>16</sup> There is rather limited literature that interested in China' productivity growth had discussed the effect of scale efficiency change (Li, Liu, & Yun, 2008; p. 3).

**Table 5**  
Decomposition of the generalized metafrontier Malmquist productivity index: 1996–2004 (east coastal, central and west regions of China).

Region		Periods	gMMPI	TEC*	TC*	SEC*
East coastal region	Yearly	1996–1997	6.704***	0.341***	6.856***	−0.479***
		1997–1998	6.608***	0.340**	6.543***	−0.267*
		1998–1999	6.369***	0.293**	6.214***	−0.133
		1999–2000	5.263***	0.207*	5.767***	−0.668**
		2000–2001	5.442***	0.200	5.433***	−0.177
		2001–2002	4.997***	0.078	5.273***	−0.324
	Average	2002–2003	4.867***	0.011	5.284***	−0.377
		2003–2004	3.882***	−0.437	5.613***	−1.186**
		1996–2000	6.236***	0.295***	6.345***	−0.387***
		2000–2004	4.797***	−0.037	5.401***	−0.516***
		1996–2004	5.516***	0.129**	5.873***	−0.451***
		1996–1997	3.352***	−0.113	3.417***	0.067
Central region	Yearly	1997–1998	2.613***	−0.780**	3.238***	0.183
		1998–1999	3.916***	0.752	2.976***	0.170
		1999–2000	3.111***	0.216	2.716***	0.173
		2000–2001	3.180***	0.194	2.648***	0.327*
		2001–2002	2.737**	−0.266	2.613***	0.388*
		2002–2003	1.754*	−1.243	2.745***	0.286**
	Average	2003–2004	1.385***	−1.695***	3.076***	0.058
		1996–2000	3.248***	0.019	3.087***	0.148**
		2000–2004	2.264***	−0.752**	2.770***	0.265***
		1996–2004	2.756***	−0.367*	2.929***	0.207***
		1996–1997	1.727***	−0.679*	1.382**	1.050**
		1997–1998	0.963	−1.812***	1.427**	1.405***
West region	Yearly	1998–1999	1.869*	−0.548	1.406**	1.043**
		1999–2000	1.384	−1.100	1.276**	1.243**
		2000–2001	1.306*	−1.622*	1.287**	1.706**
		2001–2002	1.664**	−1.128	1.341***	1.494***
		2002–2003	0.265	−2.598**	1.537***	1.426**
		2003–2004	1.610***	−1.268**	1.828***	1.092**
	Average	1996–2000	1.486***	−1.035***	1.373***	1.185***
		2000–2004	1.211***	−1.654***	1.498***	1.430***
		1996–2004	1.348***	−1.344***	1.436***	1.307***

Notes: \*\*\*, \*\*, and \* denote significance of the parameter deviating from 0 at 1%, 5%, and 10% level, respectively.

from 1996 to 2004. Furthermore, from the introduction of the metafrontier-based methodology, the productivity change should comprise three terms: technical efficiency change, technical and scale efficiency changes; while more of the change is propelled by technical progress (3.395%), and a fraction is driven by the adjustment in production scale (0.399%) and the efficiency change has an adverse effect (−0.569%). The reason for these results could be attributed to the fact that after the middle period of the 1990s, the transformation of China towards respecting development of new technology indeed demonstrated its significant achievement on affecting productivity growth. For the developing economies, technological progress usually can be achieved in a shorter period through some formal or informal channels, such as technology purchase or imitation, except for a country's own R&D. Nonetheless, relative improvement of technical efficiency would not be easy to carry out by purchase or through some other borrowing behaviors. Instead, there are needs for fumbling, trial, coordination, experience, and learning by doing, and the required time would be longer.

**Table 6**  
Mean difference test of the gMMPI and its components<sup>a</sup>.

Region	Periods	gMMPI	TEC*	TC*	SEC*
East coastal region <sup>b</sup>	1996–2000 vs. 2000–2004	−1.439***	−0.333***	−0.944**	−0.129
Central region <sup>b</sup>		−0.984**	−0.771*	−0.316	0.117
West region <sup>b</sup>		−0.274	−0.619	0.126	0.245
East coastal region vs. west region <sup>c</sup>	1996–2000	4.750***	1.330***	4.972***	−1.572***
	2000–2004	3.586***	1.617***	3.902***	−1.945***
Central region vs. west region <sup>d</sup>	1996–2004	4.168***	1.473***	4.437***	−1.759***
	1996–2000	1.763***	1.054**	1.714***	−1.037***
East coastal region vs. central region <sup>e</sup>	2000–2004	1.053**	0.901	1.272***	−1.165***
	1996–2004	1.408***	0.978***	1.493***	−1.101***
East coastal region vs. central region <sup>e</sup>	1996–2000	2.988***	0.277	3.258***	−0.535***
	2000–2004	2.533***	0.715**	2.631***	−0.781***
	1996–2004	2.760***	0.496***	2.944***	−0.658***

<sup>a</sup> The difference test employed is the one way ANOVA test with F-statistics, while \*\*\*, \*\*, and \* denote coefficient significance at 1%, 5%, and 10%, respectively.

<sup>b</sup> The positive sign here signifies that the figure of post-2000 is larger than that of pre-2000 and vice versa.

<sup>c</sup> The positive sign here signifies that the figure of the east coastal region is larger than that of the west region and vice versa.

<sup>d</sup> The positive sign here signifies that the figure of the central region is larger than that of the west region and vice versa.

<sup>e</sup> The positive sign here signifies that the figure of the east coastal region is larger than that of the central region and vice versa.

Thus, when the velocity of technological progress is faster than the velocity of enhancement of actual output level, the effect of technical efficiency change using the ratio of actual output to the output level on the technological frontier as the measure on productivity would not be as apparent. This is also the case because the contribution of the scale efficiency change on productivity seems not quite as notable on an aggregate level as compared to technical change. It is not easy for production units to directly perceive whether their own operating scale is too large or too small relative to the optimal scale, which is even more the case with the position of optimal scale. The detection usually requires time for a certain dynamic practical trial and adjustment process. This process involves adjusting and coordinating various types of labor uses and capital inputs. Hence the velocity of scale efficiency change revealed a relatively more moderate result than the technical change.

## 5. Brief review of the China Western Development policy

Since 1978 the economic regime of China was reformed from a command economy to a market economy. This reform pushed China's economy to grow abruptly, and it has drawn much attention from people around the world. However, there is an embedded worry that economic development diverged inside China. The provinces of the east coastal region benefited from the reform by a wide margin and rapidly increased their income level, but the development of inner regions significantly lagged behind. A China Western Development policy was implemented to harmonize the regional gap, which has formally functioned since March of 2000. This plan covers twelve provinces, including Inner Mongolia, Shaanxi, Gansu, Ningxia, Xinjiang, Qinghai, Tibet, Chongqing, Sichung, Zuizhou, Yunnan, and Guangxi. The core strategy of the policy includes speeding up infrastructure development, enhancing ecological protection, adjusting the industrial structure, promoting education, and magnifying the intensity of openness. In this subsection we evaluate the initial achievement of the policy in terms of productivity gain. To accommodate the review, the provinces of China are further segmented into three regions: east coastal, central and west.<sup>17</sup> The time dimension is also divided into two periods: pre-2000 (1996–2000) and post-2000 (2000–2004). Table 5 reports the calculations of productivity change and its components.

It is apparent from Table 5 that, on average, the annual productivity growth of about 5.516% in the east coastal region is the highest relative to 2.756% in the central and 1.348% in the western region. The margin of change in the east coastal region significantly weakens from 6.236% in pre-2000 to 4.797% in post-2000, even though the rate still remains high. Similarly, the margin of the changes in the central region also significantly shrinks from 3.248% in pre-2000 to 2.264% in post-2000. The significance of the differences is all checked in Table 6. In addition, Table 5 shows that the productivity growth hovers about 1.2% to 1.4% in the western region. Despite the low growth rate, Table 6 indicates that the figures of pre-2000 and post-2000 are not statistically different, implying that the productivity growth could be sustained after the year 2000. Indeed, a similar pattern also exists in the dynamics of technical efficiency change. The improved efficiency shows a significant reduction trend from 0.295% to  $-0.037%$  in the east coastal region and an even a worse trend from 0.019% to  $-0.752%$  in the central region. As for the western region, the change rates in pre-2000 and post-2000 demonstrate a downturn of about  $-1.035%$  and  $-1.654%$ , respectively. Nonetheless, the decline trend suggested in Table 6 is not statistically significant.

Regarding the technical change, the east coastal region demonstrates a fairly strong technology advancement velocity, with about 5.873% annually, and the margin slightly declines after 2000, from 6.345% to 5.401%. On the other hand, the change rates in the central and western regions are weaker, at around 2.929% and 1.436%, respectively. However, the margins of the changes in the central as well as western regions can be sustained after the year 2000. Furthermore, regarding the scale efficiency change, the east coastal region shows a  $-0.451%$  and the central regions a 0.207% annual upgrade. Interestingly, the western region manifests the strongest scale efficiency growth by a 1.307% margin. This figure is almost equivalent to the magnitudes of overall productivity change, the technical change, and the downturn of technical efficiency change in the western region. Such a result tends to support our argument in the preceding subsection that for the initial development stage of the lagging region, the effect of the scale adjustment would be one dominant factor that is non-negligible and directly apparent. Moreover, Table 6 reports that the difference of the SEC term between pre-2000 and post-2000 is not significant in the western region. The data in Table 6 implies that during the initial period of the West Development policy there remained substantial room for further increases in the input employment scale. That is, factor accumulation serves as the major driving force of economic growth for the western region in the short run. Nonetheless, from a longer-term view of molding an environment of sustainable growth, merely accumulating factors and constructing infrastructure are insufficient. The quality of production factors is particularly critical. As indicated in Fleisher et al. (2009), to put human capital investment on an equal footing in advancing China Western Development policy is important both from the angles of economic efficiency and for reducing inequality.

The empirical results of this section not only demonstrate the important role played by the scale efficiency change. The potential risk of ignoring the effect of the adjustment in production scale is also clearly revealed. Table 5 indicates that when the scale efficiency change is not taken into account, the western region then manifests a null TFP growth in the period from 1996 to 2004.

## 6. Conclusions and policy implications

This paper aims to reassess the regional productivity growth in China. To avoid the potential limitation of China's statistical data, as noted in the literature, and taking into account the characteristics of regional inequality between coastal and non-coastal

<sup>17</sup> We also have conducted a LR test for the differences between the estimations under the two assumptions that the provinces in the coastal and non-coastal regions operate under two distinct frontiers and the provinces in the east coastal, central and west regions operate under three distinct frontiers. The results are not statistically different.

regions inside China, a rigorously tailor-made methodology is needed. First, this paper embraces the concept of a metafrontier production function model as a means for accurately assessing the issue. The reason for this is mainly because the coastal and non-coastal regions of China face a potentially common metafrontier regardless of the intuitive, theoretical and empirical angles that would assign them to different technology sets and distinct group frontiers. Here, the underlying background is due to the fact that the economic infrastructure and the characteristics of the production environment in the two regions are widely recognized as heteroskedastic. Nonetheless, from a more long-term perspective, it is possible that the technology gaps might be lessened through designing programs to improve the economic infrastructure and/or to refine the characteristics of the production environment. Furthermore, this paper extends O'Donnell et al.'s (2008) metafrontier Malmquist productivity index (MMPI) approach and then develops a framework of generalized MMPI (gMMPI) for meeting the requirement. We impose the regular conditions of a well-constructed productivity index on the MMPI to rectify the potential deficiency that the MMPI does not have the property of proportionality. The major operation is to use the distance elasticity share of inputs to substitute the distance elasticity of inputs for ensuring the weight of cross-period change in inputs of the productivity measure being one to conform to the condition of homogenous of degree 1. This operation has the advantage of developing the MMPI to become a more theoretically rigorous construction. Further, we induct the revised MMPI mathematically and decompose a component of scale efficiency change from it, in addition to the other two components, technical efficiency change and technical change. The scale efficiency change gauges the extent of cross-periods adjustment of production scales toward the technically optimal productive size. Therefore the gMMPI framework is a relatively theoretically complete and rigorous productivity index measure, which gives us the advantage of being able to assess the regional productivity growth and its inclusions in China while considering the characteristic of regional inequality between the coastal and non-coastal regions inside China.

Our empirical analysis shows that on the surface of output growth, the ingredient of productivity gains indeed supports China's striking economic performance. The TFP growth is about 3.191%, which accounts for about 26.508% of annual output growth over the period from 1996 to 2004. Second, from the introduction of the metafrontier-based methodology, the productivity change should comprise three terms: technical efficiency change, technical and scale efficiency changes; while more of the change is propelled by technical progress (3.395%), and a fraction is driven by the adjustment in production scale (0.399%) and the efficiency change has an adverse effect (−0.569%).

We also ask whether the regional inequality in terms of productivity was harmonized in the past decade. We find that the margin of productivity change in the coastal region seems to shrink more even though growth remained high. Relatively, the western region can sustain its growth despite an absolute low figure. The relative productivity slow-down in the provinces of the coastal region may be due to the natural process of convergence, as discussed in Wu (2000). This paper also focuses on the China Western Development policy. Indeed, it can be inferred from this study that the Western Development policy has not significantly manifested a benefit on the dimension of TFP in the sample period of 2000 to 2004. However, our results show that the rate of productivity change is sustained for the western region after 2000. Indeed, it is not unusual to obtain such results, since the productivity growth is a concept utilizing a long-term view and there might not have been enough time yet to demonstrate the attainment of the policy. In its initial stage, the Western Development policy places the most focus on the construction of infrastructure, and it is therefore not easy to find significant achievement in the short term.

Finally, an alternative issue introduced from our empirical analysis is also noteworthy. In the past, factor accumulation was usually criticized as having no implication in productivity growth. However, we would like to indicate that it is not necessarily the case for all the development phases. Rather, once the usable technology is matched up, the factor accumulation still contributes to productivity. Perhaps the position of factor accumulation is trivial from the perspective of an advanced economy, but for emerging economies in the initial development stage, the scale adjustment plays an important and non-negligible role on TFP growth.

Some key economic policy implications can be taken from the results. While China's productivity growth has slowed since the mid-1990s, it is still a spectacular performance when compared to Asian developing and advanced countries. From the perspective of sustainable growth, how to ease the decreasing trend of productivity growth is a critical issue. China should therefore put more effort into innovative activity as well as into protecting intellectual property rights to promote economic growth. Moreover, as indicated in the above discussion, there are differences in productivity growth and its composition between coastal and non-coastal regions. This implies that the government should formulate a specific development policy for the inland region to reduce the income inequality between coastal and non-coastal regions. Essentially, the "China Western Development" policy is moving in the correct direction by enabling the western regions to have actually experienced good performance in economic growth in the short term. More importantly, as is also echoed in the recent critical literature of Fleisher et al. (2009) concerning China's regional disparity, the government should carry out some policies to promote persistent TFP growth for the inland regions, such as promoting human resources and technological capability.

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## References

- Aigner, D. J., Lovell, C. A. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6, 21–37.
- Balk, B. M. (2001). Scale efficiency and productivity change. *Journal of Productivity Analysis*, 15, 159–183.
- Banker, R. D. (1984). Estimating most productive scale size using data envelopment analysis. *European Journal of Operational Research*, 17, 35–44.
- Battese, G. E., & Coelli, T. J. (1992). Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis*, 3, 153–169.
- Battese, G. E., & Rao, D. S. P. (2002). Technology gap, efficiency and a stochastic metafrontier function. *International Journal of Business and Economics*, 1, 87–93.
- Battese, G. E., Rao, D. S. P., & O'Donnell, C. J. (2004). A metafrontier production function for estimation of technical efficiencies and technology potentials for firms operating under different technologies. *Journal of Productivity Analysis*, 21, 91–103.
- Borensztein, E., & Ostry, J. D. (1996). Accounting for China's growth performance. *American Economic Review*, 88, 224–228.
- Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of input, output and productivity. *Econometrica*, 50, 1393–1414.
- Chen, Y. (2001). Evidence of the effect of openness policy on TFP and its components: The case of Chinese provinces. Paper presented to the 3rd International Conference on Chinese Economy, Clermont-Ferrand, France.
- Chen, J., & Fleisher, B. M. (1996). Regional income inequality and economic growth in China. *Journal of Comparative Economics*, 22(2), 141–164.
- Coelli, T., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). *Introduction to efficiency and productivity analysis*, 2nd edition Heidelberg: Springer.
- Denny, M., Fuss, M., & Waverman, L. (1981). The measurement and interpretation of total factor productivity in regulated industries with an application to Canadian telecommunications. In T. G. Cowing, & R. E. Stevenson (Eds.), *Productivity measurement in regulated industries* (pp. 179–218). New York: Academic Press.
- Diewert, W. E. (1976). Exact and superlative index numbers. *Journal of Econometrics*, 4, 115–145.
- Ezaki, M., & Sun, L. (1999). Growth accounting in China for national, regional, and provincial economies: 1981–1995. *Asian Economic Journal*, 13, 39–73.
- Fare, R., Grosskopf, S., & Margaritis, D. (2006). Productivity growth and convergence in the European Union. *Journal of Productivity Analysis*, 25, 111–141.
- Fare, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *American Economic Review*, 84, 66–83.
- Fare, R., & Primont, D. (1995). *Multi-output production a duality: Theory and applications*. Boston: Kluwer Academic Publishers.
- Frisch, R. (1965). *Theory of production*. Dordrecht: D. Reidel.
- Fleisher, B. M., & Chen, J. (1997). The coast–noncoast income gap, productivity and regional economic policy in China. *Journal of Comparative Economics*, 20(2), 220–236.
- Fleisher, B.M., Li, H. and Zhao, M.Q., (2009), Human capital, economic growth, and regional inequality in China, *Journal of Development Economics*, forthcoming.
- Grifell-Tatje, E., & Lovell, C. A. K. (1999). A generalized Malmquist productivity index, top. *Sociedad Espanola de Investigacion Operativa*, 7, 81–101.
- Hu, Z. L., & Khan, M. (1997). Why is China growing so fast? *IMF Staff Papers*, 44, 103–131.
- Huang, T.H., Chen, Y.H., and Wang, M.H., (2008), A study of production efficiency and rate of total factor productivity change for ten East Asian countries, *Taiwan Economic Review*, forthcoming.
- Islam, N., Dai, E., & Sakamoto, H. (2006). Role of TFP in China's growth. *Asian Economic Journal*, 20(2), 127–159.
- Kanbur, R., & Zhang, X. (2005). Fifty years of regional inequality in China: A journey through central planning, reform, and openness. *Review of Development Economics*, 9(1), 87–106.
- Li, K. W., Liu, T., & Yun, L. (2008). Decomposition of economic and productivity growth in post-reform China. *Working paper 200806, Department of Economics, Ball State University*.
- McIllian, J., Whalley, J., & Zhu (1989). The impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy*, 97, 781–807.
- Meeusen, W., & van den Broeck, J. (1977). Efficiency estimation from Cobb–Douglas production functions with composed error. *International Economic Review*, 18, 435–444.
- O'Donnell, C. J., Rao, D. S. P., & Battese, G. E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empirical Economics*, 34(2), 231–255.
- Orea, L. (2002). Parametric decomposition of a generalized Malmquist productivity index. *Journal of Productivity Analysis*, 18, 5–22.
- Orea, L. and Kumbhakar, S.C., (2003), Efficiency measurement using a stochastic frontier latent class model, State University of New York at Binghamton, mimeo.
- Rao, D.S.P. (2006) Metafrontier frameworks for the study of firm-level efficiencies and technology gaps, 2006 productivity and efficiency seminar, Taipei, 10th March, Conference Paper.
- Ray, S. C. (1998). Measuring scale efficiency from a translog production function. *Journal of Productivity Analysis*, 11, 183–194.
- Ray, S. C., & Desli, E. (1997). Productivity growth, technical progress and efficiency change in industrialized countries: Comment. *American Economic Review*, 87, 1033–1039.
- Shephard, R. W. (1970). *The theory of cost and production functions*, Princeton. US: Princeton University Press.
- Shiu, A., & Heshmati, A. (2006). Technical change and total factor productivity growth for Chinese provinces: A panel data analysis. *IZA Discussing Paper*, No. 2133.
- Szirmai, A., Ren, R., & Bai, M. (2005). Chinese manufacturing performance in a comparative perspective, 1980–2002. *Yale University Discussion Paper No. 920*.
- Wang, Y., & Yao, Y. (2003). Sources of China's economic growth 1952–1999: Incorporating human capital accumulation. *China Economic Review*, 14(1), 32–52.
- Wu, Y. (1995). Productivity growth, technological progress and technical efficiency change in China: A three-sector analysis. *Journal of Comparative Economics*, 21, 207–229.
- Wu, Y. (2000). Is China's economic growth sustainable? A productivity analysis. *China Economic Review*, 11, 278–296.
- Yao, S. (2006). On economic growth, FDI and exports in China. *Applied Economics*, 38, 339–351.
- Yao, S., & Zhang, Z. (2001). On regional inequality and diverging clubs: A case study of contemporary China. *Journal of Comparative Economics*, 29, 466–484.
- Young, A. (1995). The tyranny of numbers: Confronting the statistical realities of the East Asian growth. *Quarterly Journal of Economics*, 110(3), 641–680.
- Young, A. (2003). Gold into base metals: productivity growth in the People's Republic of China during the reform period. *Journal of Political Economy*, 111(6), 1220–1261.
- Zheng, J., & Hu, A. (2006). An empirical analysis of provincial productivity in China, 1979–2001. *Journal of Chinese Economic and Business Studies*, 4(3), 221–239.