Centre for Efficiency and Productivity Analysis

Working Paper Series
No. WP04/2011

New Estimates and a Decomposition of Provincial Productivity Change in China

J. Laurenceson, C.J. O'Donnell

Date: April 2011

School of Economics
University of Queensland
St. Lucia, Qld. 4072
Australia

ISSN No. 1932 - 4398

New Estimates and a Decomposition of Provincial Productivity Change in China

James Laurenceson[#*]
Senior Lecturer
School of Economics
The University of Queensland

Christopher O'Donnell
Professor
School of Economics,
The University of Queensland

Abstract

Productivity and efficiency change lies at the heart of some of the key development challenges facing China's economy, the world's largest developing economy and second largest overall. This paper computes and decomposes provincial-level Hicks-Moorsteen TFP indexes for the period 1978 to 2008. On average across provinces, we find evidence of moderate TFP growth, as well as large changes in the components of TFP growth over the sample period. Considerable heterogeneity from province to province is also documented both with respect to the rate of TFP growth and its components. Policy implications are discussed.

JEL Codes – O47, O53

Corresponding author – School of Economics, The University of Queensland, St Lucia, 4072, Brisbane, QLD, Australia. Ph - +617 33656085. Email – j.laurenceson@uq.edu.au

* The authors are grateful for valuable comments received from Qing He and participants at the Western Economic Association International 9th Biennial Pacific Rim Conference, Brisbane, 26-28th July, 2011 on any earlier version of this paper.

1. Introduction

Productivity and efficiency change lies at the heart of some of the key development challenges facing China's economy, the world largest developing economy and second largest overall. One such challenge is the sustainability of its current rapid rate of economic growth. China's traditional growth model has emphasised high rates of investment and exports. The potential problems associated with this model are several. Firstly, high rates of investment require equally high rates of savings. However, demographic changes in China mean that household savings rates are expected to soon begin to decline (Curtis, et al., 2011). Secondly, high rates of investment and savings have meant that domestic consumption growth has not kept pace with output growth.[1] This in turn has made output growth vulnerable to changes in foreign demand. A number of countries, led by the US and the EU, have voiced a growing unwillingness to consume China's excess production. Thirdly, the growth model is resource intensive and has contributed to a dramatic deterioration in environmental outcomes. Some of these problems can be alleviated by moving away from strategies that emphasise investment growth towards strategies that emphasise growth in the efficiency of resource use, particularly if this shift is combined with other strategies such as those aimed at boosting domestic demand. On the face of things, the opposite appears to be happening: China's rapid economic growth appears to have become more dependent on factor accumulation, not less. The ratio of gross capital formation to GDP has risen from an already high average of 35.2% in the 1980s to 40.5% in the 2000s (CSY, various years). In 2008, this ratio reached its highest ever level at 43.5%. Unsurprisingly, these national-level data mask important heterogeneity at the provincial level. Table 1 shows the ratio of gross capital formation to GDP for China's thirty-one provinces averaged over the period 2000-2008. This ranges from 36% in Heilongjiang and Guangdong to 75% in Ningxia. These figures suggest that some provinces will be far more vulnerable than others to changes in economic conditions if the traditional growth model begins to fail.

[Table 1 here]

Another well-known challenge facing China is worsening income inequality across provinces. By 2008, per capita GDP in China's richest province, Shanghai, had reached more than eight times that in the poorest province, Guizhou. What is not clear is whether productivity and efficiency change has exacerbated the problem or helped to ameliorate it. Traditional growth theory emphasises the "catch up" phenomenon, which suggests that provinces with lower initial levels of efficiency should be able to grow quicker than those at the technology frontier. New Growth Theory, on the other hand, emphasises the endogeneity of technological change, which instead might see the more advanced provinces extending their lead.

Given the importance of productivity and efficiency change at the provincial level, several studies have emerged in recent years that have aimed to shed light on the issue. This paper contributes to that

[1] This is most clearly illustrated by China's current account surplus, which reached 9.4% of GDP in 2008.

literature by computing and decomposing provincial-level Hicks-Moorsteen (H-M) TFP indexes. As we will show in more detail later, the H-M index is appealing because, unlike the more commonly-used Malmquist TFP index, it can be decomposed into unambiguous measures of technical change and efficiency change. Moreover, the efficiency change component can be further decomposed into measures of pure technical, scale and mix efficiency change. Such decompositions of efficiency change are useful for at least two reasons. Firstly, not all types of efficiency improvements are associated with increases in net income. For example, if prices are constant then an increase in technical efficiency will always increase net income, but improvements in scale and mix efficiency may lower net income if markets are not perfectly competitive (O'Donnell, 2010a). To determine whether changes in total efficiency are associated with improvements or declines in net income (and welfare) it is necessary to decompose efficiency into its technical, scale and mix components. Secondly, different types of inefficiency typically require different public policy responses. For example, the types of policies that might be needed to address technical inefficiency (e.g., education, training and extension programs) are quite different from those that might be employed to address scale and mix inefficiency (e.g. exchange rates, taxes, subsidies and other policies that affect relative prices). Thus, the decomposition methodology we employ allows for a more complete and nuanced understanding of provincial productivity change and associated public policies. Importantly, our methodology does not require strong assumptions concerning the economic characteristics of the production technology or the nature of technical change. Nor does it require any assumptions concerning the degree of competition in input or output markets.

The outline of the paper is as follows. Section 2 reviews the findings of previous studies that have considered productivity change at the provincial level in China. Section 3 reveals how productivity and efficiency can be measured within the aggregate-quantity framework of O'Donnell (2008). Section 4 shows how this framework can be used to motivate an important class of productivity indexes that can be decomposed into a measure of technical change and various measures of efficiency change. Section 5 makes explicit the different assumptions underpinning the stochastic frontier analysis (SFA), data envelopment analysis (DEA) and growth accounting approaches to estimating these productivity indexes. Section 6 outlines the data sources. Section 7 presents and discusses the results. Section 8 concludes.

2. Previous Studies

The evolution of studies seeking to measure provincial productivity change in China largely reflects methodological advancements in the broader productivity measurement literature. To our knowledge, the first study to have considered this question is Ezaki and Sun (1999). These authors used traditional growth accounting methods to estimate TFP change and to determine the contribution of labour and capital to provincial real GDP growth over the period 1981-1995. They found evidence of impressive TFP growth over this period: the average annual rate of TFP growth across provinces was estimated to be 3.7%. They also found evidence of considerable variation in provincial TFP growth rates. For example, the average annual rate of TFP growth was estimated to be 6.9% in Anhui compared with -0.3% in Shanghai. Miyamoto and Liu (2005) also used a growth accounting methodology to measure productivity change at the provincial level over the period 1981-2000. They estimated that the average annual rate of TFP growth across provinces was 4.03%. A more recent study to have used growth accounting methodology is Zhu, et al., (2008). The main innovation in that study, which covers the period 1978-2004, was to augment the production function with a measure of human capital. These authors estimated that the average annual rate of TFP growth across provinces was 3.9%. Thus, all of the studies that use a growth accounting methodology arrive at similar, and relatively high, estimates of TFP change.

As we shall see in Section 5, growth accounting methodology is underpinned by strong assumptions concerning the nature of technical change (i.e., technical change is Hicks-neutral), levels of efficiency (i.e., all provinces are fully technically, scale and mix efficient), and market structure (i.e., markets are perfectly competitive). The fact that growth accounting measures of TFP change do not account for changes in common measures of efficiency means they can only be interpreted as measures of pure technical change (i.e., shifts in the best practice frontier).

Like Ezaki and Sun (1999), Wu (2000) sought to estimate TFP change at the provincial level over the period 1981-1995. However, he extended their work in two important ways. Firstly, he (implicitly) relaxed the growth accounting assumptions concerning technical change, technical efficiency and market structure. Secondly, he estimated the technical change and technical efficiency change components of TFP change using stochastic frontier analysis (SFA). The main finding of Wu (2000) was that technical change and technical efficiency change had contributed little to the rapid growth in provincial real GDP. While he did not present numerical results for each province, the graphs he did present and the associated discussion led him to conclude that China's provinces had a "poor record" with respect to TFP growth and that "Positive rates of TFP growth were only recorded in the 1990s" (p.287). He also found that the relatively advanced provinces of Beijing, Shanghai and Tianjin had recorded the lowest rates of TFP growth, which is consistent with the "catch up" hypothesis. Finally, he found that the TFP growth that had occurred mainly reflected efficiency change rather than technical change. Like most authors who have used SFA to undertake productivity analysis, Wu (2000) did not include measures of scale or mix efficiency change in his measure of TFP growth. Thus, his TFP index is "incomplete" in a sense that will be made clear in Section 4 below. Since Wu (2000), several other studies have used SFA methodology to estimate provincial TFP change. Ao and Fuglitini (2005) considered the period from 1978-1998. In contrast to Wu (2000), they estimated that the average annual rate of TFP growth across provinces was 3.3%. Chen, et al. (2009) considered the period from 1996-2004. They estimated that the average annual rate of TFP growth across provinces was 3.2%.[2]

---

[2] Zhang (2008) also used SFA to measure productivity change at the provincial level. However, the purpose of the paper was mainly to advocate the adoption of a particular approach to estimate provincial capital stocks. TFP results are not presented numerically and only discussed briefly.

Quo, et al. (2006) extended the literature by using an alternative frontier methodology, data envelopment analysis (DEA), to compute Malmquist indexes of TFP change over the period 1979-2003. Like Wu (2000), Quo, et al. (2006) concluded that TFP growth had been low: the average annual growth rate across provinces was just 0.25%. However, in contrast to Wu (2000), they found that the coastal provinces had recorded relatively faster TFP growth than inland provinces. Thus, their findings offered less support to the "catch up" hypothesis. They also found that low TFP growth reflected both limited technical change and efficiency change. A limitation of Malmquist TFP indexes is that they ignore the scale and mix efficiency components of TFP change and are therefore "incomplete" (O'Donnell, 2008, 2010a). Zheng and Hu (2006) also used DEA to compute Malmquist TFP indexes for China's provinces over the period 1979-2001. They estimated that the average annual rate of TFP growth across provinces was 1.99% and that these gains were driven almost exclusively by technical change rather than efficiency change.[3] There is at least as much variation in these DEA estimates of TFP change as there is in the SFA estimates discussed above.

Aside from different methodologies and sample periods, different estimates of provincial capital stocks may contribute to variations in reported estimates of TFP change. Provincial capital stock data must be constructed by individual researchers because official data are unavailable. All studies have made use of the familiar perpetual inventory method to arrive at their capital stock estimates. This involves making assumptions about the initial value of the capital stock, the price deflator for new additions to the capital stock (i.e., investment) and the depreciation rate of the existing capital stock.

Some studies make largely ad hoc assumptions regarding the initial value of the capital stock. For example, Miyamoto and Liu (2005), Zheng and Hu (2006) and Quo, et al. (2006) assumed that the national stock of fixed assets could be disaggregated according to the share of a given province in national output. Others have relied on more tried and tested approaches.[4] For example, Ao and Fulginiti (2005) dealt with the problem by assuming benchmark values for provincial capital stocks in 1952, the first year for which investment data were available, but did not begin their TFP calculations until 1978. The rationale for the delay is that over time the initial capital stock values become less important. To emphasise the point, Ao and Fulginiti (2005) noted that their TFP growth estimates were largely unaffected by changes in their assumed benchmark values.

Official, province-specific investment price deflators are also unavailable throughout the reform period. Therefore, all studies make use of proxies. For example, Ao and Fulgitini (2005) used the national retail price index, while Ezaki and Sun (1999) attempted to create an investment price deflator by utilising whatever official data were available, in their case by taking a weighted average of the "producer price index of the machine building industry" and the "producer price index of building

---

3 Unel and Zebregs (2009) also used DEA to measure productivity change at the provincial level, although their focus was labour productivity, not TFP.

4 Wu (2009) provides a useful overview of the standard approaches found in the productivity measurement literature to estimate the initial value of the capital stock.

materials". These proxy price deflators were then applied uniformly across provinces. As has been noted by Zhang (2008) and Wu (2009), this is problematic in a country as geographically large as China, which is characterised by the concentration of different industrial sectors in different regions. For example, China's North-East is best known for its high concentration of heavy industry, such as resource extraction, while the South-East is best known for its light industry, such as labour-intensive manufacturing. Zhang (2008) presented evidence that the investment price deflator has most certainly not been uniform across the country. To take one example: Zhang (2008) contends that while the investment price deflator in Beijing doubled over the period 1978-2004, it increased more than five-fold in Anhui. Only a minority of studies have attempted to deflate provincial investment data with a province-specific price deflator. One example is Wu (2000) who used provincial GDP deflators for this purpose.

A variety of assumptions have also been made with respect to an appropriate rate of depreciation for provincial capital stocks. Zheng and Hu (2006) assumed a rate of 4%, Ao and Fuglitini (2005) assumed a depreciation rate of 4.22%, Wu (2000), Miyamoto and Liu (2005) and Quo, et al. (2006) assumed a rate of 5%, Chen, et al. (2009) assumed a rate of 7.5%, while Zhang (2008) assumed a rate of 9.6%. All studies have assumed the rate applies uniformly across provinces. As with the investment price deflator, assuming a uniform rate of capital stock depreciation across provinces in a country as geographically large and diverse as China is far from ideal.

3. Measures of Productivity and Efficiency

This paper analyses productivity and efficiency within the aggregate quantity framework of O'Donnell (2008). The following two sections summarise this framework using language and notation appropriate to the analysis of data on N firms over T time periods.

Let $x_{it} = (x_{1it},...,x_{Kit})'$ and $q_{it} = (q_{1it},...,q_{Jit})'$ denote vectors of input and output quantities for firm i in period t. O'Donnell (2008) defines the TFP of the firm as

(1) $$TFP_{it} = \frac{Q_{it}}{X_{it}} \qquad \text{(TFP)}$$

where $Q_{it} \equiv Q(q_{it})$ is an aggregate output, $X_{it} \equiv X(x_{it})$ is an aggregate input, and $Q(.)$ and $X(.)$ are non-negative, non-decreasing and linearly-homogeneous aggregator functions. Among other things, this definition means that measures of efficiency can be defined as ratios of measures of TFP. For example, let TFP_t^* denote the maximum TFP that is possible using the technology available in period t. Then an overall measure of productive efficiency is the ratio of observed TFP to the maximum TFP that is possible (O'Donnell, 2008):

(2) $$TFPE_{it} = \frac{TFP_{it}}{TFP_t^*} = \frac{Q_{it} / X_{it}}{Q_t^* / X_t^*} \le 1$$ (TFP efficiency)

where Q_t^* and X_t^* are aggregates of the output and input vectors that maximise TFP. Other measures of efficiency (i.e., ratios of TFP) that feature in input-oriented decompositions of productivity change include (O'Donnell, 2008):

(3) $$ITE_{it} = \frac{Q_{it} / X_{it}}{Q_{it} / \bar{X}_{it}} = \frac{\bar{X}_{it}}{X_{it}} \le 1$$ (technical efficiency)

(4) $$ISE_{it} = \frac{Q_{it} / \bar{X}_{it}}{\tilde{Q}_{it} / \tilde{X}_{it}} \le 1$$ (pure scale efficiency)

(5) $$IME_{it} = \frac{Q_{it} / \bar{X}_{it}}{Q_{it} / \hat{X}_{it}} = \frac{\hat{X}_{it}}{\bar{X}_{it}} \le 1$$ (pure mix efficiency)

(6) $$ISME_{it} = \frac{Q_{it} / \bar{X}_{it}}{TFP_t^*} \le 1$$ (scale-mix efficiency)

where $\bar{X}_{it}$ is the minimum aggregate input possible when using a scalar multiple of x_{it} to produce q_{it}; $\hat{X}_{it}$ is the minimum aggregate input possible using *any* input vector to produce q_{it}; and $\tilde{Q}_{it}$ and $\tilde{X}_{it}$ are the aggregate output and input obtained when TFP is maximised subject to the constraint that the output and input vectors are scalar multiples of q_{it} and x_{it} respectively. The measures of input-oriented technical and scale efficiency defined by (3) and (4) are the standard measures described by Coelli et. al. (2005) and Balk (1998). The measures of input-oriented mix and scale-mix efficiency defined by (5) and (6) are newer measures defined by O'Donnell (2008, 2010c).

To illustrate relationships between some of these efficiency measures, O'Donnell (2008) considers the K = 2 input case where the input aggregator function is linear: $X(x_{it}) = \beta_1 x_{1it} + \beta_2 x_{2it}$. Figure 1 depicts this simple case in input space. The curved line passing through points B and U in Figure 1 is the usual isoquant depicted in introductory economics textbooks, while the dashed line passing through point A is an isoinput line that traces out all points that have the same aggregate input as at point A (henceforth referred to as firm A). It is evident from Figure 1 that if the output vector and the input mix are held fixed then firm A can minimise aggregate input use by radially contracting inputs to point B. Indeed, the ratio of the distance 0B to the distance 0A in Figure 1 is the standard input-oriented measure of technical efficiency defined in (3): $ITE_{it} = \bar{X}_{it} / X_{it} = \|B\| / \|A\|$. It is also evident that if restrictions on input mix are relaxed then firm A can further reduce aggregate input use by moving around the isoquant to point U. The reduction in aggregate input use associated with this change in input mix is captured by the O'Donnell (2008) measure of mix efficiency defined in (9): $IME_{it} = \hat{X}_{it} / \bar{X}_{it} = \|F\| / \|B\|$.

[Figure 1 here]

To further illustrate relationships between these and other efficiency measures, O'Donnell (2008) maps technically-feasible input-output combinations into aggregate quantity space. Figure 2 presents such a mapping for the input-output combinations represented by points A, B and U in Figure 1. In Figure 2, the curve passing through points U and E is an *unrestricted* production frontier that envelops aggregates of all technically-feasible input and output vectors. The curve passing through points B and D is a *mix-restricted* frontier that envelops aggregates of all technically-feasible input and output vectors *that can be written as scalar multiples of the output and input vectors of firm A* (i.e., all points that have the same output mix and input mix as firm A). The TFP at any point in aggregate quantity space is the slope of the ray from the origin to that point. For example, the TFP of firm A is the slope of the ray passing through point A (i.e., $TFP_{it} = Q_{it} / X_{it} = \text{slope 0A}$), and the maximum TFP that is possible using the technology available in period *t* is the slope of the ray passing through point E (i.e., $TFP_t^* = Q_t^* / X_t^* = \text{slope 0E}$). The measures of efficiency defined by (2) to (6) can all be viewed as changes in the slopes of such rays – for example, TFP efficiency can be represented as $TFPE_{it} = TFP_{it} / TFP_t^* = \text{slope 0A/slope 0E}$, and input-oriented scale efficiency can be represented as $ISE_{it} = (Q_{it} / \bar{X}_{it})/(\tilde{Q}_{it} / \tilde{X}_{it}) = \text{slope 0B/slope 0D}$. More details concerning aggregate-quantity representations of production technologies and measures of efficiency are available in O'Donnell (2008, 2010a, 2010c).

[Figure 2 here]

4. Productivity Indexes and the Components of Productivity Change

If TFP is defined as the ratio of an aggregate output to an aggregate input as in (1) then the productivity index that compares the TFP of firm *i* in period *t* with the TFP of firm *h* in period *s* is

$$(7) \qquad TFP_{hs,it} \equiv \frac{TFP_{it}}{TFP_{hs}} = \frac{Q_{it} / X_{it}}{Q_{hs} / X_{hs}} = \frac{Q_{hs,it}}{X_{hs,it}}$$

where $Q_{hs,it} \equiv Q_{it} / Q_{hs}$ is an output quantity index (a measure of output growth) and $X_{hs,it} \equiv X_{it} / X_{hs}$ is an input quantity index (a measure of input growth). Index numbers that can be written in the form of aggregate quantities as in (7) are said to be multiplicatively-complete (O'Donnell, 2008). Different multiplicatively-complete indexes are obtained by choosing different functional forms for the aggregator functions $Q(.)$ and $X(.)$. For example, let $D_O^t(x_{it}, q_{it})$ and $D_I^t(x_{it}, q_{it})$ denote the Shephard (1953) output- and input-distance functions representing the technology available in period *t*. Then the aggregator functions $Q(z) = [D_O^s(x_{hs}, z) D_O^t(x_{it}, z)]^{1/2}$ and $X(z) = [D_I^s(z, q_s) D_I^t(z, q_t)]^{1/2}$ yield the binary Hicks-Moorsteen TFP index discussed by Diewert (1992) and Bjurek (1996):

$$(8) \qquad TFP_{hs,it}^{HM} = \left(\frac{D_O^s(x_{hs}, q_{it}) D_O^t(x_{it}, q_{it})}{D_O^s(x_{hs}, q_{hs}) D_O^t(x_{it}, q_{hs})} \frac{D_I^s(x_{hs}, q_{hs}) D_I^t(x_{hs}, q_{it})}{D_I^s(x_{it}, q_{hs}) D_I^t(x_{it}, q_{it})} \right)^{1/2}.$$

The class of multiplicatively-complete TFP indexes also includes Paasche, Laspeyres, Tornquist, Fisher and Lowe TFP indexes, but not the popular Malmquist TFP index of Caves, et al. (1982).

O'Donnell (2008) shows that any multiplicatively-complete TFP index can be decomposed into various measures of technical change and efficiency change. An infinite number of decompositions are available, but perhaps the simplest decomposition involves the following re-arrangement of (2): $TFP_{it} = TFP_t^* \times TFPE_{it}$ for $i = 1, \ldots, N$ and $t = 1, \ldots, T$. It follows that:

$$(9) \qquad TFP_{hs,it} \equiv \frac{TFP_{it}}{TFP_{hs}} = \left(\frac{TFP_t^*}{TFP_s^*} \right) \left(\frac{TFPE_{it}}{TFPE_{hs}} \right).$$

The first term in parentheses on the right-hand side of (9) compares the maximum TFP possible in period *t* with the maximum TFP possible in period *s*. This is a natural measure of technical change. The second term is a measure of overall efficiency change. The efficiency change component can be further decomposed into various measures of technical, scale and mix efficiency change. For example, equations (2), (3) and (6) can be used to write (9) in the form:

$$(10) \qquad TFP_{hs,it} \equiv \frac{TFP_{it}}{TFP_{hs}} = \left(\frac{TFP_t^*}{TFP_s^*} \right) \left(\frac{ITE_{it}}{ITE_{hs}} \right) \left(\frac{ISME_{it}}{ISME_{hs}} \right).$$

Thus, TFP change can be decomposed into three intrinsically different components: a technical change component that measures movements in the production frontier; a technical efficiency change component that measures movements towards or away from the frontier; and a scale-mix efficiency change component that measures movements around the frontier surface to capture economies of scale and scope. Several other input- and output-oriented decompositions of TFP change are discussed in O'Donnell (2008, 2010c). This paper focuses on the decompositions given by (9) and (10).

5. Decomposing Productivity Indexes in Practice

Decomposing productivity indexes into technical change and efficiency change components involves estimating production frontiers of the type depicted in Figures 1 and 2. The SFA, DEA and growth accounting methodologies described in Section 2 all assume that the production frontier takes the form:

$$(11) \qquad Q(q_{it}) \leq f(x_{it}, t)$$

where the inequality sign allows for output shortfalls due to technical inefficiency, the time trend is included to allow for technical change, and $f(.)$ is assumed to be i) non-negative and ii) non-decreasing and concave in inputs. However, the three different methodologies make different additional assumptions concerning this frontier. The basic SFA model assumes (e.g., Aigner, Lovell and Schmidt, 1977):

SFA.1 $\varepsilon_{it} \equiv h(x_{it}, t) - f(x_{it}, t)$ where $h(.)$ has an arbitrary functional form;

SFA.2 ε_{it} is a normal random variable; and

SFA.3 $u_{it} \equiv f(x_{it}, t) - Q(q_{it}) \geq 0$ is a half-normal or exponential random variable.

The standard DEA model assumes (e.g., O'Donnell, 2010a):

DEA.1 $f(x_{it}, t)$ is locally linear.

Finally, the standard growth accounting approach assumes

GA.1 there is no technical inefficiency;

GA.2 the technology is input homothetic;

GA.3 technical change is Hicks-neutral;

GA.4 the technology exhibits constant returns to scale;

GA.5 marginal revenue products equal factor prices (i.e., perfect competition); and

GA.6 the input aggregator function $X(.)$ has a Cobb-Douglas functional form.

Under assumptions SFA.1 to SFA.3 it is straightforward to estimate levels of technical efficiency using maximum likelihood or Bayesian estimation methods. Additional assumptions concerning the functional forms of $Q(.)$ and $X(.)$ must then be made in order to estimate measures of productivity change and mix efficiency change. Under assumption DEA.1 it is possible to estimate levels of efficiency using linear programming methods. Again, additional assumptions concerning the aggregator functions $Q(.)$ and $X(.)$ are needed to identify measures of productivity change and mix efficiency change. Finally, under assumptions GA.1 to GA.4 the production frontier (11) takes the form[5]

(12) $$Q_{it} = A(t) X(x_{it})$$

[5] Assumption GA.1 means equation (11) holds with equality. Assumptions GA.2 and GA.3 are sufficient conditions for the technology to exhibit extended Hicks-neutrality (EHN), and EHN is a necessary and sufficient condition for the production function to be multiplicatively decomposed into the product of a term involving t only and a term involving x_{it} only, i.e., to write $f(x_{it}, t) = A(t) X(x_{it})$. Assumption GA.4 means $f(.)$ and $X(.)$ are linearly homogeneous.

where $A(t) \geq 0$ accounts for technical change. Equations (1) and (12) together imply that this technical change term (sometimes known as the "Solow residual") can be interpreted as a measure of TFP change. Assumptions GA.5 and GA.6 mean it is possible to evaluate the aggregator function $X(.)$ using observed factor cost shares.

We regard assumptions GA.1 to GA.5 as being overly restrictive. In this paper, we also seek to avoid the arbitrary distributional assumptions in SFA.1 to SFA.3. Accordingly, we estimate production frontiers and associated measures of efficiency and productivity change using DEA. In our empirical application there is only J = 1 output so there is no need for any assumptions concerning the output aggregator function Q(.). There are K = 2 inputs so we assume the input aggregator function is $X(z) = [D_I^s(z, q_s) D_I^t(z, q_t)]^{1/2}$. Recall that this is the aggregator function underpinning the Hicks-Moorsteen TFP index given by (8). DEA linear programs for estimating the Hicks-Moorsteen TFP index (and its components) are detailed in O'Donnell (2010a).

6. Data

We compute and decompose binary Hicks-Moorsteen TFP indexes for thirty provinces over the period 1978-2008. The output variable is real GDP and the input variables are labour and capital stocks. The only province missing from the dataset is Chongqing, which did not receive provincial status until 1997. Provincial real GDP data were obtained mostly from the various provincial statistical yearbooks, as well as NBS (1999). The labour force variable was the number of employed persons in each province. These data were also obtained from provincial statistical yearbooks and NBS (1999).[6] Provincial capital stock data were obtained from Wu (2009), which builds on Wu (2008). Wu (2009) provides estimates of the capital stock for the period 1978-2006. We updated these data to include 2007 and 2008. The advantage of using Wu's (2009) capital stock estimates is that they are the first to feature province-specific investment price deflators and capital stock depreciation rates. It was noted earlier that Zhang (2008) found evidence of wide variation in investment price deflators across provinces. Similarly, Wu (2009) found evidence of considerable variation in provincial capital stock depreciation rates. For example, while the average rate of depreciation across provinces was 4.2%, this ranged from 2.6% in Tibet to 6.1% in Liaoning.[7]

---

[6] CSY (various years) also provides data on the number of employed persons by province. However, this is only since 1985. Also, the level value of this data differs from that found in the provincial yearbooks and NBS (1999). For example, according to CSY (2009), the number of employed persons in Beijing in 2008 was 11.7 million, while according to Beijing Statistical Yearbook (2009), the figure was 9.81 million. Importantly, the correlation coefficient between these two series is extremely high. For example, in the case of Beijing, the correlation coefficient is 0.97. We also estimated our model using the alternative labour stock data found in CSY (various years) and the TFP growth estimates were largely unaffected. These results are available from the authors upon request.

[7] For details on how Wu (2009) constructed his provincial capital stock estimates, the interested reader should consult the source.

7. Results

We implemented the methodology described in Sections 3 to 5 using the DPIN software written by O'Donnell (2010b). This software uses the DEA programs of O'Donnell (2010a) to estimate the Hicks-Moorsteen TFP index given by (8) and the components of TFP change in equation (10).[8] DPIN also estimates the technical, scale and mix efficiency scores defined by equations (3) to (5). The O'Donnell (2008) decomposition methodology does not require strong assumptions concerning the production technology or the nature of technical change. Nor does it require any assumptions concerning the optimising behaviour of firms or the degree of competition in product markets. In this paper we employ DPIN settings that allow for i) technical progress in some years and technical regress in others, and ii) variable returns to scale.

Before presenting estimates of provincial TFP *growth* and its components, we first discuss some of the findings in terms of *levels*. Table 2 shows the TFP-maximising province in each year. These results are intuitively plausible. The TFP maximising province at the beginning of the reform period was Shanghai, China's traditional commercial and financial hub. China's capital, Beijing, became the most productive province in the mid-1980s and maintained that status until the early 1990s. Since then, apart from Liaoning in 1993, the TFP-maximising province has been Guangdong. Guangdong borders Hong Kong SAR and hosts three Special Economic Zones, including Shenzhen, and has been the conduit for China's remarkable reintegration into the global economy (Kueh, 1992). Moreover, Guangdong has also been at the forefront of domestic policy liberalisation. For example, Wang, et al. (2007) presents the results of a "marketisation index" for China's thirty-one provinces in 2001 and 2005. The degree of marketisation achieved by provinces is assessed using twenty-three variables across five broad fields (e.g., degree of government involvement in the economy). In 2001, Guangdong was ranked number one using this index. In 2005, it ranked number two, behind Shanghai, but still recorded an increase in marketisation over its 2001 level. It is worth noting that all of the TFP-maximising provinces reported in Table 2 are coastal provinces.

[Table 2 here]

Figures 3, 4 and 5 plot the provincial average scores for technical, scale and mix efficiency, respectively. Methods for estimating *levels* of scale-mix efficiency are not yet available and hence only pure technical, scale and mix efficiency scores are presented. The average across all provinces is also disaggregated into averages across coastal provinces and inland provinces.

[Figure 3 here]

[Figure 4 here]

[Figure 5 here]

---

[8] DPIN also provides other decompositions but these are the ones we present and discuss in this paper.

Figure 3 reveals that average technical efficiency scores across all provinces fluctuated between 71% and 83% over the sample period. Throughout the coastal provinces were more technically efficient than their inland counterparts. Figure 3 provides no evidence to support the "catch-up" hypothesis: the difference in technical efficiency between coastal and inland provinces was even greater at the end of the period than at the beginning. In 2008, the average technical efficiency of inland provinces was only 65%. Interestingly, the average technical efficiency of both coastal and inland provinces fell in the second half of the reform period. Results reported later in this section indicate that this is almost certainly due to outward shifts in the production frontier (i.e., technical change) rather than declining levels of provincial TFP. That is, the frontier has been moving away from the provinces rather than the provinces dropping away from the frontier.

Figure 4 shows that average scale efficiency was high during the first half of the reform period, fluctuating between 85-95%. Moreover, there were no discernable differences in scale efficiency between coastal and inland provinces. However, this began to change in the second half of the reform period. While coastal provinces maintained average scale efficiency scores of around 95%, the average across inland provinces fell to less than 85%.

The news is more positive for inland provinces with respect to mix efficiency. Figure 5 shows that the average level of input mix efficiency across inland provinces increased from approximately 60% at the beginning of the sample period to 90% at the end. Thus, changes in the capital to labour ratio appear to have increased TFP in inland provinces by approximately (0.9/0.6 – 1) = 50%. Observe from Figure 5 that the average level of input mix efficiency in inland provinces at the end of the sample period was slightly higher than the average for coastal provinces.

We now turn to a discussion of estimates of TFP *change* and its components. Figure 6 presents the average across all provinces of the Hicks-Moorsteen TFP index defined by (8). It also presents the technical change, technical efficiency change and scale-mix efficiency change components of TFP change identified in equation (10). Recall that technical change represents shifts in the best-practice frontier; technical efficiency change represents movements towards (or away from) the best practice frontier, while scale-mix efficiency change represents movements around the best practice frontier surface. The indexes depicted in Figure 6 are arithmetic[9] averages across provinces. Table 3 presents numerical estimates of TFP change and its decomposition by province. For each province the average rate of TFP growth, along with its components, is given over the full sample, as well as in two sub-periods, 1978-1993 and 1994-2008. This is done in a bid to ascertain whether any changes in productivity patterns have occurred over time. The average rate of TFP change across all provinces, as well as the average across coastal provinces and inland provinces, is also presented at the end of the table.

---

9 Our use of arithmetic averages for presentation purposes means that the indexes presented in Table 3 will not satisfy equation (10) exactly.

[Figure 6 here]

[Table 3 here]

The main findings are as follows:

a) Average productivity has improved over the thirty year period. According to the estimates provided at the end of Table 3, the average annual rate of TFP growth across provinces over the full sample was 2.23%. This figure is firmly in the mid-range of estimates found in the existing literature (and reported in Section 2). As such, while not trivial, it can best be described as a moderate rather than high rate of growth. Observe from Figure 6 that average *levels* of TFP in 2008 were approximately 2.5 times higher than they had been in 1978.

b) Rates of productivity growth were higher in the second half of the reform period than in the first half. Observe from Table 3 that the average annual rate of TFP growth across all provinces rose from 1.99% in the first half of the reform period to 2.47% in the second half.

c) The main driver of productivity growth over the sample period has been technical change. Large increases in TFP due to technical change have been offset by small declines in TFP due to lower efficiency. Observe from the bottom of Table 3 that the average annual rate of technical change across all provinces over the full sample was 3.41%, while the average annual rate of efficiency change was -1.06%.

d) There have been large changes in the composition of productivity growth between the two sub-periods. Observe from Figure 6 that technical change was particularly rapid in the second half of the reform period. In the first half of the reform period, technical change and efficiency change both contributed positively to TFP growth (at average annual rates of 0.79% and 1.21% respectively). In the second half, however, the only driver of TFP growth was technical change (at an average annual rate of 6.02%; efficiency change was a drag on TFP growth). Such findings illustrate the valued-added associated with using a TFP index that is multiplicatively complete and can be decomposed into unambiguous measures of technical change and efficiency change.

e) There were significant differences in rates of TFP growth between coastal and inland regions. The average annual rate of TFP growth in coastal provinces over the sample period was 3.90%. The corresponding figure for inland provinces was just 1.26%. Moreover, the results for the two sub-periods show that the average annual rate of TFP growth across coastal provinces accelerated in the second half of the reform period, rising from 3.13% to 4.68%, while it slowed in the case of inland provinces, falling from 1.34% to 1.19%. The TFP growth decomposition shows that while both groups experienced deteriorating efficiency in the second half of the reform period, the deterioration was particularly pronounced amongst inland provinces.

f) There were significant differences in rates of TFP growth from province to province. Over the sample period, the province that experienced the fastest average annual growth rate of TFP was Hainan at 7.88%. This was closely followed by Guangdong at 7.22%. The slowest was Anhui at -1.84%. This heterogeneity reflects vastly different rates of efficiency change. For example, in the case of Hainan the average annual rate of efficiency change was 4.48%, compared with -4.98% in the case of Anhui.

g) There were significant differences in the components of efficiency change from province to province. For example, both Hainan and Guangdong experienced rapid efficiency change at 4.48% and 3.78%, respectively. However, in the case of Hainan, efficiency change could mostly be attributed to scale-mix efficiency change, whereas in the case of Guangdong it could mostly be attributed to technical efficiency change. In the case of Anhui, which recorded the lowest rate of efficiency change, technical efficiency change and scale-mix efficiency change contributed in roughly equal measure. The heterogeneity noted in f) and g) highlight the value-added associated with undertaking a decomposition of TFP growth using provincial-level data.[10]

In Section 1 it was noted that productivity and efficiency change lies at the heart of many of the key development challenges facing China's economy. The above results only serve to heighten our earlier concerns regarding the sustainability of China's rapid economic growth. A significant finding is that moderate rates of provincial TFP growth were mainly due to technical change and not to improvements in the efficiency of resource use. This suggests that China's rapid growth remains largely tied to a growth model that emphasises high rates of investment and exports. It is possible that domestic savings rates will remain high into the medium run before the impact of demographic changes begin to bite. However, it is very difficult to conceive a situation in which foreign countries such as the US will remain willing to consume China's excess production. While domestic consumers may pick up some of the slack, there are good reasons to be pessimistic. Despite the rhetoric from the Chinese government regarding the need for higher rates of private consumption growth, the reality is that household savings rates steadily *increased* throughout the 2000s. This was driven in large part by precautionary motives (Chamon, et al., 2010). Progress with respect to much needed institutional reforms, such as establishing and funding a nationwide social security system, has been incremental at best.

The results also suggest that addressing growing provincial income inequality will prove particularly challenging. Specifically, the Chinese authorities cannot rely on the "catch up" phenomenon to help their cause. While traditional growth theory posits that provinces with initially low TFP levels should experience relatively rapid TFP growth, the results point to the contrary: differential rates of TFP

[10] Table 3 also shows that Shanghai, Jiangsu and Tibet experienced no changes in technical efficiency. This is because these three provinces were 100% technically efficient over the sample period.

growth between coastal and inland provinces have in fact exacerbated widening provincial income inequality.

Finally, the fact that the components of efficiency change varied considerably from province to province suggest that a broad suite of policy measures will be needed to address inefficiency. As noted in Section 1, the types of policies that are designed to address technical inefficiency, such as education, training and extension programs, are distinct from those that are designed to address scale-mix inefficiency, such as taxes and subsidies intended to affect relative prices. Policies that affect relative prices are especially important because price variations can lead rational optimising firms to make different input and output choices. Not only do these different input and output choices translate into different measures of efficiency and TFP, they also translate into different levels of income. Thus, variations in prices (and, for that matter, other production incentives) across provinces and over time can help explain variations in levels of TFP and income. A corollary is that policies designed to equalise prices (and other incentives) across provinces may lead to productivity convergence and a reduction in provincial income inequality.

8. Conclusion

This paper provides new estimates and a decomposition of provincial-level total factor productivity (TFP) change in China from 1978 to 2008. The investigation was motivated by the fact that productivity change lies at the heart of some of the key development challenges facing China's economy. Several previous studies have dealt with productivity change at the provincial level but these suffer from a number of shortcomings, most notably with respect to methodology. Most indexes of total factor productivity (TFP) change can be decomposed into three intrinsically different components: technical change (measuring shifts in the best-practice frontier), technical efficiency change (measuring movements towards or away from the frontier) and scale and mix efficiency change (measuring movements around the frontier surface to capture economies of scale and scope). Many previous estimates of productivity change for provincial China have been computed using a growth accounting approach. The problem with this approach is that it makes overly restrictive assumptions concerning the nature of technical change (i.e., technical change is Hicks-neutral), levels of efficiency (i.e., all provinces are fully technically, scale and mix efficient), and market structure (i.e., markets are perfectly competitive). The fact that growth accounting measures of TFP change also do not account for changes in common measures of efficiency means they are incomplete in the sense of O'Donnell (2008). Other studies to have used SFA and DEA methodologies also suffer from a number of limitations, including a failure to decompose efficiency change into technical, scale and mix efficiency change, and the use of productivity indexes such as the Malmquist index that are multiplicatively incomplete. This paper computes and decomposes Hicks-Moorsteen (H-M) TFP indexes without making any of the restrictive growth accounting assumptions. H-M TFP indexes are also multiplicatively-complete and can be decomposed into a measure of technical change and various measures of efficiency change. In providing TFP estimates, this paper also made use of capital stock data that feature province-specific investment price deflators and rates of capital depreciation.

The results point to moderate TFP growth in provincial China over the period 1978-2008 with a slight quickening of the pace in the second half of the sample period. The decomposition of TFP growth is particularly illuminating. It shows that TFP growth during the first half of the reform period (1978-1993) can be attributed to both technical change and efficiency improvement. However, in the second half of the reform period (1994-2008) it can be attributed to technical change alone. Indeed, we find that that average levels of technical and scale efficiency fell during the second half of the reform period, particularly in inland provinces. We attribute these lower efficiency estimates to an especially high rate of technical change, not to a decline in the ability of Chinese producers to transform inputs into outputs. We conjecture that Chinese producers have been increasing their productivity levels but at a rate that leaves them lagging behind a rapidly shifting frontier.

The above results point to a number of policy challenges for the Chinese authorities. First and foremost they raise serious concerns regarding the sustainability of rapid economic growth, which has to date been driven by a growth strategy that emphasises high rates of investment and exports. Secondly, the results suggest that the authorities cannot simply rely on the “catch up” phenomenon to drive a convergence in income across provinces. Provincial TFP growth appears to have exacerbated the problem of provincial income inequality, not ameliorated it. Thirdly, given that the sources of inefficiency vary from province to province, the results suggest that there exists no one-size-fits-all approach to improving efficiency. Rather, a broad policy suite will be needed.

The above analysis uses non-parametric techniques (i.e., DEA) to provide estimates of provincial TFP change. A useful extension, which we leave for future research, would be to undertake a similar exercise using parametric techniques (i.e., SFA). A disadvantage of SFA is that it requires an arbitrary assumption about the algebraic form of the production function, but it has the advantage that it is relatively easy to conduct formal tests of statistical significance.

References

Aigner, D. J., Lovell, C. A. K., and Schmidt, P. (1977) Formulation and Estimation of Stochastic Frontier Production Function Models. *Journal of Econometrics*, 6: 21-37.

Ao, X. and Fulginiti, L. (2005) *Productivity growth in China: evidence from Chinese provinces*. http://agecon.unl.edu/fulginiti/XiangAo/xianggao.pdf

Balk, B. M. (1998). *Industrial Price, Quantity, and Productivity Indices: The Micro-Economic Theory and an Application*. (Boston: Kluwer Academic Publishers).

Bjurek, H. (1996) The Malmquist Total Factor Productivity Index. *Scandinavian Journal of* Economics, 98(2), pp. 303-313.

Caves, D., Christensen, L. and Diewert, W. (1982) Multilateral comparisons of output, input and productivity using superlative index numbers, *Economic Journal*, 92, 73-86.

Chamon, M., Liu, K. and Prasad, E. (2010) *Income uncertainty and household savings in China*. IMF Working Paper WP/10/289. http://www.imf.org/external/pubs/ft/wp/2010/wp10289.pdf

Chen, K., Huang, Y. and Yang, C. (2009) Analysis of regional productivity growth in China: a generalized metafrontier MPI approach, *China Economic Review*, 20(4), pp.777-792.

China Statistical Yearbook (CSY) (various years) (Beijing: China Statistics Press).

Coelli, T., Rao, P., O'Donnell, C. and Battese, D. (2005) *An introduction to efficiency and productivity analysis* (New York: Springer).

Curtis, C., Lugauer, S. and Mark, N. (2011) *Demographic patterns and household saving in China*. NBER Working Paper No. 16828. http://www.nber.org/papers/w16828

Diewert, W.E. (1992) Fisher Ideal Output, Input, and Productivity Indexes Revisited. *Journal of Productivity Analysis*, 3(3), pp. 211-248.

Ezaki, M. and Sun, L. (1999) Growth accounting in China for national, regional and provincial economies: 1981-1995. *Asian Economic Journal*, 13(1), pp.39-71.

Färe, R., Grosskopf, Norris, M. and Zhang, Z. (1994) Productivity growth, technical progress and efficiency change in industrialized countries, *American Economic Review*, 84(1), pp. 66-83.

Kueh, Y.Y. (1992) Foreign investment and economic change in China. *The China Quarterly*, 131, pp. 637-690.

Miyamoto, K. and Liu, H. (2005) An analysis of the determinants of provincial-level performance in China's economy. *Comparative Economic Studies*, 47(3), pp. 520-542.

National Bureau of Statistics (NBS). (1999) *Comprehensive statistical data and materials on 50 years of new China* (Beijing: China Statistics Press).

O'Donnell, C.J. (2008) *An aggregate quantity-price framework for measuring and decomposing productivity and profitability change*. Centre for Efficiency and Productivity Analysis Working Paper WP07/2008. http://www.uq.edu.au/economics/cepa/docs/WP/WP072008.pdf

O'Donnell, C.J. (2010a) Measuring and decomposing agricultural productivity and profitability change. *The Australian Journal of Agricultural and Resource Economics*, 54(4), pp. 527-560.

O'Donnell, C.J. (2010b) *DPIN Version 1.0: a program for decomposing productivity index numbers*. Centre for Efficiency and Productivity Analysis Working Paper No. WP01/2010. http://www.uq.edu.au/economics/cepa/docs/WP/WP012010.pdf

O'Donnell, C. J. (2010c) *Nonparametric Estimates of the Components of Productivity and Profitability Change in U.S. Agriculture*. Centre for Efficiency and Productivity Analysis Working Paper WP02/2010. http://www.uq.edu.au/economics/cepa/docs/WP/WP022010.pdf

Quo, Q., Zhao, Z. and Jia, J. (2006. Analysis of total factor productivity of Chinese provincial economy. *Frontiers of Economics in China*, 1(3), pp. 449-464.

Shephard, R. W. (1953) *Cost and Production Functions* (Princeton: Princeton University Press).

Unel, B. and Zebregs, H. (2009) The dynamics of provincial growth in China: a nonparametric approach, *IMF Staff Papers*, 56(2), pp. 239-262.

Wang, X., Fan, G. and Zhu, H. (2007) Marketisation in China: progress and contribution to growth, in R. Garnaut and L. Song, (eds) *China: linking markets for growth*, (Canberra: ANU ePress), pp. 30-44.

Wu, Y. (2000) Is China's economic growth sustainable? A productivity analysis. *China Economic Review*, 11(3), pp. 278-296.

Wu, Y. (2008) *Productivity, efficiency and economic growth in China* (London and New York: Palgrave McMillan).

Wu, Y. (2009) *China's capital stock series by region and sector*. University of Western Australia Business School Discussion Paper 09.02. http://www.uwa.edu.au/__data/assets/pdf_file/0009/260487/09_02_Wu.pdf

Zhang, J. (2008) Estimation of China's provincial capital stock (1952-2004) with applications. *Journal of Chinese Economic and Business Studies*, 6(2), pp. 177-196.

Zheng, J. and Hu, A. (2006) An empirical analysis of provincial productivity in China (1979-2001), *Journal of Chinese Economics and Business Studies*, 4(3), pp. 221-239.

Zhu, S., Lai, M. and Fu, X. (2008) Spatial characteristics and dynamics of provincial total factor productivity in China. *Journal of Chinese Economic and Business Studies*, 6(2), pp. 197-217.

Table 1. Average Ratio of Gross Capital Formation to GDP (%), 2000-2008

Province	Gross Capital Formation Rate
Beijing	56.02
Tianjin	53.84
Hebei	46.47
Shanxi	50.63
Inner Mongolia	61.05
Liaoning	45.61
Jilin	50.55
Heilongjiang	36.12
Shanghai	46.04
Jiangsu	48.48
Zhejiang	46.35
Anhui	41.11
Fujian	47.35
Jiangxi	45.69
Shandong	48.39
Henan	46.95
Hubei	44.56
Hunan	39.83
Guangdong	36.93
Guangxi	41.63
Hainan	46.94
Chongqing	55.60
Sichuan	43.98
Guizhou	53.15
Yunnan	49.61
Tibet	63.24
Shaanxi	58.60
Gansu	47.94
Qinghai	68.48
Ningxia	75.70
Xinjiang	56.54

Source – CSY (various years)

Table 2. TFP-Maximising Provinces

Year	Province
1978	Shanghai
1979	Shanghai
1980	Shanghai
1981	Shanghai
1982	Shanghai
1983	Shanghai
1984	Beijing
1985	Beijing
1986	Beijing
1987	Beijing
1988	Beijing
1989	Beijing
1990	Beijing
1991	Beijing
1992	Beijing
1993	Liaoning
1994	Guangdong
1995	Guangdong
1996	Guangdong
1997	Guangdong
1998	Guangdong
1999	Guangdong
2000	Guangdong
2001	Guangdong
2002	Guangdong
2003	Guangdong
2004	Guangdong
2005	Guangdong
2006	Guangdong
2007	Guangdong
2008	Guangdong

Table 3. Provincial TFP Change and Decomposition (% change)

Province	Period	TFP Change	Technical Change	Efficiency Change	Technical Efficiency Change	Scale-Mix Efficiency Change
Beijing	1978-2008	3.07	3.41	-0.30	-0.39	0.10
	1978-1993	1.13	0.79	0.32	0.00	0.32
	1994-2008	5.01	6.02	-0.92	-0.78	-0.12
Tianjin	1978-2008	4.32	3.41	0.91	0.57	0.36
	1978-1993	1.98	0.79	1.19	0.62	0.59
	1994-2008	6.66	6.02	0.63	0.52	0.13
Hebei	1978-2008	1.62	3.41	-1.61	0.18	-1.76
	1978-1993	2.32	0.79	1.53	2.86	-1.21
	1994-2008	0.93	6.02	-4.76	-2.50	-2.32
Shanxi	1978-2008	1.26	3.41	-2.03	0.07	-2.05
	1978-1993	0.75	0.79	-0.05	0.59	-0.58
	1994-2008	1.77	6.02	-4.02	-0.45	-3.53
Inner Mongolia	1978-2008	2.14	3.41	-1.17	0.14	-1.29
	1978-1993	-0.10	0.79	-0.83	0.00	-0.81
	1994-2008	4.38	6.02	-1.51	0.27	-1.78
Liaoning	1978-2008	2.61	3.41	-0.73	-0.79	0.06
	1978-1993	1.37	0.79	0.57	0.00	0.57
	1994-2008	3.85	6.02	-2.02	-1.59	-0.44
Jilin	1978-2008	1.69	3.41	-1.60	0.27	-1.83
	1978-1993	1.49	0.79	0.66	1.33	-0.62
	1994-2008	1.89	6.02	-3.86	-0.80	-3.04
Heilongjiang	1978-2008	0.65	3.41	-2.60	-0.88	-1.71
	1978-1993	-0.11	0.79	-0.86	-0.80	-0.02
	1994-2008	1.41	6.02	-4.34	-0.96	-3.40
Shanghai	1978-2008	4.71	3.41	1.27	0.00	1.27
	1978-1993	2.18	0.79	1.40	0.00	1.40
	1994-2008	7.23	6.02	1.14	0.00	1.14
Jiangsu	1978-2008	4.64	3.41	1.22	0.00	1.22
	1978-1993	3.20	0.79	2.36	0.00	2.36
	1994-2008	6.08	6.02	0.07	0.00	0.07
Zhejiang	1978-2008	4.01	3.41	0.61	1.17	-0.53
	1978-1993	2.85	0.79	1.98	3.76	-1.69
	1994-2008	5.17	6.02	-0.75	-1.41	0.63
Anhui	1978-2008	-1.84	3.41	-4.98	-1.99	-3.05
	1978-1993	-1.61	0.79	-2.35	-0.72	-1.64
	1994-2008	-2.06	6.02	-7.60	-3.25	-4.46
Fujian	1978-2008	2.29	3.41	-1.00	-0.03	-0.98
	1978-1993	2.05	0.79	1.26	1.57	-0.29
	1994-2008	2.53	6.02	-3.27	-1.63	-1.67
Jiangxi	1978-2008	0.32	3.41	-2.87	-0.10	-2.74
	1978-1993	1.46	0.79	0.69	1.19	-0.44
	1994-2008	-0.82	6.02	-6.43	-1.38	-5.04
Shandong	1978-2008	0.56	3.41	-2.69	-1.19	-1.53
	1978-1993	-0.40	0.79	-1.18	0.08	-1.25
	1994-2008	1.52	6.02	-4.19	-2.47	-1.80
Henan	1978-2008	-1.05	3.41	-4.25	-1.56	-2.69
	1978-1993	-1.88	0.79	-2.63	-0.79	-1.80
	1994-2008	-0.21	6.02	-5.87	-2.32	-3.59
Hubei	1978-2008	-1.08	3.41	-4.24	-1.64	-2.63
	1978-1993	-0.99	0.79	-1.75	-0.29	-1.41
	1994-2008	-1.16	6.02	-6.73	-2.99	-3.85
Hunan	1978-2008	0.09	3.41	-3.10	-0.27	-2.78
	1978-1993	0.56	0.79	-0.19	0.99	-1.08
	1994-2008	-0.38	6.02	-6.01	-1.53	-4.47
Guangdong	1978-2008	7.22	3.41	3.78	3.10	0.77
	1978-1993	7.68	0.79	6.87	6.20	0.84
	1994-2008	6.77	6.02	0.69	0.00	0.69

Table 3. cont.

Province	Period	TFP Change	Technical Change	Efficiency Change	Technical Efficiency Change	Scale and Mix Efficiency Change
Guangxi	1978-2008	1.20	3.41	-2.00	1.13	-3.09
	1978-1993	2.44	0.79	1.69	2.67	-0.93
	1994-2008	-0.04	6.02	-5.69	-0.41	-5.24
Hainan	1978-2008	7.88	3.41	4.48	1.12	3.29
	1978-1993	10.04	0.79	9.22	1.35	7.71
	1994-2008	5.71	6.02	-0.25	0.88	-1.13
Sichuan	1978-2008	1.19	3.41	-2.04	0.57	-2.57
	1978-1993	2.43	0.79	1.65	3.04	-1.29
	1994-2008	-0.05	6.02	-5.73	-1.89	-3.86
Guizhou	1978-2008	0.78	3.41	-2.42	1.26	-3.59
	1978-1993	2.30	0.79	1.52	2.72	-1.09
	1994-2008	-0.74	6.02	-6.35	-0.21	-6.09
Yunnan	1978-2008	0.55	3.41	-2.61	0.56	-3.10
	1978-1993	2.15	0.79	1.43	2.31	-0.77
	1994-2008	-1.05	6.02	-6.66	-1.20	-5.44
Tibet	1978-2008	2.04	3.41	-1.28	0.00	-1.28
	1978-1993	0.72	0.79	-0.06	0.00	-0.06
	1994-2008	3.35	6.02	-2.50	0.00	-2.50
Shaanxi	1978-2008	1.31	3.41	-1.97	0.29	-2.20
	1978-1993	1.22	0.79	0.40	1.24	-0.76
	1994-2008	1.40	6.02	-4.33	-0.65	-3.65
Gansu	1978-2008	1.87	3.41	-1.38	1.28	-2.56
	1978-1993	2.96	0.79	2.17	2.33	-0.07
	1994-2008	0.79	6.02	-4.93	0.22	-5.04
Qinghai	1978-2008	4.49	3.41	1.09	-0.09	1.33
	1978-1993	3.42	0.79	2.59	-2.33	5.05
	1994-2008	5.57	6.02	-0.41	2.14	-2.38
Ningxia	1978-2008	4.85	3.41	1.50	-0.36	1.96
	1978-1993	5.09	0.79	4.30	-1.59	6.02
	1994-2008	4.61	6.02	-1.31	0.88	-2.10
Xinjiang	1978-2008	3.53	3.41	0.22	0.55	-0.29
	1978-1993	3.11	0.79	2.37	2.88	-0.42
	1994-2008	3.95	6.02	-1.93	-1.78	-0.15
Coast	1978-2008	3.90	3.41	0.54	0.34	0.21
	1978-1993	3.13	0.79	2.32	1.49	0.85
	1994-2008	4.68	6.02	-1.24	-0.82	-0.44
Inland	1978-2008	1.26	3.41	-1.99	-0.04	-1.90
	1978-1993	1.34	0.79	0.57	0.78	-0.14
	1994-2008	1.19	6.02	-4.54	-0.86	-3.66
National	1978-2008	2.23	3.41	-1.06	0.10	-1.13
	1978-1993	1.99	0.79	1.21	*1.04*	*0.22*
	1994-2008	2.47	6.02	-3.33	*-0.84*	*-2.48*

Note: The sum of average technical progress and efficiency change may not exactly equal average TFP change due to rounding. Likewise, the sum of technical efficiency change and combined scale-mix efficiency change may not exactly equal efficiency change.

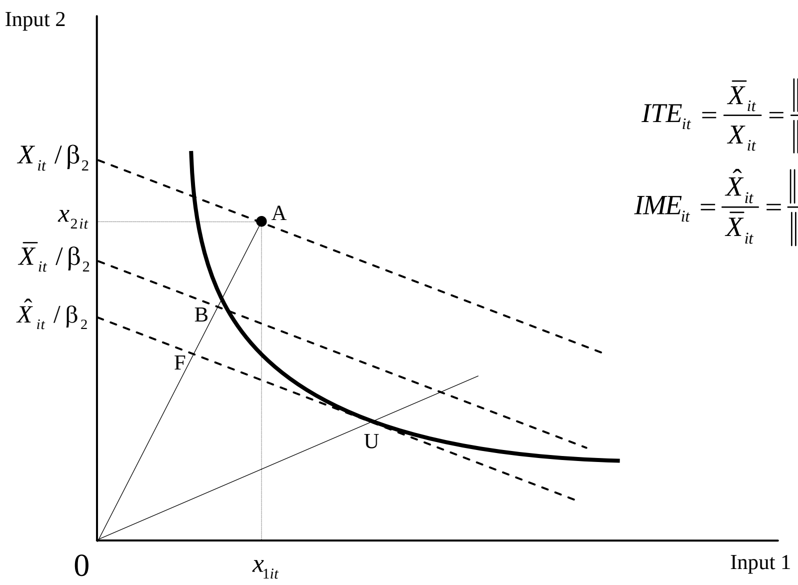

Figure 1. Input-Oriented Technical and Mix Efficiency
for a Two-Input Firm

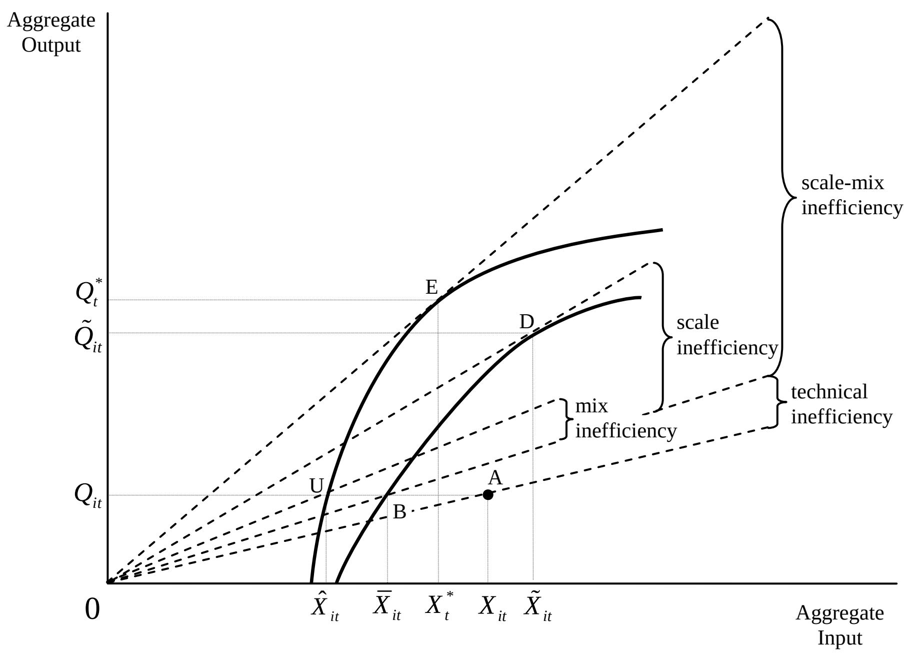

Figure 2. Input-Oriented Measures of Efficiency for a
Multiple-Input Multiple-Output Firm

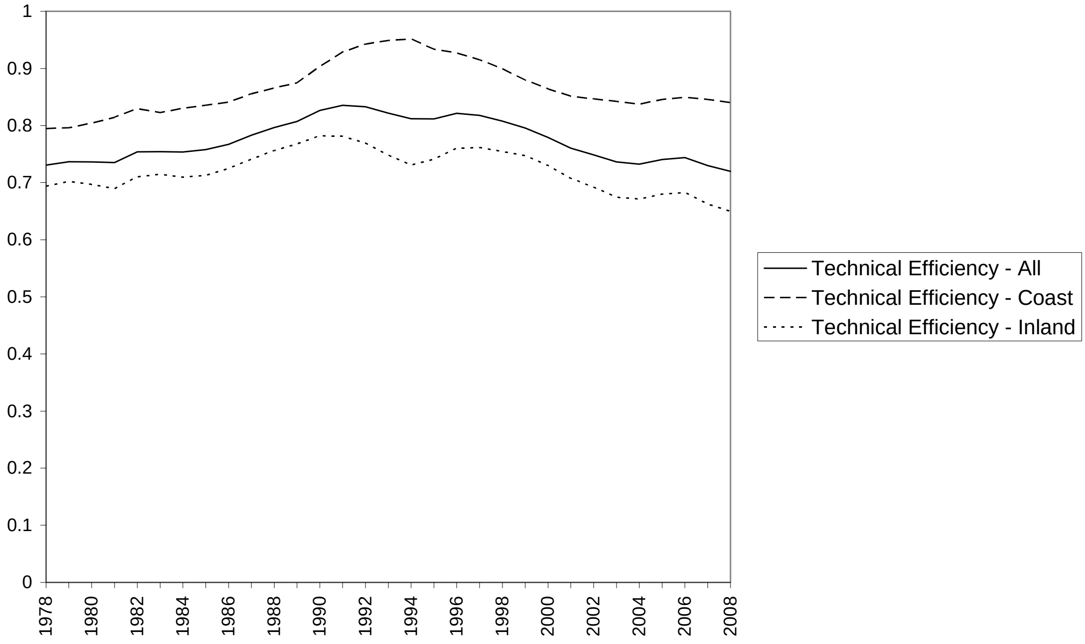

Figure 3. Average Provincial Technical Efficiency (ITE) Scores

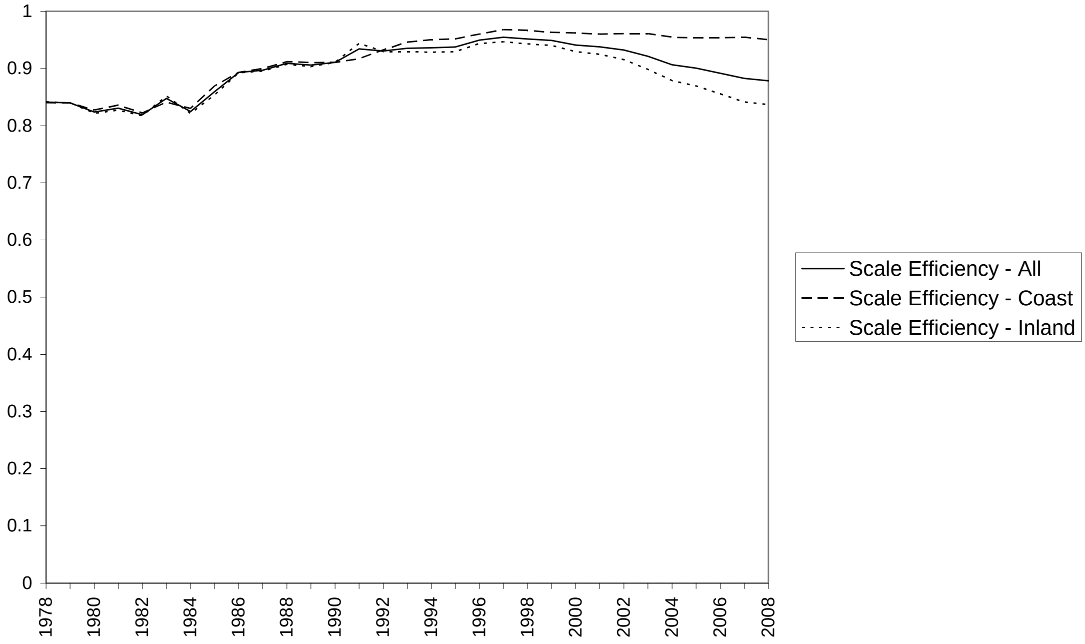

Figure 4. Average Provincial Scale Efficiency (ISE) Scores

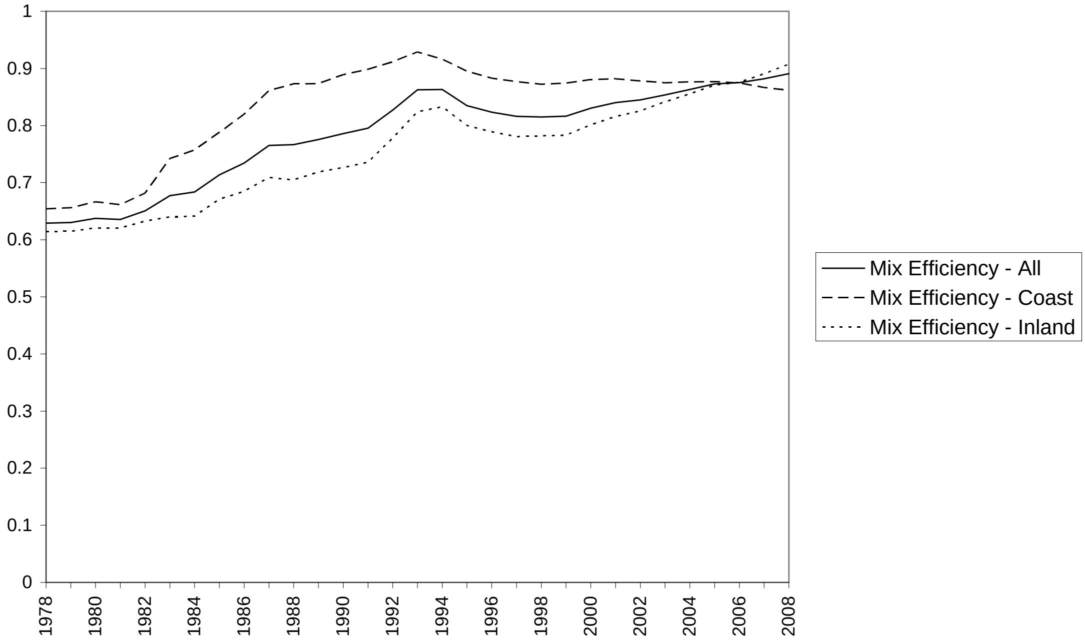

Figure 5. Average Provincial Mix Efficiency (IME) Scores

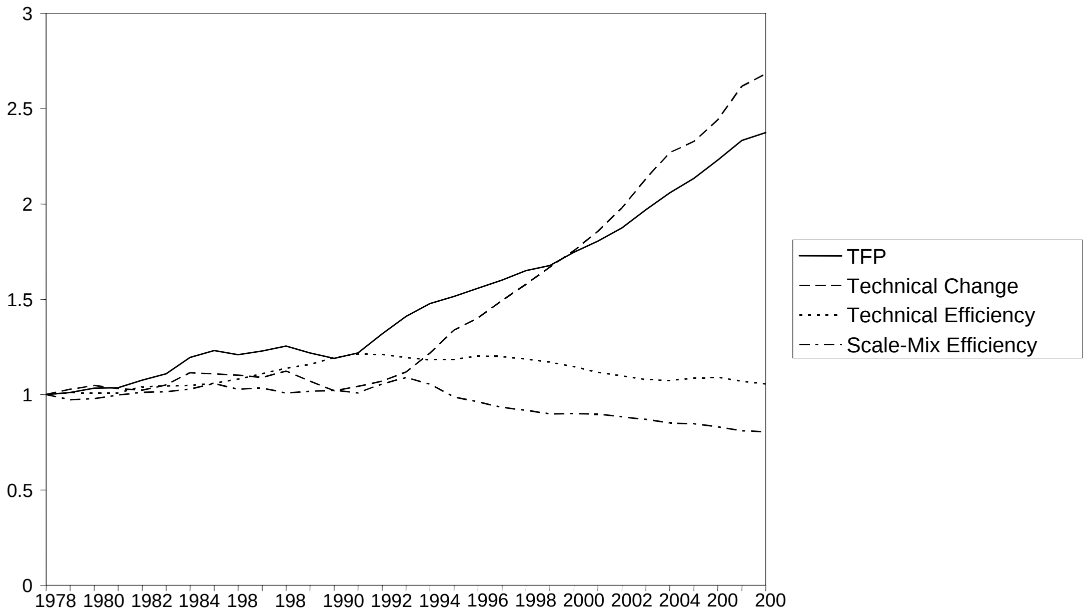

Figure 6. Components of Provincial TFP Change (1978 = 100)