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A drive up the capital coast? Contributions to post-reform growth across Chinese provinces

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Abstract

We use nonparametric production-frontier methods to decompose the growth of labor productivity of Chinese provinces in the post-reform period. These techniques, combined with kernel density estimates, allow us to decompose the shift in the distribution of labor productivity without the need for many assumptions common in the empirical growth literature. We find that (1) the distribution of output per worker across Chinese provinces is multimodal, (2) technology change is decidedly nonneutral, (3) physical capital accumulation has been the major driving force behind the growth performance of Chinese provinces and (4) it attempts to drive convergence between provinces, but (5) minimal technological progress and human capital accumulation are key factors responsible for the regional disparities in China.

JEL classification: C14; O50; P27

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1. Introduction

Since the introduction of market reforms, beginning in 1978, the Chinese economy has exhibited phenomenal growth, arguably qualifying it as another East Asian "miracle". However, the unprecedented economic boom at the national level conceals uneven growth patterns across provinces. Although economic reforms have been beneficial to all regional economies in China, in general, those located along the coast of China have been able to grow much faster than interior provinces in the Central and Western parts of the country.

The issue of uneven regional development in China has attracted a considerable amount of empirical research (for an overview, see Kanbur and Zhang, 2001; Lu and Wang, 2002). Despite differences in methodology, data sources, and time periods, most authors agree that inter-provincial disparities narrowed initially over the 1980s but have widened since the late 1980s and early 1990s. Evidence in favor of convergence in the 1980s appears to be largely attributed to declining intra-regional inequality within the group of coastal provinces. By contrast, the inter-regional inequality, especially between the coastal and interior regions, has been increasing since the start of the market transition in 1978, and has become much more pronounced over the 1990s, thereby contributing to the widening of the income gap across provinces (Jian et al., 1996; Lee, 2000; Fujita and Hu, 2001; Yao and Zhang, 2001).

A broad range of reasons have been forwarded to explain the growing regional discrepancies in China. The advantageous geographical location of coastal provinces enabled them to attract large inflows of foreign direct investment as well as domestic capital (Zhang and Zhang, 2003). In the labor-intensive export industries, foreign capital was combined with cheap labor supplied either via migration from interior provinces or from rural surplus labor within the coastal provinces (Fu, 2004; Fujita and Hu, 2001). A more developed infrastructure and higher levels of human capital in the coastal provinces gave a further boost to growth (Fleisher and Chen, 1997; Démurger, 2001).

The preferential policies extended to coastal provinces by the central government in the context of an unbalanced coast-oriented development strategy have also been blamed for the discrepancy in growth rates and income levels across regions (Démurger et al., 2002; Lu and Wang, 2002). These policies included tax breaks as well as permission to operate special economic zones that offered lucrative business conditions to foreign firms and joint-ventures, and facilitated the inflow of disproportionately large amounts of foreign capital. Aside from spill-over effects among coastal provinces, the rapid growth along the coast largely failed to spread to the interior regions, resulting in increases in regional inequality (Ying, 2000; Fu, 2004).

The objective of this paper is to determine the sources of growth at the provincial level in China and to examine their impact on regional inequality. It differs from previous works in two major aspects. First, the study uses a nonparametric production-frontier approach which relaxes restrictive assumptions common in the empirical growth literature and allows a more comprehensive decomposition of growth. Second, we examine inter-provincial convergence by analyzing the entire distribution of provincial output per worker and its dynamics over the sample period.

The nonparametric production-frontier approach to decomposing productivity growth was started by Färe et al. (1994). Since then, many papers have used nonparametric production-frontier methods with cross-country data (Badunenko et al., 2005; Kumar and Russell, 2002; Henderson and Russell, 2005; Los and Timmer, 2005; Henderson and Zelenyuk, 2007). A major benefit of this type of approach is that there is no need to specify a functional form for the technology, no need to make the assumption that technological change is neutral, or to make assumptions about market structure or the absence of market imperfections. The purpose of using this approach here is to address the debate in the empirical literature. Specifically, the question of whether the rapid economic growth of China over the reform period was driven primarily by total factor productivity growth or by factor accumulation. This issue has been addressed in the literature using national-level (Borensztein and Ostry, 1996; Hu and Khan, 1997; Young, 2000; Wang and Yao, 2001), sectoral-level (Jefferson et al., 1996; Kong et al., 1999; Fu, 2005) and provincial-level (Fleisher and Chen, 1997; Ezaki and Sun, 1999; Arayama and Miyoshi, 2004; Miyamoto and Liu, 2005) data.

Virtually all of these studies use the conventional growth-accounting method to estimate total factor productivity growth as a residual of output growth after subtracting the contribution of relevant inputs. This type of approach however relies crucially on the assumptions that the form of the production function is known and that there is neutral technological change. In this study, we instead use the nonparametric production-frontier method given in Henderson and Russell (2005) which avoids the limitations of the conventional approach and allows us to decompose the growth of labor productivity into four components attributable to technological catch-up (movements towards the frontier), technological change (shifts in the frontier), and physical and human capital accumulation (movements along the frontier).

We estimate the contribution to growth of each of the four components for 28 Chinese provinces over the period 1978–2000. In addition, we split the sample into two sub-periods to find evidence for a turning point proposed in the literature (Fujita and Hu, 2001; Lu and Wang, 2002) regarding the rise of regional inequality. Moreover, we try to shed light on the possible sources for regional disparities by estimating the relative importance of each growth component for coastal versus interior provinces.

The second feature of this study is that it examines inter-provincial convergence by analyzing the entire distribution of provincial output per worker and its dynamics between 1978 and 2000. Previous studies rely mostly on estimating the relationship between the growth rate and the initial output level to detect convergence.[1] However, this approach focuses only on the first moment of the labor productivity distribution, and thus provides only a partial view of the convergence process. It could also lead to deceiving results when the distribution of labor productivity is multimodal (Quah, 1993, 1996, 1997).

Instead, we examine the entire distribution of provincial labor productivity and analyze the effects of the four growth components on the evolution of the distribution over the 1978–2000 period. In addition, we apply nonparametric kernel methods to test formally for statistical significance of the relative contribution of each of the four components to changes in the shape of the distribution.

Our results reveal several findings. First, the distribution of output per worker across Chinese provinces is multimodal with relatively few provinces in the upper modes and

[1] A notable exception is the study by Wu and Perloff (2005) who analyze changes in income inequality in China by examining rural and urban income distributions. Their study differs from ours in the sense that they do not take into account the regional dimension of income inequality. In addition, while this article was in press we discovered a closely related study (Unel and Zebregs, 2006) which decomposes the growth of labor productivity of Chinese provinces adhering to the methodology of Kumar and Russell (2002). This study also differs from ours in several aspects. The most notable difference is that we include human capital accumulation into the decomposition.

the majority of provinces in the larger "poor" mode. However, over the sample period several poor provinces were able to catch-up and move into the "rich" modes. Second, technology change is decidedly nonneutral, with little improvement at very low capital to effective labor ratios and rapid expansion at high capital to effective labor ratios. Third, physical capital accumulation has been the major driving force behind the growth performance of Chinese provinces over the reform period. Fourth, capital deepening helped drive convergence between provinces. This was primarily driven by the initially poor coastal provinces that caught up due to intensive capital deepening coupled with large efficiency improvements. Finally, the initially rich coastal provinces were able to grow faster because of above-average rates of technological progress and human capital accumulation. This allowed us to identify the lack of technological progress and human capital accumulation as key factors responsible for rising regional disparities in China. These hindered the growth of poor regions despite their increases in efficiency and capital deepening.

The remainder of the paper is organized as follows: the second and third sections describe the methodology and data, respectively. Section 4 summarizes the results and the final section draws conclusions.

2. Methodology

2.1. Data Envelopment Analysis

Following (the nonparametric approach of) Henderson and Russell (2005), we construct China's production-frontier and the associated efficiency levels of individual provincial economies (distances from the frontier) by using Data Envelopment Analysis. The basic idea is to envelop the data in the smallest convex cone, where the upper boundary of this set represents the "best practice" production-frontier. One of the major benefits of this approach is that it does not require prior specification of the functional form of the technology. It is a data driven approach, implemented with standard mathematical programming algorithms, which allows the data to tell the form of the production function (see Kneip et al., 1998 for a proof of consistency for the Data Envelopment Analysis estimator, as well as Kneip et al., 2003 for its limiting distribution).

Our technology contains four macroeconomic variables: aggregate output and three aggregate inputs – labor, physical capital, and human capital. Let $\langle Y_{it}, K_{it}, L_{it}, H_{it}\rangle$, $t = 1, 2, \ldots, T$, $i = 1, 2, \ldots, N$, represent T observations on these four variables for each of the N provinces. We adopt a standard approach in the macroeconomic literature and assume that human capital enters the technology as a multiplicative augmentation of physical labor input, so that our NT observations are $\langle Y_{it}, K_{it}, \widehat{L}_{it}\rangle$, $t = 1, 2, \ldots, T$, $i = 1, 2, \ldots, N$, where $\widehat{L}_{it} = L_{it}H_{it}$ is the amount of labor input measured in *efficiency* units in province i at time t. The constant returns to scale technology for China in period t is constructed by using all the data up to that point in time as

$$\mathscr{T}_t = \left\{ \begin{array}{l} \langle Y, \widehat{L}, K\rangle \in \Re^3_+ | Y \leqslant \sum\limits_{\tau\leqslant t} \sum\limits_{i} z_{i\tau} Y_{i\tau},\ \widehat{L} \geqslant \sum\limits_{\tau\leqslant t} \sum\limits_{i} z_{i\tau}\widehat{L}_{i\tau}, \\ K \geqslant \sum\limits_{\tau\leqslant t} \sum\limits_{i} z_{i\tau} K_{i\tau}, z_{i\tau} \geqslant 0\ \forall i, \tau \end{array} \right\}, \tag{1}$$

where $z_{i\tau}$ are the activity levels. By using all the previous years data, we preclude implosion of the frontier over time. It is difficult to believe that the technological frontier could implode. Thus, following an approach first suggested by Diewert (1980), we chose to adopt a construction of the technology that precludes such technological degradation.

The Farrell (output-based) efficiency index for province i at time t is defined by

$$E(Y_{it}, \widehat{L}_{it}, K_{it}) = \min\{\lambda | \langle Y_{it}/\lambda, \widehat{L}_{it}, K_{it}\rangle \in \mathscr{T}_t\}. \tag{2}$$

This index is the inverse of the maximal proportional amount that output Y_{it} can be expanded while remaining technologically feasible, given the technology and input quantities. It is less than or equal to unity and takes the value of unity if and only if the *it* observation is on the period-t production-frontier. In our special case of a scalar output, the output-based efficiency index is simply the ratio of actual to potential output evaluated at the actual input quantities.

2.2. Quadripartite decomposition

To decompose productivity growth into components attributable to (1) changes in efficiency (technological catch-up), (2) technological change, (3) capital deepening (increases in the capital–labor ratio), and (4) human capital accumulation, we again follow the approach of Henderson and Russell (2005). We first note that constant returns to scale allows us to construct the production-frontiers in $\hat{y} \times \hat{k}$ space, where $\hat{y} = Y/\widehat{L}$ and $\hat{k} = K/\widehat{L}$ are the ratios of output and capital, respectively, to effective labor. By letting b and c stand for the base period and current period respectively, we see, by definition, that potential outputs per efficiency unit of labor in the two periods are given by $\bar{y}_b(\hat{k}_b) = \hat{y}_b/e_b$ and $\bar{y}_c(\hat{k}_c) = \hat{y}_c/e_c$, where e_b and e_c are the values of the efficiency indexes in the respective periods as calculated in (2) above. Accordingly,

$$\frac{\hat{y}_c}{\hat{y}_b} = \frac{e_c}{e_b} \cdot \frac{\bar{y}_c(\hat{k}_c)}{\bar{y}_b(\hat{k}_b)}. \tag{3}$$

Let $\tilde{k}_c = K_c/(L_c H_b)$ denote the ratio of capital to labor measured in efficiency units under the counterfactual assumption that human capital had not changed from its base period and $\tilde{k}_b = K_b/(L_b H_c)$ the ratio of capital to labor measured in efficiency units under the counterfactual assumption that human capital were equal to its current-period level. Then $\bar{y}_b(\tilde{k}_c)$ and $\bar{y}_c(\tilde{k}_b)$ are the potential output per efficiency unit of labor at $\tilde{k}_c$ and $\tilde{k}_b$ using the base-period and current-period technologies, respectively. By multiplying the numerator and denominator of (3) alternatively by $\bar{y}_b(\hat{k}_c)\bar{y}_b(\tilde{k}_c)$ and $\bar{y}_c(\hat{k}_b)\bar{y}_c(\tilde{k}_b)$, we obtain two alternative decompositions of the growth of $\hat{y}$

$$\frac{\hat{y}_c}{\hat{y}_b} = \frac{e_c}{e_b} \cdot \frac{\bar{y}_c(\hat{k}_c)}{\bar{y}_b(\hat{k}_c)} \cdot \frac{\bar{y}_b(\tilde{k}_c)}{\bar{y}_b(\hat{k}_b)} \cdot \frac{\bar{y}_b(\hat{k}_c)}{\bar{y}_b(\tilde{k}_c)}, \tag{4}$$

and

$$\frac{\hat{y}_c}{\hat{y}_b} = \frac{e_c}{e_b} \cdot \frac{\bar{y}_c(\hat{k}_b)}{\bar{y}_b(\hat{k}_b)} \cdot \frac{\bar{y}_c(\hat{k}_c)}{\bar{y}_c(\tilde{k}_b)} \cdot \frac{\bar{y}_c(\tilde{k}_b)}{\bar{y}_c(\hat{k}_b)}. \tag{5}$$

The growth of productivity, $y_t = Y_t/L_t$, can be decomposed into the growth of output per efficiency unit of labor and the growth of human capital, as follows:

$$\frac{y_c}{y_b} = \frac{H_c}{H_b} \cdot \frac{\hat{y}_c}{\hat{y}_b}. \tag{6}$$

Combining (4) and (5) with (6), we obtain

$$\frac{y_c}{y_b} = \frac{e_c}{e_b}\cdot\frac{\bar{y}_c(\hat{k}_c)}{\bar{y}_b(\hat{k}_c)}\cdot\frac{\bar{y}_b(\tilde{k}_c)}{\bar{y}_b(\hat{k}_b)}\cdot\left[\frac{\bar{y}_b(\hat{k}_c)}{\bar{y}_b(\tilde{k}_c)}\cdot\frac{H_c}{H_b}\right] \equiv \text{EFF}\times\text{TECH}^c\times\text{KACC}^b\times\text{HACC}^b, \tag{7}$$

and

$$\frac{y_c}{y_b} = \frac{e_c}{e_b}\cdot\frac{\bar{y}_c(\hat{k}_b)}{\bar{y}_b(\hat{k}_b)}\cdot\frac{\bar{y}_c(\hat{k}_c)}{\bar{y}_c(\tilde{k}_b)}\cdot\left[\frac{\bar{y}_c(\tilde{k}_b)}{\bar{y}_c(\hat{k}_b)}\cdot\frac{H_c}{H_b}\right] \equiv \text{EFF}\times\text{TECH}^b\times\text{KACC}^c\times\text{HACC}^c. \tag{8}$$

These identities decompose the growth of labor productivity in the two periods into changes in efficiency, technology, the capital–labor ratio, and human capital accumulation. The decomposition in (4) measures technological change by the shift in the frontier in the output direction at the current-period capital to effective labor ratio, whereas the decomposition in (5) measures technological change by the shift in the frontier in the output direction at the base-period capital to effective labor ratio. Similarly, (7) measures the effect of physical and human capital accumulation along the base-period frontier, whereas (8) measures the effect of physical and human capital accumulation along the current-period frontier.

These two decompositions do not yield the same results unless the technology is Hicks neutral. In other words, the decomposition is path dependent. This ambiguity is resolved by adopting the "Fisher Ideal" decomposition, based on geometric averages of the two measures of the effects of technological change, capital deepening and human capital accumulation and obtained mechanically by multiplying the numerator and denominator of (3) by $(\bar{y}_b(\hat{k}_c)\bar{y}_b(\tilde{k}_c))^{1/2}(\bar{y}_c(\hat{k}_b)\bar{y}_c(\tilde{k}_b))^{1/2}$

$$\frac{y_c}{y_b} = \text{EFF}\times(\text{TECH}^b\cdot\text{TECH}^c)^{1/2}\times(\text{KACC}^b\cdot\text{KACC}^c)^{1/2}\times(\text{HACC}^b\cdot\text{HACC}^c)^{1/2} \equiv \text{EFF}\times\text{TECH}\times\text{KACC}\times\text{HACC}. \tag{9}$$

3. Data

At the provincial level, China is divided into 33 regions, including 22 provinces, five autonomous regions (ethnic minority areas in West and Southwest China), four metropolises (e.g., Beijing and Shanghai), and two special administrative regions. For simplicity, we will use the terms regions and provinces interchangeably. The data set includes output, labor, capital, and human capital variables for 28 Chinese provinces over the period 1978–2000.[2] The data is drawn from official publications of the Chinese statistical agency. The two major sources are the *Comprehensive Statistical Data and Materials on 50 Years of*

[2] Hainan and Tibet were dropped from the data set due to incomplete data. The city of Chongqing which received provincial status in 1997 is still treated as part of Sichuan. Hong Kong and Macau are excluded because they came under Chinese control in 1997 and 1999, respectively.

New China (National Bureau of Statistics, 1999) and various issues of the *China Statistical Yearbook* (National Bureau of Statistics, 1997–2000).[3]

3.1. Output and labor

Nominal GDP is deflated by a province-specific price index, with 1952 as the base year.[4] The price index for each province obtained from Wu (2004) is constructed using nominal GDP values and real GDP growth rates, and corresponds approximately to the average of the retail price index and the GDP deflator.

In absence of data on the number of hours worked at the regional level in China, we follow previous studies in using the number of employees in a given year as a proxy for the labor force.

3.2. Capital stock

The capital stock of each province is estimated using the perpetual inventory method. Data on investment in fixed assets is available for all provinces in our sample for the period 1952–2000. Although investment deflators have been constructed at the national level, lack of data prevents us from computing their equivalents at the regional level. Therefore, we deflate fixed investment using the same province-specific price index as for GDP with 1952 as the base year.

To construct the capital stock from investment flows we adopt a depreciation rate of 4% as in Chow (2002) and assume that it is constant across provinces.[5] To obtain initial values for the capital stock of each province, we use a procedure similar to Nehru and Dhareshwar (1993) and Hall and Jones (1999). Accordingly, the initial value of the 1952 capital stock for province i is constructed as

$$K_{i,1952} = \frac{I_{i,1952}}{(\delta + g_i)}, \tag{10}$$

where I denotes the real value of fixed investment, δ is the depreciation rate and g_i is the average growth rate of real fixed investment between 1952 and 1977 for province i. The capital stock for each province is computed for the 1952–2000 period. The relatively low initial value of capital in 1952 and the high rates of investment ensure that the estimates of the capital stock for our sample period 1978–2000 are not sensitive to the 1952 benchmark value.

[3] The reliability of Chinese economic statistics has been questioned in the literature (see the special issue of the China Economic Review 2001, volume 12, issue 4). Falsifications of data at the provincial level, lay-offs of statistical personnel, and a rapidly changing institutional and economic structure have resulted in an exaggeration of real output growth, especially after 1998 (Rawski, 2001; Rawski and Xiao, 2001). Despite these shortcomings, official Chinese statistics generally seem to be fairly accurate for econometric analysis (Chow, 2002; Marton, 2000).

[4] The GDP data can be thought of as being measured in constant 1952 or 1978 prices, since the price level in China changed little between 1952 and the start of market reforms in 1978.

[5] This is the average depreciation rate of fixed assets of state-owned enterprises over the period 1952–1992 (National Bureau of Statistics, 1997–2000).

3.3. Human capital

Previous studies on Chinese regional growth that incorporate human capital in the production function use either enrollment rates or the number of graduates at a certain level of education as proxies for the quality of labor.[6] Recently, Wang and Yao (2001) derived a time series of China's human capital stock in terms of the average years of schooling based on the methodology of Barro and Lee (2000), however their method is difficult to replicate at the regional level in China due to lack of data.

Instead, we estimate the average years of schooling using data from the three most recent national censuses conducted in 1982, 1990 and 2000. Census data includes the level of education of individuals in the age group 15–64 by province. The average years of schooling for each of the three years in which a census took place was estimated by

$$\epsilon_{it} = \frac{(6G_{1it} + 9G_{2it} + 12G_{3it} + 15.5G_{4it})}{G_{it}}, \tag{11}$$

where G_{jit} is the number of individuals aged 15–64 in year t in province i, with j being the highest level of education attained ($j = 1$ for primary, 2 for junior secondary, 3 for senior secondary and 4 for tertiary level). G_{it} denotes the population in the age group 15–64 in province i in year t. The data on the number of individuals with a certain educational level is thus weighted by the length of the respective schooling cycles and divided by the entire population in province i aged 15–64 to produce the average years of schooling ϵ.[7] The average years of schooling for the remaining periods are obtained by interpolation. However, they correspond closely to the numbers reported by Zhang et al. (2005) who rely on data from household surveys conducted in several provinces over the 1988–2001 period.

To construct a human capital index using the average years of schooling, we adopt the approach of Bils and Klenow (2000) and define labor in efficiency units in province i at time t by

$$\widehat{L}_{it} = H_{it}L_{it} = h(\epsilon_{it})L_{it} = e^{f(\epsilon_{it})}L_{it}, \tag{12}$$

where

$$f(\epsilon_{it}) = \frac{\theta}{1-\psi}\epsilon_{it}^{1-\psi}. \tag{13}$$

The parameter ψ measures the curvature of the Mincer (1974) earnings function, whereby a larger value is associated with a higher rate of diminishing returns to schooling. Bils and Klenow (2000) estimate that $\psi = 0.58$ using data from Psacharopoulos (1994) for a sample of 56 countries (including China). Since the rate of return to education is

[6] For instance, Fleisher and Chen (1997) use the annual flow of university graduates as a proxy for human capital. Alternatively, Chen and Fleisher (1996) and Jones et al. (2003) employ the number of high school students as a share of all people of high-school age.

[7] The schooling cycles were assumed to be 6 years for primary, 9 years for junior secondary, 12 years for senior secondary, and 15.5 years for tertiary education. The number of individuals with a tertiary education includes those with a junior college degree (15 years) and those with a university degree (16 years). Because the data did not us allow to separate these two groups, the average number of years was adopted as the length of the tertiary education.

$$\frac{\mathrm{d}\ln h(\epsilon_{it})}{\mathrm{d}\epsilon_{it}} = f'(\epsilon_{it}) = \frac{\theta}{\epsilon_{it}^{\psi}} \tag{14}$$

the parameter $\theta = 0.32$ so that the average of $\theta/\epsilon_{it}^{\psi}$ equals the average rate of return to education from the Psacharopoulos (1994) sample.[8]

4. Results

4.1. Production-frontier and efficiency

China's production-frontier in 1978, 1990, and 2000 along with scatter plots of $\hat{y}$ vs. $\hat{k}$ are presented in Fig. 1. The single kink on each curve indicates that there is only one efficient provincial economy, Shanghai, which defines the frontier in each of the three years. Note that the production-frontier shifted up from 1978 to 2000 but not by the same proportion for every value of $\hat{k}$ implying that technological change was nonneutral. It is evident from the graph that, for the majority of provinces with lower ratios of capital to efficient labor, the production-frontier is almost identical in 1978, 1990, and 2000. The largest shifts of the frontier occur for the few regions with a high degree of capitalization, including the three metropolises with provincial status (Beijing, Shanghai and Tianjin).

To assess the efficiency of provincial economies we examine their location relative to the frontier. The efficiency index of each province in 1978 and 2000 is reported in the first two columns of Table 1. On average,[9] China's provincial economies moved closer to the best practice frontier over the 1978–2000 period. This is not surprising given that the transition towards a market economy in China witnessed the emergence of privately-managed firms, export-oriented corporations, and foreign joint-ventures that were more efficient in their use of inputs than state-owned enterprises. The new firms had clearly defined property rights, operated under hard-budget constraints, and responded to market incentives whereas state-owned enterprises were plagued by overproduction, misallocation of resources, and inefficient government subsidies (Shiu, 2002).

The results also reveal that the largest efficiency gains were achieved in the second half of the reform period.[10] Tables 2 and 3 show that between 1978 and 1989, efficiency improved by only 3% as opposed to 17% between 1990 and 2000. The reason is that incremental measures to reform state-owned enterprises were initiated only in the mid-1980s and were soon put on hold or even reversed when serious macroeconomic imbalances coupled with political discontent led to massive protests on Tiananmen Square in 1989. Start-

[8] This is an oversimplification of the Bils and Klenow (2000) model. Their construction of current human capital also incorporates (positive) externalities from past capital accumulation of human capital (as first proposed in Borjas, 1992).

[9] In addition to the arithmetic average, we also include the weighted average. This method, developed in Färe and Zelenyuk (2003), allows one to weight the efficiency scores by the relative output of the province.

[10] We chose 1989 as a breaking point for two reasons. It is clearly a turning point in the rise of regional inequality in China (Fujita and Hu, 2001; Lu and Wang, 2002). Moreover, in the aftermath of the Tiananmen Square incident economic growth stumbled, and thus 1989 marks a watershed between two periods of rapid growth. We also tried the years 1990, 1991 and 1992 which resulted in minor differences. The results are available upon request.

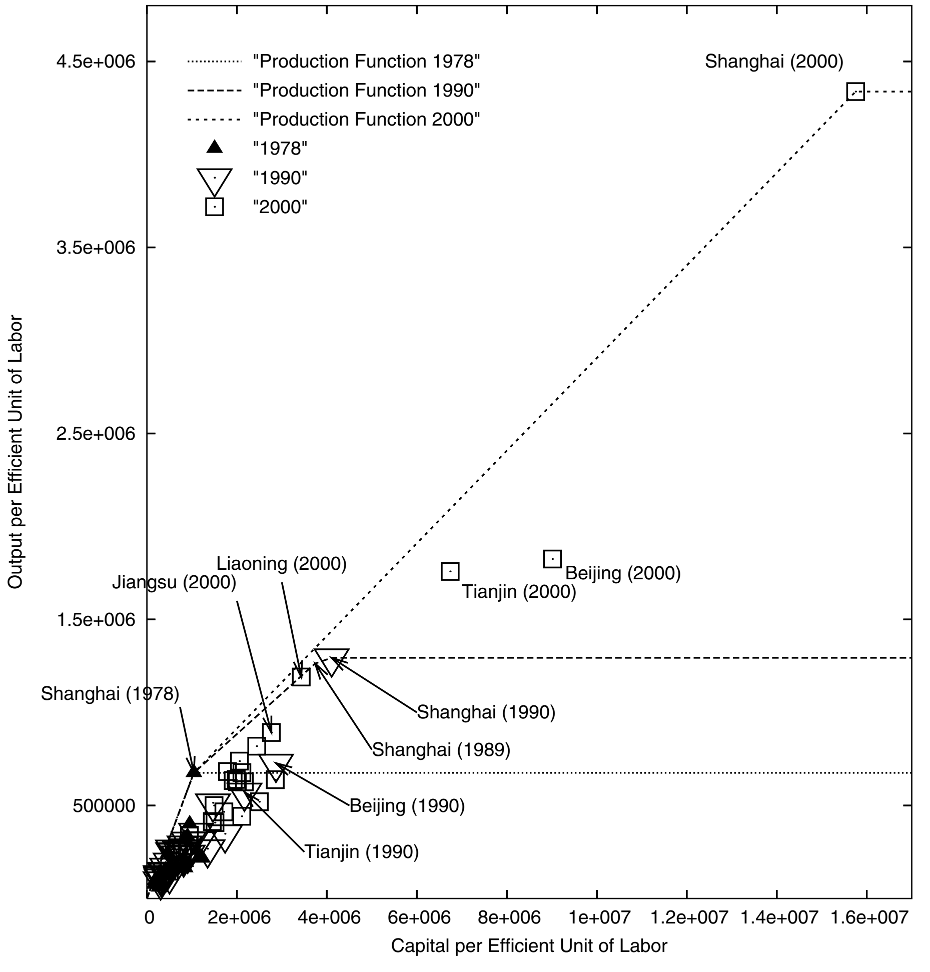

Fig. 1. Production Functions and observations in 1978, 1990, and 2000.

ing in 1992, a new round of economic liberalization promoted the privatization of state enterprises, the gradual elimination of price controls, the creation of stock exchanges, and an enhanced role for trade and foreign investment, all of which contributed to higher efficiency.

From looking at the province-specific estimates, it is evident that the improvements in efficiency vary widely across regions. Shanghai, the richest regional economy in China, is also the most efficient one. With an efficiency score of 1.00, it is the only province located on the best practice frontier throughout the 1978–2000 period. Whereas the wealthy province of Guangdong was already highly efficient at the start of economic reforms and its efficiency score changed little in the following two decades, other coastal provinces including Fujian, Jiangsu, and Zhejiang were able to catch up with large efficiency improvements. By contrast, poor provinces in Southwest China such as Guizhou, Sichuan or Yunnan were far away from the best practice frontier in 1978, and experienced only modest increases in efficiency by 2000.

Table 1
Percentage change of quadripartite decomposition indexes, 1978–2000

#	Province	TE_b	TE_c	Productivity change	EFF-1 × 100	TECH-1 × 100	KACC-1 × 100	HACC-1 × 100
1	Anhui	0.62	0.57	414.2	−8.4	0.0	460.8	0.1
2	Beijing	0.65	0.69	466.1	5.5	43.4	236.2	11.3
3	Fujian	0.66	0.80	780.1	20.0	1.7	568.4	7.8
4	Gansu	0.30	0.53	259.8	78.5	0.8	81.6	10.1
5	Guangdong	0.81	0.79	802.1	−1.8	1.4	757.0	5.7
6	Guangxi	0.51	0.60	337.8	16.8	0.0	274.8	0.0
7	Guizhou	0.34	0.46	240.7	32.0	0.0	158.1	0.0
8	Hebei	0.57	0.70	457.5	23.6	1.6	315.8	6.7
9	Heilongjiang	0.79	0.71	203.3	−10.4	1.5	221.7	3.6
10	Henan	0.46	0.50	371.3	6.9	0.0	332.3	2.0
11	Hubei	0.52	0.63	589.2	22.3	0.9	419.9	7.5
12	Hunan	0.68	0.60	336.0	−11.3	0.0	391.6	0.0
13	Inner Mongolia	0.49	0.66	396.1	34.6	1.9	244.5	5.0
14	Jiangsu	0.66	0.81	920.6	22.6	2.5	655.6	7.4
15	Jiangxi	0.60	0.56	449.4	−6.8	0.0	457.0	5.8
16	Jilin	0.52	0.72	349.9	39.1	1.8	206.6	3.6
17	Liaoning	0.59	0.94	335.3	58.8	3.0	154.6	4.5
18	Ningxia	0.32	0.50	224.1	66.4	2.7	69.9	11.6
19	Sha'anxi	0.45	0.52	331.7	14.8	0.9	245.0	8.0
20	Shandong	0.55	0.69	627.3	24.6	1.7	432.7	7.8
21	Shanghai	1.00	1.00	675.4	0.0	83.1	285.4	9.9
22	Shanxi	0.44	0.55	330.4	25.8	1.2	220.2	5.6
23	Sichuan	0.39	0.43	334.2	11.2	0.0	281.4	2.4
24	Tianjin	0.57	0.84	553.9	47.6	27.2	213.6	11.0
25	Qinghai	0.35	0.47	181.5	35.8	1.8	94.0	5.0
26	Xinjiang	0.41	0.57	535.0	38.5	2.6	327.6	4.5
27	Yunnan	0.47	0.48	324.2	1.7	0.0	286.8	7.9
28	Zhejiang	0.66	0.80	910.3	20.6	2.2	676.9	5.5
Average		0.549	0.646	421.3	19.7	5.5	290.4	5.7
Weighted average		0.623	0.725					

These results are in line with the findings of several previous works. Wu (1995) and Ao and Fulginiti (2003) report provincial efficiency estimates for the periods 1985–1991 and 1978–1998, respectively. Although both studies use parametric frontier techniques, do not include human capital, and focus on shorter time periods, their estimates are similar to ours, indicating that Shanghai and Guangdong are at the top and Guizhou is at the bottom of the efficiency rankings.

The averages of the efficiency indexes for the sub-samples of coastal and interior provinces are reported in Table 4. These averages indicate that the provinces along China's coast are more efficient and improved their efficiency by larger amounts than the provinces of Central and Western China. Moreover, the coastal provinces with output per worker below the 1978 median value were also the ones that managed to catch up in terms of efficiency due to their advantageous geographical location that allowed them to benefit most from the opening of China to foreign trade and investment. This corresponds to convergence within the group of coastal provinces reported in the literature (Fujita and Hu, 2001).

Table 2
Percentage change of quadripartite decomposition indexes, 1978–1989

#	Province	TE_b	TE_c	Productivity change	EFF-1 × 100	TECH-1 × 100	KACC-1 × 100	HACC-1 × 100
1	Anhui	0.62	0.63	94.4	1.1	0.0	92.3	0.0
2	Beijing	0.65	0.71	100.6	9.2	23.5	42.1	4.6
3	Fujian	0.66	0.68	143.8	3.1	0.0	136.5	0.0
4	Gansu	0.30	0.42	48.1	42.4	0.0	4.0	0.0
5	Guangdong	0.81	0.72	181.7	−11.4	0.0	217.8	0.0
6	Guangxi	0.51	0.52	53.0	1.5	0.0	50.7	0.0
7	Guizhou	0.34	0.49	85.3	42.3	0.0	30.2	0.0
8	Hebei	0.57	0.56	85.0	−2.4	0.0	89.6	0.0
9	Heilongjiang	0.79	0.52	50.1	−34.0	0.0	124.8	1.2
10	Henan	0.46	0.52	114.2	12.2	0.0	90.9	0.0
11	Hubei	0.52	0.59	120.9	14.3	0.0	93.2	0.0
12	Hunan	0.68	0.66	73.1	−2.0	0.0	76.7	0.0
13	Inner Mongolia	0.49	0.53	104.1	8.5	0.0	88.1	0.0
14	Jiangsu	0.66	0.57	163.9	−14.2	0.0	207.5	0.0
15	Jiangxi	0.60	0.60	96.8	−0.1	0.0	97.0	0.0
16	Jilin	0.52	0.54	52.5	3.9	0.0	46.7	0.0
17	Liaoning	0.59	0.69	69.2	17.6	4.8	33.5	2.9
18	Ningxia	0.32	0.43	85.3	35.3	12.9	9.0	11.2
19	Sha'anxi	0.45	0.47	104.0	4.0	0.0	96.1	0.0
20	Shandong	0.55	0.54	123.9	−2.1	0.0	128.9	0.0
21	Shanghai	1.00	1.00	103.6	0.0	36.7	42.7	4.4
22	Shanxi	0.44	0.42	85.2	−4.5	0.0	93.9	0.0
23	Sichuan	0.39	0.40	85.4	4.2	0.0	77.9	0.0
24	Tianjin	0.57	0.62	80.5	8.3	14.6	39.0	4.7
25	Qinghai	0.35	0.36	47.3	4.1	4.4	30.8	3.5
26	Xinjiang	0.41	0.42	152.2	3.2	0.5	131.5	5.0
27	Yunnan	0.47	0.57	96.1	22.3	0.0	60.4	0.0
28	Zhejiang	0.66	0.63	158.3	−5.5	0.0	173.3	0.0
Average		0.549	0.565	95.4	4.6	3.2	78.7	1.3
Weighted average		0.623	0.618					

4.2. Quadripartite decomposition of labor productivity

To gain a more detailed understanding of the factors that contributed to the growth performance of China's provinces, we decompose productivity growth into components attributable to (1) efficiency changes, (2) technological changes, (3) capital deepening, and (4) human capital accumulation. The growth in labor productivity of each province is shown in the third column of Tables 1–3. It is evident that over the entire sample period Chinese provinces experienced stunning increases in productivity. On average, regional output per worker in China quadrupled over a period of 22 years, rivaling the performance of the East Asian "growth miracles". At one end of the spectrum, the coastal provinces Jiangsu and Zhejiang saw their productivity grow almost tenfold, at the other end, the productivity of the landlocked Western province of Qinghai less than doubled. As can be seen from Table 4, coastal provinces have higher growth rates over the sample period as well as over each of the two sub-periods. The difference between the growth rates

Table 3
Percentage change of quadripartite decomposition indexes, 1990–2000

#	Province	TE_b	TE_c	Productivity change	EFF-1 × 100	TECH-1 × 100	KACC-1 × 100	HACC-1 × 100
1	Anhui	0.59	0.57	165.0	−4.0	0.0	176.1	0.0
2	Beijing	0.68	0.69	182.8	1.2	47.1	74.9	8.6
3	Fujian	0.67	0.80	247.8	18.9	1.7	176.1	4.2
4	Gansu	0.41	0.53	138.6	28.8	0.8	72.3	6.6
5	Guangdong	0.71	0.79	193.3	11.8	1.4	149.9	3.5
6	Guangxi	0.53	0.60	175.7	12.4	0.0	145.2	0.0
7	Guizhou	0.48	0.46	85.4	−5.5	0.0	96.2	0.0
8	Hebei	0.53	0.70	194.4	31.9	1.6	110.8	4.1
9	Heilongjiang	0.52	0.71	96.6	36.7	1.7	36.2	3.9
10	Henan	0.50	0.50	118.2	0.0	0.0	118.1	0.0
11	Hubei	0.57	0.63	202.8	10.8	0.9	158.2	4.9
12	Hunan	0.65	0.60	147.4	−6.9	0.0	165.7	0.0
13	Inner Mongolia	0.52	0.66	129.6	27.4	1.9	71.9	2.9
14	Jiangsu	0.53	0.81	273.3	52.3	2.5	130.4	3.8
15	Jiangxi	0.58	0.56	176.8	−3.3	0.0	178.9	2.6
16	Jilin	0.50	0.72	192.1	44.3	1.8	94.0	2.5
17	Liaoning	0.67	0.94	157.4	40.0	3.9	68.0	5.3
18	Ningxia	0.42	0.50	75.0	18.9	3.6	31.9	7.7
19	Sha'anxi	0.44	0.52	111.0	16.4	0.9	70.5	5.3
20	Shandong	0.51	0.69	216.6	34.8	1.7	121.7	4.1
21	Shanghai	1.00	1.00	269.5	0.0	93.0	79.7	6.5
22	Shanxi	0.41	0.55	125.2	36.0	1.2	57.5	3.8
23	Sichuan	0.39	0.43	128.4	9.1	0.0	108.8	0.3
24	Tianjin	0.62	0.84	243.9	35.0	29.6	81.1	8.5
25	Qinghai	0.36	0.47	89.4	30.1	2.4	32.2	7.5
26	Xinjiang	0.44	0.57	132.3	27.7	2.8	67.3	5.7
27	Yunnan	0.58	0.48	103.4	−17.6	0.0	141.6	2.1
28	Zhejiang	0.60	0.80	281.2	32.5	2.2	172.7	3.3
Average		0.551	0.646	159.9	17.2	6.0	101.5	3.8
Weighted average		0.601	0.725					

Table 4
Average percentage change of quadripartite decomposition indexes by geographical classification

Comparison	Category	TE_b	TE_c	Productivity change	EFF-1 ×100	TECH-1 × 100	KACC-1 × 100	HACC-1 × 100
1978–2000	Coastal	0.66	0.79	624.2	21.7	15.3	415.5	7.1
1978–1989	Coastal	0.66	0.66	114.9	0.4	7.2	105.6	1.5
1990–2000	Coastal	0.64	0.79	221.4	24.6	16.8	119.1	4.7
1978–2000	Interior	0.48	0.56	345.4	21.8	0.9	264.6	4.9
1978–1989	Interior	0.48	0.51	87.9	9.2	1.0	73.1	1.2
1990–2000	Interior	0.49	0.56	130.4	14.6	1.1	98.7	3.3

of the coastal and interior provinces in 1990–2000 is much larger than in 1978–1989, pointing towards increasing divergence between the two groups in the second decade of reforms.

The contributions of changes in efficiency, technological change, capital deepening, and human capital accumulation for the entire sample period are displayed in the last four columns of Tables 1–3. It is obvious that physical capital accumulation is by far the major driving force behind the spurt in labor productivity at the provincial level in China confirming the findings of previous studies (Arayama and Miyoshi, 2004; Miyamoto and Liu, 2005; Wang and Yao, 2001). The average contribution of efficiency change is 20% followed by technological change and human capital accumulation, each less than 6%.

Several individual economies deserve special attention. For the two rich metropolises, Beijing and Shanghai, the contribution of efficiency is negligible because their economies were either close to or on the frontier at the start of the sample period. Although physical capital accumulation contributes the most, the percentage increase is below the provincial average. Thus, capital accumulation cannot solely explain their above average change in productivity. Their growth is also strongly driven by technological change and human capital accumulation. The contribution of each of the two components is well above the provincial average. This is most likely the result of a high concentration of top national universities and research institutes in these cities. Moreover, their high level of urbanization ensures that school enrollment rates are higher than in provinces with a predominantly rural population (Heckman, 2005).

The provinces Fujian, Jiangsu, and Zhejiang were not among the richest regions at the start of the reform period but exhibited phenomenal growth over the following two decades. They are located along the coast between Hong Kong and Shanghai, and across from Taiwan, which made them a magnet for foreign direct investment from abroad. This was facilitated by the creation of special economic zones in these provinces offering tax breaks, relaxed labor regulation and duty-free imports of inputs to foreign firms and joint-ventures. In addition, fiscal decentralization and the preferential policies of the central government allowed coastal provinces to keep large amounts of their fiscal resources which were used to support further industrialization (Tochkov, 2007). It is therefore not surprising to see that their growth spurts resulted largely from physical capital accumulation.

Interestingly, technological innovation does not represent any significant contribution to growth for these three provinces. However, the inflow of foreign capital and expertise, and the closure of inefficient state-owned enterprises, seems to have brought above-average improvements in efficiency. In fact, Shiu (2002) shows that the foreign-funded enterprises and state-owned enterprises of the heavy industry sector in the coastal provinces were on average more efficient than their counterparts in Central and Western China. Furthermore, Wu (2000) provides empirical evidence for technological catch-up between Fujian and Guangdong, and the highly efficient neighboring economies of Hong Kong and Taiwan.

A similar story can be told about the wealthy coastal province Guangdong. It is located next to and has the closest economic ties with Hong Kong, has the largest number of special economic zones, and absorbed large amounts of investment from abroad. Guangdong has received preferential treatment from the central government and has always been at the forefront of any economic reforms. Its eightfold increase in labor productivity over the sample period is attributable solely to physical capital accumulation which has the highest contribution to growth of all provinces. Neither technological change, nor human capital accumulation are above average, and given that Guangdong was very close to the frontier at the start of the reforms precludes large increases in efficiency.

Two groups of provinces that showed below-average productivity growth are also noteworthy. Jilin and Liaoning are located in the Northeast, home to the traditional industrial base of socialist China. The large amount of old state-owned enterprises has prevented them from catching up. Their growth comes primarily from above-average efficiency improvements resulting from reforms and privatization of the state sector, and in the case of Liaoning (a coastal province) from foreign investment. The other group includes Gansu, Qinghai and Ningxia, three isolated provinces in the Northwest. Their labor productivity only doubled over a period of 22 years with technological change and physical capital accumulation both contributing well below the provincial average. Growth here was heavily driven by large improvements in efficiency, and in the case of Gansu and Ningxia, by human capital accumulation. The importance of human capital for these provinces is surprising, but has been confirmed in prior studies (Arayama and Miyoshi, 2004; Miyamoto and Liu, 2005). We can only speculate, but it could be that the introduction of compulsory secondary education in China boosted enrollment rates dramatically in these two provinces.

Table 4 shows the average changes in productivity and the quadripartite decomposition for coastal and interior provinces. The rich coastal provinces experienced increases in labor productivity due to faster-than-average rates of technological progress as reflected in shifts of the frontier documented above. The contribution of human capital accumulation is also well above average. The weaker growth performance of interior provinces is attributable to the lack of technological progress and below-average human capital accumulation, although in terms of efficiency improvements, they were close to the rich coastal provinces.[11]

4.3. Productivity distributions

The labor productivity distributions (nonparametric kernel-based density estimates) appear in Fig. 2.[12] The solid and dashed curves represent the distributions of output per worker in the base and current period, respectively, with their corresponding mean values shown as vertical lines.

It is evident that the distribution in each year is in fact multimodal, underlying the importance of conducting a distributional analysis.[13] However, a profound change in

[11] For the sake of completeness we also examined the impact of the four growth components on regional income differences by regressing the change in labor productivity and its four components on the initial level of output per worker. The results (available upon request) suggest that the market transition in China has led to a more unequal provincial income distribution. Specifically, we found that the poor provinces were catching up with the rich during the 1980's, but a divergence resulted after 1990 (Lu and Wang, 2002). Further, only capital accumulation continuously attempted to equate incomes across provinces. The effects of technological change and human capital accumulation led to further distance between the rich and poor. Efficiency did little, if anything, to equalize incomes.

[12] In the estimation of all densities we use the Gaussian kernel function and the Sheather and Jones (1991) selector to determine the "optimal" bandwidth. Note that the distributions often appear flat. This due to Shanghai being in the far right tail of the distribution and alternative bandwidth selection criteria do not significantly alter the shape of the density estimate.

[13] We are able to confirm this by employing the calibrated Silverman test of Hall and York (2001). Using this test we are able to reject unimodality in each period at the 5% level (the p-values of the tests for 1978, 1989, 1990 and 2000 are 0.037, 0.020, 0.010 and 0.002, respectively). Using the uncalibrated Silverman (1981) test used in Henderson and Russell (2005), we are only able to reject the null at the 10% level. For more details on this test, see Hall and York (2001) and Henderson et al. (2006).

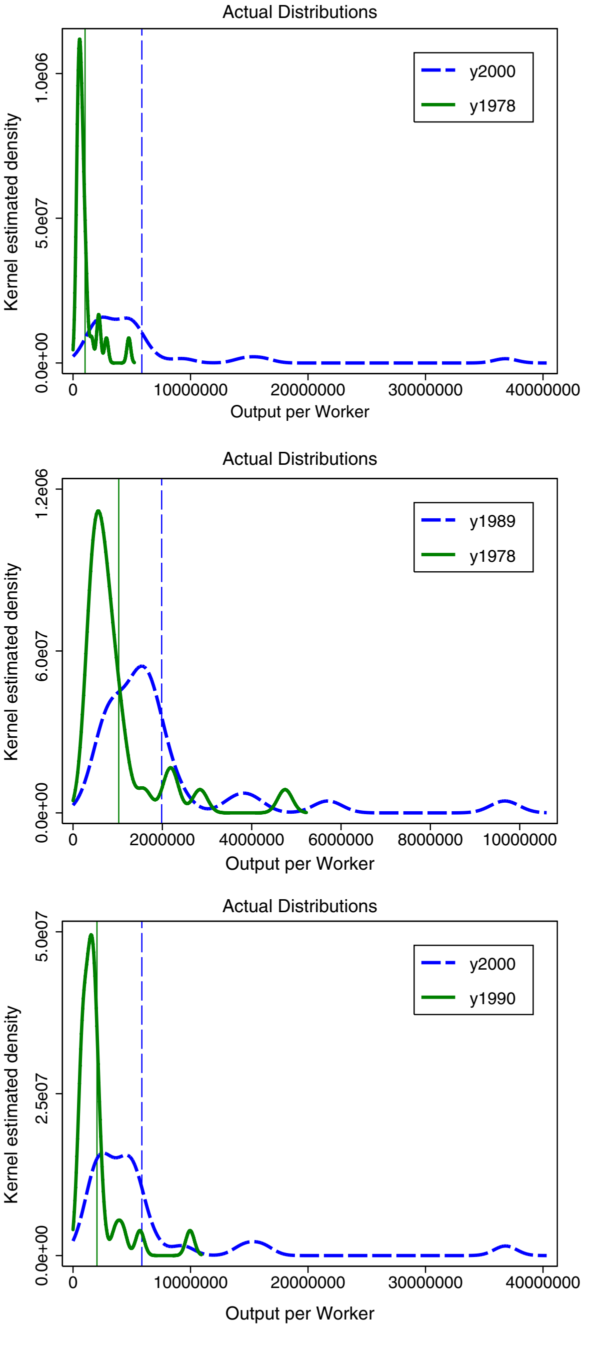

Fig. 2. Actual Output per Worker Distributions. *Notes*: Upper panel presents actual Output per Worker Distributions in 1978 and 2000; middle panel – in 1978 and 1989; the lower panel – in 1990 and 2000. The solid curve is the actual "base" distribution and the solid vertical line represents the "base" mean value. The dashed curve is the actual "current" distribution and the dashed vertical line represents the "current" mean value.

the shape of the distribution occurred over the sample period. In 1978, the majority of provinces were concentrated around a relatively low value of output per worker. Close to this "poor" mode we observe several smaller modes at higher income levels. By 2000, the "poor" mode shifted to the right, resulting in a higher mean labor productivity but also an increase in the variance of output per worker. The reason for this increase is that some poor provinces failed to grow as fast, whereas others, such as the middle group of coastal provinces, were able to catch up with regions considered rich in 1978. Furthermore, the relatively small but distinct "rich" modes of 1978 moved far to the right of the "poor" mode as indicated by the long tail of the distribution in 2000. In other words, a few rich provinces achieved higher growth which led to a widening of the income gap between them and the majority of provinces.

By using the quadripartite decomposition of productivity growth, we can explore the role of each of the four components in the transformation of the productivity distribution over the sample period. For this purpose we adhere to the methodology of Henderson and Russell (2005) and rewrite (9) as follows:

$$y_{\mathrm{c}} = (\mathrm{EFF} \times \mathrm{TECH} \times \mathrm{KACC} \times \mathrm{HACC}) \times y_{\mathrm{b}}. \tag{15}$$

Accordingly, the labor productivity distribution in the current period can be constructed by consecutively multiplying the labor productivity in the base period by each of the four components. To isolate the impact of each component, we create counterfactual distributions by introducing each of the components in sequence. For instance, we assess the shift of the labor productivity distribution due solely to efficiency changes by examining the counterfactual distribution of the variable

$$y^{\mathrm{E}} = \mathrm{EFF} \times y_{\mathrm{b}} \tag{16}$$

assuming no capital deepening, technological change or human capital accumulation. These counterfactual distributions are shown as dotted curves in Panel A of Figs. 3–5 along with the actual distributions in the base and current periods. The moderate loss of probability mass at the "poor" mode, for the entire sample period, and the gains in the probability mass at the "rich" modes reflect the fact that some of the poor provinces in 1978 were able to move closer to the production-frontier by 2000. This result is driven by changes in the second sub-period. Panel A of Fig. 4 shows that efficiency changes at the beginning of the sample led to an increase in the probability mass of the "poor" mode, while changes in efficiency led to a large decrease in the mass of the "poor" mode towards the end of the sample (Panel A of Fig. 5). However, the small shift in the mean labor productivity (the vertical dotted line), in each figure, indicates that improvements in efficiency played a minor role in the increase of the average output per worker.

The counterfactual distribution of the variable

$$y^{\mathrm{EK}} = (\mathrm{EFF} \times \mathrm{KACC}) \times y_{\mathrm{b}} = \mathrm{KACC} \times y^{\mathrm{E}}, \tag{17}$$

drawn in Panel B of Figs. 3–5, isolates the joint effect of efficiency changes and capital deepening on the base period distribution. The large increase in the mean labor productivity provides strong evidence that capital accumulation is the primary driving force in increasing output per worker. Furthermore, it is obvious that by introducing capital deepening, the counterfactual distribution becomes almost identical to the current period distribution. The prominent "poor" and "rich" modes are replaced by a wide lower mode

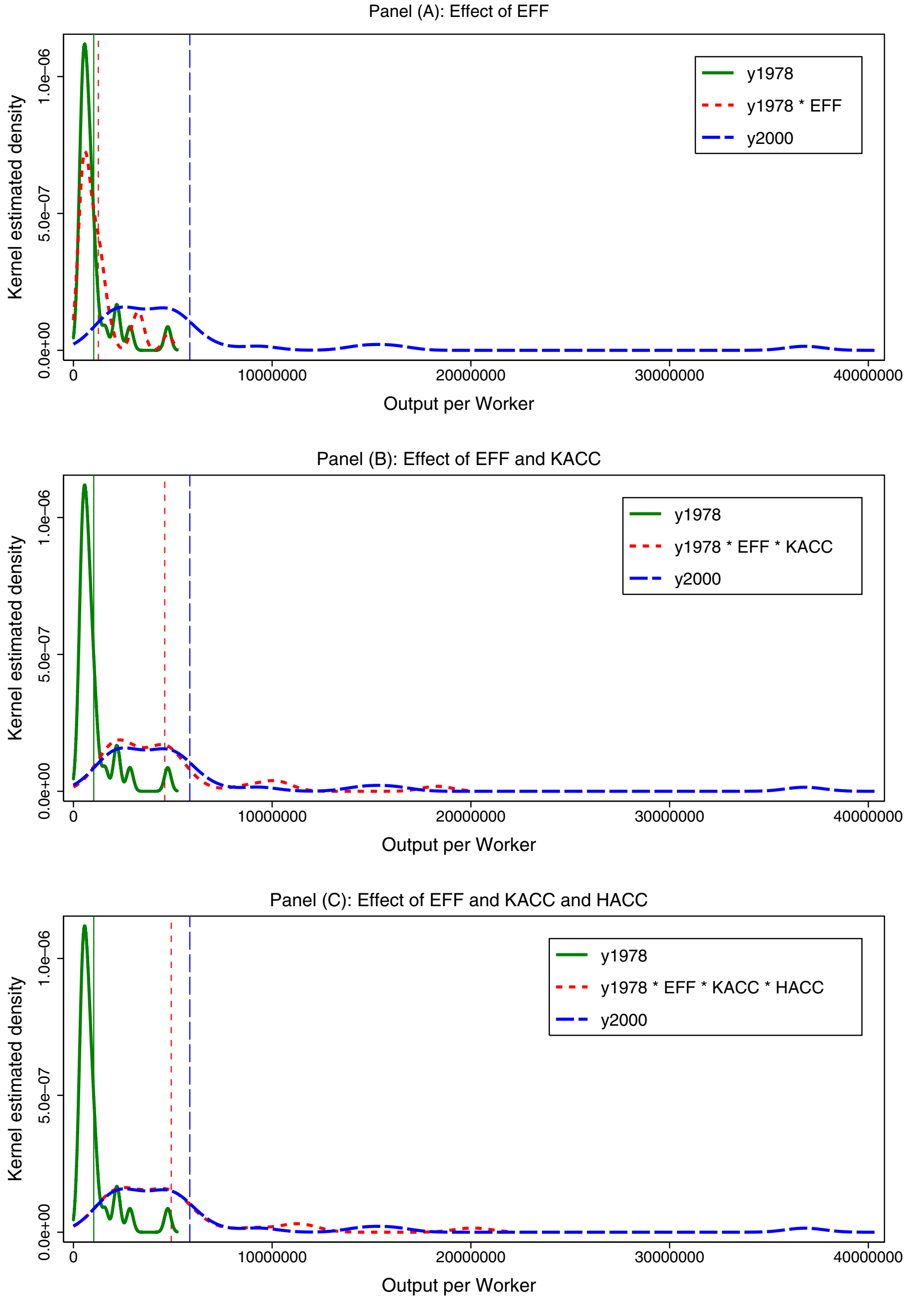

Fig. 3. Counterfactual distributions of Output per Worker. Sequence of introducing effects of decomposition: EFF, KACC, and HACC. *Notes*: In each panel, the solid curve is the actual 1978 distribution and the solid vertical line represents the 1978 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of efficiency change, capital deepening, and human capital accumulation on the 1978 distribution, and the dotted vertical line represents the respective counterfactual mean.

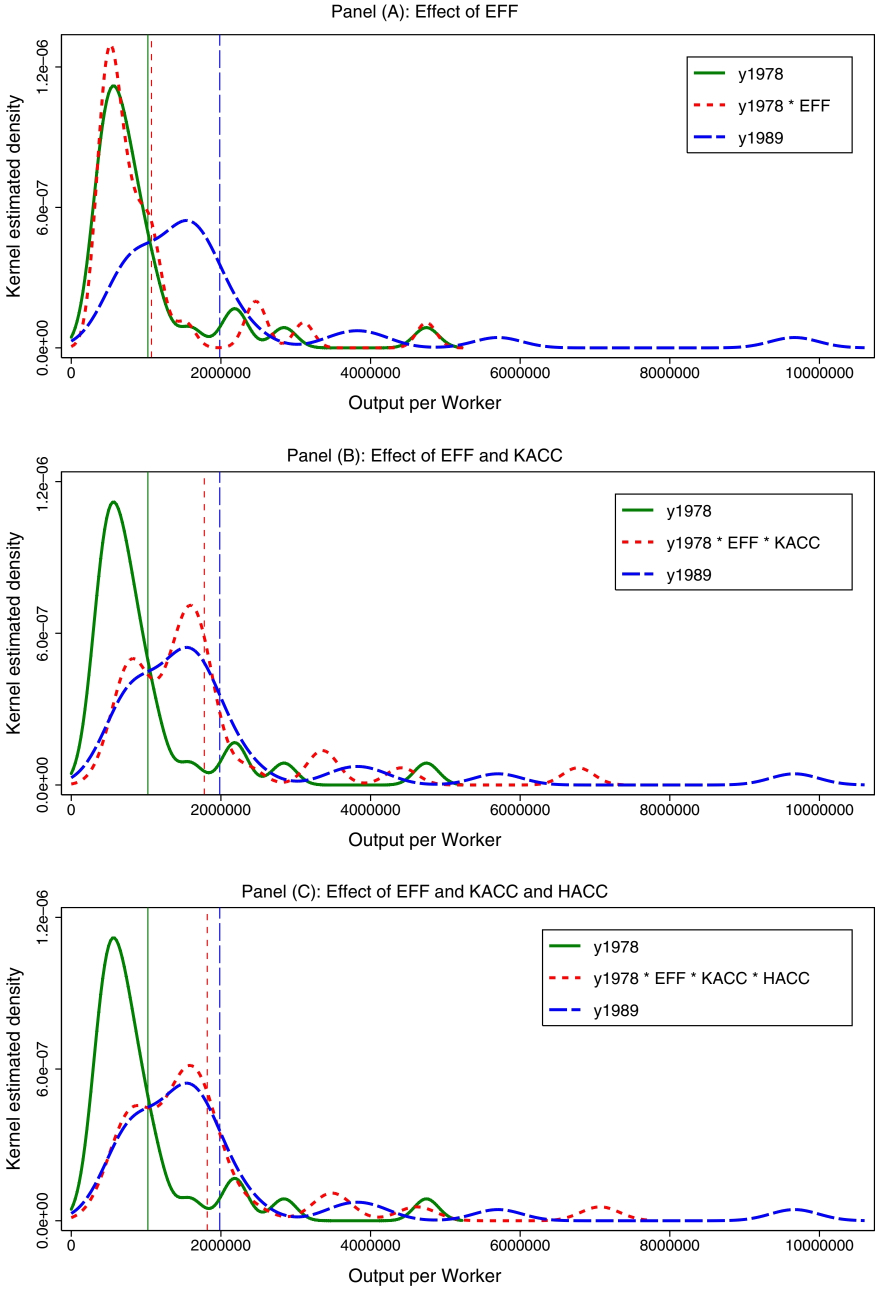

Fig. 4. Counterfactual distributions of Output per Worker. Sequence of introducing effects of decomposition: EFF, KACC, and HACC. *Notes*: In each panel, the solid curve is the actual 1978 distribution and the solid vertical line represents the 1978 mean value. The dashed curve is the actual 1989 distribution and the dashed vertical line represents the 1989 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of efficiency change, capital deepening, and human capital accumulation on the 1978 distribution, and the dotted vertical line represents the respective counterfactual mean.

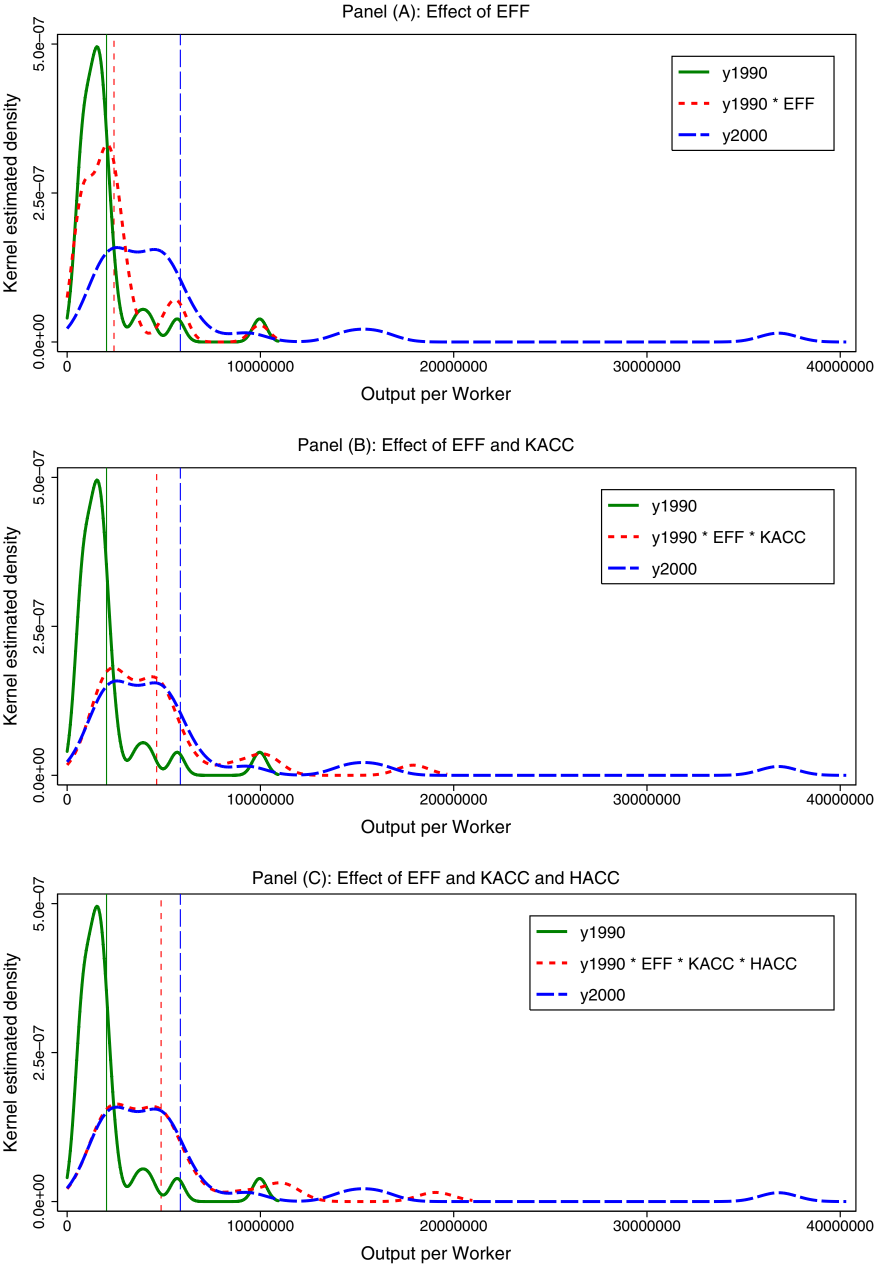

Fig. 5. Counterfactual distributions of Output per Worker. Sequence of introducing effects of decomposition: EFF, KACC, and HACC. *Notes*: In each panel, the solid curve is the actual 1990 distribution and the solid vertical line represents the 1990 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of efficiency change, capital deepening, and human capital accumulation on the 1990 distribution, and the dotted vertical line represents the respective counterfactual mean.

and a relatively short tail at higher income levels. This reflects the equalizing effect of capital deepening across provinces.

The additional effect of human capital accumulation on the distribution of y^{EK} can be observed by successfully multiplying HACC

$$y^{\mathrm{EKH}} = (\mathrm{EFF} \times \mathrm{KACC} \times \mathrm{HACC}) \times y_{\mathrm{b}} = \mathrm{HACC} \times y^{\mathrm{EK}}. \tag{18}$$

The resulting counterfactual distributions are shown in Panel C of Figs. 3–5. Besides a minor increase in the mean productivity, the distribution is almost identical to that in Panel B. The only visible change is the slightly longer upper tail of the distribution indicating that human capital accumulation has more than proportionally benefited rich provinces and has thus contributed to provincial divergence. The effect of the last component, technological change, can be deduced from comparing the counterfactual distribution of y^{EKH} and the actual distribution in 2000. As with human capital accumulation, the only contribution of technological change seems to be an additional extension of the tail of the distribution towards higher levels of income resulting in a higher mean labor productivity and further divergence.[14]

To complement the counterfactual distributions, we perform formal tests for statistical significance of differences between the actual and counterfactual distributions.[15] The first test in Table 5 indicates that the distributions in 1978 and 2000 are significantly different at the 1% significance level.[16] The next four tests compare the actual distribution in 2000 with the counterfactual distributions, assuming that only one of the four components is introduced each time. The small changes in the test statistics show that efficiency changes, technological changes and changes in human capital did little to shift the base period distribution. However, solely including physical capital decreases the test statistic such that the p-value $= 0.757$. In other words, if only physical capital accumulation is added to the 1978 distribution, the resulting counterfactual distribution is not significantly different from the actual 2000 distribution. This confirms our findings above that capital deepening alone can explain the overall change in the distribution from 1978 to 2000. The remaining tests offer further evidence. In fact, regardless of whether we test the combined

[14] We also performed the distribution analysis using different sequencing combinations. The results are not sensitive to changes in the sequencing order. The introduction of capital deepening always leads to a large increase in mean labor productivity, whereas human capital accumulation, technological change and efficiency improvements contribute only modestly to higher output per worker. With respect to the transformation of the distribution, it is again capital deepening that can explain the shift of the probability mass between the base and current periods. Technological change and human capital accumulation lead only to longer tails and divergence whereas efficiency leads to distinct modes and mild divergence. These results are available from the authors upon request.

[15] An interesting related analysis is conducted by Maasoumi et al. (2007) who use stochastic dominance techniques to detect differences in the distributions of growth rates of per capita output between OECD and non-OECD economies.

[16] We formally test for statistical significance of differences between (actual and counterfactual) distributions using the test developed by Li (1996). The Li-test tests the null hypothesis $H_0: f(x) = g(x)$ for all x, against the alternative $H_1: f(x) \neq g(x)$ for some x. In practice, the critical values of this test needs to be calculated via a bootstrap procedure. We choose the bootstrap developed in Li (1999) which was designed specifically for this test. Also note that in the test we use the Gaussian kernel function and the Sheather and Jones (1991) selector to determine the "optimal" bandwidth. We tried different bandwidths (e.g., rules of thumb and plug-in methods), but these lead only to minor changes that do not alter the conclusions of the paper. For further details see Fan and Ullah (1999); Li (1996, 1999); Pagan and Ullah (1999).

Table 5
Distribution hypotheses tests

H_0: Distributions are equal H_1: Distributions are not equal	Value of statistic	Bootstrap p-value	Conclusion of testing H_0
1978–2000			
$g(y_{2000})$ vs. $f(y_{1978})$	13.5423	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{EFF})$	10.7953	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{TECH})$	14.0844	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{KACC})$	0.2078	0.7570	Fail to reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{HACC})$	13.1475	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{EFF} \times \text{TECH})$	11.0298	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{EFF} \times \text{KACC})$	0.0760	0.9186	Fail to reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{EFF} \times \text{HACC})$	10.1118	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{TECH} \times \text{KACC})$	0.1964	0.7640	Fail to reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{TECH} \times \text{HACC})$	13.3958	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{KACC} \times \text{HACC})$	0.1109	0.8748	Fail to reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{EFF} \times \text{TECH} \times \text{KACC})$	0.0080	0.9910	Fail to reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{EFF} \times \text{TECH} \times \text{HACC})$	9.9615	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{EFF} \times \text{KACC} \times \text{HACC})$	0.0695	0.9196	Fail to reject
$g(y_{2000})$ vs. $f(y_{1978} \times \text{TECH} \times \text{KACC} \times \text{HACC})$	0.0598	0.9346	Fail to reject
1978–1989			
$g(y_{1989})$ vs. $f(y_{1978})$	5.2432	0.0002	Reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{EFF})$	5.3956	0.0000	Reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{TECH})$	5.1430	0.0004	Reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{KACC})$	−0.1343	0.8454	Fail to reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{HACC})$	5.1089	0.0002	Reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{EFF} \times \text{TECH})$	5.4117	0.0002	Reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{EFF} \times \text{KACC})$	0.0163	0.9800	Fail to reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{EFF} \times \text{HACC})$	5.3659	0.0002	Reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{TECH} \times \text{KACC})$	−0.1028	0.8896	Fail to reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{TECH} \times \text{HACC})$	4.9277	0.0006	Reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{KACC} \times \text{HACC})$	−0.1301	0.8462	Fail to reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{EFF} \times \text{TECH} \times \text{KACC})$	0.0030	0.9968	Fail to reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{EFF} \times \text{TECH} \times \text{HACC})$	5.5721	0.0000	Reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{EFF} \times \text{KACC} \times \text{HACC})$	0.0039	0.9958	Fail to reject
$g(y_{1989})$ vs. $f(y_{1978} \times \text{TECH} \times \text{KACC} \times \text{HACC})$	−0.0869	0.9050	Fail to reject
1990–2000			
$g(y_{2000})$ vs. $f(y_{1990})$	6.0909	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{EFF})$	3.0500	0.0054	Reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{TECH})$	6.1581	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{KACC})$	1.1952	0.0720	Fail to reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{HACC})$	5.9276	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{EFF} \times \text{TECH})$	3.5532	0.0008	Reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{EFF} \times \text{KACC})$	0.0458	0.9506	Fail to reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{EFF} \times \text{HACC})$	3.1455	0.0046	Reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{TECH} \times \text{KACC})$	1.0664	0.0854	Fail to reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{TECH} \times \text{HACC})$	6.0031	0.0000	Reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{KACC} \times \text{HACC})$	1.2491	0.0612	Fail to reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{EFF} \times \text{TECH} \times \text{KACC})$	− 0.0011	0.9994	Fail to reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{EFF} \times \text{TECH} \times \text{HACC})$	3.5104	0.0018	Reject

(*continued on next page*)

Table 5 (*continued*)

H_0: Distributions are equal H_1: Distributions are not equal	Value of statistic	Bootstrap *p*-value	Conclusion of testing H_0
$g(y_{2000})$ vs. $f(y_{1990} \times \text{EFF} \times \text{KACC} \times \text{HACC})$	0.0707	0.9266	Fail to reject
$g(y_{2000})$ vs. $f(y_{1990} \times \text{TECH} \times \text{KACC} \times \text{HACC})$	1.1133	0.0778	Fail to reject

Notes: We used the bootstrapped Li (1996) Tests with 5000 bootstrap replications and the Sheather and Jones (1991) bandwidth.

effect of two or three components on the 1978 distribution, unless physical capital accumulation is included, the test concludes that the actual and counterfactual distributions are significantly different from one another. The results hold for the two sub-periods.

5. Conclusion

In this paper, we attempted to identify the sources of growth for provincial economies in China and to determine their contribution to increasing regional disparities over the reform period. Our results indicate that (1) the distribution of output per worker across Chinese provinces is multimodal with relatively few provinces in the upper modes and the majority of provinces in the larger ‘‘poor’’ mode. Fortunately, over the 22 year period, several ‘‘poor’’ (predominantly coastal) provinces moved to the ‘‘rich’’ modes. (2) Technological change is decidedly nonneutral, with virtually all progress taking place in the highly capital-intensive region of input space. (3) The phenomenal growth of Chinese provinces was mainly driven by physical capital accumulation, thus questioning the sustainability of their growth performance. (4) Capital deepening helped drive convergence between provinces. This was primarily driven by the initially poor costal provinces catching up due to intensive capital deepening along with large efficiency improvements. (5) Minimal technological progress and human capital accumulation are key factors responsible for the regional disparities in China. This appears to have occurred because the initially rich coastal provinces were able to grow faster because of above-average rates of technological progress and human capital accumulation. On the other side, interior provinces improved their efficiency and increased their levels of physical capital, however most were unable to catch up with the rich because of a lack of technology advances and human capital accumulation.

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References

Ao, X., L. Fulginiti, 2003. Productivity growth in China: Evidence from Chinese Provinces. Mimeo, University of Nebraska-Lincoln.

Arayama, Y., Miyoshi, K., 2004. Regional diversity and sources of economic growth. World Economy 27, 1583–1607.

Badunenko, O., Henderson, D.J., Zelenyuk, V., 2005. Technological change and transition: Relative contributions to worldwide growth during the 1990s. Mimeo, State University of New York at Binghamton.

Barro, R.J., Lee, J-W., 2000. International data on educational attainment: updates and implications. Oxford Economic Papers 53, 541–563.

Bils, M., Klenow, P.J., 2000. Does schooling cause growth? American Economic Review 90, 1160–1183.

Borensztein, S., Ostry, J.D., 1996. Accounting for China's growth performance. American Economic Review 86, 224–228.

Borjas, G., 1992. Ethnic capital and intergenerational mobility. Quarterly Journal of Economics 107, 123–150.

Chen, J., Fleisher, B., 1996. Regional income inequality and economic growth in China. Journal of Comparative Economics 22, 141–164.

Chow, G.C., 2002. China's Economic Transformation. Blackwell Publishing, Oxford.

Démurger, S., 2001. Infrastructure development and economic growth: An explanation for regional disparities in China? Journal of Comparative Economics 29, 95–117.

Démurger, S., Sachs, J.D., Woo, W.T., Bao, S., Chang, G., Mellinger, A., 2002. Geography, economic policy, and regional development in China. NBER Working Papers 8897.

Diewert, W.E., 1980. Capital and the theory of productivity measurement. American Economic Review 70, 260–267.

Ezaki, M., Sun, L., 1999. Growth accounting in China for national regional and provincial economies. Asian Economic Journal 13, 39–71.

Fan, Y., Ullah, A., 1999. On goodness-of-fit tests for weakly dependent processes using kernel method. Journal of Nonparametric Statistics 11, 337–360.

Färe, R., Zelenyuk, V., 2003. On aggregate Farrell efficiency scores. European Journal of Operational Research 146, 615–620.

Färe, R., Grosskopf, S., Norris, M., Zhang, Z., 1994. Productivity growth, technical progress, and efficiency change in industrialized countries. American Economic Review 84, 66–83.

Fleisher, B., Chen, J., 1997. The coast-noncoast income gap, productivity, and regional economic policy in China. Journal of Comparative Economics 25, 220–236.

Fu, X., 2004. Limited linkages from growth engines and regional disparities in China. Journal of Comparative Economics 32, 148–164.

Fu, X., 2005. Exports, technical progress and productivity growth in a transition economy: A non-parametric approach for China. Applied Economics 37, 725–739.

Fujita, M., Hu, D., 2001. Regional disparity in China 1985–1994: The effects of globalization and economic liberalization. Annals of Regional Science 35, 3–37.

Hall, R.E., Jones, C.I., 1999. Why do some countries produce so much more output per worker than others? Quarterly Journal of Economics 114, 83–116.

Hall, P., York, M., 2001. On the calibration of Silverman's test for multimodality. Statistica Sinica 11, 515–536.

Heckman, J.J., 2005. China's human capital investment. China Economic Review 16, 50–70.

Henderson, D.J., Russell, R.R., 2005. Human capital and convergence: A production-frontier approach. International Economic Review 46, 1167–1205.

Henderson, D.J., Zelenyuk, V., 2007. Testing for (efficiency) catching-up. Southern Economic Journal 73.

Henderson, D.J., Parmeter, C.F., Russell, R.R., 2006. Modes, weighted modes, and calibrated modes: Evidence of clustering using modality tests. Mimeo, State University of New York at Binghamton.

Hu, Z., Khan, M.S., 1997. Why is China growing so fast? IMF Staff Papers 44, 103–131.

Jefferson, G., Rawski, T., Zhen, Y., 1996. Chinese industrial productivity: Trends, measurement issues, and recent developments. Journal of Comparative Economics 23, 146–180.

Jian, T., Warner, A.M., Sachs, J.D., 1996. Trends in regional inequality in China. China Economic Review 7, 1–21.

Jones, D.C., Li, C., Owen, A.L., 2003. Growth and regional inequality in China during the reform era. China Economic Review 14, 186–200.

Kanbur, R., Zhang, X., 2001. Fifty years of regional inequality in China: A journey through revolution, reform and openness. CEPR Discussion Papers 2887.

Kneip, A., Park, B.U., Simar, L., 1998. A note on the convergence of nonparametric DEA estimators for production efficiency scores. Econometric Theory 14, 783–793.

Kneip, A., Simar, L., Wilson, P., 2003. Asymptotics for DEA estimators in non-parametric frontier models. Discussion Paper, Institute of Statistics, Université Catholique de Louvain, Belgium.

Kong, X., Robert, E.M., Wan, G.H., 1999. Technical efficiency, technological change, and total factor productivity growth in Chinese state-owned enterprises in the early 1990s. Asia Economic Journal 13, 267–281.

Kumar, S., Russell, R.R., 2002. Technological change, technological catch-up, and capital deepening: Relative contributions to growth and convergence. American Economic Review 92, 527–548.

Lee, J., 2000. Changes in the source of China's regional inequality. China Economic Review 11, 232–245.

Li, Q., 1996. Nonparametric testing of closeness between two unknown distribution functions. Econometric Reviews 15, 261–274.

Li, Q., 1999. Nonparametric testing the similarity of two unknown density functions: Local power and bootstrap analysis. Journal of Nonparametric Statistics 11, 189–213.

Los, B., Timmer, M.P., 2005. The 'appropriate technology' explanation of productivity growth differentials: An empirical approach. Journal of Development Economics 77, 517–531.

Lu, M., Wang, E., 2002. Forging ahead and falling behind: Changing regional inequalities in post-reform China. Growth and Change 33, 42–71.

Maasoumi, E., Racine, J., Stengos, T., 2007. Growth and convergence: A profile of distribution dynamics and mobility. Journal of Econometrics 136, 483–508.

Marton, A.M., 2000. China's Spatial Development: Restless Landscapes in the Lower Yangzi Delta. Routledge, London.

Mincer, J., 1974. Schooling, Experience, and Earnings. NBER Press, New York.

Miyamoto, K., Liu, H., 2005. An analysis of the determinants of provincial-level performance in China's economy. Comparative Economic Studies 47, 520–542.

National Bureau of Statistics, 1997–2000. China Statistical Yearbook. China Statistics Press, Beijing.

National Bureau of Statistics, 1999. Comprehensive Statistical Data and Materials on 50 Years of New China. China Statistics Press, Beijing.

Nehru, V., Dhareshwar, A., 1993. A new database on physical capital stock: Sources, methodology and results. Revista de Analisis Economico 8, 37–59.

Pagan, A., Ullah, A., 1999. Nonparametric Econometrics. Cambridge University Press, Cambridge.

Psacharopoulos, G., 1994. Returns to investment in education: A global update. World Development 22, 1325–1343.

Quah, D., 1993. Empirical cross-section dynamics in economic growth. European Economic Review 37, 426–434.

Quah, D., 1996. Twin peaks: growth and convergence in models of distribution dynamics. Economic Journal 106, 1045–1055.

Quah, D., 1997. Empirics for growth and distribution: Stratification, polarization, and convergence clubs. Journal of Economic Growth 2, 27–59.

Rawski, T.G., 2001. What's happening to China's GDP statistics? China Economic Review 12, 347–354.

Rawski, T.G., Xiao, W., 2001. Roundtable on Chinese economic statistics introduction. China Economic Review 12, 298–302.

Sheather, S.J., Jones, M.C., 1991. A reliable data based bandwidth selection method for kernel density estimation. Journal of Royal Statistical Society, Series B 53, 683–690.

Shiu, A., 2002. Efficiency of Chinese enterprises. Journal of Productivity Analysis 18, 255–267.

Silverman, B.W., 1981. Using kernel density estimates to investigate multimodality. Journal of the Royal Statistical Society, Series B 43, 97–99.

Tochkov, K., 2007. Interregional transfers and the smoothing of provincial expenditure in China. China Economic Review 18, 54–65.

Unel, B., Zebregs, H., 2006. The dynamics of provincial growth in China: A nonparametric approach. IMF Working Paper 06/55.

Wang, Y., Yao, Y., 2001. Sources of China's economic growth, 1952–99: Incorporating human capital accumulation. China Economic Review 14, 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. Productivity, growth, and economic integration in the southern China region. Asian Economic Journal 14, 39–54.
Wu, Y., 2004. China's Economic Growth: A Miracle with Chinese Characteristics. Routledge, Curzon, New York.
Wu, X., Perloff, J.M., 2005. China's income distribution, 1985–2001. Review of Economics and Statistics 87, 763–775.
Yao, S., Zhang, Z., 2001. Regional growth in China under economic reforms. Journal of Development Studies 38, 167–186.
Ying, L.G., 2000. Measuring the spill-over effects: Some Chinese evidence. Papers in Regional Science 79, 75–89.
Young, A., 2000. Gold into base metals: Productivity growth in the People's Republic of China during the reform period. NBER Working Papers 7856.
Zhang, X., Zhang, K.H., 2003. How does globalization affect regional inequality within a developing country? Evidence from China. Journal of Development Studies 39, 47–67.
Zhang, J., Zhao, Y., Park, A., Song, X., 2005. Economic returns to schooling in urban China, 1988 to 2001. Journal of Comparative Economics 33, 730–752.