Working Paper

INTERNATIONAL MONETARY FUND

WP/06/55

IMF Working Paper

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European Department

The Dynamics of Provincial Growth in China: A Nonparametric Approach

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Authorized for distribution by Lorenzo Figliuoli

February 2006

Abstract

China's growth record since the start of its economic reforms in 1978 has been extraordinary. Yet, this impressive performance has been associated with an increasing regional income disparity. We use a recently developed nonparametric approach to analyze the variation in labor productivity growth across China's provinces. This approach imposes less structure on the data than the standard growth accounting framework and allows for a breakdown of labor productivity into capital deepening, efficiency gains, and technological progress. Like other studies before us, we do not find strong evidence of convergence in labor productivity across China's provinces during 1978-98. However, our results show that provinces converged in efficiency levels, while they diverged in capital deepening and technological progress.

JEL Classification Numbers: O1, O2, O3, O53, and P2

Keywords: Provincial Growth in China, Labor Productivity, Convergence, Data Envelopment Analysis

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Contents

I. Introduction

China's growth record since the start of economic reforms in 1978 has been impressive, but the contribution of its provinces to per capita income growth has been highly uneven.[2] Although average annual growth of real per capita GDP has picked up across all regions, coastal provinces have tended to grow faster than northern and western provinces. According to Aziz and Duenwald (2003), real GDP per capita in coastal provinces such as Fujian, Guangdong, and Zhejiang grew at an average annual rate about twice that of western provinces such as Gansu, Ningxia, and Qinghai during 1978-97. The dispersion of growth rates has not been purely a reflection of different stages of development. Indeed, among the initially poorer provinces those in the west have fallen further behind, while those at or near the coast have caught up with or even surpassed provinces that had the highest per capita incomes at the start of economic reforms. This uneven performance has been reflected in a growing income disparity across regions, which has become particularly pronounced after the second wave of economic reforms in the early 1990s posing a key challenge to policymakers in Beijing.

Several studies have investigated the differences in economic performance across China's provinces and concluded that China's provinces have not shown a tendency toward *absolute* β-convergence in terms of real per capita GDP over the past two and a half decades. That is, there is no strong evidence of China's provinces converging to the same steady state. Bell, Khor, and Kochhar (1993) and Jian et al. (1996) found that income dispersion had declined between 1981 and 1990 as poorer provinces tended to grow faster than richer ones, but this result does not hold up when the sample period is extended. The absence of absolute convergence among China's provinces is in contrast with the behavior of U.S. states, Japanese prefectures, and selected regions in western Europe, where absolute β-convergence appears to be the norm rather than the exception over extended periods of time (Barro and Sala-i-Martin 2004).

However, there is evidence of *conditional* β-convergence with provinces converging to unique steady states distinguished by structural factors and preferential economic policies, which have been part of China's dual track approach to economic reforms. Démurger et al. (2002) found that, after controlling for opennes and proximity to fast growing economies in East Asia, growth in coastal provinces benefited significantly from preferential policies, which have fostered marketization and internationalization. Dayal-Gulati and Husain (2002) found that the prevalence of state-owned enterprises (SOEs) and a high ratio of bank loans-to-deposits—an indication of large directed lending—were often associated with lower growth. They also found that the coastal and north/northeastern regions have been able to attract more FDI because of their relative prosperity and more developed

[2] Jian, Sachs, and Warner (1996), Li, Liu, and Rebelo (1998), Démurger et al. (2002), Dayal-Gulati and Husain (2002), and Aziz and Duenwald (2003).

infrastructure, which has contributed to the high growth rates of these regions. These findings suggest that the poorest provinces, especially those that are landlocked and have weak infrastructure, have realized the smallest increases in per capita income, while the coastal provinces, because of their geography and preferential policies, have caught up with the formerly richest provinces, of which many are now burdened by the large presence of inefficient SOEs and a more limited commercial orientation.

Whereas most previous studies have focussed on explaining the distribution of overall GDP growth across China's provinces within the framework of the augmented Solow growth model, this paper looks at the evolution of three components of labor productivity growth: efficiency gains (movements toward the production frontier), technological progress (outward shifts of the production frontier), and capital deepening (movements along the production frontier). This decomposition of productivity growth allows us to investigate to what extent the growing income disparity among provinces can be explained by the dynamics of each of these three factors, thus offering a more detailed analysis of the nature of the growing provincial income disparity.

For our analysis we use a recently developed nonparametric technique known as Data Envelopment Analysis (DEA). For each date in our sample period we construct a production frontier for China as a whole using all observed input-output combinations at the province level up to that date. The inputs are capital and labor, and output is GDP. After identifying the frontier, we can measure the efficiency level of each province with respect to this frontier. Having determined the evolution of capital-labor ratios and efficiency indices for each province, we can derive the contribution of technological progress to labor productivity growth in each province.

DEA was developed by Farrell (1957) and Afriat (1972), and was further extended by Färe et al. (1994, 1995) and Kumar and Russell (2002).[3] Our approach is similar to that by Kumar and Russell (2002), except that in constructing the production possibility frontier at time t we follow Diewert (1980) by using all data available up to time t, rather than just the observations at time t. This modification prevents technology from regressing, a feature in the Kumar and Russell (2002) findings. Using DEA has several advantages over standard growth accounting. First, in this approach the production frontier is directly constructed from the data. Hence we do not have to impose any restrictions other than a functional form that satisfies a constant returns to scale technology. Second, our approach allows us to identify separately the contributions of efficiency and technological improvements to productivity growth. Finally and more importantly, our approach does

[3] Färe et al. (1994) use DEA to analyze the productivity growth in 17 member countries of the Organization for Economic Cooperation and Development, while Kumar and Russell used the same technique with a different decomposition of labor productivity to analyze the productivity performance across 57 countries in the world.

not impose any kind of structure on markets, whereas in the standard growth accounting framework it is usually assumed that markets are competitive, which is a possibly critical assumption in the case of China, where government regulation of markets is still extensive.

Our results can be summarized as follows. First, labor productivity growth in China's provinces has largely been driven by capital deepening, a finding that is in line with studies of the Chinese economy as a whole.[4] In particular, we find that on average capital deepening accounted for about 70 percent of total labor productivity growth, while efficiency and technological improvements accounted for about 15 percent each. Second, while on average productivity growth was largely attributable to capital deepening, there is considerable dispersion in provincial level trends. In most coastal, northeastern, and southeastern provinces, capital deepening accounted for more than 75 percent of productivity growth, whereas in most western and northern provinces it accounted for less than 70 percent of productivity growth. Third, improvement in efficiency was higher in initially less advanced provinces than in richer ones, which suggests that the former have been catching up with the latter and have moved closer to the technology frontier. Finally, relatively more productive provinces have benefited more from technological progress than less developed provinces.

The rest of the paper is organized as follows. Section II explains the construction of the country-wide production frontier along with the calculation of efficiency levels and demonstrates how we decompose labor productivity into the three components described above. In Section III, we present our results and discuss their implications. Section IV offers some concluding remarks.

II. Theoretical Framework

Let $\mathbf{Z}_t = (K_t, L_t)$ denote a bundle of capital-labor inputs to produce a single output Y_t at time t. We denote this single output technology by means of a production function F_t that gives the maximum amount $F_t(\mathbf{Z}_t)$ of output that can be produced using input amounts $\mathbf{Z}_t$. This production technology gives rise to the production set:

$$\tilde{\mathcal{P}}_t = \left\{ (\mathbf{Z}_t, Y_t)' \in \mathbb{R}^3_+ : \ F_t(\mathbf{Z}_t) - Y_t \geq 0 \text{ and } \mathbf{Z}_t \geq \mathbf{0} \right\}. \tag{1}$$

The set of boundary points of $\mathcal{P}_t$ is called the production (or transformation) frontier, which we shall denote by $\tilde{\mathcal{F}}_t$ and is completely characterized by production function F_t; that is, $(K_t, L_t, Y_t) \in \tilde{\mathcal{F}}_t$ if and only if $F_t(K_t, L_t) = Y_t$. With these definitions, any

[4] Chow (1993), Chow and Li (1999), and Heytens and Zebregs (2003) find that capital accumulation was the main contributor to GDP growth in China both before and after the start of economic reforms.

input-output combination in the interior of the production set represents an inefficient transformation of $\mathbf{Z}_t$ into Y_t and the distance between such a combination and the boundary will be a measure of the level of inefficiency. Thus, in order to measure the scale of inefficiency, it is important to identify the production frontier.

In this paper, we confine ourselves to constant returns to scale (CRS) production technologies, i.e. F_t is a CRS production function. With this assumption, $F_t(K_t, L_t) = Y_t$ can be rewritten as $f_t(k_t) = y_t$, where $k_t = K_t/L_t$, $y_t = Y_t/L_t$, and $f_t(k_t) = F_t(K_t/L_t, 1)$. With this transformation, the transformed production set is described by

$$\mathcal{P}_t = \left\{ (k_t, y_t)' \in \mathbb{R}^2_+ : \ f_t(k_t) - y_t \geq 0 \text{ and } k_t \geq 0 \right\}. \tag{2}$$

Note that when F_t exhibits CRS, f_t exhibits non-increasing returns to scale (NIRS).

As discussed in the introduction, our approach to constructing production sets (and frontiers) is data-driven. Roughly speaking, we define the production set at time t as the smallest convex set that envelopes all available data at time t. The boundary of this set will represent the production frontier. Formally, the production frontier is constructed from the data as follows.

$$\mathcal{F}_t = \left\{ (k_t, y_t)' \in \mathbb{R}^2_+ : \ y_t \leq \sum_{\tau=1}^{t} \sum_{i=1}^{I} \theta^i_\tau y^i_\tau, \ \sum_{\tau=1}^{t} \sum_{i=1}^{I} \theta^i_\tau k^i_\tau \leq k_t, \ \theta^i_\tau \geq 0, \text{ and } \sum_{\tau=1}^{t} \sum_{i=1}^{I} \theta^i_\tau \leq 1 \right\}, \tag{3}$$

where θ^i_τ's represent "weights" and $(k^i_\tau, y^i_\tau)'$ represents the intensive form of the input-output vector of province i at time τ. As Kumar and Russell (2002) noted, this construction implies that each point in the production set is either a linear combination of observed points or a point dominated by a linear combination of observed points.[5] By imposing the restriction $\sum_{\tau=1}^{t} \sum_{i=1}^{I} \theta^i_\tau \leq 1$, we make the production technology exhibit NIRS (Afriat 1972). Note that this production technology also satisfies the free-disposal condition, that is inputs and output can be disposed of at no cost. It is important to emphasize that in constructing the frontier we follow Diewert (1980) in that we use all available data up to time t. This approach is different from the one developed by Kumar and Russell (2002) and Färe et al. (1994), who construct the frontier by only using the input-output data observed at time t. We incorporated previous observations to prevent the possibility of technological regress.[6]

[5]For an excellent discussion of the construction of production frontiers and DEA, see Farrell (1957), Afriat (1972), and Färe et al. (1995). In particular Färe et al. (1995) give a comprehensive account of various extensions of DEA.

[6]Nothing suggests that China has experienced a decline in its technological knowledge since it started economic reforms. Hence, the technology that was available at date t was at least as advanced as the technology available at date $s < t$. However, our method is data driven and by not including previous observations it could produce an estimate of the production set at date t, which does not include all the elements in the production set at date $s < t$.

Given the production frontier $\mathcal{F}_t$, we are now ready to describe how to calculate efficiency indexes. For a given point $(k_t, y_t)' \in \mathcal{P}_t$, following Farrell (1957), we define the output-based (or Farrell) efficiency function as follows:

$$E_t(k_t, y_t) = min\{\lambda : \; (k_t, y_t/\lambda)' \in \mathcal{P}_t\}. \tag{4}$$

In words, this function is defined as the inverse of the maximum proportional amount that labor productivity y_t can be expanded, while remaining in the production set $\mathcal{P}_t$, given the capital intensity k_t. For each province i, we calculate the efficiency index λ_t^i at time t by solving the following linear programming problem:

$$Min_{\lambda_t^i, \theta_1^1, \ldots, \theta_t^I} \quad \lambda_t^i \tag{5}$$

subject to

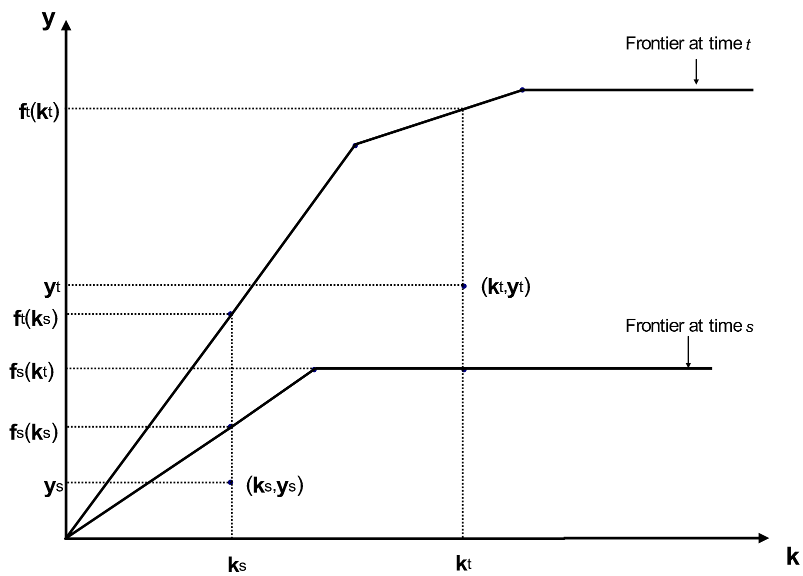
$$\begin{aligned} y_t^i/\lambda_t^i &\leq \sum_{\tau=1}^{t} \sum_{j=1}^{I} \theta_\tau^j y_\tau^j \\ k_t^j &\geq \sum_{\tau=1}^{t} \sum_{j=1}^{I} \theta_\tau^j k_\tau^i \\ 1 &\geq \sum_{\tau=1}^{t} \theta_\tau^i \\ \theta_\tau^j &\geq 0, \qquad \tau = 1, \ldots, t, \text{ and } j = 1, \ldots, I. \end{aligned}$$

Having calculated the efficiency indexes we can, following Kumar and Russell (2002), decompose productivity growth into efficiency, technological change, and capital deepening components.[7]

To illustrate the decomposition of output per worker Figure 1 depicts two production sets for time periods s and t, with $s < t$. Points (k_s, y_s) and (k_t, y_t) represent the input-output combinations of the same economy in periods s and t, respectively. Note that these observed input-output combinations are in the interiors of the corresponding production sets, hence, they are inefficient. Given k_s units of input, under the production technology available at time s, this economy can produce at most $f_s(k_s) = y_s/\lambda_s$ units of output, where λ_s is the efficiency index for the observed production. Similarly, when the input level is k_t, the maximum amount of output that can be produced, under the production technology available at time t, is $F_t(k_t) = y_t/\lambda_t$, where λ_t is the efficiency index for the

[7] Färe et al. (1994) propose a different method involving the decomposition of a (Malumquist) productivity index into technical change, pure efficiency change, and scale change. We chose to follow the method in Kumar and Russell (2002) because it allows us to assess the role of capital deepening in productivity growth.

Figure 1: Decomposition of output per worker



observed production in period t. Combination of these two observations yields

$$\frac{y_t}{y_s} = \frac{\lambda_t \times f_t(k_t)}{\lambda_s \times f_s(k_s)}. \tag{6}$$

Multiplying the numerator and denominator on the right hand side by $f_s(k_t)$, which is the maximum output that can be produced with input level k_t under the first period production technology, and rearranging terms we obtain

$$\frac{y_t}{y_s} = \frac{\lambda_t}{\lambda_s} \times \frac{f_t(k_t)}{f_s(k_t)} \times \frac{f_s(k_t)}{f_s(k_s)}. \tag{7}$$

The left hand side of this equation represents the change in output per worker between periods s and t. The first term on the right hand side represents the change in efficiency over these two periods. The second term represents the shift in the production frontier at capital intensity of k_t. The last term represents the change in maximum output per worker owing to the change in capital intensity between the two periods. Thus, identity (7) decomposes labor productivity into three components: change in efficiency change, change in technology, and change in capital intensity. Note that this is not the only way to decompose output per worker. Considering again equation (6), multiplying the numerator and denominator on the right hand side by $f_t(k_s)$, which is the maximum output that can be produced with input level k_t under the first period production technology, and rearranging terms we get

$$\frac{y_t}{y_s} = \frac{\lambda_t}{\lambda_s} \times \frac{f_t(k_s)}{f_s(k_s)} \times \frac{f_t(k_t)}{f_t(k_s)}, \tag{8}$$

where each term on the right hand side is interpreted in the same way as in equation (7). Note that unless the production technology F is Hicks neutral, there is no reason to expect that $\frac{f_t(k_s)}{f_s(k_s)}$ equals $\frac{f_t(k_t)}{f_s(k_t)}$. Hence, we have two different representations of technical change (and of the change in potential output owing to the change in capital intensity, that is the third term in equations 7 and 8). Following Caves et al. (1982), Färe et al. (1994), and Kumar and Russell (2002), we avoid having two arbitrary decompositions of output per worker by considering the geometric mean of the right hand sides of (7) and (8):

$$\frac{y_t}{y_s} = \frac{\lambda_t}{\lambda_s} \times \left(\frac{f_t(k_t)}{f_s(k_t)} \frac{f_t(k_s)}{f_s(k_s)}\right)^{1/2} \times \left(\frac{f_s(k_t)}{f_s(k_s)} \frac{f_t(k_t)}{f_t(k_s)}\right)^{1/2}. \tag{9}$$

Taking the logarithms of both sides of (9) and dividing by $t-s$ (number of years between two periods), we have

$$g_y = g_{eff} + g_{tech} + g_{cap}, \tag{10}$$

where g_y represents the average annual growth rate of output per worker, and g_{eff}, g_{tech}, g_{cap} are the average annual growth rate of efficiency index, the average annual growth rate of technical progress, and the average annual growth rate of the potential outputs (due to the change in capital intensity) between two periods, respectively. This completes the theoretical framework of our approach. Before moving further, let us recap briefly what we have introduced in this section. We started with the construction of a production frontier from the observed data. Then we showed how to measure the associated (in)efficiency indexes by solving the corresponding linear programming problem. Finally, we illustrated how, after having calculated the efficiency indexes, growth in output per worker can be decomposed into changes in efficiency, technology, and capital intensity.

Several remarks are in order. First, the production frontier is constructed from the data and consequently it is defined relative to the best technology of the provinces in our sample. Thus, this frontier may be below the true frontier, which in turn implies that the efficiency indexes represent lower bounds of true inefficiencies. In the standard growth accounting framework the true frontier is also not known, but in that framework each province's performance is compared only with its previous-year performance, not with a common benchmark across all provinces. Moreover, since we want to compare the relative performance of the provinces, we think that our nonparametric approach is more suitable.[8] Second, our approach allows for the separation of changes in efficiency from technological

[8] Our approach does not take into account possible measurement errors. There is an alternative technique,

progress. In the standard growth accounting approach, each province is assumed to be on "its" own frontier, hence it is impossible to make the same separation. We interpret the variation in efficiency indexes across provinces as a reflection of differences in institutions, resources, allocation of factor inputs, and geography. Third, in growth accounting calculation of TFP levels requires that technological progress is Hicks-neutral, which we did not have to assume in our analysis. Indeed, our analysis in the next section suggests that technological progress is not Hicks-neutral. Finally, and more importantly, in calculating productivity growth rates we did not impose any condition on market behavior, while in growth accounting TFP is derived under the assumption that markets are competitive. To illustrate this point we postulate the following production function

$$Y(t) = F(K(t), L(t), t),$$

where t represents an index of technology at time t. Taking the logarithm of both sides, differentiating with respect to time, and rearranging the terms, we obtain

$$g_A = g_Y - \varepsilon_K g_K + \varepsilon_L g_L,$$

where ε_K and ε_L are elasticity of capital and labor with respect to output and g_X denotes the growth rate of the variable X. In practice, we do not know these elasticities. To overcome this difficulty it is assumed that (i) F exhibits CRS, which we also assumed, and (ii) markets are competitive, which implies that the labor elasticity can be replaced with the share of labor in total output. For advanced countries with considerable market competition, it may be reasonable to use the labor share as a proxy for ε_L, but in the case of China, where many product and factor markets remain heavily regulated, this is obviously more problematic. DEA therefore seems a more suitable approach for analyzing productivity growth in China's provinces than the standard growth accounting framework.[9]

III. Empirical Analysis

We calculate labor productivity growth and efficiency levels for a sample of 28 provinces[10] between 1978 and 1998. Value added and investment data are from the

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known as the stochastic frontier approach, to calculate the efficiency indexes under possible measurement errors. We did not consider that approach in our study, because implementation of that approach imposes additional restrictions on the functional form of the frontier and error terms.

[9]We were confronted with two additional problems. First, for most of the provinces we did not have data on labor compensation. Second, for the provinces where data were available, the labor shares were very small, an issue that was also noted by Young (2003) who used data from other auxiliary sources to correct for potential measurement errors in labor shares.

[10]Hainan and Tibet Autonomous Region were excluded for lack of data on value-added and fixed-capital investment.

provincial yearbook of China. Labor data are from Young (2000), who compiled it from provincial yearbooks, *A Compilation of Historical Statistics* (State Statistical Bureau, 1990), and Hsueh, Li and Liu (1993). More detailed information about data sources and the construction of variables is provided in the appendix.

Before turning to the discussion of efficiency indexes, it will be interesting to look at the dynamics of productivity change across provinces. All provinces recorded increases in labor productivity between 1978 and 1998 (Table 1). The average annual growth rate for all provinces was 7.4 percent over this period, but productivity performances varied substantially between subsets of provinces. While labor productivity in the coastal provinces of Fujian, Guangdong, Jiangsu, and Zhejiang grew at an annual rate of about 10 percent, labor productivity in the landlocked provinces of Heilongjiang, Gansu, and Qinghai grew at an average annual rate of only 4-5 percent.[11] The difference in average growth rates between the two groups of provinces is consistent with their initial levels of labor productivity. In 1978, the coastal provinces were on average less productive than the landlocked provinces. In a ranking of provinces by level of labor productivity in 1978, with the most productive province at rank 1, Fujian, Guangdong, and Zhejiang ranked 17^{th}, 12^{th}, and 16^{th}, respectively, while Qinghai and Gansu ranked 8^{th} and 10^{th}, respectively. However, the coastal provinces did not just catch up with the initially more productive landlocked provinces, they surpassed them, as by 1998, Fujian, Guangdong, and Zhejiang ranked 8^{th}, 5^{th}, and 7^{th}, respectively, while Qinghai and Gansu ranked 22^{th} and 25^{th}, respectively. These developments fit in the broader pattern of China's growth dynamics with a limited amount of absolute convergence in provincial per capita income in the 1980s and a growing income disparity in the 1990s. Previous research has suggested that these dynamics are reflecting the convergence of provinces to different steady state levels of per capita income. We will analyze to what extent capital deepening, efficiency gains, and technological progress have contributed to the observed pattern in China's provincial growth dynamics.

Turning now to the efficiency indexes reported in Table 1, we note that both Liaoning and Shanghai had efficiency indexes of 1 in 1978.[12] This result implies that our nonparametric approach excluded 26 provinces from the technology frontier. Figure 2 illustrates the positions of the provinces relative to the technology frontier in 1978 and suggests considerable dispersion of production activities.

The last column of Table 1 reports the efficiency indexes in 1998. In that year, only

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[11] Aziz and Duenwald (2003) report qualitatively similar results for comparisons of per capita GDP across provinces.

[12] The efficiency indexes were calculated by solving the linear programming problem (5) for 1978 and 1998. In 1978 we had only 28 observations. Consequently, we only used these 28 observations in solving problem (5). In 1998, however, we had 588 observations (28 for each year over 21 years).

Table 1: Capital intensity, labor productivity, and efficiency, 1978-98

Province	*Capital per Worker* k_{1978}	*Output per Worker* y_{1978}	*Efficiency Index* λ_{1978}	*Capital per Worker* k_{1998}	*Output per Worker* y_{1998}	*Efficiency Index* λ_{1998}
Beijing	4906	2451	0.773	36833	10860	0.747
Tainjin	4489	2254	0.765	28242	9564	0.797
Hebei	2181	868	0.523	8674	4049	0.743
Shanxi	2595	912	0.472	8197	3392	0.653
Inner Mongolia	2315	889	0.505	8145	3619	0.701
Liaoning	2405	1828	1.000	13514	6247	0.851
Jiling	2547	1270	0.667	8576	4213	0.781
Heilongjiang	2412	1736	0.948	9398	4404	0.753
Shanghai	6278	3907	1.000	59225	19367	1.000
Jiangsu	1254	897	0.941	15001	7300	0.933
Zhejiang	1115	689	0.813	11959	5906	0.861
Anhui	989	608	0.809	4774	2644	0.796
Fujian	1239	718	0.762	9294	5358	0.926
Jiangxi	2174	694	0.420	5418	2942	0.801
Shandong	1873	759	0.533	7622	3864	0.792
Henan	1297	580	0.589	5286	2618	0.727
Hubei	1460	790	0.712	8303	4433	0.845
Hunan	1099	645	0.772	3849	2292	0.836
Guangdong	1446	817	0.743	12864	6402	0.896
Guanxi	1307	521	0.524	3682	1974	0.749
Sichuan	1557	580	0.490	4877	2323	0.688
Guizhou	1567	442	0.372	3673	1474	0.561
Yunnan	1415	526	0.489	4737	1981	0.600
Shaanxi	1941	754	0.511	7072	2677	0.585
Gansu	3823	933	0.360	5052	2248	0.647
Qinghai	3532	1074	0.441	7316	2397	0.509
Ningxia	3096	959	0.436	7810	2849	0.572
Xingiang	2409	794	0.434	13318	4007	0.550
Mean	2312	1068	0.636	11525	4691	0.746
Std Dev.	1283	752	0.198	11830	3662	0.127

Sources: Provincial Yearbooks of China and authors estimates

Note: Capital intensity (capital per worker) and labor productivity (labor per worker) are in terms of Yuan per worker.

Figure 2: Production set and frontier, 1978

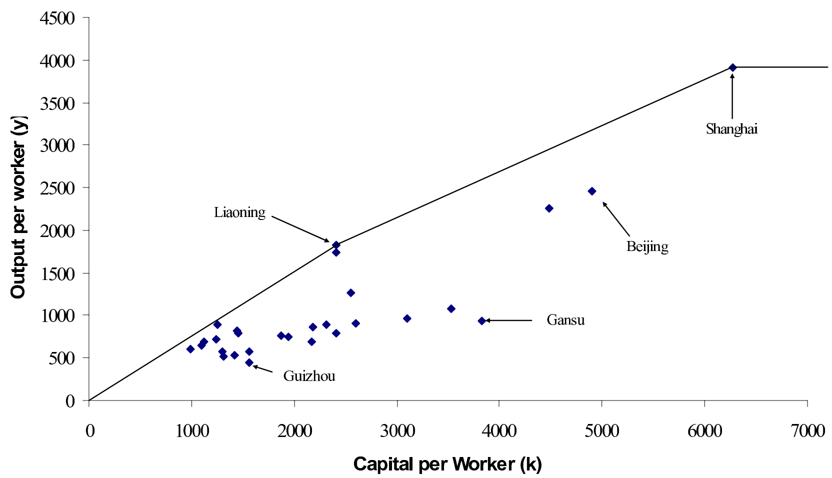


Figure 3: Production set and frontier, 1998

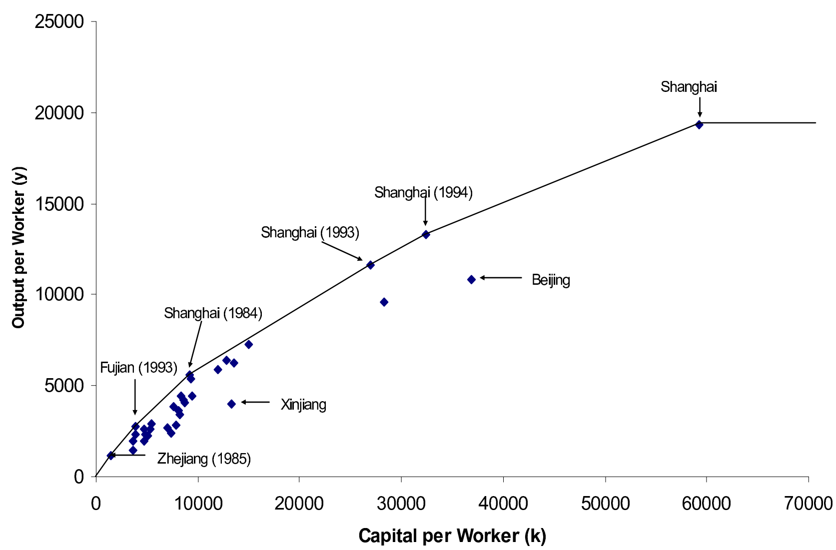
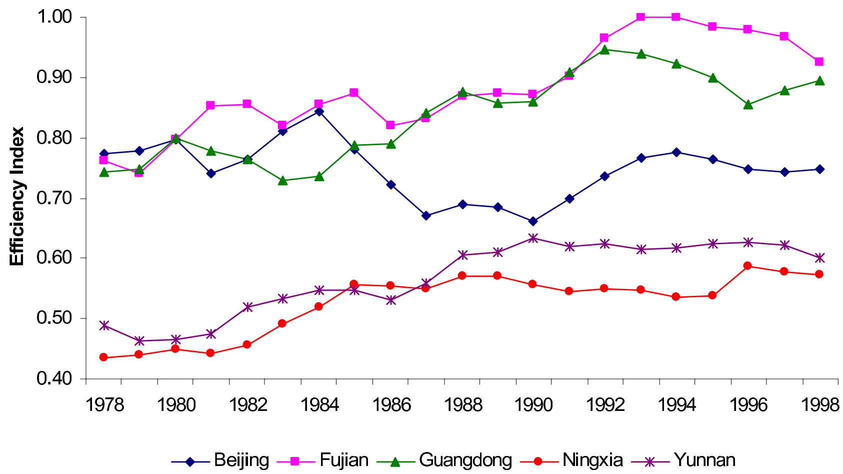


Figure 4: Selected provinces: Efficiency index, 1978-98



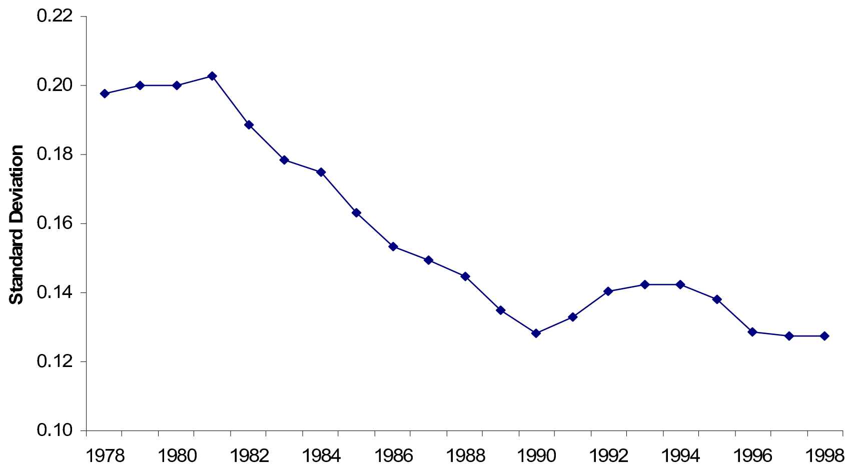
Shanghai had an efficiency index of 1.[13] Figure 3 represents the production set and its frontier in 1998. The frontier is shaped by the input-output combinations of Zheijang in 1985, Fujian in 1993, Shanghai in 1984, and Shanghai in 1993, 1994, and 1998. To clearly show the relative positions of the provinces in 1998, we excluded all other previous observations in the interior of the production set shown in Figure 3. Compared with the Figure 2, we note that production activities were generally closer to the frontier in 1998 than in 1978. Indeed, the average efficiency index for all provinces increased from 0.636 in 1978 to 0.746 in 1998, while the standard deviation declined from 0.198 to 0.128 over the same period. These trends suggests convergence both in the mean (β-convergence) and the standard deviation (σ-convergence) of efficiency indexes across provinces.[14]

Figures 4 and 5 further illustrate these trends. Figure 4 shows the time paths of the efficiency indexes of randomly selected provinces (Beijing, Fujian, Guandong, Ningxia, and Yunnan), which, except for Beijing, all trended upward between 1978 and 1998. Figure 5 depicts the time path of the standard deviation of the cross-sectional distribution of efficiency indexes, which shows that the dispersion of efficiency indexes across provinces declined sharply until the end of the 1980s and then remained broadly constant in the 1990s. Apparently, there was convergence in efficiency levels during the 1980s, but this process ended in the early 1990s. Further analysis reveals that most of the reduction in

[13] We have calculated these statistics for each year and we found that Shanghai always remained on the frontier. These results are available from the authors upon request.

[14] We formally tested for absolute β-convergence in efficiency across provinces by running the regression $g_{\lambda}^{i} = \beta_0 + \beta_1 \ln(\lambda_{1978}^{i}) + \varepsilon^{i}$, where g_{λ}^{i} denotes the average annual growth rate of efficiency index of province i between 1978 and 1998 and ε^{i} is the associated error term. The estimate of β_1 is -0.028 and is significant with a standard error of 0.004, supporting our contention of absolute convergence in efficiency indexes.

Figure 5: Standard deviation of efficiency indexes across all provinces, 1978-98



dispersion is explained by the improvement in efficiency indexes in landlocked provinces. The coastal provinces were already close to the technology frontier in 1978, and they remained close to the frontier over the next two decades. The convergence in efficiency indexes was possibly an important factor in the convergence in per capita income across provinces in the 1980s reported by Bell, Khor, and Kochhar (1993) and Jian et al. (1996).

Next, we turn to the decomposition of labor productivity into capital deepening, efficiency gains, and technological progress. Table 2 shows the results of this decomposition and the relative contributions of the three factors to productivity growth between 1978 and 1998. Note that average productivity growth is 7.4 percent of which 5.2 percentage points are contributed by capital deepening. Thus, about 70 percent of countrywide productivity growth across China's provinces is explained by capital deepening. The high contribution of capital accumulation to labor productivity growth is in line with findings of studies of the sources of overall GDP growth in China (Chow (1993); Chow and Li (1999); and Heytens and Zebregs (2003) and with studies of the sources of GDP growth in other East-Asian economies (Young 1995).

Although on average most of the productivity improvement was attributable to capital deepening, provincial level decompositions show disparate trends. We found, for example, that the contribution of capital deepening to average annual labor productivity growth in Fujian, Jiangsu, and Zhejiang during 1978-1998 was 8-9 percentage points, while it was less than 3.5 percentage points in Gansu, Ningxia, and Qinghai. As we noted before, in almost all coastal provinces capital deepening accounted for at least 75 percent of labor productivity growth. The high rates of capital accumulation in coastal provinces reflect in part very large inflows of foreign direct investment (FDI). The coastal provinces have been able to attract large amounts of FDI because of their initially low capital-labor ratios,

Table 2: Decomposition of labor productivity growth, 1978-98 (in percent)

Province	Productivity Growth g_y	Change in Efficiency g_{eff}	Change in Technology g_{tech}	Capital Deepening g_{cap}	Relative Contribution of: Efficiency	Technology	Capital
Beijing	7.4	-0.2	3.4	4.1	-2.3	46.5	55.8
Tainjin	7.2	0.2	3.0	4.1	2.8	41.1	56.1
Hebei	7.7	1.8	0.9	5.1	22.8	11.5	65.7
Shanxi	6.6	1.6	0.7	4.2	24.7	11.3	64.0
Inner Mongolia	7.0	1.6	0.7	4.7	23.4	10.4	66.3
Liaoning	6.1	-0.8	1.6	5.4	-13.2	25.8	87.4
Jiling	6.0	0.8	0.8	4.4	13.2	13.9	72.9
Heilongjiang	4.7	-1.2	1.0	4.8	-24.7	21.9	102.8
Shanghai	8.0	0.0	4.2	3.9	0.0	51.8	48.2
Jiangsu	10.5	0.0	1.9	8.6	-0.4	18.2	82.2
Zhejiang	10.7	0.3	1.6	8.9	2.7	14.7	82.7
Anhui	7.3	-0.1	0.3	7.1	-1.1	4.5	96.6
Fujian	10.0	1.0	1.1	7.9	9.7	11.4	78.9
Jiangxi	7.2	3.2	0.2	3.8	44.7	2.8	52.5
Shandong	8.1	2.0	0.7	5.5	24.3	8.4	67.3
Henan	7.5	1.1	0.3	6.1	14.0	4.6	81.4
Hubei	8.6	0.9	0.9	6.9	9.9	10.4	79.7
Hunan	6.3	0.4	0.3	5.6	6.3	4.7	89.0
Guangdong	10.3	0.9	1.7	7.7	9.1	16.3	74.6
Guanxi	6.7	1.8	0.3	4.6	26.8	4.5	68.7
Sichuan	6.9	1.7	0.4	4.9	24.5	5.1	70.5
Guizhou	6.0	2.1	0.3	3.6	34.5	5.0	60.9
Yunnan	6.6	1.0	0.3	5.3	15.4	5.0	79.6
Shaanxi	6.3	0.7	0.5	5.1	10.7	8.2	81.1
Gansu	4.4	2.9	0.3	1.2	66.7	6.6	26.8
Qinghai	4.0	0.7	0.6	2.7	17.9	13.9	68.3
Ningxia	5.4	1.4	0.7	3.4	24.9	12.6	62.3
Xingiang	8.1	1.2	1.6	5.3	14.6	19.4	65.9
Mean	7.4	1.0	1.1	5.2	14.3	14.7	71.0
Std Dev.	1.7	1.0	1.0	1.8	17.7	12.7	15.6

Sources: Provincial Yearbooks of China and authors' estimates based on equations (9) and (10).

geographic location, and preferential policies from the national government that allowed them to establish special economic zones (SEZs) and open cities, which offer a more liberal investment and trade regime than other areas, as well as tax incentives. The large inflows of FDI have helped to boost GDP growth in the recipient provinces. Zebregs (2003) estimated that FDI inflows contributed 1.6 percentage points to average annual GDP growth in provinces with SEZs and open cities during 1990-97, while FDI inflows contributed only 0.2 percentage points to average annual GDP growth in other provinces.[15] It should also be noted that even though the coastal provinces were among the least advanced provinces in 1978, their level of efficiency was high compared to many other provinces, a fact that also may have contributed to the large inflow of FDI.[16]

An important remaining question is whether there is any systematic relationship between the growth rates of the three components of labor productivity growth and the initial level of labor productivity. To investigate this, we first regressed the average annual growth rate of efficiency indexes on initial labor productivity. We found that the coefficient of labor productivity is negative and statistically significant.[17] This finding suggests that improvement in efficiency was higher in initially less advanced provinces than in richer ones, which is consistent with our earlier observation. When we regressed change in technology on initial productivity level, we found a positive and statistically significant relation, which suggests that initially more productive provinces have benefited more from technological progress than less developed provinces.[18] This result is in support of theories of technological diffusion that conjecture that the cost of adopting new technologies declines with the level of economic development or the abundance of human capital in the receiving location.[19] Finally, regressing the growth rate of capital deepening on the initial (log) level of labor productivity yielded a negative and statistically significant relation, suggesting that capital deepening was higher in initially less developed provinces.[20] We also regressed the growth rate of productivity growth on the initial (log) productivity level. Although the coefficient was negative (-0.004), it was not

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[15] These contributions only reflect the impact of FDI on capital accumulation. Zebregs (2003) also investigated the impact of FDI on growth in total factor productivity and estimated that through this channel FDI contributed 2.5 percentage points per year to overall GDP growth during the 1990s.

[16] It is of course possible that the causality runs in the other direction as well, as the large exposure of coastal provinces to foreign trade and investment is likely to have had a positive impact on efficiency.

[17] Specifically, given the growth rates of efficiency indexes in Table 2 and initial labor productivity levels in Table 1, we ran the regression $g^i_\lambda = c + \beta \ln(y^i_{1978}) + \varepsilon^i$, where c is the intercept, g^i_λ is the average annual growth rate of the efficiency index of province i, y^i_{1978} is the initial productivity level and ε^i is the associated error term. The estimate of β is -0.010 and is significant with a standard error of 0.003.

[18] The corresponding point estimate of the coefficient on labor productivity is 0.016 with a standard error of 0.002.

[19] See for example Nelson and Phelps (1966) and Findlay (1978).

[20] The corresponding point estimate of the coefficient on labor productivity is -0.009 with a standard error of 0.003.

statistically significant (0.005).

IV. Conclusion

We have used a recently developed nonparametric approach to decompose labor productivity growth in China's provinces into three components: capital deepening, efficiency gains, and technological progress. This decomposition has allowed us to investigate the contribution of each of the three factors to the pattern of productivity growth across provinces. We found that capital deepening was by far the biggest source of labor productivity growth in China's provinces between 1978 and 1998. In line with the standard neoclassical growth model, the rate of capital deepening tended to be higher in initially less advanced provinces. But other factors also appear to have been important in promoting investment as the coastal provinces, which benefitted from preferential policies and close proximity to Hong Kong SAR and Taiwan Province of China, recorded the highest rates of capital deepening.

Efficiency improved between 1978 and 1998, especially in the initially least productive provinces which often had the largest agricultural sectors. The efficiency gains are almost certainly a reflection of China's economic reforms, which have facilitated a profound transformation of the country's economic structure, including a large reallocation of labor from unproductive farming and state-owned enterprises to more productive industries in the non-state sector.

Technological progress was generally largest in the initially more productive provinces in line with theories of technological diffusion. Perhaps somewhat surprisingly, technological progress in the coastal provinces, which recorded the largest inflows of FDI, was not noticeably higher than in other provinces. A possible explanation is that FDI in the coastal provinces did not introduce important new technologies because it was concentrated in low-tech sectors or did not have significant spillovers to the rest of the local economy. This explanation may hold up for the 1980s when FDI was dominated by investors based in Hong Kong SAR and Taiwan Province of China who sought to exploit low-cost labor in SEZs for export processing, but not for the 1990s when FDI became increasingly dominated by European, Japanese, and U.S. multinationals seeking to supply the Chinese market through local production capacity and alliances emerged between foreign-funded enterprises and local township and village enterprises. Separate decompositions of productivity growth for the 1980s and 1990s could perhaps shed more light on this puzzle.

Our analysis has shown that although there appears to be no absolute convergence in labor productivity across China's provinces, there is evidence of absolute convergence in efficiency. We also found evidence of absolute convergence in capital deepening, but this result may be sensitive to the choice of our sample period. The importance of capital deepening for productivity growth together with the observation that by 1998 the initially poorer coastal provinces had surpassed several initially richer landlocked provinces points to conditional convergence in capital deepening.

This paper has provided a qualitative analysis of the factors that might explain the observed patterns of capital deepening, efficiency gains, and technological progress across China's provinces. We plan to extend our work with a more rigorous econometric analysis of the determinants of provincial productivity growth in China. It will be interesting to understand better how geography, preferential policies, openness, and other structural factors have affected the three components of labor productivity growth in China's provinces.

A DATA APPENDIX

This appendix provides additional information about our data sources and the construction of capital stocks. We obtained provincial level output (GDP) data from various issues of the *Statistical Yearbook of China*.

Labor data reported in the *Statistical Yearbook of China* contain large swings and do not take into account the possible change in employment due to migration between provinces. For example, according to the reported series there was a substantial decline in employment levels since the middle of the 1980s. We, instead, used a data set compiled by Young (2000), who used provincial yearbooks, *A Compilation of Historical Statistics* (State Statisitcial Bureau, 1990), data from Hsueh, Li and Liu (1993), and various issues of provincial yearbooks.

Physical capital is accumulated according to

$$K_{t+1} = I_t + (1-\delta)K_t,\ K_0 > 0,$$

where I_t and K_t denote investment and capital stocks, respectively, at time t; $\delta > 0$ represents the depreciation rate and K_0 is the initial capital stock. Thus, to compute capital stocks at time t we need investment data, depreciation rates, and estimates of initial capital stocks. We used investment data from various issues of the provincial yearbook. These data are available from 1952. We, however, noted that the data were considerably low and volatile in the pre-1978 era. Moreover, the investment data before 1978 were not available for Guangdong and Jiangxi. To be fully comparable across provinces, we, therefore, restricted ourselves to the investment data between 1978 and 1998.[21] We assumed that the

[21] We further noted that the investment data for Qinghai and Ningxia were relatively high over 1978-98. For

depreciation rate δ is 5 percent. We calculated initial capital stocks by $K_0 = I_0/(g+\delta)$, where g is the annual growth rate of the capital stocks before 1978,[22] which we also assumed to be 5 percent.

example, their investment to GDP ratios were above 50 percent and in some years even reached 70 percent. Given that there were no significant changes in their output trends, we concluded that measurement errors could be one possible reason for these high investment levels. Consequently, we assumed that the investment to output ratio in each of these provinces is the same with the average of the investment to output ratios of other provinces in the region: Shaanxi, Gansu, and Xinjiang. These adjustments do not have any impact on either the position of frontier or the efficiency levels of other provinces. Without these adjustments, we estimated considerably lower efficiency indexes for these provinces.

[22]Implicit in this formula is the assumption that the capital series has been growing at constant rate before the investment data became available. Young (1995) and Hall and Jones (1999) also used the same technique to estimate initial capital stocks.

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