# Decomposition of Economic and Productivity Growth in

# Post-reform China

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ABSTRACT

This paper examines and applies the theoretical foundation of the decomposition of economic and productivity growth to the thirty provinces in China's post-reform economy. The four attributes of economic growth are input growth, adjusted economies of scale effect, technical progress, and efficiency growth. A stochastic frontier model is used to estimates the growth attributes, and a human capital variable is incorporated in the translog production function. The empirical results show that input growth is the major contributor to economic growth and human capital is inadequate even though it has a positive and significant effect on growth. Technical progress is the main contributor to productivity growth and the scale economies has become important in recent years, but technical efficiency has edged downwards in the sample period. The relevant policy implication for a sustainable post-reform China economy is the need to promote human capital accumulation and improvement in technical efficiency.

1.  **Introduction**

China's post-reform economy has been characterized by high and persistent growth. Many empirical studies have explored its sources of economic growth and productivity change (Borensztein and Ostry, 1996; Lin, 2000; Wang and Yao, 2003, and Fleisher *et al*., 2005). Recent studies used physical capital constructed from investment data to examine growth and productivity. Chow and Li (2002) and Li (2003) constructed the national and provincial capital stock data using different investment sources to estimate productivity change in China, while Liu and Li (2006) further extended the analysis on growth and productivity to incorporate the human capital variable and provincial performances.

In studying the technical change in the U.S., Solow (1957) differentiated the movements along the production function from the shifts of the production function. The former is caused by the input growth while the latter is defined as technical progress. Assuming constant returns to scale and perfect competition in the product market, he showed that the growth of output per unit of labor can be decomposed into technical progress and the weighted growth of capital per unit of labor. Alternatively, technical progress can be estimated with the time series data of output per unit of labor, capital per unit of labor, and the share of capital. This measure of technical progress is referred to as "Solow residual."

For a production function with multiple inputs, the total factor productivity (TFP) growth is widely used in measuring productivity change. The classical approach to the study of TFP growth often assumed optimality in production capacity. The output-oriented stochastic frontier production approach (Aigner *et al*., 1977) argues that, with given sets of factor inputs and due to possible technical inefficiency, there can be deviation between actual and optimal output. The measure of technical inefficiency can be added to the analysis of TFP growth through the use of stochastic frontier model. Alternatively, both the data envelopment analysis (DEA) (Charnes *et al*., 1978) and the distant function approach (Fu, 2005; Brummer *et al*., 2006) can also be used to measure technical efficiency, but due to their non-parametric and deterministic nature, the stochastic frontier analysis tends to be the more popular approach.

There are at least three different ways to measure TFP growth: the index-number

approach, the production function approach, and the cost function approach (Cowing and Stevenson, 1981; Denny *et al*., 1981; Bauer, 1990). The index-number approach has been used mostly in the earlier studies. The production function approach is more convenient than the cost function approach since it does not require any cost information. In spite of different measurement approaches, the TFP growth is a composition of technical progress, technical efficiency change, and economies of scale effect (Bauer, 1990; Kumbhakar and Lovell, 2000). Technical progress refers to an outward shift of the economy's entire production frontier due probably to a greater use of technology and innovation and attained a larger production capacity. Technical efficiency change refers to an overall movement from a position within the production frontier towards the production frontier. The economies of scale effect incorporates the output and productivity changes due to the returns of scale. With an increasing returns-to-scale production, output increases at a higher percentage with respect to input increases and induces productivity improvement. The empirical study of this decomposition of the TFP growth has been applied to the TFP growth in Korea with the production function approach by Kim and Han (2001) and with the cost function approach by Kwack and Sun (2005), and in the U.S. with the production function approach by Sharma *et al*., (2007).

This paper follows Denny *et al*., (1981), Bauer (1990), and Kumbhakar and Lovell (2000) to examine the theoretical foundation of the decomposition of economic and productivity growth and applies the composition to study the economic growth in post-reform China. We begin the theoretical discussion of the decomposition with the production function approach in Solow's (1957) classical model. In addition to relaxing his two key assumptions of constant returns to scale and perfect competition in the product market, we consider technical inefficiency in a stochastic frontier model. The output growth is then decomposed into: input growth, adjusted economies of scale effect, technical progress, and efficiency growth. Furthermore, the productivity (or TFP) growth is decomposed into: adjusted economies of scale effect, technical progress, and efficiency growth. This decomposition is similar to that in Kunbhakar and Lovell (2000).

The empirical part of this paper expands the work by Liu and Li (2006) and Li (2003) and estimates the components of the economic and productivity growth for China's thirty provinces, grouped into four geographical and economic regions, during

the period of 1985-2000. The estimation is based on the stochastic frontier model with a translog production function (Christensen *et al.*, 1971) that incorporates a human capital variable. The production stochastic frontier analysis has been used in the studies of Chinese economy. Several studies have investigated the production efficiency of economic sectors. Kalirajan *et al.* (1996) used the provincial-level agricultural data during the period 1970-87 to study the sources of TFP growth with a decomposition of technical progress and changes in technical efficiency. Using grain, cash-crop, and rural industrial sectors data, Carter and Estrin (2001) estimated a multiple-output stochastic production frontier for the period of 1986 -1995. Based on the panel data for 30 provinces of China during 1991-1997, Hu and McAller (2005) studied the technical efficiency changes for the agricultural growth at the national and regional levels. Tong (1999) estimated the production frontier efficiency of the township and village enterprise (TVEs) during the period of 1988-1993 for the coastal and non-coastal regions. Based on the data of 1984-1989 for 200 rural enterprises located in ten provinces, Dong and Putterman (1997) find that these enterprises displayed large differences in productivity. Using panel data for the period of 1985-1991, Wu (1995) studied the three sectors of state industry, rural industry and agriculture; his results showed that technical progress has dominated technical efficiency changes as the main source of TFP grow in all of the three sectors of the economy; with an exception that technical efficiency change in agriculture appears to be the main component of productivity growth in most provinces in 1985. Wu (2000) examined the two components of productivity growth; technical progress and technical efficiency, of the Chinese economy by exploring frontier production models for its 27 provinces in the period of 1981-1995. He argued that growth in inputs and efficiency improvement attributed to economic growth in the 1980s, while the contribution of technical progress was dominant in the 1990s. Wu (2003) used unelaborated investment data, a constant return assumption and an assumed rate of depreciation to study the sources of productivity growth in China's post-reform economy. These studies of the TFP growth focus on either one or two components of productivity change; while technical progress or economies of scale, or both have been overlooked.

In our study, the thirty provinces in China are divided into four regions. These four sub-regions in China are chosen to reflect the geographical strength and economic

growth concentration. The South region comprises nine southern provinces, commonly known as the Pearl River Delta region of Fujian, Guangdong, Guangxi, Hainan, Jiangxi, Hunan, Sichuan, Guizhou and Yunnan. The East region consists of twelve provinces, including mainly provinces in the Yellow River and Yangtze River Delta regions of Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Shandong, Anhui, Henan, Hubei, Shanxi and Gansu. The West region refers to the remote provinces of Mongolia, Tibet, Shaanxi, Qinghai, Ningxia, and Xinjiang. The remaining three provinces in the North East region are Jilin, Heilongjiang and Liaoning, which consist of the traditional state-owned heavy industries.

Section 2 elaborates on the growth experience in post-reform China, giving various sources of data used in the empirical analysis. Section 3 discusses the theoretic foundation of the decomposition of economic and productivity growth and introduces the empirical model. Section 4 presents the empirical results; section 5 concludes the study.


## 2.    China's Post-reform Economic Performance

The reliability of China's macroeconomic data has been a concern (Young 2000 and 2003; Rawski and Xiao 2001; Holz 2004). For example, Holz (2006) and Chow (2006) debated on the various measurement problems in estimating the physical capital stock series. After taking into account the various additional estimations and assumptions, such as scrap rate, depreciation rate of the same capital equipment at different years, Holz (2006) concluded that the estimation of China's physical capital stock based on different assumptions do not vary much. The fact is that various capital stock series can be used as estimates to represent an acceptable scenario for empirical time series analysis.[1] Chow and Li (2002) rightly argued that China's macroeconomic data collection system is constantly improving, and believed that discrete statistical differences may cancel out each other in a trend analysis.[2]

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[1]  Recent studies (e.g. OECD 2001) argue that the more relevant contribution of a capital asset is the flow of capital services provided by the asset.

[2]  While it is believed that China's GDP data are over-estimated, recent reports showed that due to the increase in the informal sector, China's GDP has been under-estimated and was revised upwards by US$300 billion in December 2005 (*South China Morning Post*, December 13 and 21, 2005 and January 13, 2006).

The data for China's thirty provinces used in this paper comes mainly from the latest issue of the *Statistical Yearbook of China*, the *Comprehensive Statistical Data and Materials in 50 Years of New China* (1999), and the two Chinese censuses of 1990 and 2000. Figure 1 shows China's national and regional real GDP for the two decades of 1984 – 2004. The national real GDP has increased tremendously, giving an annual average real GDP growth rate of 9.8 percent in the two decades. China experienced a double or close to double digit real GDP growth rate for the period of 1992 - 2004. The twelve provinces in the East region experienced the highest average real GDP, and its growth has accelerated since 1992. Although the real GDP growth rate of the six provinces in the West region remained high, they experienced the lowest real GDP, and widened the real GDP gap between provinces in the East and West regions. The real GDP in the South and North East regions is close to the national average.

The estimation on the production function requires an indicator for the physical capital stock, which can often be approximated from investment figures (Chow and Li 2002; Young 2003; Wu 2000). We followed the methodology and updated the capital stock used in Chow and Li (2002), Li (2003) and Liu and Li (2006) to 2004. Figure 2 shows the average national and regional physical capital stock series for the sample period. The large average physical stock in the three provinces in the North East region has been overtaken by provinces in the East region in 2004. Despite the large export in light manufacturing, provinces in the South region has a lower than national average capital stock, while provinces in the West region have the lowest level of physical capital stock.

Human capital is generally related to the level of education, though empirically, a number of indicators are used as proxy for human capital (Barro and Lee, 1993, 1996 and 2001; Benhabib and Spiegel, 2005; Gemmell, 1996).[3] Barro and Lee (2001) and Howitt (2005) maintained that life expectancy can impact economic development via human capital-adjusted mortality rate. An increase in life expectancy would lead to an increase in human capital accumulation. Scholars made various assumptions and proxies in constructing China's human capital stock (Young 2003; Wang and Yao 2003). Liu and Li

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[3] These indicators include (1) total years of schooling derived from educational enrolment ratios; (2) international test scores; and (3) numbers of workers pass through primary, secondary and tertiary education.

(2006, Table 2 and Appendix B) discussed China's post-reform education performance and constructed China's human capital stock using a perpetual inventory approach (Barro and Lee, 1993, 1996 and 2001). The initial human capital data are derived from Population Censuses of 1990 and 2000. The annual graduates of the six schooling levels (Higher Education with 14.5 years, Specialized Secondary, Vocational Secondary and Senior Secondary with 11 years, Junior Secondary with 8 years and Primary Education with 5 years) and the total numbers of persons that have attained various schooling levels within the age 15 - 64 years in 1990 are used as the benchmark. Data on the annual graduates in each schooling level are adjusted by the mortality rate and inter-provincial migration figures. Due to a change in the classification on the education level of graduates after 2000, we can only extend the data for human capital stock in Liu and Li (2006, Appendix B) to 2000.[4]

Figure 3 shows China's human capital stock measured in term of the average schooling years. The number of average schooling years has improved, with an national average of 4 years in 1984 increased to over 5 years in 2000.[5] Provinces in the North East and East regions showed higher average schooling years than the national average, due probably to the demand by the traditional heavy industries, while provinces in the West and South regions showed a lower level of human capital.

## 3.    Decomposition and Estimation Model

We begin with Solow's (1957) simple Cobb-Douglas function with output $Y$ and two inputs, labor ($L$) and capital ($K$), at time $t$ to demonstrate the decomposition of economic growth.

$$Y_t = A_t L_t^{\alpha} K_t^{\beta},$$
(1)

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[4]  The statistics on the number of graduates at Specialized Secondary and Vocational Secondary education levels are not available since 2004.

[5]  China's average schooling years derived for 1985, 1990, 1995 and 2000 are 4.17, 4.62, 5.10 and 6.27 years, respectively. Based on enrolment ratios for the total population aged 25 and above, Barro and Lee's (2001) estimates are 4.15, 5.23, 5.48 and 5.74 years, respectively.

where $A_t$ measures the cumulative shift of the production function and $\alpha$ and $\beta$ are parameters. Since $A_t$ is *parametrically* separated from the rest of other inputs, the shift in the production function represents a neutral technical change. Taking logarithm transformation and then differentiation with respect to time *t*,

$$\dot{Y}_t = \dot{A}_t + \alpha \dot{L}_t + \beta \dot{K}_t, \tag{2}$$

where a dot over a variable represents the percentage change. For example, $\dot{Y}_t = \dfrac{\partial Y_t / \partial t}{Y_t}$.

$\dot{A}_t$ represents the technical progress or technical change. A constant returns to scale applies when $\alpha + \beta = 1$. Define output per unit of labor as $y = \dfrac{Y}{L}$ and capital per unit of labor as $k = \dfrac{K}{L}$. Then

$$\dot{y}_t = \dot{A}_t + \beta \dot{k}_t. \tag{3}$$

The two major components for economic growth are technical progress and input growth. The weight $\beta$ is the capital share if factors are paid by their marginal products and the product market is perfectly competitive. Rearranging the terms, Solow (1957) considers the following estimation for the technical progress:

$$\dot{A}_t = \dot{y}_t - \beta \dot{k}_t. \tag{4}$$

This has led to the so-called "Solow residual." Given a measure of capital share, the technical progress can be estimated with the data on output, capital and labor growth. The decomposition shown in Equations (3) and (4) is called the *growth accounting* approach, which has been standardized in growth textbooks and analysis (Romer, 2001; Mankiw *el al.*, 1992).

   The Cobb-Douglas production function can be generalized into a production

function with stochastic frontier (Aigner *et al.*, 1977; Battese and Coelli, 1988 and 1992; Greene 2005),

$$Y_t = F(X_{1t}, X_{2t}, \cdots, X_{nt}, t) e^{-u_t},$$ (5)

where $Y$ is the actual level of output; $X_{it}$ is $i^{th}$ input; and $u$ is a half-normally distributed random variable with a positive mean. $F$ is the potential production function with $n$ inputs. The inclusion of $t$ in $F$ allows for the production function to shift over time, due to technical progress. The last term in Equation (5) measures technical inefficiency. Taking logarithm transformation yields

$$\log Y_t = \log F(X_{1t}, X_{2t}, \cdots, X_{nt}, t) - u_t.$$ (6)

Technical inefficiency occurs when $u_t > 0$ and the level of $\log Y_t$ is less than the level of $\log F$. Differentiating Equation (6) with respect to time yields the following output growth equation:

$$\dot{Y}_t = \sum_i \frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F} \dot{X}_{it} + \frac{\partial F / \partial t}{F} - \frac{\partial u_t}{\partial t},$$ (7)

Define the technical efficiency (*TE*) as the ratio of the actual output and the potential output:

$$TE_t = \frac{Y}{F} = e^{-u_t}.$$ (8)

Then technical progress $\dot{A}_t$ and the growth of the technical efficiency $\dot{TE}_t$ are

$$\dot{A}_t = \frac{\partial F / \partial t}{F},$$ (9)

$$T\dot{E}_t = -\frac{\partial u_t}{\partial t}. \tag{10}$$

Substituting (9) and (10) into (7),

$$\dot{Y}_t = \sum_i \frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t. \tag{11}$$

This equation shows that output growth can be decomposed into three components: input growth, technical progress, and growth of technical efficiency. Intuitively, $\frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F}$ is a weight and the first component is the weighted sum of individual input growth.

When there is no technical efficiency term, Equation (11) can be reduced into Solow's decomposition with two assumptions. If the product and factors markets are perfectly competitive, the first-order condition for profit maximization of $PF - \sum_i w_{it} X_{it}$ gives $\frac{\partial F}{\partial X_{it}} = \frac{w_{it}}{P}$, where $P$ is the price of output and $w_{it}$ is the nominal price of input $X_{it}$. This first-order condition means factors are paid the value of their marginal products. Equation (11) becomes

$$\dot{Y}_t = \sum_i \frac{w_{it} X_{it}}{PF} \dot{X}_{it} + \dot{A}_t \tag{12}$$

If the product market is perfectly competitive, price is equal to the average cost; $PF$ is equal to the total cost (C); and $\frac{w_{it} X_{it}}{PF} = \frac{w_{it} X_{it}}{C_t}$. Denote the cost share for input $X_{it}$ as $s_{it} = \frac{w_{it} X_{it}}{C_t}$. Then the weight $\frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F}$ in Equation (11) is equal to the cost share for each input ($\frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F} = s_{it}$) and Equation (12) becomes

$$\dot{Y}_t = \sum_i s_{it} \dot{X}_{it} + \dot{A}_t. \tag{13}$$

This equation can be simplified into Equation (3) if $F$ is a Cobb-Douglas function with constant returns to scale and two inputs.

To relax Solow's (1957) assumptions, we focus on the *weight* $(\frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F})$ in Equation (11). This weight is actually the output elasticity with respect to input $X_{it}$.

Denote $\eta_{it} = \frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F}$ and let $\eta_t = \sum_i \eta_{it}$ (the sum of the elasticity to each input). It can be shown that $\eta_t$ is a measure of economies of scale. Suppose changes in all inputs have the same scale, $\Delta X_{it} = aX_{it}$. Consider the changes in output $\Delta F$ by taking the total derivative of $F(X_1, X_2, \cdots, X_n, t)$ and substituting $\Delta X_{it} = aX_{it}$ into $\Delta F$, we have

$$\Delta F = \sum_i \frac{\partial F}{\partial X_{it}} \Delta X_{it} + \frac{\partial F}{\partial t} \Delta t = F \sum_i \frac{\partial F}{\partial X_{it}} \frac{aX_{it}}{F} + F\dot{A}_t = Fa \sum_i \eta_{it} + F\dot{A}_t$$

$$= aF\eta_t + F\dot{A}_t. \tag{14}$$

The production shows increasing (constant, decreasing) returns to scale when $\eta_t > 1$ (= $1, < 1$).

To rewrite the *weight* or the term of output elasticity with respect to input, we consider the following cost minimization problem under perfect competition in the factors markets, but not necessary in the product market.

$$\min_{X_{it}} C_t = \sum_i w_{it} X_{it} \quad \text{subject to} \quad Y_t = F(X_{1t}, X_{2t}, \cdots, X_{nt}, t)e^{-u_t}. \tag{15}$$

Write the objective function and the constraint in the Lagrangian form.

$$L(X_{it}, \lambda) = \sum_i w_{it} X_{it} + \lambda(Y_t - Fe^{-u_t}), \tag{16}$$

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where $\lambda$ is the Lagrange multiplier. The first-order condition for minimization is

$$w_{it} = \lambda \frac{\partial F}{\partial X_{it}} e^{-u_t}. \tag{17}$$

The Lagrange multiplier has the following property.

$$\lambda = \frac{\partial C_t}{\partial Y_t}, \tag{18}$$

where $C$ is the minimized cost in the minimization problem. Substitute (18) into (17),

$$w_{it} = \frac{\partial C_t}{\partial Y_t} \times \frac{\partial F}{\partial X_{it}} e^{-u_t}. \tag{19}$$

Under the profit maximization, marginal cost $\dfrac{\partial C_t}{\partial Y_t}$ is equal to marginal revenue. This implies that input price does not equal to the marginal revenue of product if there is technical inefficient. Multiplying both side by $X_{it}$ and divided by the total cost ($C$), we get the following cost share equation:

$$\frac{w_{it} X_{it}}{C_t} = \frac{\partial C_t}{\partial Y_t} \frac{\partial F}{\partial X_{it}} \frac{X_{it}}{C_t} e^{-u_t} = \frac{\partial C_t}{\partial Y_t} \frac{Y_t}{C_t} \frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F_t}. \tag{20}$$

Denote $\theta_t = \dfrac{\partial C_t}{\partial Y_t} \dfrac{Y_t}{C_t}$ as the cost elasticity with respect to output. Then

$$\frac{w_{it} X_{it}}{C_t} = \theta_t \eta_{it}. \tag{21}$$

Taking the sum for all inputs gives $1 = \theta_t \sum_i \eta_{it}$ and $1 = \theta_t \eta_t$. Then

$$\eta_t = \theta_t^{-1}. \tag{22}$$

This implies that output elasticity to input is the inverse of the cost elasticity to output (Hanoch, 1975). When production is increasing (decreasing, constant) returns to scale, the cost elasticity to output is less than (greater than, equal to) one. Substituting Equation (22) into Equation (21) and rearranging the terms, the weight is

$$\frac{\partial F}{\partial X_{it}} \frac{X_{it}}{F} = \eta_t \frac{w_{it} X_{it}}{C_t}. \tag{23}$$

Substituting (23) into the output growth Equation (11) gives

$$\dot{Y}_t = \eta_t \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t, \tag{24}$$

By subtracting and adding $\sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it}$ and rearranging terms to consider the unit economies of scale, Equation (24) becomes

$$\dot{Y}_t = \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} + (\eta_t - 1) \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t. \tag{25}$$

Output growth can now be decomposed into four components: weighted sum of input growth, adjusted economies of scale effect, technical progress, and growth of technical efficiency. The weight in the first term for each input growth is equal to the cost share of each input. For the second term, the economies of scale effect $\eta_t - 1$ is adjusted by the growth of aggregate input $\sum \frac{w_{it} X_{it}}{C_t} \dot{X}_{it}$. Using Equation (22), the scale effect term

$\eta_t - 1$ becomes

$$\eta_t - 1 = \theta_t^{-1} - 1 = \frac{AC_t}{MC_t} - 1 = \frac{AC_t - MC_t}{MC_t}, \tag{26}$$

since the cost elasticity $\theta_t$ is the ratio of marginal cost and average cost ($\theta_t = \frac{MC_t}{AC_t}$,

where $MC_t = \frac{\partial C_t}{\partial Y_t}$ and $AC_t = \frac{Y_t}{C_t}$ ). This implies the economies of scale effect is

determined by the difference between $AC_t$ and $MC_t$. This difference can be considered

as a markup effect when the market is not perfectly competitive.

The decomposition in Equation (25) has relaxed the two assumptions in Solow's
(1957) decomposition. First, the assumption of constant returns to scale is no longer
required since $\eta_t$ need not equal to one. When production is constant returns to scale,
$\eta_t = 1$, Equation (25) can be reduced to Equation (13). This implies that perfect
competition in the product market is not required to derive Equation (13); only the
constant returns to scale is sufficient. Second, the assumption of perfect competition in
the product market is not required for the growth decomposition formula. Equation (25)
can be used for a non-competitive industry or economy with either increasing, constant,
or decreasing returns to scale.

Equations (21) and (22) gives $\frac{w_{it} X_{it}}{C_t} = \frac{\eta_{it}}{\eta_t}$. Then Equation (25) becomes

$$\dot{Y}_t = \sum_i \frac{\eta_{it}}{\eta_t} \dot{X}_{it} + (\eta_t - 1) \sum_i \frac{\eta_{it}}{\eta_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t. \tag{27}$$

Equation (27) shows the decomposition without cost information (*w*). As long as the
parameters of the production function can be estimated, Equation (27) can be used for the
empirical estimation of the sources of output growth.

The above decomposition of economic growth can be extended to the

decomposition of productivity growth. The productivity for a production function with single output ($Y_t$) and single input ($X_t$) at time $t$ is $\dfrac{Y_t}{X_t}$. For a production function with multiple inputs as Equation (5), we can consider labor productivity as in Solow (1957). Rewrite Equation (25) as the growth of the output per unit of labor by subtracting the growth of labor from both sides of Equation (25). It gives

$$\dot{Y}_t - \dot{L}_t = \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} - \dot{L}_t + (\eta_t - 1) \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t.$$

(28)

Let $X_{1t} = L_t$. Then,

$$\dot{Y}_t - \dot{L}_t = \sum_{i \neq 1} \frac{w_{it} X_{it}}{C_t} (\dot{X}_{it} - \dot{L}_t) + (\eta_t - 1) \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t \qquad (29)$$

and

$$\dot{y}_t = \sum_{i \neq 1} \frac{w_{it} X_{it}}{C_t} \dot{x}_{it} + (\eta_t - 1) \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t, \qquad (30)$$

where $x_{it} = \dot{X}_{it} - \dot{L}_t$. This decomposition is similar to Solow's decomposition. However, the adjusted scale effect term is included and the economies of scale can affect labor productivity.

In addition to labor productivity, a commonly used concept for the productivity is the total factor productivity (TFP), which can be defined as

$$TFP_t = \frac{Y_t}{\Phi_t}, \qquad (31)$$

where $\Phi$ is the aggregate input. Taking logarithm and differentiation with respect to time, the TFP growth is

$$TF\dot{P}_t = \dot{Y}_t - \dot{\Phi}_t, \tag{32}$$

where $\dot{\Phi}_t$ is the growth of aggregate input. Although it is not feasible to measure $\Phi$ since it is the aggregate of individual inputs with different unit of measurements, a commonly used measure of the growth of aggregate input is the Divisia index (Jorgenson and Griliches, 1967).

$$\dot{\Phi}_t = \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it}. \tag{33}$$

Substituting Equations (25) and (33) into (32), the TFP growth is

$$TF\dot{P}_t = (\eta_t - 1) \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t. \tag{34}$$

Using $\dfrac{w_{it} X_{it}}{C_t} = \dfrac{\eta_{it}}{\eta_t}$, it gives

$$TF\dot{P}_t = (\eta_t - 1) \sum_i \frac{\eta_{it}}{\eta_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t. \tag{35}$$

The TFP growth now has three components: adjusted economies of scale effect, technical progress, and growth of technical efficiency. When production is constant returns to scale, $\eta_t = 1$, and without technical inefficiency, the decomposition is reduced to $TF\dot{P} = \dot{A}$ as in Solow (1957).

The decomposition of the TFP growth in Equations (34) and (35) is similar to the decomposition by Bauer (1990) and Kumbhakar and Lovell (2000, pp. 284)). Assuming the absence of allocative inefficiency, Kumbhakar and Lovell (2000, pp. 284) derive the same decomposition as in Equation (35). However, Equations (21) and (22) show that the cost share is always equal to the relative output elasticity; the absence of allocative

inefficiency assumption is not required for Equation (35). To show further that the allocative efficiency assumption is not needed, we consider the first-order condition for the cost minimization in the absence of technical inefficiency:

$$w_{it}^* = \frac{\partial C_t}{\partial Y_t} \times \frac{\partial F}{\partial X_{it}} ,$$ (36)

where $w_{it}^*$ is the *optimal* wage level in the absence of technical inefficiency. Using Equations (19) and (36), the measure of cost efficiency (*CE*) can be defined as

$$CE_t = \frac{\sum_i w_{it} X_{it}}{\sum_i w_{it}^* X_{it}} = e^{-u_{it}} .$$ (37)

This implies that

$$CE_t = TE_t .$$ (38)

This equality of technical efficiency and cost efficiency provides a proof of the dual relationship between the production function frontier and the cost function frontier. This equation also shows that the allocative efficiency term defined in Equation (16) in Bauer (1990) should be zero.

Substituting Equation (22) into Equation (34) gives

$$T\dot{F}P = (\theta^{-1} - 1) \sum_i \frac{w_{it} X_{it}}{C_t} \dot{X}_{it} + \dot{A}_t + T\dot{E}_t .$$ (39)

This equation is similar to Equation (17) in Denny *et al*., (1981, p. 193) and Equation (3) in Bauer (1990). In order to consider cost efficiency (CE) and the cost information (*w*) in Equation (39), Denny *et al*., (1981) and Bauer (1990) derive the decomposition of the TFP growth based on the cost function approach. The duality of the efficiency in

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Equation (38) shows that the estimation of the TFP growth should only consider one type of inefficiency. Therefore, the estimation of the TFP growth in Equations (34) and (35) is not biased by the existence of cost inefficiency. Since the cost elasticity to output is the inverse of the output elasticity to input and the cost share is equal to the ratio of output elasticity of each input to the economies of scale, Equation (35) provides the decomposition formula for the TFP growth without using cost information. In short, as long as the parameters of the production function can be estimated, Equations (27) and (35) can be used for the empirical estimation of the sources of output growth and TFP growth. The economic interpretation of these two decomposition equations is shown in Equations (25) and (34).

For our empirical estimation, we use panel data estimation with thirty provinces and from 1985 to 2000. The output for the production function is the provincial real GDP ($Y$) and the inputs are labor ($L$), physical capital ($K$), and human capital ($H$). The Appendix Table gives the statistical summary of main variables and the result of the partial correlations matrix.

The estimation model is the production with a second-order transcendental logarithmic (translog) form.

$$\ln Y_{it} = \alpha + \beta_K \ln K_{it} + \beta_L \ln L_{it} + \beta_{KK} (\ln K_{it})^2 + \beta_{LL} (\ln L_{it})^2 + \beta_{KL} \ln K_{it} \ln L_{it}$$
$$+ \beta_H H_{it} + \sum_t \delta_t + \sum_r \gamma_r DR_r + v_{it} - u_{it}, \qquad (40)$$

where the subscript $i$ is for $i$th province and $t$ is for time period; $\delta_t$ is time fixed effect; $DR_r$ is the dummy variable for different regions that will capture the region-specific effects; $H_{it}$ is the human capital variable expressed in average schooling years[6]. To capture the indirect effects of the human capital stock on production, we follow Hall and Jones (1999) and Bils and Klenow (2000) by augmenting the logarithmic production

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[6] To control for the possible endogeneity of human capital, Liu and Li (2006) applied the two lags of human capital as instruments. Due to the complicity of the stochastic frontier model, this paper compromises the possible endogeneity of human capital, and focuses on output elasticity of the respective input variables and technical efficiency. If endogeneity is serious, the estimated coefficients will be biased and the conclusion from this paper may be conservative.

function with the index of human capital stock per working population. The parameter $\delta_t$ can be used to measure technical level over time. The technical progress or the rate of change in technical level is $\delta_t - \delta_{t-1}$. The random error $v_{it}$ is symmetric and normally distributed with $v_{it} \sim N(0, \sigma_v^2)$ and $u_{it}$ is a non-negative truncated normal random error with the probability distribution of $N(\mu, \sigma_u^2)$, where $\mu$ is the mode of normal distribution. The non-negative property of the random error $u_{it}$ is used to measure technical inefficiency as in Equation (8). Technical inefficiency can either be time variant ($u_{it}$) or time invariant ($u_i$). In the case of time variant technical inefficiency, $u_{it}$ can be expressed as a monotonic 'decay' function as (Battese and Coelli, 1992):

$$u_{it} = \tau_t u_i, \tag{41}$$

where $\tau_t = \exp[-\tau(t - T)]$, and $\tau$ is an unknown scalar parameter. $u_{it}$ can either be increasing (if $\tau < 0$), decreasing (if $\tau > 0$) or remained constant (if $\tau = 0$). The minimum-mean-square-error predictor of the technical efficiency for the $i^{\text{th}}$ province at the $t^{\text{th}}$ time period is shown as (Battese and Coelli, 1992; Kumbhakar, 1990; Kumbhakar and Lovell, 2000; Coelli, 1996; Battese and Corra, 1977)[7]:

$$TE_{it} = E(e^{-u_{it}} | \varepsilon_{it}), \tag{42}$$

where $\varepsilon_{it} = v_{it} - u_{it}$.

From Equation (40), the output elasticity for physical capital, labor, and human capital for the $i^{\text{th}}$ province at the $t^{\text{th}}$ time period, which are denoted as $\eta_{K_{it}}$, $\eta_{L_{it}}$, and $\eta_{H_{it}}$, respectively, can be derived as follows:

$$\eta_{K_{it}} = \beta_K + 2\beta_{KK} \ln K_{it} + \beta_{KL} \ln L_{it}, \tag{43}$$

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[7]  The detailed steps on the derivation of technical efficiency are provided in Battese and Coelli (1992, Appendix Equations A.1 - A.11).

$$\eta_{L_{it}} = \beta_L + 2\beta_{LL}\ln L_{it} + \beta_{KL}\ln K_{it}, \tag{44}$$

$$\eta_{H_{it}} = \beta_H H_{it}. \tag{45}$$

The economies of scale is measured as $\eta_{it} = \eta_{K_{it}} + \eta_{L_{it}} + \eta_{H_{it}}$. Using Equations (27) and (35), the decomposition of output growth and the TFP growth is shown as follows:

$$\dot{Y}_{it} = \frac{\eta_{K_{it}}}{\eta_{it}}\dot{K}_{it} + \frac{\eta_{L_{it}}}{\eta_{it}}\dot{L}_{it} + \frac{\eta_{H_{it}}}{\eta_{it}}\dot{H}_{it} + Scale_{it} + \Delta\delta_t + T\dot{E}_{it}, \tag{46}$$

$$\dot{TFP}_{it} = Scale_{it} + \Delta\delta_t + T\dot{E}_{it}, \tag{47}$$

where $Scale_{it} = (\eta_{it} - 1)\left(\frac{\eta_{K_{it}}}{\eta_{it}}\dot{K}_{it} + \frac{\eta_{L_{it}}}{\eta_{it}}\dot{L}_{it} + \frac{\eta_{H_{it}}}{\eta_{it}}\dot{H}_{it}\right)$ is a measure of the adjusted economies of scale effect.

The maximum likelihood method is generally used to estimate the parameters in a stochastic frontier production (Battese and Coelli, 1988 and 1992; Kumbhakar and Lovell, 2000). After estimating the parameters in Equation (40), Equation (42) is used to derive the estimates of technical efficiency; Equations (43) – (45) are used for the estimates of input growth and the adjusted economies of scale effect; the estimated coefficient for $\delta_t$ gives the estimates of the technical progress; Equations (46) and (47) give the decomposition of economic growth and the TFP growth. Because the translog specification is used, the performance of these estimates varies depending on provinces and years.

## 4.    Empirical results

Table 1 reports maximum likelihood estimates of the stochastic frontier production for a panel of thirty provinces of China for the period of 1985-2000, with a total of 470 observations. The dependent variable is log real GDP. Columns (1) and (2) show the results without regional dummy variables, while columns (3) and (4) show the results

with regional dummy variables. The difference between columns (1) and (2) and that between columns (3) and (4) is the use of the functional form. Columns (1) and (3) contain the results from the basic function of the production model, while columns (2) and (4) show the results from the translog specification of the production function.

The last three rows in Table 1 show the three sets of model specification tests. The first set contains the likelihood ratio tests for the joint effects of regional dummy variables. The statistics shown in columns (3) and (4) are statistically insignificant. Therefore, the regional dummy variables can be removed from the model. The second set contains the likelihood test for the joint effects of technology progress. All statistics in this row show that the technical progress over time is significant. The third set contains the likelihood ratio tests for the joint effects of quadratic and interaction terms in the translog specifications. The results in columns (2) and (4) show these tests are statistically significant. In sum, the translog specification function without regional dummy variables shown in column (2) represents a preferred model for further analysis.

The estimates in column (2) show that the positive effects of physical capital are clearly predominant in the production functions. The coefficients for the two labor terms are negative and the coefficient of the interactive term between physical capital and labor is positive. The net impact of labor can be shown with the output elasticity of labor (shown in the next table). The effects of human capital on provincial GDP are positive and statistically significant. The estimated technical inefficiency parameter, $\tau$, is negative and statistically significant, which indicates that the overall inefficiency is increasing over time. On the contrary, the estimates show that there is technical progress over the observed period, as the coefficients of $\delta_t$ are positive (results are not reported here), and their joint effects are statistically significant.

Based on the translog production function estimates shown in column (2) and Equations (42) – (47), we derive the following measures: the output elasticity with respect to inputs, economies of scale ($\eta$), the adjusted economies of scale effect, rate of technical progress ($\Delta\delta_t$), growth of technical efficiency ($T\dot{E}$) and the components of output growth and total factor productivity growth ($T\dot{F}P$) for $i^{\text{th}}$ province and $t^{\text{th}}$ time. The averages of these measures on different provinces in the sample period are shown in

Tables 2, 3, and 4. Table 2 shows the cost shares of inputs and input growth for different years and overall means are summarized in the last row. The cost shares of inputs in columns (1) – (3) show that the cost share for physical capital is the highest with 64 percent on average; the share for labor is 24 percent while the share for human capital is only 12 percent. Columns (4) – (6) show the weighted input growth for the three inputs and the last column shows the growth of aggregate input. The growth of aggregate input has an average of 7.15 percent. Physical capital accounts for 90 percent (6.45% out of 7.15%) of the growth of aggregate input while labor and human capital accounts for 5 percent each. This implies that physical capital is the most important factor for the input growth. Columns (1) and (4) show that the share of physical capital and its growth contribution are declining in recent years. However, its importance is still dominant.

Table 3 shows the output elasticity with respect to each input, economies of scale, and adjusted economies of scale effect. China's physical capital input gives the largest output elasticity with values more than 0.6752. Labor has output elasticity that ranges between 0.2540 and 0.2846; human capital has output elasticity that ranges between 0.1127 and 0.1692. All these elasticities show a steadily increasing trend in the sample period. The values of economies of scale in column (4) are between 1.0419 and 1.1505 with an increasing trend. Since these values are greater than one, this increasing return to scale gives positive adjusted economies of scale effect. Columns (5) – (7) show that the scale effect is mostly derived from physical capital; column (5) shows the weighted physical capital growth are larger than the weighted growth of the other two inputs and has an increasing trend. The last column show the scale effect has an increasing trend from 0.0032 to 0.0092, with an average of 0.0061. On average, the physical capital explains about 92 percent (0.56% out of 0.61%) of the scale effect.

The decomposition of output growth and the TFP growth is shown in Table 4. For the four sources of the output growth, columns (2) – (5) show that: the major contributor to the economic growth is input growth, while both the adjusted economies of scale effect (Scale) and technical progress $(\Delta\delta_t)$ are positive, but the contribution from technical efficiency is negative in all years. On average, the input growth accounts for 76 percent of output growth (7.15% out of 9.43%). The scale effect has increased significantly from 0.0032 in 1986 to 0.0092 in 2000 as shown in Table 3. In spite of this significant increase

over the sample period, its estimates are still about one-half to one-third of the estimates of technical progress for the last three years in our sample. The estimates of technical progress are all positive, except in 1989, and the estimates reached the highest level between 1992 and 1994 with values of 0.0694, 0.058 and 0.0499.

For the decomposition of the TFP growth, we only check the importance of the components in columns (3) – (5). The overall mean of the TFP growth is 3.07 percent, which is close to the other earlier studies (Borenstein and Ostry, 1996; Chow and Li, 2002; Li, 2003). The three components of its source are: 0.61 percent from the scale effect, 3.09 percent from technical progress, and -0.63 percent from the growth of technical efficiency. These findings show that although factor accumulation may lead to the TFP growth through the increase in scale of economy, the most important factor for China's growth in TFP is technical progress. In addition, the adverse effect from the change in technical efficiency reduced the potential growth in the TFP.

For the regional analysis, estimates in column (2) of Table 1 are fitted into Equations (42) – (47) and averaged over different years to derive the measures for individual province. These measures are grouped into four different regions for the decomposition of regional growth as shown in Tables 5, 6, and 7. Table 5 shows the cost shares of inputs and input growth for the four regions. The South region has the highest cost share of physical capital (69.73%), and followed by the East, the Northeast, and the West (65.52%, 60.31%, and 53.33%, respectively); the weighted physical capital growth for these four regions have the same order with 7.44 percent, 7.01 percent, 5.27 percent, and 4.85 percent, respectively. Since physical capital accounts for the largest proportion of input growth, the aggregate input growth for these four regions have the same ranking; the magnitudes of the input growth for the South and East regions (8.08% and 7.64%, respectively) are much higher than the Northeast and West regions (5.88% and 5.77%, respectively).

Table 6 shows the output elasticities and adjusted economies of scale effect for four regions. The output elasticities from physical capital are similar for the Northeast, East, and South regions with the values ranging between 0.6975 and 0.7065, and that the West is the lowest with 0.6255; the output elasticity from labor in the West region (0.4223) is comparatively larger than other regions (0.2742, 0.2274, and 0.1906); the output

elasticity from human capital for the Northeast (0.1848) is the highest and the South is the lowest (0.1141). Because of the large difference in output elasticity from labor, it gives the West region the largest adjusted scale effect and the South region the lowest adjusted scale effect.

The decomposition of the growth in four different regions in Table 7 shows that the high output growth in the South and the East (10.60% and 10.55%, respectively) have contributed to the input growth (8.08% and 7.64%, respectively). For the TFP growth, the Northeast and West regions have larger growth (3.25% and 3.24%, respectively) than the East and South regions (3.18%, and 2.49%, respectively). Note that technical progress is only measurable from the change in time. Therefore, technical progress is the same for all regions and cannot be used to differentiate the improvement of technology in different regions. The larger TFP growth in the West and Northeast regions than those in the East and South regions is mainly caused by the adjusted scale effect.

One can conclude from Tables 5, 6, and 7 that the high economic growth in the East and South regions are mainly related to the growth of physical capital. The high output elasticity to labor and adjusted scale effect in the Northeast and West regions are important for the TFP growth for these two regions. In general, different types of inputs have different impacts on regional growth. It is advisable for China to go beyond mere factor accumulation and concentrate on resource allocation policies.


## 5.      Conclusions

This paper examines the theoretic foundation of the decomposition of economic and productivity growth and applies the decomposition to the economic growth in post-reform China. Our theoretic discussion follows that of Solow (1957), Denny *et al*., (1981), Bauer (1990), and Kumbhakar and Lovell (2000). Our theoretical results show that cost information is not required to estimate the components of decomposition and the production function approach is sufficient for the empirical work. The economic growth is decomposed into input growth, adjusted economies of scale effect, technical progress, and the growth of technical efficiency. With this decomposition, the total productivity growth simply contains the last three components. The growth of aggregate input is the

weighted sum of individual input growth and the weight is the cost share of each input. The adjusted economies of scale effect depends on the size of economies of scale. This effect is zero for constant returns to scale. For increasing and decreasing returns to scale, this effect is adjusted by the growth of aggregate input. The technical progress in this decomposition mainly represents the shift of the production over time. The technical efficiency can be measured and derived from stochastic frontier model.

For our empirical work on the production function, we have derived the physical and human capital stocks data using the inventory method for the thirty provinces of China for the period 1984-2004. The average number of schooling years is used as the proxy for the human capital stock, where the numbers of graduates, provincial immigration and mortality at various education levels are taken into account. Due to the change in the classification of graduates, the human capital stock series is constructed to 2000. We have updated and extended the TFP analysis in Chow and Li (2002), Li (2003) and Liu and Li (2006) with provincial and regional analysis.

We estimate the stochastic frontier translog production function using the maximum-likelihood estimation method. Our empirical results show that the three factor inputs (physical capital, labor and human capital) are important for output performance and physical capital is the most important factor to China's post-reform economic growth. This conclusion is consistent with earlier studies (Galor and Moav, 2003; Goldin and Katz, 1998, 1999 and 2001). The role of human capital will become significant in the more mature stage of economic development, and it is important for China to upgrade its human capital for sustainable economic development.

When the three sources of the growth of TFP are considered, we found that the major contributor to the TFP growth is technology progress, with the exception in 1989 and 1990. The adjusted scale effect accounts for about one-third of the TFP growth during the last three years in our sample period, but the negative change in technical efficiency reduced the potential growth in TFP. The higher economic growth in the South and East regions in China than in the Northeast and West regions is because of physical capital growth. With high output elasticity to labor and adjusted economies of scale, the Northeast and West regions are characterized by higher TFP growth.

The empirical results do bring forward several policy implications on the

sustainability of the post-reform China economy. It is necessary for China to promote investments that are more productive, especially those embodied with technology. Policies should be geared to improve technical efficiency and utilize resources effectively.

While labor is plentiful, developed human capital is scarce in China. It will take a relatively long time for individuals to be educated and trained. Thus, continuous investment in education and training is necessary. Mobility of human capital can facilitate knowledge spillovers across different provinces in China, and encouraging international in-flows of talents might also be necessary. It will be interesting for future analysis, for example, to consider the efficiency level among industries in different regions in the post-reform China.

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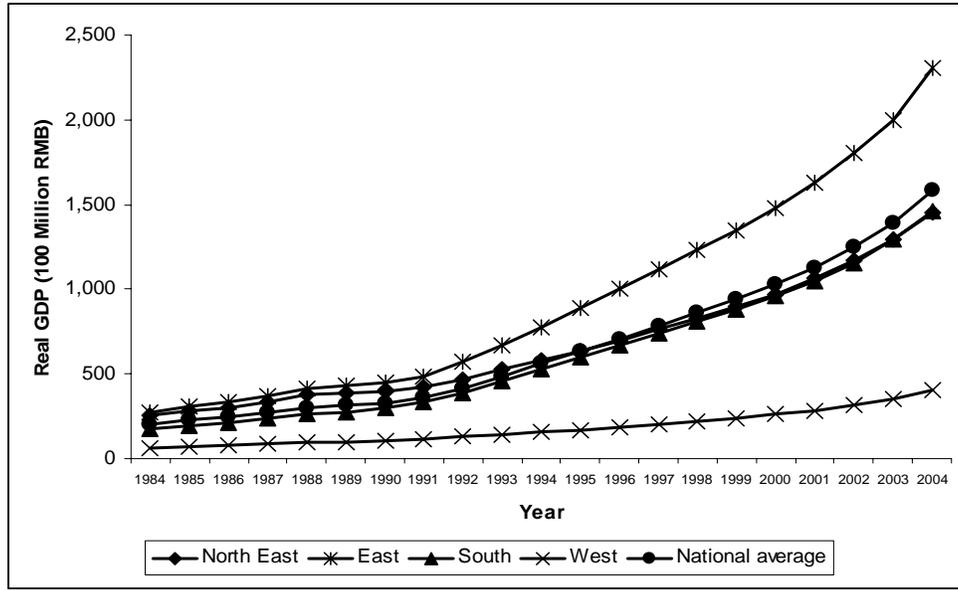Figure 1 China's national and regional real GDP.
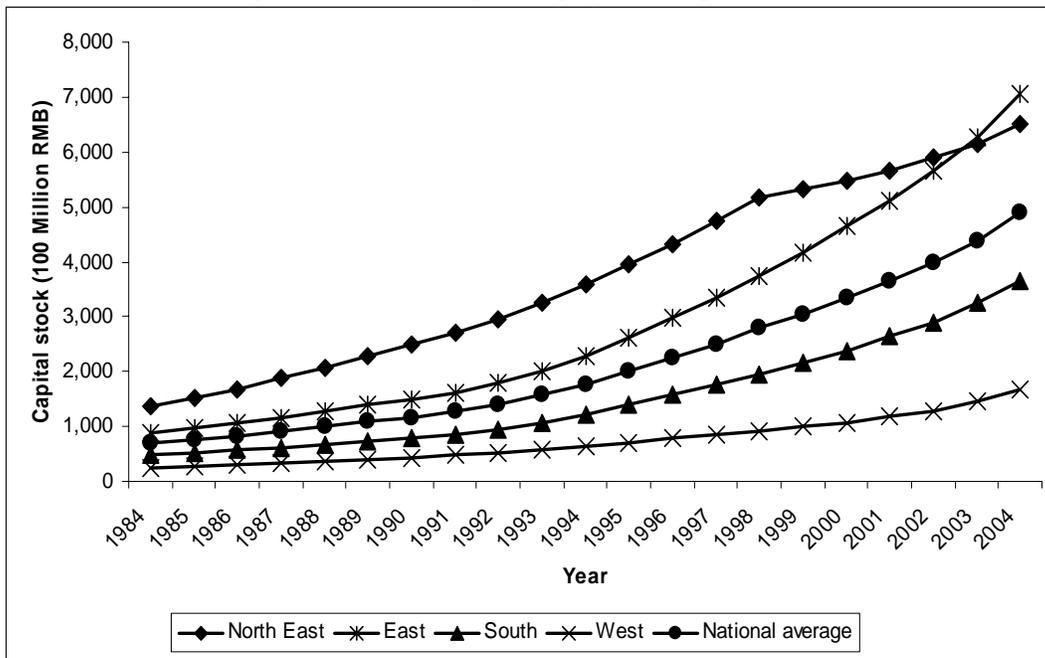


Figure 2 China's regional physical capital stock.

Figure 3 China's human capital per capita.
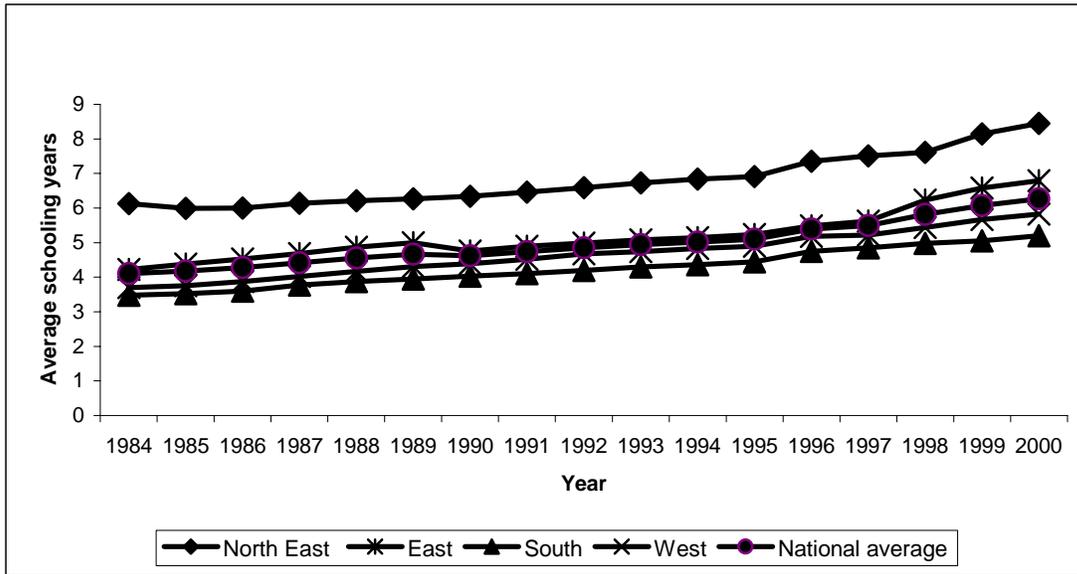
Table 1 Maximum Likelihood Estimates of the Stochastic Frontier Production (1985-2000)

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| lnK | 0.674 *** | 0.726 *** | 0.671 *** | 0.733 *** |
| | (0.030) | (0.116) | (0.029) | (0.130) |
| lnL | 0.229 *** | -0.425 ** | 0.238 *** | -0.459 ** |
| | (0.035) | (0.183) | (0.037) | (0.193) |
| lnK*lnK | − | 0.004 | − | 0.004 |
| | − | (0.007) | − | (0.008) |
| lnL*lnL | − | -0.089 *** | − | -0.097 *** |
| | − | (0.020) | − | (0.021) |
| lnK*lnL | − | 0.047 ** | − | 0.050 ** |
| | − | (0.023) | − | (0.024) |
| H | 0.017 ** | 0.027 ** | 0.016 ** | 0.028 ** |
| | (0.007) | (0.012) | (0.007) | (0.013) |
| Northeast region | − | − | -0.011 | -0.118 |
| | | | (0.090) | (0.092) |
| East region | − | − | -0.071 | -0.084 |
| | | | (0.076) | (0.076) |
| South region | − | − | -0.050 | -0.099 |
| | | | (0.074) | (0.077) |
| $\mu$ | 0.433 *** | 0.419 *** | 0.379 * | 0.390 ** |
| | (0.166) | (0.133) | (0.218) | (0.158) |
| $\tau$ | -0.026 *** | -0.026 *** | -0.025 *** | -0.025 *** |
| | (0.003) | (0.004) | (0.003) | (0.004) |
| $\sigma_u^2$ | 0.199 | 0.120 | 0.239 | 0.132 |
| | (0.097) | (0.057) | (0.132) | (0.069) |
| $\sigma_v^2$ | 0.003 | 0.003 | 0.003 | 0.003 |
| | (0.0002) | (0.0002) | (0.0002) | (0.0002) |
| Log likelihood | 641.794 | 653.108 | 642.395 | 654.284 |
| Log-Likelihood Ratio Tests ($\chi^2$): | | | | |
| $\gamma_r = 0$, for all r | − | − | 1.20 | 2.14 |
| $\delta_t = 0$, for all t | 242.09 *** | 131.24 *** | 209.45 *** | 117.94 *** |
| $\beta_{KK,LL,LK} = 0$ | − | 23.46 *** | − | 24.67 *** |

*Notes*: The numbers in parentheses are standard errors. The superscripts *, **, and *** indicate that the estimated coefficient is statistically significant at the 10%, 5% and 1% level, respectively.

Table 2 Cost Shares of Inputs and Input Growth (1985-2000)

| Year | Cost Shares | | | Input Growth | | | |
|---|---|---|---|---|---|---|---|
| | $\dfrac{\eta_K}{\eta}$ | $\dfrac{\eta_L}{\eta}$ | $\dfrac{\eta_H}{\eta}$ | $\dfrac{\eta_K}{\eta}\dot{K}$ | $\dfrac{\eta_L}{\eta}\dot{L}$ | $\dfrac{\eta_H}{\eta}\dot{H}$ | $\dot{\Phi}$ |
| | (1) | (2) | (3) | (4) | (5) | (6) | (4)+(5)+(6) |
| 1985 | 0.6480 | 0.2438 | 0.1082 | – | – | – | – |
| 1986 | 0.6473 | 0.2422 | 0.1105 | 0.0598 | 0.0067 | 0.0030 | 0.0695 |
| 1987 | 0.6461 | 0.2405 | 0.1134 | 0.0598 | 0.0064 | 0.0037 | 0.0699 |
| 1988 | 0.6444 | 0.2392 | 0.1163 | 0.0633 | 0.0060 | 0.0036 | 0.0729 |
| 1989 | 0.6427 | 0.2388 | 0.1185 | 0.0559 | 0.0043 | 0.0028 | 0.0630 |
| 1990 | 0.6445 | 0.2379 | 0.1176 | 0.0510 | 0.0062 | 0.0022 | 0.0595 |
| 1991 | 0.6440 | 0.2359 | 0.1201 | 0.0531 | 0.0066 | 0.0031 | 0.0629 |
| 1992 | 0.6419 | 0.2360 | 0.1221 | 0.0662 | 0.0042 | 0.0030 | 0.0733 |
| 1993 | 0.6402 | 0.2360 | 0.1238 | 0.0797 | 0.0055 | 0.0023 | 0.0875 |
| 1994 | 0.6378 | 0.2373 | 0.1249 | 0.0792 | 0.0034 | 0.0020 | 0.0845 |
| 1995 | 0.6352 | 0.2387 | 0.1262 | 0.0772 | 0.0031 | 0.0021 | 0.0823 |
| 1996 | 0.6297 | 0.2383 | 0.1319 | 0.0712 | 0.0035 | 0.0076 | 0.0823 |
| 1997 | 0.6270 | 0.2393 | 0.1337 | 0.0671 | 0.0028 | 0.0027 | 0.0726 |
| 1998 | 0.6198 | 0.2404 | 0.1398 | 0.0670 | 0.0002 | 0.0040 | 0.0713 |
| 1999 | 0.6098 | 0.2463 | 0.1438 | 0.0607 | -0.0080 | 0.0060 | 0.0587 |
| 2000 | 0.6056 | 0.2474 | 0.1471 | 0.0564 | 0.0009 | 0.0043 | 0.0616 |
| Mean | 0.6353 | 0.2399 | 0.1249 | 0.0645 | 0.0035 | 0.0035 | 0.0715 |

Table 3 Output Elasticities, Economies of Scale and Adjusted Economies of Scale Effect (1985-2000)

| Year | $\eta_K$ | $\eta_L$ | $\eta_H$ | $\eta$ | $(\eta-1)\dfrac{\eta_K}{\eta}\dot{K}$ | $(\eta-1)\dfrac{\eta_L}{\eta}\dot{L}$ | $(\eta-1)\dfrac{\eta_H}{\eta}\dot{H}$ | Scale Effect |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (5)+(6)+(7) |
| 1985 | 0.6752 | 0.2540 | 0.1127 | 1.0419 | – | – | – | – |
| 1986 | 0.6772 | 0.2534 | 0.1156 | 1.0462 | 0.0028 | 0.0003 | 0.0001 | 0.0032 |
| 1987 | 0.6792 | 0.2528 | 0.1192 | 1.0512 | 0.0031 | 0.0003 | 0.0002 | 0.0036 |
| 1988 | 0.6810 | 0.2528 | 0.1229 | 1.0568 | 0.0036 | 0.0003 | 0.0002 | 0.0041 |
| 1989 | 0.6825 | 0.2536 | 0.1258 | 1.0620 | 0.0035 | 0.0003 | 0.0002 | 0.0040 |
| 1990 | 0.6843 | 0.2526 | 0.1249 | 1.0618 | 0.0032 | 0.0004 | 0.0001 | 0.0037 |
| 1991 | 0.6862 | 0.2514 | 0.1280 | 1.0656 | 0.0035 | 0.0004 | 0.0002 | 0.0041 |
| 1992 | 0.6879 | 0.2529 | 0.1308 | 1.0716 | 0.0047 | 0.0003 | 0.0002 | 0.0052 |
| 1993 | 0.6899 | 0.2543 | 0.1334 | 1.0776 | 0.0062 | 0.0004 | 0.0002 | 0.0068 |
| 1994 | 0.6915 | 0.2573 | 0.1354 | 1.0842 | 0.0067 | 0.0003 | 0.0002 | 0.0072 |
| 1995 | 0.6930 | 0.2604 | 0.1377 | 1.0910 | 0.0070 | 0.0003 | 0.0002 | 0.0075 |
| 1996 | 0.6945 | 0.2628 | 0.1455 | 1.1029 | 0.0073 | 0.0004 | 0.0008 | 0.0085 |
| 1997 | 0.6959 | 0.2656 | 0.1484 | 1.1099 | 0.0074 | 0.0003 | 0.0003 | 0.0080 |
| 1998 | 0.6967 | 0.2702 | 0.1571 | 1.1241 | 0.0083 | 0.0000 | 0.0005 | 0.0088 |
| 1999 | 0.6958 | 0.2810 | 0.1641 | 1.1410 | 0.0086 | -0.0011 | 0.0008 | 0.0083 |
| 2000 | 0.6967 | 0.2846 | 0.1692 | 1.1505 | 0.0085 | 0.0001 | 0.0006 | 0.0092 |
| Mean | 0.6880 | 0.2600 | 0.1357 | 1.0836 | 0.0056 | 0.0002 | 0.0003 | 0.0061 |

Table 4 Decomposition of Output Growth and the TFP growth
(1986-2000)

| Year | $\dot{Y}$ | $\dot{\Phi}$ | Scale | $\Delta\delta_t$ | $T\dot{E}$ | $T\dot{F}P$ |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (3)+(4)+(5) |
| 1986 | 0.0658 | 0.0695 | 0.0032 | 0.0099 | -0.0055 | 0.0076 |
| 1987 | 0.0961 | 0.0699 | 0.0036 | 0.0333 | -0.0084 | 0.0285 |
| 1988 | 0.1029 | 0.0729 | 0.0041 | 0.0403 | -0.0057 | 0.0387 |
| 1989 | 0.0424 | 0.0630 | 0.0040 | -0.0129 | -0.0058 | -0.0147 |
| 1990 | 0.0555 | 0.0595 | 0.0037 | 0.0044 | -0.0149 | -0.0068 |
| 1991 | 0.0807 | 0.0629 | 0.0041 | 0.0272 | -0.0061 | 0.0253 |
| 1992 | 0.1331 | 0.0733 | 0.0052 | 0.0694 | -0.0061 | 0.0685 |
| 1993 | 0.1364 | 0.0875 | 0.0068 | 0.0580 | -0.0062 | 0.0586 |
| 1994 | 0.1253 | 0.0845 | 0.0072 | 0.0499 | -0.0063 | 0.0508 |
| 1995 | 0.1114 | 0.0823 | 0.0075 | 0.0379 | -0.0064 | 0.0390 |
| 1996 | 0.1070 | 0.0823 | 0.0085 | 0.0335 | -0.0065 | 0.0355 |
| 1997 | 0.0990 | 0.0726 | 0.0080 | 0.0336 | -0.0065 | 0.0351 |
| 1998 | 0.0887 | 0.0713 | 0.0088 | 0.0175 | 0.0033 | 0.0296 |
| 1999 | 0.0813 | 0.0587 | 0.0083 | 0.0305 | -0.0066 | 0.0322 |
| 2000 | 0.0883 | 0.0616 | 0.0092 | 0.0315 | -0.0067 | 0.0340 |
| Mean | 0.0943 | 0.0715 | 0.0061 | 0.0309 | -0.0063 | 0.0307 |

Table 5 Cost Shares of Inputs and Input Growth: Regional Summary

| | Cost Shares | | | Input Growth | | | |
|---|---|---|---|---|---|---|---|
| | $\dfrac{\eta_K}{\eta}$ | $\dfrac{\eta_L}{\eta}$ | $\dfrac{\eta_H}{\eta}$ | $\dfrac{\eta_K}{\eta}\dot{K}$ | $\dfrac{\eta_L}{\eta}\dot{L}$ | $\dfrac{\eta_H}{\eta}\dot{H}$ | $\dot{\Phi}$ |
| | (1) | (2) | (3) | (4) | (5) | (6) | (4)+(5)+(6) |
| Northeast | 0.6031 | 0.2371 | 0.1598 | 0.0527 | 0.0023 | 0.0037 | 0.0588 |
| East | 0.6552 | 0.2109 | 0.1339 | 0.0701 | 0.0023 | 0.0040 | 0.0764 |
| South | 0.6973 | 0.1894 | 0.1134 | 0.0744 | 0.0037 | 0.0027 | 0.0808 |
| West | 0.5333 | 0.3601 | 0.1066 | 0.0485 | 0.0060 | 0.0032 | 0.0577 |
| Mean | 0.6222 | 0.2493 | 0.1284 | 0.0614 | 0.0036 | 0.0034 | 0.0684 |

Table 6 Output Elasticities, Economies of Scale and Adjusted Economies of Scale Effect:
Regional Summary

| | $\eta_K$ | $\eta_L$ | $\eta_H$ | $\eta$ | $(\eta-1)\dfrac{\eta_K}{\eta}\dot{K}$ | $(\eta-1)\dfrac{\eta_L}{\eta}\dot{L}$ | $(\eta-1)\dfrac{\eta_H}{\eta}\dot{H}$ | Scale Effect |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (5)+(6)+(7) |
| Northeast | 0.6975 | 0.2742 | 0.1848 | 1.1565 | 0.0082 | 0.0004 | 0.0006 | 0.0092 |
| East | 0.7065 | 0.2274 | 0.1444 | 1.0783 | 0.0055 | 0.0002 | 0.0003 | 0.0060 |
| South | 0.7017 | 0.1906 | 0.1141 | 1.0064 | 0.0005 | 0.0000 | 0.0000 | 0.0005 |
| West | 0.6255 | 0.4223 | 0.1251 | 1.1729 | 0.0084 | 0.0010 | 0.0006 | 0.0100 |
| Mean | 0.6828 | 0.2786 | 0.1421 | 1.1035 | 0.0056 | 0.0004 | 0.0004 | 0.0064 |

Table 7 Decomposition of Output Growth and the TFP Growth:
Regional Summary

| | $\dot{Y}$ | $\dot{\Phi}$ | Scale | $\Delta\delta_t$ | $T\dot{E}$ | $T\dot{F}P$ |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (3)+(4)+(5) |
| Northeast | 0.0881 | 0.0588 | 0.0092 | 0.0309 | -0.0076 | 0.0325 |
| East | 0.1055 | 0.0764 | 0.0060 | 0.0309 | -0.0052 | 0.0318 |
| South | 0.1060 | 0.0808 | 0.0005 | 0.0309 | -0.0065 | 0.0249 |
| West | 0.0848 | 0.0577 | 0.0100 | 0.0309 | -0.0086 | 0.0324 |
| Mean | 0.0961 | 0.0684 | 0.0064 | 0.0309 | -0.0070 | 0.0304 |

**Appendix Table**

| | Summary statistics of the main variables (1985-2000) | | | | | Correlation of the main variables (1985-2000) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Obs. | Mean | Std. Dev. | Min | Max | lnGDP | lnL | lnK | H |
| lnGDP | 480 | 5.790 | 1.092 | 2.579 | 8.089 | 1.000 | | | |
| lnL | 480 | -2.000 | 0.951 | -4.550 | -0.585 | 0.805 (0.000) | 1.000 | | |
| lnK | 480 | 6.999 | 0.978 | 4.482 | 9.408 | 0.948 (0.000) | 0.650 (0.000) | 1.000 | |
| H | 470 | 5.028 | 1.586 | 0.901 | 10.725 | 0.493 (0.000) | 0.044 (0.340) | 0.609 (0.000) | 1.000 |