The Productivity Debate of East Asia Revisited:

A Stochastic Frontier Approach

1. Introduction

After 1960, East Asian countries enjoyed continuous and rapid economic growth until the advent of the financial crisis that hit the region in late 1997. Numerous studies attempted to identify the causes of this economic growth in East Asia, in order to discover how this economic success was sustained over such a long period. However, following the crisis in 1997, the rate of economic growth in East Asia decreased drastically, and this change has rekindled the debate over the primary causes of the East Asian productivity growth miracle. Some researchers have perceived the crisis as signifying a permanent drop in the long-term growth potential and productivity of the region, while others have viewed the crisis as merely a reflection of a financial debacle and expect that the Asian economies involved will recover their former growth trend sufficiently to continue rapid development.

This debate has centered, in the main, on a decomposition of Asian economic growth into factor-accumulation and productivity-growth components, mostly using the Solow (1957) growth accounting method, and it has raised the question of whether growth in the region has been driven by the accumulation of factors or by productivity. Pessimists have argued that East Asia's growth was largely driven by input accumulation, and that productivity increases were negligible. Based on the empirical studies of Young (1994, 1995) and Kim and Lau (1994), Krugman (1994) argued that East Asian countries achieved rapid economic growth largely through an "astonishing mobilization of resources," which resulted, in turn, from an exceptionally high investment rate and a rapid increase in the quality and quantity of the labor force.

Contrary to the pessimist's view of the East Asian Miracle, optimists believed that the rapid economic growth of the region was due to the high rate of technical change made possible by the diffusion of technology from developed countries. They showed that TFP estimates, measured as Solow residuals, for the Asian countries were much greater than those reported by pessimists (World Bank, 1993; Sarel, 1996). Chen (1997) indicated that embodied technological change, which has largely been deducted from TFP in pessimistic studies, was the predominant source of productivity growth in East Asia. Chen (1997) also argued that the pessimists simply interpreted the sources-of-growth estimates without considering the potential for dynamic changes in East Asia.

The debate about East Asian economic growth underscores the limitations of the Solow residual as a measure of TFP.[1] Not only does the residual not accurately represent actual TFP under certain economic circumstances, but it also varies widely, depending on its actual implementation. Furthermore, the traditional growth accounting approach makes no direct multilateral comparisons, as each country is compared only to itself in previous periods, with no reference to a common benchmark (Fare et al., 1994). Thus, productivity comparisons between countries (or among groups of countries) may be more straightforward with respect to growth accounting methods than other methods that employ pooled datasets, in which each country's productivity is compared with an explicit benchmark. This would be especially notable if the data processing involved in the growth accounting method varied with each country's data availability.

As an alternative approach to the growth accounting method, some researchers have proposed the stochastic frontier production model for use in the decomposition of TFP growth into technical change and technical efficiency change. Unlike the Solow residual approach, in which technical progress is usually considered to be the unique source of TFP growth, the stochastic frontier approach acknowledges that changes in technical efficiency—the gap between frontier technology and a firm's actual production—can also contribute to productivity growth. But conventional growth accounting does not take into consideration TFP growth resulting from technical efficiency change, catching-up to the frontier. Technical progress is related to innovation that shifts the production frontier, while technical efficiency change is related to learning-by-doing, the diffusion of new technological knowledge, improved managerial practice, and improvements in the mix of raw materials. As the first to propose the new decomposition, Nishimizu and Page (1982) have indicated that the distinction between technological progress and changes in technical efficiency is particularly relevant when studying the productivity performance of developing economies, where the productivity gain from 'technological mastery' is substantial and may outweigh gains from technological progress. Having reviewed the theory and the empirical evidence, Pack and Page (1993) concluded that TFP growth in industrialized economies results largely from technical progress, while that in industrializing economies is mostly due to changes in technical efficiency.

In the context of East Asian growth, the importance of the catching-up process has been well established by the assimilationist view of East Asian growth, which emphasizes entrepreneurship, innovation, and learning, all of which were encouraged by the policy regimes. Nelson and Pack (1999) suggested that investment in human and physical capital was necessary, but that it was only part of the assimilation process that propelled rapid

East Asian growth, a concept that has been ignored, in the main, in the accumulationist view of East Asian growth. Pack (2001) has demonstrated that the East Asian economies were able to accumulate historically unprecedented levels of capital over the past 35 years, without encountering diminishing returns, because of their successful assimilation of the new capital. Pack (2001) argued that the NIES borrowed much of their technology from more advanced economies and put enormous effort into absorbing it productively, thus continuously catching-up to international best practice during their economic development.

Empirically, several studies have used the stochastic frontier production model to decompose the productivity growth of various segments of several East Asian economies. Mahadevan and Kalirajan (2000) used a stochastic frontier production function to decompose the productivity growth of the manufacturing sector of Singapore; they showed that technical inefficiency was the cause of its low and declining TFP growth. Kim and Han (2001) applied a stochastic frontier approach to Korean manufacturing industries and showed that technical efficiency had a significant positive effect on its productivity growth. However, despite the findings of these studies, no study, to date, has applied a stochastic frontier approach to the decomposition of the productivity growth rates of the East Asian countries, and compared them with those of other countries. [2]

This paper uses a stochastic frontier production approach to estimate productivity growth for a sample of 49 countries over the period 1965-1990, and decomposes TFP changes into efficiency changes (catching-up) and shifts in technology (innovation). In the productivity debate, optimists have predicted that the effects of efficiency changes on TFP growth will be especially great for those rapidly developing countries that have tried to imitate the frontier technologies of developed countries. However, the Solow growth accounting approach generally has ignored this catching-up effect in measuring the TFP of developing countries, possibly yielding lower TFP estimates as a result.

The stochastic frontier production model employed in this paper was developed recently by Lee (2003); it allows us to estimate each region's temporal pattern of efficiency, as well as each country's overall efficiency. The stochastic frontier model, generalized by Lee and Schmidt (1993), in which technical efficiency is time-varying with an arbitrary temporal pattern of technical efficiency (TE), eliminates the unrealistic restriction that the temporal pattern be the same for all firms. Thus, with this model, we can assume that each country or region follows a specific time pattern of TE movements and resulting TFP changes. This assumption will be very useful in this study with respect to identifying and estimating the unique temporal pattern of productivity changes in certain regions, as distinct from those in other regions, thus enabling us to compare regional characteristics, such as those of developed countries in relation to those of East Asia, which are inherent to efficiency and productivity changes.

This paper is organized as follows. Section 2 presents the model, and Section 3 discusses the data and estimation results. Section 4 concludes the study.

2. The Model

Aigner et al. (1977) and Meeusen and van den Broeck (1977) introduced, independently, the stochastic frontier production model, following Farrell's (1957) definition of relative production efficiency. The central goal of this approach was a solution to the problem of the conflict between available data sets and the definition of a production function. The output data we observe are smaller than, or equal to, the maximum possible quantity, due to the existence of technical inefficiency, but a production function specifies the maximum possible quantity of output, given the quantities of a set of inputs. The stochastic frontier production models resolve this conflict by constructing a regression production function with two error terms: one representing the production loss caused by technical inefficiency, which is smaller than or equal to zero, and the other representing statistical noise.

A standard panel data model was implemented in the estimation of the stochastic production frontier, in the sense that inter-firm differences in the firm effects of the fixed-effects model were interpreted as differing measures of technical inefficiency (Pitt and Lee, 1981; Schmidt and Sickles, 1984). The initial panel data models assumed technical inefficiency to be time-invariant, but this assumption may not be reasonable when there are many time observables. Thus, some authors have allowed TE to be time-varying.

These models usually replace the time-invariant efficiency model with a structured function of time; the functional form in Cornwell et al. (1990) was quadratic in time, and those of Kumbhakar (1990) and Battese and Coelli (1992) had specific exponential forms. However, Lee and Schmidt (1993) incorporated an arbitrary temporal pattern of TE (henceforth the L-S model). All of these models, except Cornwell et al. (1990), imposed the restriction that the temporal pattern was the same for all firms.

Recently, Lee (2003) generalized the L-S model by loosening this restriction and imposing, instead, the assumption that firms from the same group had an identical temporal pattern of TE, while firms from different groups had different temporal patterns of TE (henceforth the Generalized L-S model). This last model allows us to compare the temporal patterns of TE in East Asia and other regions and is well fitted to our purpose.

The stochastic frontier production function is defined by

$$y_{it} = \alpha + x_{it}\beta + v_{it} - u_{it} = x_{it}\beta - \alpha_{it} + v_{it}, \quad (1)$$

where y_{it} is the log of output for country i (i=1,...,N) at time t (t=1,...,T), and x_{it} are the corresponding $1 \times K$ input vectors. v_{it} is an *iid* $N(0, \sigma_v^2)$ statistical noise, and u_{it} is the non-negative technical inefficiency error at time t for country i. Here, $\alpha_{it} = \alpha + u_{it}$ is the intercept for country i at time t.[3]

This is a standard setup, and different models, emerging as different choices for the form of α_{it} (or, equivalently, u_{it}), are made. The L-S model denotes an arbitrary temporal pattern of technical inefficiency as

$$\mu_{it} = \theta_t \mu_i, \quad (2)$$

where θ_t is a parameter to be estimated. Since θ does not have a subscript i, this model assumes that the temporal pattern of technical inefficiency is the same across firms or countries. To consider different temporal patterns across groups of firms or countries, the generalized L-S model modifies equation (2) as

$$\mu_{it} = \theta_{gt} \mu_i, \quad (3)$$

where the subscript g represents the country group (g=1,...,G). By extending the L-S model in a straightforward manner, Lee (2003) applied the Concentrated Least Squares Method to the estimation of (1) and (3) and derived the within-group and generalized-least-squares estimators, which are consistent and asymptotically normal. The within-group estimates of β and θ_g are as follows.

$$\hat{\beta} = (\sum_i X_i^{'} M_g X_i)^{-1} (\sum_i X_i^{'} M_g y_i), \ \forall i \in g \quad (4)$$

$$\hat{\theta}_g = \text{the eigenvector of } \sum_i (y_i - X_i\hat{\beta})(y_i - X_i\hat{\beta})' \quad (5)$$

corresponding to the largest eigenvalue, $\forall i \in g$, and

$$\hat{\alpha}_i = (\hat{\theta}_g'\hat{\theta}_g)^{-1}\hat{\theta}_g'(y_i - X_i\hat{\beta}), \forall i \in g, \quad (6)$$

where y_i is the $T \times 1$ vector $[y_{i1}, y_{i2,}..., y_{it}]'$, X_i is the $T \times K$ matrix $[x_{i1}', x_{i2}',..., x_{iN}']'$, and $M_g = I_N - \theta_g\theta_g' / (\theta_g'\theta_g)$.

As we can see from (4) and (5), $\hat{\beta}$ is a function of $\hat{\theta}_g$, which is, in turn, a function of $\hat{\beta}$. Thus, these estimates can be calculated by iteration, given any initial value of $\hat{\beta}$.

Certain hypotheses about $\hat{\theta}_g$ are of interest. The most obvious is the hypothesis that the $\hat{\theta}_g$ s are identical for all g, in which case the Generalized L-S model reduces to the L-S model. Lee (2003) provided tests of this hypothesis, developed along the lines of Gallant (1985).

Time-varying technical efficiency can be estimated in two steps. In the first step, (1) and (3) are estimated to obtain consistent estimates for $\hat{\beta}$ and $\hat{\alpha}_{it} = \hat{\theta}_{gt}\hat{\alpha}_i$. In the second step, technical inefficiency for country *i* in region *g* at time *t* can be separated from the estimates of α_{it} as

$$\hat{u}_{it} = \hat{\theta}_{gt}(\hat{\alpha}_0 - \hat{\alpha}_i), \text{ where } \hat{\alpha}_0 = \max_j(\hat{\alpha}_j). \quad (7)$$

Equation (7) derives a constant term by finding the most efficient country among all *i*, in which u_i is assumed to be zero.

TE at each data point is then calculated as

$$TE_{it} = \exp(-\hat{u}_{it}). \quad (8)$$

In the most efficient country, $\hat{u}_{it} = 0$, and $TE_{it} = 1$, for a given t^{th} period; then the range for any TE is [0, 1]. The most efficient country is assumed to be perfectly efficient, and the efficiency of country *i* is measured as its efficiency relative to that of the most efficient country.

For empirical analysis, a translog stochastic frontier production function is assumed to specify the technology in countries. Then (1) can be rewritten as

$$\ln y_{it} = \alpha_0 + \sum_j \alpha_j \ln x_{jit} + \sum_j \sum_l \beta_{jl} \ln x_{lit} \ln x_{jit} + v_{it} - u_{it} \quad j,l = L, K , \tag{9}$$

where the subscripts *j* and *l* represent the factor inputs of labor (*L*) and capital (*K*), respectively. From equation (8), technical change can be derived as

$$\tau_t = \partial \ln y_{it} / \partial t = \beta_T + \beta_{TT} t + \beta_{LT} \ln L_{it} + \beta_{KT} \ln K_{it} . \tag{10}$$

The growth rate of total factor productivity, as a sum of technical change and TE change, can be derived from (7) and (10).

3. Data and Empirical Results

3.1. Data

The dataset used to compare growth and TFP among the countries was derived from the Penn World Tables of Summers and Heston (1991) over the period 1965-1990.[4] Sample countries were selected based on the following three criteria: the presence of capital stock data, a population of more than one million, and per capita income of more than US$ 1,000. Among the sample of 49 countries, four countries belonged to Africa, eight to North and Central America, six to South America, eleven to Asia, eighteen to Europe, and two to Oceania.

Table 1 represents the average annual growth rates of GDP and factor inputs for the sample countries. The percentage GDP growth rate was highest in Korea (9.51), followed by those of by Taiwan (8.62), Hong Kong (8.03), and Thailand (7.34). The capital stock grew the fastest in Taiwan (11.83 %), which was followed by Korea (11.68%), Iran (11.2%), Thailand (9.62%), and Japan (9.23%).

Of the regions considered, East Asia grew the fastest at 7.9%, even in the late 1980s, but the growth rate of the capital stock decreased from about ten percent during the period 1960-1970 to about five percent.[5] North America sustained stable economic growth at about three percent, without much fluctuation throughout the period 1960-1990, and its capital stock also remained above four percent while exhibiting a slight downward trend. Europe and Oceania grew relatively fast from the late 1960s through the early 1970s, when the capital stock grew by over seven percent, but the growth rate of GDP and the capital stock decreased in the 1980s to two percent and three percent, respectively. Labor growth was also slowest in this continent at about one per cent. South America experienced a rapid decline in both economic and capital growth in the 1980s.

The per capita GDP growth rate, which is derived by subtracting labor growth from GDP growth, also grew the fastest in East Asia; Europe, North America, and South America followed this region, at 4.91% per annum. Per capita GDP growth rates roughly represent economic growth, after the elimination of labor growth. Thus, the fact that East Asia exhibited the fastest per capita GDP growth rate implies that East Asian growth has been driven by other components of economic growth, such as capital accumulation, technical progress, and technical efficiency gains. More specifically, economic growth in the region was most rapid at 6.31% during the late 1980s, when capital growth was at its slowest rate of 5.71%; this implies that the fastest productivity growth took place during this period.

3.2. Empirical Results

Parameter Estimates

Table 2 presents the concentrated least squares estimates of the parameters in the translog stochastic frontier production function, defined by equation (9), for both the L-S and Generalized L-S models. The hypothesis that time-variant efficiency differs across regions was tested to find out whether the Generalized L-S model was appropriate for the data set. The null hypothesis of the L-S model, $\theta_{1t} = \theta_{2t} = \theta_{3t} = \theta_{4t}$, for all *t*, had a likelihood ratio test statistic of 318.02 and was rejected at the one percent significance level.[6] Thus, the test results indicated that the generalized L-S model represented underlying TE better than did the L-S model, and that TE should be specified as time-varying at region-specific rates.

The parameter θ_{gt} was estimated after normalizing the data for the initial year of 1965 to one for each region and is not reported here because of the large number of estimates involved. However, the parameter estimates are graphically illustrated in Figure 1 to show how time-variant efficiency evolved for each region. It is apparent that TE increased rapidly throughout the whole sampling period for East Asia. The TE for this region had more than doubled by 1990. TE slowly increased until 1981 and 1975 but decreased slightly below one thereafter for the G6 countries and Europe, respectively. TE decreased noticeably after 1976 for "Others." The figure suggests that East Asian countries had successfully adapted frontier technology, technology that had been developed by other industrial countries, throughout the sampling period.

The yearly variances of TE for the G6 countries and Europe, θ_{1t} and θ_{2t}, were limited to a very small range and did not show much deviation from the initial value of one. The null hypothesis that each year's technical variation was equal to one, $\theta_{gt} = 1$, was tested by a t-test to find out whether there had been significant time-varying change in technical efficiency for every region. The hypothesis test did not allow the rejection of the null hypothesis for every year for the G6 countries and Europe. The hypothesis test allowed the rejection of the null hypothesis for East Asia for every year, except for the three initial years, as technical efficiency sharply increased during that time. The test allowed the rejection of the null hypothesis for every year after 1977 for "Others," when technical efficiency began to decline.

Technical Efficiency

TE was estimated for each observation based on the Generalized L-S model, and Table 3 reports the average TE for each country for some selected periods, along with its ranking. The rankings show a high level of uniformity of TE for the countries examined, throughout the periods considered, with the exceptions of Hong Kong and Japan; Hong Kong and Japan improved their rankings from 34 and 36 in the initial period to 6 and 18 in the final period, respectively. The list is headed by the United States, followed by Canada, the Netherlands, France, Australia, and Hong Kong. The top quartile comprises all G6 countries and Europe, a category that includes Australia and New Zealand.

Hong Kong, which showed a significant improvement in its efficiency ranking throughout the periods considered, was ahead of the other East Asian countries, which were followed by Japan. Taiwan and Korea ranked 30th and 35th during the final period, exhibiting substantial gains in both their technical efficiencies and rankings.

The average TE gap that existed between the U.S. and East Asia (Hong Kong, Taiwan and Korea) narrowed by 22%, from 0.6% to 0.38% during the period 1965-70. Despite the steady and rapid catching up that has been accomplished by the East Asian countries, there remains a considerable difference in TE between the U.S. and East Asia, as the production frontier has continuously shifted up. This implies that further East Asian growth will continuously depend on closing this gap.

Total Factor Productivity

Table 4 presents estimates of the averages of the rates of technical change (*TP*), changes in technical efficiency ($\dot{TE}$), and total factor productivity growth ($\dot{TFP}$), along with growth rates of output, labor and capital ($\dot{Y}$, $\dot{L}$ and $\dot{K}$) for the period 1965-90.[7]

Hong Kong led $\dot{TFP}$ by 3.85% per annum and was followed by other East Asian countries, including Japan (3.53%), Taiwan (2.85%) and Korea (2.18%). For the East Asian countries, technical change was relatively slow, and they ranked lower than Japan's standing of 22; however, this modest technical progress coincided with full-blown TE growth. The combination of rapid TE growth and moderate technical change has characterized East Asian growth, which suggests that regional economic growth was the result, in part, of fast productivity growth and of closing the gap in frontier production technology.

The top quartile of $\dot{TFP}$ is comprised of all G6 countries, as well as Switzerland, Norway, and Finland. The patterns of TFP component change in these instances are the reverse of those found in East Asian countries, in that faster technical progress coincided with a slight loss in TE. These developed countries led the world economy by extending the production frontier of the world with major inventions and breakthroughs; however, East Asian countries rapidly caught up to this frontier through adaptation and imitation. Overall, $\dot{TFP}$, a sum of TP and $\dot{TE}$, was much faster in East Asian countries than in the other countries with fast $\dot{TFP}$.

Table 5 presents the average annual growth rates of various components of output growth for several selected periods and countries. Temporal movement shows that all of the developed countries presented in Table 5 experienced a drop in $\dot{TFP}$ until the mid-1980s, when it reversed with about a one percent gain. This decrease in the $\dot{TFP}$ of the G6 countries resulted from a continuous drop in TE that ranged from about 0.1% to 1.4%; this offset a steady and slight gain in technical change that had ranged from about 1.0% to 2.1%.

The East Asian countries experienced a sharp increase in $\dot{TFP}$ throughout all the periods considered, though this growth was especially prominent during the late 1980s, when it increased by more than twice its former level. Hong Kong experienced the highest $\dot{TFP}$ of 0.024-0.060; it was followed by Japan (0.025-0.056), Taiwan (0.022-0.047), and Korea (0.017-0.037). The regional movement in $\dot{TFP}$ resulted from a sharp rise in TE that ranged from about 0.6% to 4.7% and coincided with a steady gain in TP that ranged from about 0.2% to 1.8%.

Yearly movements in component changes in output are illustrated in Figure 2 for the U.S. and the four East Asian countries. The U.S. was on the upper frontier of $\dot{TE}$

throughout the periods considered. The wide gap that had existed in TE between the U.S. and the East Asian countries narrowed rapidly, as the latter countries kept gaining TE throughout the sampling period. Specifically, the TE increase was most apparent for the East Asian countries after the mid-1980s. Among the East Asian countries, Hong Kong was closest to the frontier, followed by Japan, Taiwan and Korea.

The U.S. led TP until 1984, when Japan took the leading role by a narrow margin. The U.S. and Japan registered technical change that ranged about from 0.015 to 0.018. TP was very similar for Taiwan and Korea, and increased rapidly, though it was relatively slow for Hong Kong.

$\dot{TFP}$ was led by Hong Kong, followed by Japan, Taiwan, and the U.S., which provided a lower boundary for most of the sampling period after the 1970s. TFP movement was governed by $\dot{TE}$, as countries with faster TE gains showed greater increases in TFP. The TFP gaps among the countries widened after the mid-1980s.[8]

The empirical results showed that the absorption of increasingly modern technology has been the critical component of East Asian productivity growth. The technological learning that has allowed East Asian economies to catch up to other modern industrial economies has been closely related to the policy environment in the East Asian countries.

East Asian governments used a combination of fundamental policies and selective intervention policies to promote industrial development and productivity growth (World Bank, 1993). Fundamental policies provided macroeconomic stability, high investment in human capital, stable financial systems, limited price distortions, and openness to foreign technology. Furthermore, selective intervention policies provided mild financial repression, directed credit, selective industrial promotion, and export promotion. These policies were implemented together to provide a favorable environment for firms' catching-up and innovation activities. For example, firms in East Asian countries had strong incentives to improve their efficiency to compete in the world market because their governments implemented various policies, ranging from subsidized credit to a tariff rebate system, which supported export growth. In turn, the success of export promotion in East Asia coincided with a stable macroeconomic environment, characterized by limited inflation, in which manufacturers were able to concentrate on improving productivity rather than coping with the rapidly changing relative prices of inputs and outputs.

Providing greater access to best-practice technology, export growth was instrumental in the technological upgrading of East Asian countries (World Bank, 1993). Exports enhanced the firms' catching-up process, not only because the managers and engineers of exporting firms tried to satisfy world standards, but also because exporting firms involved in contracting with industrialized countries received technological assistance from their partners (Pack and Westphal, 1986). However, successful technology absorption and entrepreneurship in East Asia were greatly facilitated by the growing supply of well trained people (Nelson and Pack, 1999). East Asian countries spent considerable resources on technical education, adding to their already high levels of general education at the beginning of their period of rapid growth. A large proportion of the technically educated members of the labor force was able to learn and absorb advanced technologies effectively. This interaction between advanced education and technology imports was made possible by the development of a very effective education system that emphasized technical subjects (Pack, 2001).

The government policies that provided the basis for a stable economic environment, as well as various incentives for firms to compete in the world market, and a well-developed education system, were all indispensable catalysts of East Asian productivity growth.[9]

4. Conclusions

The empirical results of this study show that, although productivity growth was driven mainly by technical progress, changes in TE had a significant positive effect on productivity growth. East Asian countries led the whole world in TFP growth, mainly because their TE gain was so much faster than that of other countries. East Asian countries also registered rapid technical change, which was comparable to that of the G6 countries after the late 1980s. Thus, the results provide evidence that negate the hypothesis that East Asian growth was mostly input-driven and unsustainable.

Despite the steady and rapid catching up that has been accomplished by the East Asian countries, there remains a considerable gap in TE between the U.S. and East Asia, as the production frontier continuously shifts up. This implies that further East Asian growth will continue to depend, largely, on catching-up, but also on the significant role that technical change will play for furthering faster growth in the region. Thus, East Asian countries should emphasize innovation to bolster economic growth while also trying to improve the efficiency with which known technologies are applied in actual production.

This study decomposed TFP changes into efficiency changes (catching up) and shifts in technology (innovation), using a stochastic frontier production model. This study supports the premise that the effects of efficiency changes on TFP change will be very important for fast growing developing countries, especially for East Asian countries that try to adopt the frontier technologies of developed countries. The Solow growth accounting approach has generally ignored these catching-up effects when measuring the TFP of developing countries; this omission may have yielded TFP estimates that were biased toward developed countries. This study demonstrates, therefore, that the stochastic frontier production model could constitute a complementary and alternative approach to growth accounting methods for measuring and explaining productivity growth.

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Table 1. Average growth rate (%) in GDP, labor and capital (1965-1990)

Country	Region	GDP	L	K
Canada	G6	4.042	2.218	5.719
U.S.A.	G6	2.836	1.700	4.535
France	G6	3.252	0.872	5.283
Germany. W	G6	2.749	0.552	5.664
Italy	G6	3.660	0.452	4.419
U.K.	G6	2.445	0.492	4.129
Austria	Europe	3.217	0.477	6.510
Belgium	Europe	2.977	0.595	4.192
Denmark	Europe	2.364	0.996	4.520
Finland	Europe	3.535	0.738	4.829
Greece	Europe	3.969	0.521	5.834
Ireland	Europe	4.276	0.772	5.513
Netherlands	Europe	3.118	1.397	4.659
Norway	Europe	3.658	1.469	2.496
Portugal	Europe	5.037	0.911	6.107
Spain	Europe	3.842	0.736	7.138
Sweden	Europe	2.247	0.985	4.763
Switzerlands	Europe	2.180	0.812	4.405
Turkey	Europe	5.461	1.954	6.859
Yugoslavia	Europe	3.635	0.834	6.029
Australia	Europe	3.682	2.189	4.788
New Zealand	Europe	2.018	1.675	4.142
Hong Kong	E. Asia	8.029	2.677	5.399
Japan	E. Asia	5.739	1.031	9.229
Korea R.	E. Asia	9.515	2.412	11.685
Philippines	E. Asia	4.116	2.542	4.083
Taiwan	E. Asia	8.622	2.535	11.830
Thailand	E. Asia	7.335	2.731	9.622
Kenya	Others	5.693	4.155	3.421
Madagascar	Others	0.770	2.098	2.879
Morocco	Others	4.902	3.061	4.395
Zambia	Others	1.453	2.999	0.825
Dominican R.	Others	4.843	2.956	8.548
Guatemala	Others	3.668	2.578	4.876
Honduras	Others	4.153	3.253	5.136
Jamaica	Others	2.118	2.142	2.147
Mexico	Others	4.826	3.111	6.335
Panama	Others	4.098	2.742	6.501
Argentina	Others	1.360	1.057	3.995
Bolivia	Others	3.449	2.225	5.518
Chile	Others	3.106	2.241	4.935
Colombia	Others	4.753	2.560	5.131
Peru	Others	2.210	2.695	3.998
Venezuela	Others	2.372	3.776	4.758
India	Others	4.499	1.962	5.732
Iran	Others	3.947	3.527	11.198
Israel	Others	5.396	2.722	5.123
Sri Lanka	Others	4.124	1.840	5.039
Syria	Others	6.616	3.054	4.928

Table 2. Coefficient estimates of the stochastic frontier production function

	Simple L-S		Gen. L-S	
C	-3.433	(-0.882)	-4.875	(-1.256)
L	0.249	(0.323)	-0.378	(-0.535)
K	1.494	(3.637)	1.965	(3.279)
T	-0.088	(-2.560)	-0.044	(-1.323)
L^2	-0.017	(-0.363)	0.016	(0.340)
K^2	-0.040	(-1.404)	-0.059	(-2.454)
T^2	0.000	(0.215)	0.000	(0.182)
LK	0.035	(0.492)	0.049	(0.894)
LT	-0.004	(-0.738)	-0.007	(-1.908)
KT	0.008	(2.097)	0.006	(1.850)
$\overline{R}^2$	0.995		0.996	

Note: t-statistics are in parentheses.

Table 3. Average technical efficiency and its (ranking) for selected periods

Country	Region	1965-70		1971-80		1981-85		1986-90	
U.S.A.	G6	0.933	(1)	0.958	(1)	0.877	(1)	0.879	(1)
Canada	G6	0.858	(4)	0.880	(3)	0.809	(2)	0.811	(2)
Netherlands	Europe	0.889	(3)	0.888	(2)	0.774	(3)	0.742	(3)
France	G6	0.755	(11)	0.773	(9)	0.716	(5)	0.717	(4)
Australia	Europe	0.837	(5)	0.836	(5)	0.733	(4)	0.703	(5)
Hong Kong	E. Asia	0.405	(34)	0.504	(31)	0.575	(18)	0.691	(6)
Italy	G6	0.721	(12)	0.737	(12)	0.684	(9)	0.686	(7)
Germany. W	G6	0.708	(16)	0.723	(13)	0.673	(10)	0.674	(8)
U.K.	G6	0.708	(17)	0.723	(14)	0.673	(11)	0.674	(9)
Belgium	Europe	0.796	(6)	0.795	(6)	0.700	(6)	0.673	(10)
New Zealand	Europe	0.790	(7)	0.789	(7)	0.696	(7)	0.669	(11)
Sweden	Europe	0.788	(8)	0.788	(8)	0.694	(8)	0.667	(12)
Switzerland	Europe	0.759	(10)	0.759	(10)	0.671	(12)	0.646	(13)
Austria	Europe	0.721	(13)	0.720	(15)	0.640	(14)	0.617	(14)
Spain	Europe	0.713	(15)	0.713	(16)	0.634	(15)	0.611	(15)
Denmark	Europe	0.698	(18)	0.697	(18)	0.621	(16)	0.599	(16)
Venezuela	Others	0.900	(2)	0.877	(4)	0.669	(13)	0.589	(17)
Japan	E. Asia	0.355	(36)	0.425	(35)	0.473	(28)	0.550	(18)
Norway	Europe	0.633	(22)	0.632	(21)	0.569	(19)	0.550	(19)
Ireland	Europe	0.630	(23)	0.629	(22)	0.566	(20)	0.548	(20)
Iran	Others	0.771	(9)	0.753	(11)	0.590	(17)	0.527	(21)
Finland	Europe	0.599	(24)	0.599	(24)	0.541	(22)	0.524	(22)
Israel	Others	0.718	(14)	0.703	(17)	0.558	(21)	0.501	(23)
Argentina	Others	0.692	(19)	0.677	(19)	0.541	(23)	0.487	(24)
Guatemala	Others	0.647	(20)	0.634	(20)	0.513	(24)	0.465	(25)
Portugal	Europe	0.518	(29)	0.517	(29)	0.474	(27)	0.461	(26)
Mexico	Others	0.639	(21)	0.626	(23)	0.507	(25)	0.460	(27)
Yugoslavia	Europe	0.505	(30)	0.505	(30)	0.463	(31)	0.451	(28)
Greece	Europe	0.495	(31)	0.495	(32)	0.455	(32)	0.443	(29)
Taiwan	E. Asia	0.314	(40)	0.361	(36)	0.393	(34)	0.443	(30)
Chile	Others	0.595	(25)	0.584	(25)	0.479	(26)	0.437	(31)
Syria	Others	0.579	(26)	0.568	(26)	0.469	(29)	0.429	(32)
Dominican R.	Others	0.579	(27)	0.568	(27)	0.469	(30)	0.429	(33)
Morocco	Others	0.538	(28)	0.528	(28)	0.442	(33)	0.407	(34)
Korea R.	E. Asia	0.280	(43)	0.311	(41)	0.332	(37)	0.363	(35)
Jamaica	Others	0.452	(32)	0.445	(33)	0.384	(35)	0.358	(36)
Peru	Others	0.435	(33)	0.429	(34)	0.372	(36)	0.349	(37)
Panama	Others	0.362	(35)	0.358	(37)	0.322	(38)	0.306	(38)
Colombia	Others	0.352	(37)	0.348	(38)	0.314	(39)	0.299	(39)
Bolivia	Others	0.341	(38)	0.338	(39)	0.307	(40)	0.293	(40)
Honduras	Others	0.333	(39)	0.330	(40)	0.301	(41)	0.288	(41)
Turkey	Europe	0.299	(41)	0.299	(42)	0.288	(42)	0.284	(42)
Zambia	Others	0.298	(42)	0.295	(43)	0.275	(43)	0.266	(43)
Philippines	E. Asia	0.230	(44)	0.241	(44)	0.248	(44)	0.257	(44)
Thailand	E. Asia	0.223	(46)	0.231	(45)	0.237	(45)	0.244	(45)
Kenya	Others	0.224	(45)	0.223	(46)	0.219	(46)	0.216	(46)
Sri Lanka	Others	0.205	(47)	0.205	(47)	0.203	(47)	0.203	(47)
Madagascar	Others	0.204	(48)	0.204	(48)	0.203	(48)	0.202	(48)
India	Others	0.095	(49)	0.096	(49)	0.110	(49)	0.117	(49)

Table 4. Sources of economic growth (%) for the sample countries (1965-1990)

Country	Region	$\dot{Y}$	$\dot{L}$	$\dot{K}$	$\dot{TE}$	rank	TP	rank	$\dot{TFP}$	rank
Hong Kong	E. Asia	7.648	1.654	2.139	2.727	1	1.129	25	3.855	1
Japan	E. Asia	5.768	0.961	1.269	2.231	2	1.307	22	3.538	2
Taiwan	E. Asia	8.676	1.758	4.064	1.757	3	1.097	28	2.854	3
Korea R.	E. Asia	7.891	1.785	3.922	1.323	4	0.861	35	2.185	4
Germany. W	G6	2.714	0.462	0.613	-0.137	11	1.776	4	1.639	5
Canada	G6	4.409	1.752	1.138	-0.158	15	1.676	9	1.519	6
France	G6	3.018	0.742	0.857	-0.144	13	1.562	12	1.419	7
Switzerland	Europe	2.918	0.578	0.934	-0.683	29	2.089	1	1.406	8
Norway	Europe	3.043	0.970	0.680	-0.590	24	1.983	2	1.393	9
U.S.A.	G6	3.294	1.677	0.244	-0.167	16	1.540	14	1.373	10
Italy	G6	2.525	0.376	0.789	-0.139	12	1.499	16	1.360	11
Finland	Europe	3.119	0.489	1.410	-0.563	22	1.782	3	1.220	12
U.K.	G6	2.398	0.414	0.865	-0.137	10	1.256	23	1.120	13
New Zealand	Europe	3.461	1.009	1.432	-0.703	32	1.723	6	1.021	14
Denmark	Europe	3.059	0.666	1.374	-0.640	25	1.658	10	1.018	15
Belgium	Europe	2.529	0.417	1.118	-0.706	33	1.700	7	0.994	16
Australia	Europe	3.708	1.632	1.084	-0.732	35	1.723	5	0.991	17
Philippines	E. Asia	4.451	1.840	1.624	0.574	6	0.413	43	0.987	18
Sweden	Europe	2.964	0.697	1.287	-0.702	31	1.682	8	0.980	19
Greece	Europe	3.218	0.347	1.948	-0.465	18	1.388	18	0.923	20
Austria	Europe	3.234	0.311	2.035	-0.656	28	1.544	13	0.888	21
Netherlands	Europe	3.074	1.011	1.187	-0.763	37	1.639	11	0.876	22
Sri Lanka	Others	4.068	1.211	2.031	-0.043	9	0.869	34	0.826	23
Ireland	Europe	3.519	0.442	2.282	-0.588	23	1.383	19	0.795	24
Thailand	E. Asia	6.711	2.002	4.004	0.458	7	0.247	44	0.704	25
Spain	Europe	3.068	0.569	1.833	-0.651	26	1.317	21	0.665	26
India	Others	4.353	1.794	1.907	0.922	5	-0.270	49	0.652	27
Panama	Others	4.978	1.369	3.039	-0.759	36	1.330	20	0.571	28
Portugal	Europe	3.542	0.580	2.533	-0.488	20	0.918	31	0.430	29
Turkey	Europe	4.322	1.466	2.430	-0.209	17	0.635	40	0.426	30
Colombia	Others	3.882	1.818	1.681	-0.722	34	1.104	27	0.382	31
Yugoslavia	Europe	3.174	0.585	2.401	-0.476	19	0.663	38	0.187	32
Bolivia	Others	4.015	1.212	2.698	-0.685	30	0.790	36	0.106	33
Madagascar	Others	2.849	1.183	1.648	-0.039	8	0.057	47	0.018	34
Peru	Others	3.286	1.780	1.490	-0.988	38	1.005	30	0.017	35
Honduras	Others	4.396	1.577	2.819	-0.653	27	0.654	39	0.001	36
Israel	Others	3.420	1.595	1.920	-1.619	47	1.524	15	-0.095	37
Syria	Others	3.694	1.818	1.992	-1.349	42	1.233	24	-0.116	38
Zambia	Others	1.572	1.514	0.345	-0.513	21	0.225	45	-0.288	39
Mexico	Others	3.720	2.461	1.611	-1.472	44	1.119	26	-0.352	40
Jamaica	Others	1.765	1.022	1.105	-1.036	39	0.674	37	-0.362	41
Kenya	Others	4.037	2.389	2.027	-0.155	14	-0.224	48	-0.379	42
Venezuela	Others	3.545	2.574	1.417	-1.903	49	1.457	17	-0.445	43
Chile	Others	3.001	1.390	2.114	-1.383	43	0.880	33	-0.503	44
Argentina	Others	1.502	0.778	1.258	-1.572	46	1.037	29	-0.535	45
Iran	Others	5.521	2.518	3.816	-1.708	48	0.895	32	-0.813	46
Dominican R.	Others	5.433	1.518	4.733	-1.349	41	0.531	41	-0.818	47
Guatemala	Others	3.021	1.364	2.680	-1.488	45	0.465	42	-1.024	48
Morocco	Others	3.000	1.823	2.269	-1.256	40	0.163	46	-1.093	49

Table 5. Sources of economic growth for selected countries and year

Country	Group	Periods	$\dot{Y}$	$\dot{L}$	$\dot{K}$	$\dot{TE}$	TP	$\dot{TFP}$
Canada	G6	1965-70	0.062	0.020	0.014	0.014	0.014	0.028
		1971-80	0.048	0.025	0.011	-0.003	0.016	0.013
		1981-85	0.025	0.010	0.010	-0.013	0.018	0.005
		1986-90	0.037	0.008	0.011	-0.002	0.019	0.018
U.S.A.	G6	1965-70	0.047	0.016	0.003	0.014	0.013	0.028
		1971-80	0.036	0.023	0.002	-0.004	0.015	0.011
		1981-85	0.018	0.013	0.002	-0.014	0.016	0.003
		1986-90	0.028	0.009	0.003	-0.002	0.017	0.016
France	G6	1965-70	0.044	0.006	0.014	0.012	0.012	0.024
		1971-80	0.029	0.008	0.009	-0.003	0.015	0.012
		1981-85	0.019	0.009	0.005	-0.012	0.017	0.006
		1986-90	0.030	0.007	0.006	-0.002	0.018	0.017
Germany. W	G6	1965-70	0.034	0.000	0.009	0.012	0.013	0.025
		1971-80	0.022	0.000	0.007	-0.003	0.018	0.015
		1981-85	0.019	0.007	0.003	-0.011	0.020	0.009
		1986-90	0.038	0.015	0.004	-0.001	0.021	0.019
Italy	G6	1965-70	0.036	0.001	0.011	0.012	0.012	0.023
		1971-80	0.023	0.003	0.008	-0.003	0.015	0.011
		1981-85	0.018	0.008	0.006	-0.011	0.017	0.005
		1986-90	0.027	0.005	0.006	-0.001	0.018	0.016
U.K.	G6	1965-70	0.038	0.004	0.013	0.012	0.010	0.021
		1971-80	0.022	0.004	0.008	-0.003	0.012	0.009
		1981-85	0.011	0.004	0.004	-0.011	0.014	0.003
		1986-90	0.027	0.004	0.010	-0.001	0.015	0.014
Hong Kong	E. Asia	1965-70	0.084	0.012	0.027	0.035	0.009	0.044
		1971-80	0.087	0.025	0.030	0.021	0.011	0.032
		1981-85	0.041	0.014	0.003	0.012	0.012	0.024
		1986-90	0.083	0.006	0.016	0.047	0.013	0.060
Japan	E. Asia	1965-70	0.077	0.017	0.025	0.029	0.007	0.036
		1971-80	0.051	0.008	0.013	0.017	0.012	0.030
		1981-85	0.040	0.008	0.007	0.009	0.016	0.025
		1986-90	0.070	0.006	0.007	0.039	0.018	0.056
Korea R	E. Asia	1965-70	0.105	0.022	0.063	0.017	0.002	0.019
		1971-80	0.079	0.019	0.041	0.010	0.008	0.018
		1981-85	0.056	0.018	0.021	0.006	0.011	0.017
		1986-90	0.077	0.011	0.029	0.023	0.014	0.037
Taiwan.	E. Asia	1965-70	0.108	0.023	0.058	0.023	0.005	0.027
		1971-80	0.089	0.019	0.047	0.014	0.010	0.023
		1981-85	0.068	0.017	0.029	0.007	0.014	0.022
		1986-90	0.080	0.011	0.023	0.031	0.016	0.047

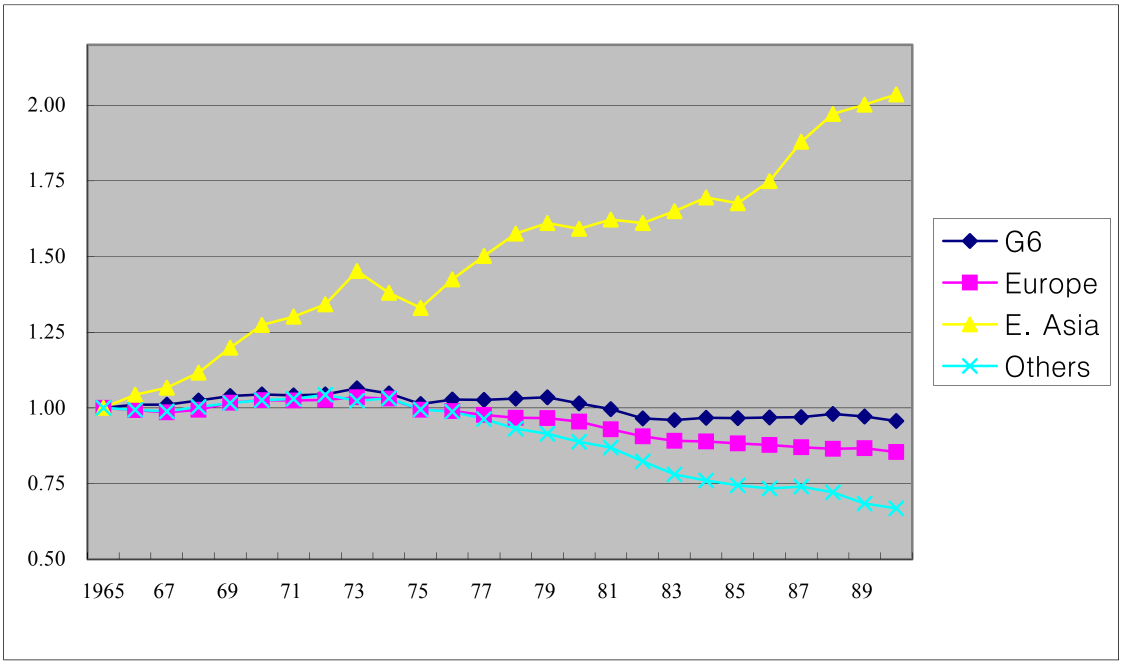

Figure 1. Temporal pattern of technical inefficiency by region

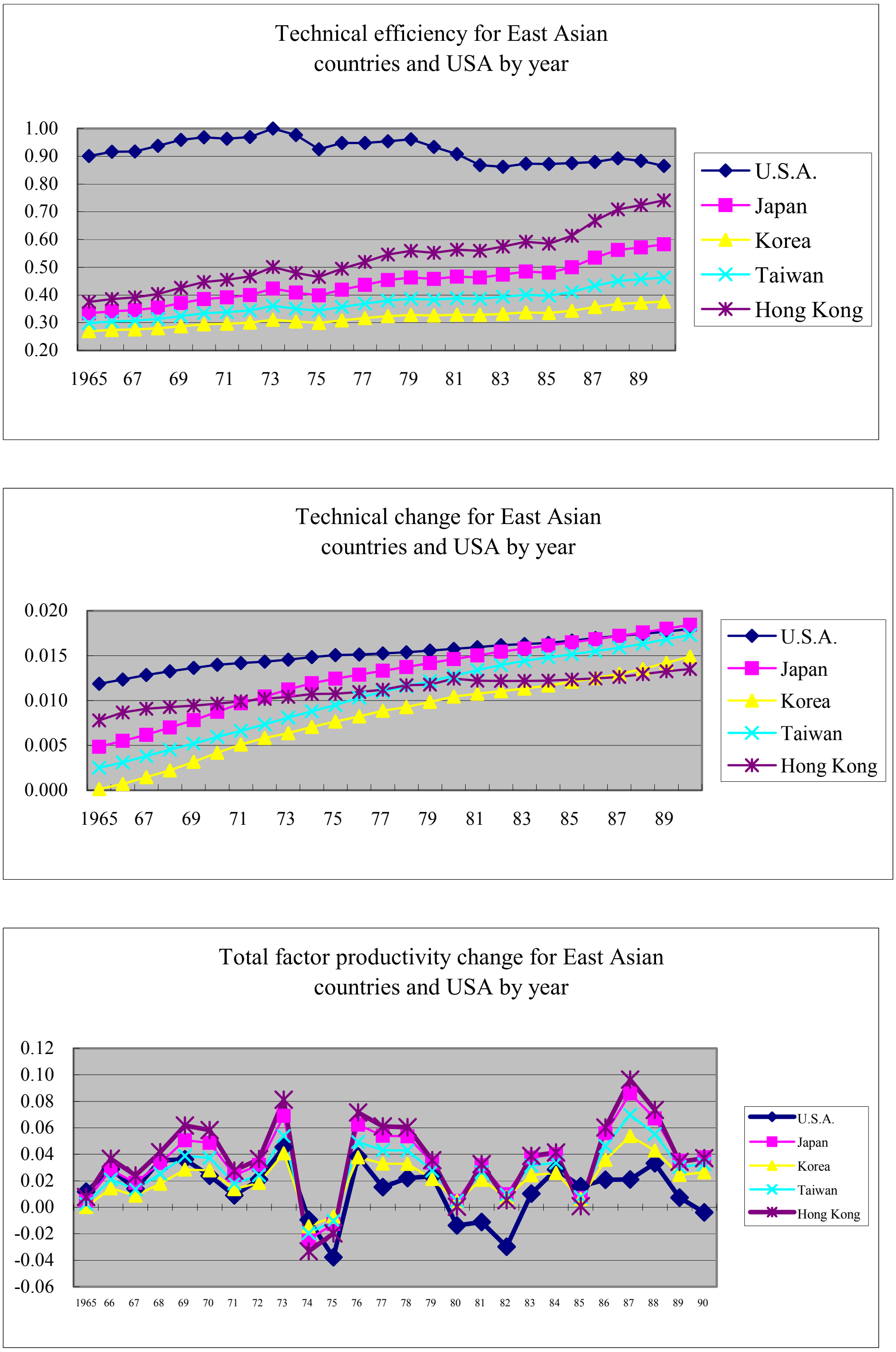

Figure 2. TE, technical change, and TFP for East Asian countries and USA by year

Notes

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[1] For a critical assessment of the debate on TFP in East Asia, see Chen (1997).

[2] Using the conventional growth accounting method, the World Bank (1993) estimated the average rate of TFP change for high income economies as the international best practice level and decomposed this TFP growth into technical change and technical efficiency change. The study showed that technical efficiency change was dominated by high performing Asian economies.

[3] In the time-invariant model, u_{it} becomes u_i, and α_{it} becomes $\alpha_i = \alpha_0 - u_i$.

[4] For a detailed discussion of the data, see Summers and Heston (1991).

[5] A table, which represents the average annual growth rate of GDP and factor inputs by period, with the sample countries classified by continent, is omitted to save space.

[6] The degrees of freedom of the test statistic were 3*(T-1)=75.

[7] The by-year-decomposition results are omitted to save space, but they are available from the authors upon request.

[8] An anonymous referee suggested that the theoretical basis for these empirical results can be derived from the Solow-Swan growth model, which is modified to incorporate endogeneous technical change. According to the growth model, the equilibrium growth rate is determined by the fraction of GDP devoted to the catching-up and innovative activities that raises labor productivity. The empirical results in this paper are consistent with the hypothesis that the growth effects of labor productivity resulting from these activities are fairly large for the East Asian countries.

[9] For a more thorough discussion of the policy background, see Little (1982), World Bank (1993), Pack (2001), and Stiglitz and Yusuf (2001).