The Sources of East Asian Economic Growth Revisited

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Abstract

Kim and Lau (1994a, 1994a) found that the postwar economic growth of the East Asian newly industrialized economies (NIEs)—Hong Kong, South Korea, Singapore and Taiwan--was mostly the result of the growth of tangible inputs--tangible capital and labor--and not technical progress or equivalently the increase in total factor productivity. By contrast, the economic growth of the developed Group-of-Five (G-5) countries—France, West Germany, Japan, the United Kingdom and the United States--was mostly attributable to technical progress. These empirical results, as well as those of Alwyn Young's (1994, 1995), form the basis of Paul Krugman's (1994) provocative article on the "The Myth of the East Asian Miracle". Krugman's interpretation of these results is very pessimistic—according to Krugman, because of the absence of technical progress, economic growth in these East Asian NIEs is bound to slow down and come to a halt eventually as a result of the diminishing returns to additional capital accumulation.

Our own interpretation is, however, that the absence of measured technical progress in the East Asian developing economies is the result of the lack of investment in intangible capital (including but not limited to R&D capital). Given the empirically established complementarity between tangible and intangible capital, investment in intangible capital has become much more profitable in the East Asian NIEs in recent years, and such investment has risen sharply. Augmenting the data used by Kim and Lau with data from more recent years, we find that beginning in the mid-1980s, there is evidence of positive measured technical progress in the East Asian NIEs, and that the measured technical progress can be largely attributed to the growth in the R&D capital stocks in these economies. However, controlling for the growth in the R&D capital stocks, once again the hypothesis of no technical progress cannot be rejected for the East Asian NIEs but can be rejected for the developed economies.

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1. Introduction

East Asia has been the fastest growing region in the world for the past several decades, the East Asian currency crisis of 1997-1998 notwithstanding. On average, the East Asian developing economies as a group, including China, Hong Kong, Indonesia, South Korea, Malaysia, Philippines, Singapore, Taiwan and Thailand, has grown at almost eight percent per annum since the 1960s. The notable exception is Philippines, which has only been able to grow at less than half the average rate. In contrast, the non-Asian Group-of-Five (G-5) developed economies--France, West Germany, the United Kingdom and the United States--have grown at an average rate of a little over three percent per annum. Japan, a member of the G-5 countries but also an East Asian economy, has grown at an average annual rate of almost six percent, an intermediate rate between the East Asian developing economies and the non-Asian G-5 countries, during the same period. It is this sustained rapid economic growth in the East Asian economies, spanning over several decades, that has led some economists to refer to it as the "East Asian miracle."[1] Data on the rates of growth of real output and inputs of the East Asian developing economies and the G-5 countries are presented in Table 1.1.

An examination of Table 1.1 reveals that the developing economies of East Asia, again with the exception of Philippines, have also had very high rates of growth in their inputs. Their average annual rates of growth of the tangible capital stock range between 8.8 and 12.3 percent, compared to below 4 percent for the non-Asian G-5 countries. Their annual rates of growth of total labor hours are above 2.3 percent, compared to negative rates for the European G-5 countries, 0.6 percent for Japan, and 1.3 percent for the United States. Since the rates of growth of both factor inputs, capital and labor, are significantly higher in the East Asian developing economies than in the non-Asian G-5 countries, it is no wonder that

[1] See, for example, World Bank (1993).

their rates of growth of real output are also significantly higher. The interesting question is: How much of the postwar economic growth of the East Asian developing economies can be attributed to the growth in factor inputs—tangible capital and labor, and how much can be attributed to technical progress, or equivalently, the growth of total factor productivity (TFP)?

Table 1.1: Average Annual Rates of Growth of Real Output and Inputs (Entire Sample Period), percent

	Sample Period	Output (Real GDP)	Tangible Capital Stock	Utilized Tangible Capital	Employment	Total Labor Hours	Average Years of Education of the Working-Age Population[1]	Total Years of Education of the Working-Age Population[1]	Average Share of Labor Earnings to GDP
Hong Kong	**66-95**	**7.36**	**8.79**	**8.79**	**2.56**	**2.44**	**2.09**	**4.80**	**0.51**
South Korea	**60-95**	**8.49**	**12.28**	**12.28**	**3.06**	**3.35**	**3.72**	**6.31**	**0.37**
Singapore	**64-95**	**8.88**	**10.23**	**10.23**	**4.29**	**4.70**	**3.28**	**5.92**	**0.38**
Taiwan	**53-95**	**8.45**	**11.76**	**11.76**	**2.69**	**2.33**	**2.72**	**5.40**	**0.44**
Indonesia	**70-94**	**6.68**	**10.73**	**10.88**	**2.72**	**2.72**	**7.70**	**10.34**	**0.31**
Malaysia	**70-95**	**7.32**	**9.65**	**9.65**	**4.15**	**4.68**	**4.88**	**8.02**	**0.34**
Philippines	**70-95**	**3.53**	**5.32**	**5.40**	**3.37**	**3.94**	**4.46**	**7.41**	**0.33**
Thailand	**70-94**	**7.40**	**9.69**	**9.68**	**2.74**	**2.93**	**4.75**	**8.00**	**0.25**
China	**65-95**	**8.30**	**11.60**	**11.63**	**2.55**	**2.55**	**3.12**	**5.99**	**0.54**
Japan	**57-94**	**5.88**	**8.12**	**7.98**	**1.12**	**0.56**	**0.98**	**2.15**	**0.62**
Canada	**57-94**	**3.80**	**4.76**	**4.65**	**2.30**	**1.85**	**1.01**	**2.91**	**0.60**
France	**57-94**	**3.33**	**3.93**	**3.88**	**0.40**	**-0.24**	**1.11**	**1.95**	**0.64**
West Germany	**57-94**	**3.25**	**3.25**	**3.09**	**0.08**	**-0.29**	**1.00**	**1.55**	**0.65**
Italy	**59-94**	**3.52**	**5.20**	**5.33**	**0.00**	**-0.27**	**1.32**	**1.86**	**0.71**
United Kingdom	**57-94**	**2.41**	**3.90**	**3.81**	**0.23**	**-0.11**	**0.83**	**1.14**	**0.65**
United States	**49-94**	**3.13**	**3.03**	**3.30**	**1.71**	**1.31**	**0.81**	**2.06**	**0.66**

Note: 1. Working-age population is defined as the number of persons in the population aged between 15 and 64, inclusive.

Several previous studies provide empirical evidence in favor of the hypothesis that there has been no technical progress in the East Asian Newly Industrialized Economies (NIEs)--Hong Kong, South Korea, Singapore, and Taiwan--such as Tsao (1985) and Young (1992) for Singapore, and Kim and Lau (1994a, 1994b) and Young (1994, 1995) for the four East Asian NIEs.[2] Kim and Lau (1996) extend their two-input analysis to include additional East Asian developing economies--China and the other ASEAN economies (Indonesia, Malaysia, Philippines and Thailand)--and reach the same conclusion of no technical progress. Kim and Lau (1995) extend their analysis for the four East Asian NIEs by including explicitly human capital, measured as the average number of years of education of the working-age population, as a factor of production in addition to tangible capital and labor. They also find no technical progress; as does Senhadji (1999) for the East Asian and South Asian economies. In other words, the conclusion that one can draw from these studies is that the postwar economic growth in the East Asian developing economies has been primarily driven by the growth of tangible inputs.

However, there have also been empirical findings against the hypothesis of no technical progress in the East Asian NIEs, such as Young (1992) for Hong Kong, the World Bank (1993), Collins and Bosworth (1997), Klenow and Rodriguez-Clare (1997), Sarel (1997) for the ASEAN economies, Easterly and Levine (2001), and Iwata, Khan and Murao (2002). The credibility of some of these studies is undermined by restrictive maintained hypotheses such as constant returns to scale, neutrality of technical progress, and instantaneous competitive profit maximization; and in the case of the World Bank (1993) and Easterly and Levine (2001) by the additional assumptions of the Cobb-Douglas functional form and identical production elasticities of capital and labor across all countries. All of these various maintained hypotheses have been consistently rejected by statistical tests.[3]

The objective of this study is to revisit the question of the existence of technical progress in the East Asian developing economies by extending the sample period to include the early to mid-1990s. We seek to determine whether there have been any significant recent changes in the sources of economic growth in these economies. After all, more than half a decade of additional data have become available since Kim and Lau (1994a, 1994b). One interpretation of Kim and Lau's finding of no technical progress is that measured technical progress reflects the effects of investment in intangible capital (including but not limited to human capital and R&D capital) and since the East Asian NIEs invested relatively little in such intangible capital (other than possibly human capital), one should not expect to find much measured

[2] The findings of Kim and Lau (1994a, 1994b) and of Young (1992) provide the empirical basis for Krugman (1994).
[3] See, for example, Kim and Lau (1994a, 1994b).

technical progress. However, in recent years, some of these East Asian NIEs, such as South Korea, Singapore and Taiwan, have increased their investments in R&D and other forms of intangible capital very significantly. It is thus possible that positive measured technical progress may begin to be detectable in these economies.

In addition to extending the sample period, the sample of economies for the three-input (tangible capital, human capital and labor) analysis is also expanded to include China and four other ASEAN economies (Indonesia, Malaysia, Philippines and Thailand) in addition to the four East Asian NIEs. Finally, the analysis is further extended to the four-input case for economies for which data on R&D capital are available. In this process the roles of tangible and intangible capital in East Asian economic growth are examined in detail.

In Section 2, a summary of the results of the previous research of Kim and Lau is provided. In Section 3, there is a brief discussion of the alternative approaches to accounting for the sources of economic growth and their respective advantages and disadvantages. In Section 4, the methodology and the data used in this study are described. In Section 5, the empirical results of the traditional two-input (tangible capital and labor) analysis based on the extended sample period are reported for the four original East Asian NIEs, the four additional ASEAN economies, and China. In Section 6, the empirical results of the three-input analysis, which includes human capital, measured as the total number of years of formal education of the working-age population (defined to be persons of age between 15 and 64, inclusive), as an additional explicitly distinguished measured input, are presented. In Section 7, we test whether there have been changes in the economy-specific rates of commodity augmentation, which represent technical progress, over time. In particular, we examine whether there may have been measurable technical progress in the East Asian NIEs in the more recent period (since 1986). In Section 8, the role of the R&D capital stock is explicitly examined in a four-input (tangible capital, labor, human capital and R&D capital) analysis. In Section 9, we provide a brief explanation as to why positive measured technical progress is found in some of the East Asian developing economies in the more recent period but not in the earlier period and not in other East Asian developing economies. Brief concluding remarks are made in Section 10.

2. Has Technical Progress Been an Important Source of East Asian Economic Growth?

Interpretation of Technical Progress

Technical progress, or the growth of TFP, is defined as the growth in output holding measured inputs constant--in other words, the growth in output net of the growth of measured inputs. It is usually measured as a "residual" or as the effect of a time trend variable. Although technical progress thus measured cannot be attributed to any of the measured inputs, it does not follow that technical progress is simply "manna from heaven" and can be realized without serious efforts or inputs. Our interpretation of technical progress is that it represents the improvements in the production technology accruing from the growth in the (stock of) unmeasured intangible investments such as human capital and R&D capital, to the extent that they have not been explicitly included in the analysis as measured factors of production, as well as advertising, goodwill, market development, information system, software, business methods, etc. It also reflects the growth (or depletion) in other omitted and unmeasured inputs such as land, natural resources, water resources and the environment, etc. Finally, it also reflects genuine improvements in technical and allocative efficiency, if any.

Findings of Kim and Lau (1994a, 1994b, 1996) for the Two-Input Case (Tangible Capital and Labor)

Kim and Lau (1994a, 1994b) apply the meta-production function approach to the analysis of the economic growth of the four East Asian NIEs in conjunction with the industrialized Group-of-Five (G-5) countries--France, West Germany, Japan, the United Kingdom and the United States--in the context of a two-input (tangible capital and labor) model. The results of their series of tests of hypotheses indicate that technical progress may be represented as purely tangible-capital-augmenting in all of the economies in the sample, identical to what is found by Boskin and Lau (1990) for the G-5 countries alone. However, there is a sharp contrast between the East Asian NIEs and the G-5 countries. First, the hypothesis of no technical progress cannot be rejected for the East Asian NIEs, whereas it can be decisively rejected for the G-5 countries. Second, tangible capital accumulation is found to be the most important source of growth for the East Asian economies, including Japan, in the postwar period. However, technical progress is found to be the most important source of growth for the G-5 countries, with the exception of Japan, confirming the earlier findings of Boskin and Lau (1990). As for Japan, tangible capital accumulation accounts for the largest portion of its economic growth, with technical progress a close second. The basic findings are the same for an extended sample of fourteen economies (including, additionally, China, Indonesia, Malaysia, Philippines and Thailand) analyzed in Kim and Lau (1996).

Findings of Kim and Lau (1995) for the Three-Input Case (Tangible Capital, Labor and Human Capital)

Kim and Lau (1995) introduce human capital explicitly as an additional explicitly distinguished measured input in the aggregate meta-production function. The inclusion of human capital, measured as the average number of schooling years per person in the working-age population, does not alter the basic findings of Kim and Lau (1994a, 1994b). Technical progress is found to be statistically insignificant for the four East Asian NIEs whereas it continues to be statistically significant for the G-5 countries. Tangible capital is the most important source of growth for East Asian economies including Japan, while technical progress is the most important for the Non-Asian G-5 countries. Kim and Lau (1995) also find, by testing a series of hypotheses, that technical progress is simultaneously purely tangible-capital-augmenting and purely-human-capital augmenting, and hence complementary to both tangible capital and human capital. Purely tangible-capital-augmenting technical progress and purely human-capital-augmenting technical progress may be represented in the production functions in equations (2.1) and (2.2) respectively:

(2.1) $Y_t = A_0F(A_K(t)K_t, A_LL_t, A_HH_t)$;

(2.2) $Y_t = A_0F(A_KK_t, A_LL_t, A_H(t)H_t)$, where Y_t is the quantity of real output, K_t, L_t, and H_t are the quantities of tangible capital, labor and human capital respectively, t is an index of chronological time, and A_0, A_K, A_L and A_H are functions of t referred to as the augmentation factors for output, capital, labor and human capital respectively; wherever t is suppressed, it implies that the corresponding augmentation factor is a constant. Simultaneously purely tangible-capital-augmenting and purely human-capital-augmenting technical progress implies and is implied by the following form of the production function:

$$(2.3)\ Y_t = A_0 F(A_{KH}(t) K_t^{\lambda} H_t^{1-\lambda}, A_L L_t)\ ,$$

where λ is, without loss of generality, a non-negative constant between zero and one.[4] In other words, tangible capital and human capital together form a composite capital input that has the Cobb-Douglas form which we may call "total capital". This composite capital input is in turn augmented by technical progress. Thus, tangible capital and human capital are complementary to each other as well as to technical progress--they enhance one another's marginal productivity. This is also a macroeconomic manifestation of the phenomenon known as capital-skill complementarity, found in microeconomic studies.[5] However, for the East Asian NIEs, the augmentation factor $A_{KH}(t)$ is found to be empirically a constant, indicating that there has been no technical progress.

3. Approaches to Accounting for Growth

A principal objective of a growth accounting exercise is the measurement of technical progress. The growth in measured output over time, controlling for the growth in measured inputs, if any, could have originated from either economies of scale (including diseconomies of scale), or technical progress, or both. It is in general difficult to identify separately technical progress and the scale effects for an economy growing steadily over time, since both the economies of scale and technical progress effects result in higher rates of growth of measured output controlling for the rates of growth of measured inputs. This problem is usually resolved through the imposition of assumptions on the degree of returns to scale,

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[4] See Lau (1980).

e.g., by maintaining the hypothesis of constant returns to scale. This is true of both the traditional growth accounting approach and the econometrically estimated production function approach, especially in the analysis of the data of a single economy. An alternative approach, called the extended "meta-production function approach," introduced by Boskin and Lau (1990), which pools time-series data across different economies for the joint econometric estimation of the aggregate production functions, allows the separate identification of the magnitudes of economy-specific technical progress and degrees of returns to scale as well as their biases, if any.

The Traditional Growth-Accounting Formula

Given a two-input aggregate production function, $Y_t = F(K_t, L_t, t)$, a given change in output can be decomposed into a part explained by the changes in inputs, K_t and L_t, and a part attributable to technical progress, represented by the time trend variable, t. Differentiating the production function totally, and suppressing the t subscript, we obtain:

$$(3.1)\quad \frac{d\ln Y}{dt} = \frac{\partial \ln F}{\partial \ln K}\cdot\frac{d\ln K}{dt} + \frac{\partial \ln F}{\partial \ln L}\cdot\frac{d\ln L}{dt} + \frac{\partial \ln F}{\partial t},$$

where the last term may be identified as the proportional rate of growth of output, holding inputs constant; in other words, the rate of technical progress or growth of TFP. Equation (3.1) may be referred to as the fundamental equation of growth accounting--the rate of growth of output is equal to the sum of the weighted sum of the rates of growth of inputs, with the weights given by the output elasticities of the respective inputs, and the rate of technical progress. Transposing equation (3.1), we obtain:

$$(3.2)\quad \frac{\partial \ln F}{\partial t} = \frac{d\ln Y}{dt} - \frac{\partial \ln F}{\partial \ln K}\cdot\frac{d\ln K}{dt} - \frac{\partial \ln F}{\partial \ln L}\cdot\frac{d\ln L}{dt},$$

Thus, the rate of technical progress can be derived as the residual of the growth in output less the portion attributable to the growth in inputs. The calculation requires, in addition to the rates of growth of the measured output and inputs, the knowledge of the values of the elasticities of output with respect to

[5] See the discussion in Griliches (1969).

tangible capital and labor. Traditional growth accounting generally imposes the assumption of instantaneous profit maximization under perfectly competitive output and input markets, which then permits the identification of the elasticity of output with respect to labor with the share of labor in output. Moreover, under the additional assumption of constant returns to scale, the elasticity of output with respect to capital may be estimated as one minus the output elasticity of labor. Finally, the assumption of Hicksian neutrality of (or, equivalently, purely output-augmenting) technical progress permits the measurement of the rate of technical progress over T periods as the summation of the rates of technical progress over the individual intervening periods. Thus, instantaneous profit maximization under perfectly competitive output and input markets, constant returns to scale, and neutrality of technical progress are the three critical assumptions behind the traditional implementation of the growth-accounting formula (3.2). With these assumptions, equation (3.2) may be rewritten as:

$$(3.3)\quad \frac{\partial \ln F}{\partial t} = \frac{d\ln Y}{dt} - \left(1 - \frac{wL}{pY}\right) \cdot \frac{d\ln K}{dt} - \frac{wL}{pY} \cdot \frac{d\ln L}{dt},$$

where w is the wage rate and p is the price of output. The entire right-hand side of equation (3.3) then consists of observable variables and can be empirically implemented to provide an estimate of technical progress.

Pitfalls of Traditional Growth Accounting

One weakness of the traditional growth accounting approach stems from the fact that the method requires crucial un-tested assumptions. If the assumptions fail to hold, the approach generates biased estimates for the rates of technical progress and the contributions to growth of the specific inputs. For example, if returns to scale are increasing rather than constant, technical progress is then over-estimated and the contribution of the inputs is underestimated (and vice versa). For another example, if technical progress is not Hicksian neutral, simple summation over time cannot be justified. Regarding the assumption of instantaneous profit maximization, the existence of constraints to instantaneous adjustments of inputs in response to market conditions, or monopolistic (or monopsonistic) influences in the output and input markets, may cause the observed factor shares to deviate from the production elasticities. Thus, the estimates of technical progress as well as the contributions of inputs using the factor shares as estimates of the production elasticities may also be subject to biases.

Moreover, if two or more fixed or quasi-fixed inputs are to be explicitly distinguished, their factor shares cannot in general be separately identified without additional independent information beyond that of the labor share in GDP, even under the assumption of constant returns to scale. For example, in the three-input case, the aggregate production function takes the form:

(3.4) $Y_t = F(K_t, L_t, H_t, t)$.

Equation (3.1) then becomes:

$$(3.5)\quad \frac{d\ln Y}{dt} = \frac{\partial \ln F}{\partial \ln K}\cdot\frac{d\ln K}{dt} + \frac{\partial \ln F}{\partial \ln L}\cdot\frac{d\ln L}{dt} + \frac{\partial \ln F}{\partial \ln H}\cdot\frac{d\ln H}{dt} + \frac{\partial \ln F}{\partial t},$$

resulting in:

$$(3.6)\quad \frac{\partial \ln F}{\partial t} = \frac{d\ln Y}{dt} - \frac{\partial \ln F}{\partial \ln K}\cdot\frac{d\ln K}{dt} - \frac{\partial \ln F}{\partial \ln L}\cdot\frac{d\ln L}{dt} - \frac{\partial \ln F}{\partial \ln H}\cdot\frac{d\ln H}{dt}.$$

However, in order to use equation (3.6) to measure technical progress empirically, one needs to know, in addition to the rates of growth of the outputs and inputs, the values of the three production elasticities. Even with the assumption of constant returns to scale, which implies that the sum of the three production elasticities is equal to unity:

$$(3.7)\quad \frac{\partial \ln F}{\partial \ln K} + \frac{\partial \ln F}{\partial \ln L} + \frac{\partial \ln F}{\partial \ln H} = 1,$$

the values of the production elasticities of capital and human capital cannot be separately determined from the knowledge of the labor share alone.[6]

Econometric Estimation of the Aggregate Production Function

Econometric estimation of the aggregate production function provides an alternative for the measurement of the rate of technical progress, in most cases, from the effect of a time trend variable on real output, holding all measured inputs constant. However, potential problems of identification may arise if the variations in the quantities of inputs (or their ratios) or the relative prices of the inputs are small. The restricted range of variation and near constancy of factor (or price) ratios will give rise to multicollinearity problems. Moreover, with data from only a single economy, in which both capital and labor have been growing steadily, it is often difficult to identify the rate of technical progress separately, let alone disentangle the scale effects from the technical progress effects.

The Advantages of the Meta-Production Function Approach

Boskin and Lau (1990) extend the meta-production function approach by pooling time-series data across economies to estimate the parameters of aggregate production function simultaneously with the scale and technical progress effects as well as their biases, if any. The basic assumption behind the meta-production function approach is that all economies have potential access to the same technology but each may operate on a different part of it depending on specific individual circumstances. By pooling data across economies, the ranges of variation in the quantity (and price) variables are expanded. It is also far less likely that factor (or price) ratios are constant across economies. The problem of multicollinearity is therefore much less likely to occur. The basic intuition for the simultaneous identifiability of scale and

[6] There are two potential difficulties here. First, the marginal products of capital and human capital may not be equal to the respective normalized (by the price of output) user costs (rental prices) of capital and human capital, that is, there may be deviations from instantaneous competitive profit maximization for these fixed and quasi-fixed inputs. Second, even if one is willing to maintain the hypothesis of instantaneous competitive profit maximization, the user costs of capital and human capital cannot in

technical progress effects with pooled time-series data across economies is as follows: At any one time, there are economies operating at different scales; and the same scale of operation is found at different times. Thus it is possible to identify separately the scale and technical progress effects.

One consequence of pooling data across economies, especially if they are diverse in terms of size and endowments, is the expansion in the ranges of variation in the values of the quantities of the inputs. Thus, a simple functional form, such as the Cobb-Douglas, which may be viewed as a first-order approximation (in the natural logarithms) of an arbitrary production function, may no longer be adequate.[7] In order to accommodate the expanded domain of definition of the production function, a flexible functional form (for example, the transcendental logarithmic function introduced by Christensen, Jorgenson and Lau (1973)) should be specified for the aggregate production function. The questions raised by the pooling of data, such as whether these economies share a common identical aggregate meta-production function, or whether data employed are comparable among them, can be directly confronted in the meta-production approach through statistical tests. Finally, using the estimated parameters from an aggregate meta-production function, relative efficiencies of the outputs and inputs and the technological levels across the different economies can be directly derived.

4. Methodology and Data

Methodology

The Basic Meta-Production Function Model

The methodology used in this study follows closely the meta-production function approach introduced by Hayami and Ruttan (1970, 1985) and extended Lau and Yotopoulos (1989) and Boskin and Lau (1990, 2002). One potential problem of this approach is the lack of precision of the estimates, which

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general be directly observed in the respective markets.

[7] For example, the average shares of labor in our sample of economies range between 0.25 (Thailand) and 0.66 (the United States) in Table 1.1. It is most unlikely that all these economies could have a common constant output elasticity with respect to labor as required by the assumption of a single, identical Cobb-Douglas functional form.

may arise if the variations in either the quantities or the relative prices of the inputs in the sample are not large enough. To avoid this problem, we pool the data from the East Asian economies with those from the non-Asian developed economies. However, the focus of our analysis remains the East Asian economies.

There are three basic assumptions for the meta-production function model. They are, for the two-input case:

(1) All economies have the same underlying aggregate meta-production function F(.) in terms of standardized, or "efficiency-equivalent", quantities of outputs and inputs, i.e.

(4.1) $Y_{it}^{*}=F(K_{it}^{*},L_{it}^{*})$, i=1,...,n,

where Y_{it}^{*}, K_{it}^{*}, and L_{it}^{*} are the quantities of "efficiency-equivalent" outputs and inputs of the ith economy in the tth period, respectively, and n is the number of economies.[8]

(2) The measured quantities of outputs and inputs of the different economies may be converted into the unobservable standardized, or "efficiency-equivalent", units of outputs and inputs by multiplicative economy-, output- and input-specific time-varying augmentation factors, $A_{ij}(t)$'s, i=1,...,n; j=output (0), capital (K), and labor (L):

(4.2) $Y_{it}^{*} =A_{i0}(t)Y_{it}$;

(4.3) $K_{it}^{*} =A_{iK}(t)K_{it}$;

(4.4) $L_{it}^{*} =A_{iL}(t)L_{it}$; i=1,...,n.

The commodity-augmentation factors represent differences in climate, natural resources, infrastructure, quality and technical efficiencies across economies. In this study, the commodity-augmentation factors are assumed to have a constant geometric form with respect to time.

(4.5) $Y_{it}^{*} =A_{i0} (1+c_{i0})^{t}Y_{it}$;

(4.6) $K_{it}^{*} =A_{iK} (1+c_{iK})^{t}K_{it}$;

(4.7) $L_{it}^{*} =A_{iL} (1+c_{iL})^{t}L_{it}$, i=1,..., n, where the A_{i0}'s, A_{iK}'s, A_{iL}'s, c_{i0}'s, c_{iK}'s and c_{iL}'s are constants. A_{i0}'s, A_{iK}'s and A_{iL}'s are referred to as augmentation level parameters and c_{i0}'s, c_{iK}'s and c_{iL}'s as augmentation rate parameters. Since the augmentation level parameters can only be identified relative to some standard, without loss of generality, the augmentation level parameters for the United States are assumed to take a value of unity. With this normalization, all of the remaining level and rate parameters are estimable without further restrictive assumptions.

(3) A flexible functional form is chosen for F(.) in order to accommodate the wide range of variations of the quantities of inputs in the pooled multiple-economy sample and also to allow the possibility of non-neutral returns of scale and technical progress. In this study, the meta-production function is specified to be the transcendental logarithmic (translog) functional form introduced by Christensen, Jorgenson and Lau (1973). With two inputs, tangible capital and labor, the translog production function takes the following form.

$$(4.8)\ \ln Y_{it}^{*}=\ln Y_0+a_K \ln K_{it}^{*}+a_L \ln L_{it}^{*}+B_{KK}(\ln K_{it}^{*})^2/2+B_{LL}(\ln L_{it}^{*})^2/2+B_{KL}(\ln L_{it}^{*})(\ln K_{it}^{*}),\ i=1,\ldots n.$$

Equation (4.8) consists entirely of unobservable variables and cannot be econometrically estimated. However, by substituting equations (4.5) through (4.7) into equation (4.8) and simplifying, we obtain an equation consisting entirely of observable variables:

$$\begin{aligned}(4.9)\ \ln Y_{it} = {} & \ln Y_0+ \ln A_{i0}^{*} + a_{iK}^{*} \ln K_{it} + a_{iL}^{*} \ln L_{it} \\ & + B_{KK}(\ln K_{it})^2/2 + B_{LL}(\ln L_{it})^2/2 + B_{KL}(\ln L_{it})(\ln K_{it}) + c_{i0}^{*}\, t \\ & + (B_{KK}\ln(1+c_{iK})+B_{KL}\ln(1+c_{iL}))(\ln K_{it})t + (B_{KL}\ln(1+c_{iK})+B_{LL}\ln(1+c_{iL}))(\ln L_{it})t \\ & + (B_{KK}(\ln(1+c_{iK}))^2+2B_{KL}\ln(1+c_{iK})\ln(1+c_{iL}) +B_{LL}(\ln(1+c_{iL}))^2)t^2/2,\ i=1,\ldots n,\end{aligned}$$

where the A_{i0}^{*}, c_{i0}^{*}, a_{iK}^{*} and a_{iL}^{*}'s are economy-specific constants. B_{KK}, B_{LL} and B_{KL} are the only common parameters across economies under the maintained hypothesis of a single identical meta-production function for all economies. Thus one can test the hypothesis of a single identical meta-production function by testing whether these parameters are identical across economies. Another feature of the

[8] Note that F(.) itself is assumed to be independent of t. t affects the production function only through its

representation in equation (4.9) is that for each economy, the parameter for the t^2 term is completely determined by the other identifiable parameters for that economy. Thus one can test the hypothesis of commodity-augmentation representation of technical progress by testing whether this restriction holds.

In addition to the meta-production function in equation (4.9), we also examine the empirical behavior of the share of labor in the value of output as a function of capital, labor and time:

$$(4.10)\quad w_{it}L_{it}/p_{it}Y_{it} = a_{iL}^{**} + B_{iKL}\ln K_{it} + B_{iLL}\ln L_{it} + B_{iLt}t, \quad i=1,..., n.$$

The hypothesis of instantaneous profit maximization under perfectly competitive output and input markets implies that the marginal product of labor is equal to the wage rate divided by the price of output, which in turn implies that the output elasticity of labor is equal to the share of labor costs in the value of output. By differentiating equation (4.9) with respect to the natural logarithm of labor, we obtain:

$$(4.11)\quad \frac{\partial \ln Y_{it}}{\partial \ln L_{it}} = a_{iL}^{*} + B_{KL}\ln K_{it} + B_{LL}\ln L_{it} + (B_{KL}\ln(1+c_{iK})+B_{LL}\ln(1+c_{iL}))t, \quad i=1,..., n.$$

Under the hypothesis of profit maximization, the labor share, $w_{it}L_{it}/p_{it}Y_{it}$, is equal to the output elasticity of labor. Thus, the parameters in equation (4.10) must be equal to the corresponding parameters in equation (4.11), which are derived from the parameters in equation (4.9). This provides a basis for testing the hypothesis of instantaneous profit maximization with respect to labor in the ith economy.

In our empirical implementation, the system of two equations consisting of (4.9) and (4.10) will be jointly estimated. Without loss of generality, the above derivation can be generalized to the case of any finite number of inputs.

The Statistical Method

Since macroeconomic time-series data often display non-stationarity, our estimation of equations (4.9) and (4.10) is done in the first-differenced form. Under the assumption that the stochastic disturbance terms have a joint normal distribution, the production function and the labor share equation

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effects on the commodity-augmentation factors.

(and their various specializations) are estimated as a system of simultaneous equations. In order to avoid potential biases that may result from endogeneity of the factor input variables, the method of nonlinear instrumental variables three-stage least-squares is used (See Gallant and Jorgenson (1979)). The stochastic disturbance terms of the aggregate production function and labor share equations are further adjusted for possible heteroscedasticity.

The quasi-likelihood ratio is used for the tests of hypotheses. Under the assumptions, the test statistic used for inference, the difference between the weighted sum of squares of residuals of the system of two equations projected in the space spanned by the instrumental variables, with and without the restrictions implied by the null hypothesis, is asymptotically distributed as the chi-squared distribution with the appropriate degrees of freedom under the null hypothesis (See Gallant and Jorgenson (1979)).

Tests of Hypotheses

A series of hypotheses are tested with the overall level of significance set at 0.10. Different levels of significance are assigned to the different hypotheses of interest, keeping the sum of the levels under 0.10 to ensure that the overall level of significance of the series is less than or equal to 0.10. The tested hypotheses are as follows:

I. The maintained hypotheses of the meta-production function approach: (1) The production functions of all economies are identical in terms of “efficiency-equivalent" units of output and inputs; and (2) Technical progress can be represented in the commodity-augmentation form, with constant geometric augmentation factors.

II. Conditional on the validity of the maintained hypotheses of the meta-production function approach, the hypotheses which are maintained traditionally in the growth accounting exercises are tested. They are the hypotheses of homogeneity, constant returns to scale in all measured inputs, neutrality of technical progress, and competitive profit maximization.

III. Specific hypotheses on the nature of the production technology are tested conditional on the maintained hypotheses of the meta-production function approach: (A) The hypotheses of identical augmentation level parameters across economies for tangible capital and labor, respectively; and (B) The hypotheses of the existence of biases in technical progress—comprising of the hypotheses of purely-output-augmenting technical progress (same implications as the hypothesis of neutrality), purely-tangible-capital-augmenting, and purely-labor-augmenting technical progress.

IV. Based on the results of these tests, we estimate a restricted specification incorporating all the restrictions corresponding to all the hypotheses that are not rejected. Conditional on the validity of the restricted specification, the hypothesis of no technical progress is tested separately for the developed and the developing economies.[9]

Data Description

The econometric analyses reported in the following Sections are based on the extended meta-production function approach of Boskin and Lau (1990) applied to pooled time-series aggregate data for nine East Asian developing economies--Hong Kong, South Korea, Singapore, Taiwan, Indonesia, Malaysia, Philippines, Thailand and China--and a sample of developed economies (e.g., the G-5 countries). Developed economies are not the focus of our study, however, their inclusion in the econometric analyses provides the variations in the data that enable the more precise identification and estimation of the parameters of the aggregate meta-production function.

The sample of aggregate-level data from the eight East Asian economies used in Kim and Lau (1995, 1996) is extended to include on average five more years (1991-1995). The specific sample periods for these economies are as follows: Hong Kong, 1966-1995; South Korea, 1960-1995; Singapore, 1964-1995; Taiwan, 1953-1995; Indonesia, 1970-1994; Malaysia, 1970-1995; Philippines, 1966-1995 and

[9] It is also possible to test the hypothesis of no technical progress conditional on the validity of the maintained hypotheses of the meta-production function approach. This is also done as a way to assure the robustness of our results.

Thailand, 1966-1994. The details of relevant data sources are discussed in Kim and Lau (1995) and Park (1999). In addition to these economies, China is also included (for the period 1965-1995). All Chinese data except for the gross fixed investment series are obtained from various issues of the China Statistical Yearbook. The gross fixed investment series are taken from Statistics on Investment in Fixed Assets of China. As for the G-5 countries, the sample period is 1958-1994 except for the U.S. (1950-1994). The data for the G-5 countries are taken from Boskin and Lau (2002).

The variables included in the data set are real GDP, Y, utilized tangible capital stock, K, total labor hours worked, L, human capital stock, H, R&D capital stock, R, and labor share, wL/pY, where w is the wage rate and p is the price of output. The real GDP and utilized tangible capital stocks are in constant 1980 U.S. dollars. The utilized tangible capital stocks are obtained by multiplying the capacity utilization rates in the manufacturing sector to the tangible capital stocks. Boskin and Lau (2002) discuss in detail the construction of the gross tangible capital stocks from gross investment data using the perpetual inventory method with retirement rates. In economies where the capacity utilization rates are not available, they are estimated by the "peak-to-peak" method and normalized through a scalar adjustment.

The annual total number of labor hours per (employed) person is estimated as follows. For Hong Kong, South Korea, Singapore, Malaysia and Philippines, it is obtained by multiplying the average number of hours worked per person per week by 52. For Taiwan and Thailand, it is obtained by multiplying the average number of hours worked per person per month by 12. For China and Indonesia, data on either weekly or monthly average hours worked are not available for the entire labor force—the average of the average numbers of hours worked per person per week for Malaysia, Philippines and Thailand is used instead. This number is multiplied by 52 to arrive at an estimate of the average number of hours worked per person per year. To adjust for the effect of vacations or leaves, a month is taken out by multiplying the annual number of hours worked by 11/12. The total number of labor hours is then obtained by multiplying the adjusted average number of hours worked per person per year by the total number of person employed.

Human capital is measured as the total number of schooling years (primary, secondary and tertiary education) of the working-age population (defined to be persons of age between 15 and 64, inclusive).[10] It is derived from the accumulation of annual aggregate educational enrollment figures using the perpetual inventory method, taking into account the survival rates of the different age groups.[11] The estimation of the human capital variable for the developed economies is documented in Boskin and Lau (2002). As for the East Asian economies, the human capital series have been extended and revised based on the data of Kim and Lau (1995). The basic approach which accumulates long historical time series of enrollment data is used for South Korea and Singapore. However, due to the lack of long historical time series for enrollment and the potential impacts of large population movements due to wars and natural calamities, the benchmark approach is used for Hong Kong, Taiwan, Indonesia, Malaysia, Philippines, Thailand and China. The census publication of each economy provides the educational attainment at various levels--primary, secondary and tertiary--for each age cohort of the total population in the census year. The educational attainment tables of the years 1956 for Taiwan, 1971 for Hong Kong, 1969 for Indonesia, 1957 for Malaysia, 1970 for Philippines, 1960 for Thailand and 1982 for China are taken as the benchmark distributions of the human capital stock in the populations of the respective economies. The enrollment figures for the subsequent years (and prior years when applicable) are successively added to the benchmark distributions of the human capital stock to derive estimates of the average educational attainment levels for each year. As for Hong Kong, the levels of average schooling years are further adjusted to match the educational attainment figures for all census years after 1961 reported in the census publications of Hong Kong. The levels of average schooling years for China are adjusted to match the

[10] This definition of the human capital variable is different from Kim and Lau (1995). Human capital is defined as the total number of years of formal education of the working-age population rather than the average number of years of education. The difference in definition will have no effect on the results of the tests of hypotheses because the estimating equation based on one definition can be equivalently transformed into that based on the other definition.

educational attainment figures in the 1964 census. Data for working-age population are taken from Labor Force Statistics, OECD for the G-5 developed economies and from economy-specific statistical yearbooks for the nine East Asian developing economies. The average annual rates of growth of outputs and inputs have been presented in Table 1.1 for the entire sample period.

Data on the aggregate R&D expenditures (GERD--gross expenditure in research and development) for the Group-of-Seven (G-7) countries are taken from OECD, Basic Science and Technology Statistics, and OECD, Science and Technology Statistics. Data on the aggregate R&D expenditures for South Korea, Singapore and Taiwan are taken from the respective national statistical yearbooks. Since initial benchmarks for the R&D capital stocks are not available, log-linear extrapolations using all available data on R&D expenditures are used to estimate the earlier investments in R&D, leading back to 1850 for the United Kingdom and the United States, to 1900 for the other G-7 countries, and to 1950 for the three NIEs.[12] The R&D investments, converted to a constant-price basis, are then accumulated into a R&D capital stock series using the perpetual inventory method with an assumed rate of depreciation of ten percent per annum.[13]

The instrumental variables used in the estimation include lagged output, twice-lagged output, lagged employment, economy dummies, world population, male and female population, arable land, contemporaneous and lagged world prices of cotton, oil and iron ore relative to the world price of wheat.[14] Data on world and economy-specific total, male and female populations are taken from United Nations Statistical Yearbook. Data on world prices of cotton, oil, iron and wheat are taken from International Financial Statistics.

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[11] For detailed discussions, Kim and Lau (1995).

[12] The trends of R&D expenditures in the three NIEs have undergone significant changes over the sample period. Thus, only the five earliest available observations have been used in the estimation of the parameters used in the extrapolation of the R&D expenditures back to an earlier period.

[13] For a related discussion, see Griliches and Lichtenberg (1984).

[14] Male and female life expectancies, which were included in the list of instrumental variables for the related previous works on the East Asian NIEs, have been excluded from the list due to the lack of data for the four ASEAN countries and China. The regressions with or without the life expectancies as instrumental variables are very similar for the East Asian NIEs.

5. The Role of Tangible Inputs

In this Section we evaluate the role of tangible inputs--tangible capital (structures and equipment) and labor--in the growth of the four NIEs, four ASEAN economies and China. We extend the sample period used by Kim and Lau (1994a, 1994b, 1996) to 1994 05 1995, depending on availability of data, and we also revise and update the data as necessary. We re-estimate the aggregate meta-production function model used by Kim and Lau with pooled time-series data from the nine East Asian developing economies and the G-5 countries. On the basis of the estimated model, we perform the statistical tests and compute the growth accounts. The purpose of this exercise is to ascertain whether the addition of more recent years to the sample period, during which the industrial structures of the East Asian developing economies have undergone rapid transformations, would alter the conclusion reached by Kim and Lau (1994a, 1994b and 1996) that there has been no technical progress in the East Asian developing economies.[15]

(1) Tests of the Hypotheses of the Meta-Production Function Model

We begin by testing a series of hypotheses that are critical for the validity and usefulness of the meta-production function approach. The tests are performed on the two separate pooled samples: the pooled sample of the G-5 countries and the four East Asian NIEs and the pooled sample of the G-5 countries and the nine East Asian developing economies. First, we test the maintained hypotheses of the meta-production function approach, that is, whether we are justified in pooling the data of all the economies together. Second, we test the maintained hypotheses of traditional growth-accounting--constant returns to scale,

[15] Even though there might not have been technical progress at the level of the aggregate economy in the East Asian NIEs, it is possible that there may have been technical progress in some of the sectors, especially the export-oriented ones. A natural candidate for testing this hypothesis is the manufacturing sector, the growth of which has been the fastest and the structural transformation of which has been the most rapid and far-reaching (from textiles and shoes to semiconductor chips), with a heavy utilization of imported capital goods and technology and an orientation towards the open global markets. However,

neutrality of technical progress, and competitive profit maximization (with respect to labor). If the maintained hypotheses of traditional growth-accounting were valid, then the use of the meta-production function approach, which is independent of these maintained hypotheses, would not be as compelling. Third, we test hypotheses on the nature of the production technology. We test separately whether the tangible capital and labor augmentation level parameters are identical across the economies--that is, whether the efficiency levels of tangible capital and labor are the same in the base year, which is taken to be 1980. We also test whether technical progress may be characterized as purely output-augmenting (Hicks-neutral), purely tangible-capital-augmenting (Solow-neutral), or purely labor-augmenting (Harrod-neutral). We assign levels of significance to individual hypotheses in our series of tests so that the overall level of significance for an entire series of tests based on a given sample of data is less than or equal to 10 percent (see Tables 5.1a and 5.1b).[16]

The results of the tests of hypotheses are presented in Tables 5.1a and 5.1b. We find that: (i) The maintained hypotheses of the meta-production function approach cannot be rejected; (ii) The maintained hypotheses of traditional growth-accounting are all rejected; (iiia) The hypotheses of identical tangible capital and labor augmentation level parameters cannot be rejected; and (iiib) The hypotheses of purely tangible-capital-augmenting technical progress cannot be rejected whereas the hypothesis of purely labor-augmenting technical progress is rejected.[17] We note that our results here lend further empirical support to the hypothesis that technical progress is purely tangible-capital-augmenting, first found and reported by Boskin and Lau (1990) for the G-5 countries.

Lau and Park (1998) find similar results of no technical progress for the manufacturing sector of the four East Asian NIEs.

[16] P-Values are presented in the tables reporting the results of the tests of hypotheses so that the readers can substitute their own desired levels of significance for the different tests if they wish.

[17] The rejection of at least one of the hypotheses of purely tangible capital- or labor-augmenting technical progress implies that the hypothesis of no technical progress in all of the economies is rejected.

Table 5.1a: Tests of Hypotheses (4 East Asian NIEs + G-5 Countries)
(Two-Input Model)

Tested Hypothesis	Maintained Hypothesis[1]	Assigned Level of Significance	Number of Restrictions	p-value
I. Maintained Hypotheses of the Meta-production Function Approach				
(1) Single Meta-Production Function	Unrestricted	0.005	24	0.5522
(2) Commodity Augmentation	I(1)	0.005	9	0.7245
II. Traditionally Maintained Hypotheses				
(1a) Homogeneity	I	0.005	2	0.0000[2]
(1b) Constant Returns to Scale	I+II(1a)	0.005	1	0.3642
(2) Neutrality	I	0.01	18	0.0000[2]
(3) Profit Maximization	I	0.01	27	0.0000[2]
III. The Nature of the Production Technology				
(A) Hypotheses on Augmentation Levels				
(1) Identical Augmentation Levels for Tangible Capital	I	0.005	8	0.8993
(2) Identical Augmentation Levels for Labor	I	0.005	8	0.1476
(B) Hypotheses on Augmentation Rates				
(1) Purely Output-Augmenting[3]	I	0.01	18	0.0000[2]
(2) Purely Tangible-Capital-Augmenting	I	0.005	18	0.1210
(3) Purely Labor-Augmenting	I	0.005	18	0.0000[2]

Notes: 1. The variance-covariance matrix is updated at the non-identical production function, identical production function, and commodity augmentation stages and fixed thereafter.
2. Due to rounding.
3. Same restrictions as the hypothesis of neutrality of technical progress.

Table 5.1b: Tests of Hypotheses (4 East Asian NIEs + 4 ASEAN Economies + China + G-5 Countries)
(Two-Input Model)

Tested Hypothesis	Maintained Hypothesis[1]	Assigned Level of Significance	Number of Restrictions	p-value
I. Maintained Hypotheses of the Meta-production Function Approach				
(1) Single Meta-Production Function	Unrestricted	0.005	39	1.0000[2]
(2) Commodity Augmentation	I(1)	0.005	14	0.9971
II. Traditionally Maintained Hypotheses				
(1a) Homogeneity	I	0.005	2	0.0000[2]
(1b) Constant Returns to Scale	I+II(1a)	0.005	1	0.2104
(2) Neutrality	I	0.01	28	0.0000[2]
(3) Profit Maximization	I	0.01	42	0.0003
III. The Nature of the Production Technology				
(A) Hypotheses on Augmentation Levels				
(1) Identical Augmentation Levels for Tangible Capital	I	0.005	13	0.7610
(2) Identical Augmentation Levels for Labor	I	0.005	13	0.9094
IV. Hypotheses on Augmentation Rates				
(1) Purely Output- Augmenting[3]	I	0.01	28	0.0000[2]
(2) Purely Tangible-Capital-Augmenting	I	0.005	28	0.0533
(3) Purely Labor-Augmenting	I	0.005	28	0.0000

Notes: 1. The variance-covariance matrix is updated at the non-identical production functions, identical production functions, and commodity augmentation stages and fixed thereafter.
2. Due to rounding.
3. Same restrictions as the hypothesis of neutrality of technical progress.

(2) Has There Been Technical Progress?

Having found through hypothesis testing that the tangible capital and labor augmentation level parameters are identical across economies and that technical progress is purely tangible-capital-augmenting, we estimate a restricted specification imposing these restrictions. We then proceed to test the principal hypotheses of interest: Has there been technical progress in either the East Asian developing economies or the G-5 countries? We assign a level of significance of 0.01 each to the two groups of economies: the East Asian developing economies and the G-5 countries in these tests.

In Table 5.2 we present the results of the tests of the hypothesis of "no technical progress" conditional on the restricted specification. At the assigned levels of significance, the hypothesis that there has been no technical progress at the aggregate level in the four East Asian NIEs cannot be rejected. The test results also indicate no significant technical progress in the four ASEAN economies and China as a group. Our results provide confirmation of the original findings of Kim and Lau (1994a, 1994b, 1996) that there has been no technical progress in the four NIEs and the four ASEAN economies. By contrast, the hypothesis that there has been no technical progress at the aggregate level in the developed economies is decisively rejected, as is the case in the original studies of Kim and Lau. We thus reaffirm the empirical findings of Kim and Lau that in the postwar period there has been no technical progress in the East Asian developing economies whereas there has been significant technical progress in the developed economies, including Japan.[18]

[18] It is also possible to test the hypothesis of no technical progress conditional on the maintained hypotheses of the meta-production function approach rather than the restricted specification. These tests have been performed separately for the three groups: G-5 countries, 4 East Asian NIEs and 5 East Asian developing economies (4 ASEAN and China). The p-values for these tests are respectively 0.00000, 0.54261 and 0.22597, also indicating that the hypothesis of no technical progress can be rejected for the G-5 countries but not for the East Asian developing economies at the 1-percent levels of significance.

Table 5.2: p-Values for Tests of the Hypothesis of No Technical Progress (Two-Input Model)

	Sample			
	Full Sample for 4 NIEs and G-5		Full Sample for 4 NIEs, 4 ASEAN, China and G-5	
	c_{iK}=0	Level of Significance	c_{iK}=0	Level of Significance
4 NIEs	0.06243	0.01	0.01907	0.005
4 ASEAN + China	N.A.		0.21692	0.005
9 Developing Economies	N.A.		0.07782	
G-5	0.00000	0.01	0.00000	0.01
All Economies	0.00000		0.00000	

Note: Restricted specification:

$$d \ln Y_t = a_K \cdot d \ln((1+c_{iK})^t K_t) + a_L \cdot d \ln L_t + B_{KK} \cdot d(\ln((1+c_{iK})^t K_t))^2 / 2 + B_{LL} \cdot d(\ln L_t)^2 / 2$$
$$+ B_{KL} \cdot d[\ln((1+c_{iK})^t K_t) \cdot \ln L_t],$$

where d is the first difference operator, K_t is the tangible capital stock, and L_t is total labor hours.

(3) Accounting for Economic Growth

The estimated final specification for the aggregate meta-production function is reported in Table 5.3. Using the estimated parameters, we perform a growth-accounting exercise, attributing economic growth to the three possible sources: tangible capital, labor, and technical progress. The results are reported in Table 5.4. They are almost identical with the original findings of Kim and Lau (1994a, 1994b). Tangible capital is the most important source of economic growth for the East Asian NIEs in the postwar period, accounting between 65 and 85 percent of economic growth, followed by labor. In contrast, technical progress is the most important source of economic growth for the non-Asian G-5 countries, accounting for almost 60 percent on average, followed by tangible capital, with an almost negligible contribution from labor. Japan, however, occupies an intermediate position as before. It has, like the other G-5 countries, significant technical progress, which accounts for more than 45 percent of its economic growth, but, like the East Asian NIEs, tangible capital remains its most important source of growth. The results for the pooled sample of nine East Asian developing economies and the G-5 countries also lead to qualitatively very similar conclusions. For China, almost 95 percent of its economic growth can be attributed to the growth of tangible capital stock alone.

Table 5.3: Estimated Parameters for the Final Specification
(Two-Input Model)

Parameter		4 NIEs and G-5 Estimate	4 NIEs and G-5 t-statistic	4 NIEs, 4 ASEAN, China and G-5 Estimate	4 NIEs, 4 ASEAN, China and G-5 t-statistic
a_K		0.212	2.247	0.130	1.843
a_L		0.777	3.092	0.937	4.591
B_{KK}		-0.074	-6.752	-0.083	-10.812
B_{LL}		-0.052	-0.724	-0.106	-1.933
B_{KL}		0.026	0.934	0.052	2.733
c_{iK}[1]	France	0.066	8.945	0.060	11.245
	West Germany	0.081	8.165	0.075	9.579
	Japan	0.077	4.372	0.063	5.405
	United Kingdom	0.034	5.461	0.030	6.287
	United States	0.050	6.069	0.044	8.013
Adjusted R-squared			0.740		0.711
D.W.			1.805		1.679
No. of observations			330		458

Note: 1. The c_{iK}'s for the East Asian developing economies are restricted to zero in accordance with the results of the tests of hypotheses.
2. Parameters for the unrestricted share equation are also estimated but not reported here.
3. Final specification:

$$d\ln Y_t = a_K \cdot d\ln((1+c_{iK})^t K_t) + a_L \cdot d\ln L_t + B_{KK} \cdot d(\ln((1+c_{iK})^t K_t))^2/2 + B_{LL} \cdot d(\ln L_t)^2/2$$
$$+ B_{KL} \cdot d[\ln((1+c_{iK})^t K_t) \cdot \ln L_t],$$

where d is the first difference operator, K_t is the tangible capital stock, and L_t is total labor hours.

Table 5.4: Growth Accounts: Contributions of the Sources of Growth
(Two-Input Model)

	Tangible Capital	Labor	Technical Progress
(1) Full Sample : 4 NIEs and G-5			
Hong Kong	74.46	25.54	0.00
South Korea	78.20	21.80	0.00
Singapore	64.80	35.20	0.00
Taiwan	84.04	15.96	0.00
Japan	49.90	4.84	45.26
Non-Asian G-5 Countries	38.71	2.77	58.52
(2) Full Sample: 4 NIEs, 4 ASEAN, China and G-5			
Hong Kong	74.61	25.39	0.00
South Korea	82.95	17.05	0.00
Singapore	63.41	36.59	0.00
Taiwan	86.60	13.40	0.00
Indonesia	88.79	11.21	0.00
Malaysia	66.68	33.32	0.00
Philippines	66.10	33.90	0.00
Thailand	83.73	16.27	0.00
China	94.84	5.16	0.00
Japan	55.01	3.70	41.29
Non-Asian G-5 Countries	41.51	1.97	56.53

Note: The parameters are taken from Table 5.3. They have been estimated under the restrictions of c_{iK}=0 for all East Asian developing economies.

6. The Role of Human Capital

In this Section, we evaluate the role of human capital, as distinct from and in addition to tangible capital (structures and equipment) and labor, in the growth of the nine East Asian developing economies. Our interpretation of technical progress is that it mostly reflects the effects of unmeasured, and possibly unmeasurable, intangible inputs. An important and typically unmeasured, but measurable, intangible input is that of human capital. In this study, human capital is measured as the total number of years of schooling of the working-age population. If measured technical progress is in fact attributable to the growth of intangible inputs such as human capital, then the explicit introduction of human capital as an input in an empirically estimated aggregate production function should result in a lower rate of measured technical progress as well as a lower estimated contribution of technical progress to economic growth.

The exercise undertaken in this Section is similar to that of Section 5, but with the explicit inclusion of the human capital input in the aggregate meta-production function. We apply the three-input meta-production function model first to the pooled sample of the four East Asian NIEs and the G-5 countries and then to the pooled sample of the nine East Asian developing economies and the G-5 countries.

(1) Tests of the Hypotheses of the Meta-Production Function Model

We begin by testing the same series of hypotheses that have become standard in the meta-production function approach on the pooled sample of the four East Asian NIEs and the G-5 countries and then on the pooled sample of the nine East Asian developing economies and the G-5 countries. The results of the tests of hypotheses are presented in Tables 6.1a and 6.1b for the cases of the four East Asian NIEs and the nine East Asian developing economies respectively. For both cases, we find that: (i) The maintained hypotheses of the meta-production function approach cannot be rejected; (ii) The maintained hypotheses of traditional growth-accounting are all rejected; (iiia) The hypotheses of identical tangible capital, labor and human capital augmentation level parameters cannot be rejected; and (iiib) The hypotheses of purely tangible-capital-augmenting and purely human-capital-augmenting technical progress cannot be rejected whereas the hypothesis of purely labor-augmenting technical progress is rejected.

We note that our results here lend further empirical support to the hypothesis that technical progress is purely tangible-capital-augmenting, first found and reported by Boskin and Lau (1990) for the G-5 countries. We also confirm the finding of Kim and Lau (1995) and Boskin and Lau (2002) that technical progress is also purely human-capital-augmenting. As discussed in Section 2 above, under the maintained hypotheses of the meta-production function approach, technical progress can be represented in the general commodity-augmentation form in the aggregate production function as:

(6.1) $Y_{it} = A_{i0}(t)\ F\ (A_{iK}(t)K_{it},\ A_{iL}(t)L_{it},\ A_{iH}(t)H_{it}).$

Purely tangible-capital-augmenting technical progress implies that the production function takes the form:

(6.2) $Y_{it} = A_{i0}\ F\ (A_{iK}(t)K_{it},\ A_{iL}L_{it},\ A_{iH}H_{it}).$

Purely human-capital-augmenting technical progress implies that the production function takes the form:

(6.3) $Y_{it} = A_{i0}\ F\ (A_{iK}K_{it},\ A_{iL}L_{it},\ A_{iH}(t)H_{it}).$

Is it possible that technical progress is simultaneously purely tangible-capital-augmenting and purely human-capital-augmenting? The answer is yes--there is one and only one possible form for the production function, as shown in Lau (1980), and that is:

(6.4) $Y_{it} = A_{i0}\ F\ (A_{iKH}(t)K_{it}^{\lambda}\ H_{it}^{1-\lambda},\ A_{iL}L_{it}),$

where λ is, without loss of generality, a positive constant between zero and one.

Table 6.1a: Tests of Hypotheses (4 NIEs and G-5 Countries)
(Three-Input Model with Human Capital)

Tested Hypothesis	Maintained Hypothesis[1]	Assigned Level of Significance	Number of Restrictions	p-value
I. Maintained Hypotheses of the Meta-production Function Approach				
(1) Single Meta-Production Function	Unrestricted	0.005	48	1.0000[2]
(2) Commodity Augmentation	I(1)	0.005	9	0.9866
II. Traditionally Maintained Hypotheses				
(1a) Homogeneity	I	0.005	3	0.0000[2]
(1b) Constant Returns to Scale	I+II(1a)	0.005	1	0.0724
(2) Neutrality	I	0.01	27	0.0000[2]
(3) Profit Maximization	I	0.01	36	0.0003
III. The Nature of the Production Technology				
(A) Hypotheses on Augmentation Levels				
(1) Identical Augmentation Levels for Tangible Capital	I	0.003	8	0.7649
(2) Identical Augmentation Levels for Labor	I	0.003	8	0.2764
(3) Identical Augmentation Levels for Human Capital	I	0.003	8	0.8840
(B) Hypotheses on Augmentation Rates				
(1) Purely Output-Augmenting[3]	I	0.01	27	0.0000[2]
(2) Purely Tangible-Capital-Augmenting	I	0.0067	27	0.3458
(3) Purely Labor-Augmenting	I	0.0067	27	0.0000[2]
(4) Purely Human-Capital-Augmenting	I	0.0067	27	0.3924
V. No Human Capital Effect	I	0.01	4	0.0000[2]

Notes: 1. The variance-covariance matrix is updated at the non-identical production function, identical production function, and commodity-augmentation stages and fixed thereafter.
2. Due to rounding.
3. Same restrictions as the hypothesis of neutrality of technical progress.

Table 6.1b: Tests of Hypotheses (4 NIEs, 4 ASEAN, China and G-5 Countries)
(Three-Input Model with Human Capital)

Tested Hypothesis	Maintained Hypothesis[1]	Assigned Level of Significance	Number of Restrictions	p-value
I. Maintained Hypotheses of the Meta-production Function Approach				
(1) Single Meta-Production Function	Unrestricted	0.005	78	1.0000[2]
(2) Commodity Augmentation	I(1)	0.005	14	0.6731
II. Traditionally Maintained Hypotheses				
(1a) Homogeneity	I	0.005	3	0.0000[2]
(1b) Constant Returns to Scale	I+II(1a)	0.005	1	0.1134
(2) Neutrality	I	0.01	42	0.0000[2]
(3) Profit Maximization	I	0.01	56	0.0022
III. The Nature of the Production Technology				
(A) Hypotheses on Augmentation Levels				
(1) Identical Augmentation Levels for Tangible Capital	I	0.003	13	0.7445
(2) Identical Augmentation Levels for Labor	I	0.003	13	0.9930
(3) Identical Augmentation Levels for Human Capital	I	0.003	13	0.9841
(B) Hypotheses on Augmentation Rates				
(1) Purely Output-Augmenting[3]	I	0.01	42	0.0000[2]
(2) Purely Tangible-Capital-Augmenting	I	0.0067	42	0.0566
(3) Purely Labor-Augmenting	I	0.0067	42	0.0003
(4) Purely Human-Capital-Augmenting	I	0.0067	42	0.3174
V. No Human Capital Effect	I	0.01	4	0.0000[2]

Notes: 1. The variance-covariance matrix is updated at the non-identical production function, identical production function, and commodity-augmentation stages and fixed thereafter.
2. Due to rounding.
3. Same restrictions as the hypothesis of neutrality of technical progress.

(2) Does Human Capital Matter?

We test the hypothesis that the human capital stock variable, as measured, has no effect on the aggregate production function. This hypothesis implies that the parameters a_H, B_{KH}, B_{LH}, and B_{HH} are all zeroes (of course, when all the human capital-related parameters in the production function are zeroes, it no longer matters whether the human capital augmentation rate parameters are zeroes or not). We assign a level of significance of 0.01 to this hypothesis. It is decisively rejected (p-value=0.0000) (see Tables 6.1a and 6.1b) and we conclude that human capital, as measured, has a positive and statistically significant effect on aggregate real output.

(3) Has There Been Technical Progress?

Next, we impose the restrictions implied by the results of our tests of hypotheses--that tangible capital, labor, and human capital augmentation level parameters are identical across economies and technical progress is simultaneously purely tangible-capital- and human-capital augmenting—to estimate a restricted specification. Conditional on the restricted specification, we test whether there has been technical progress in the four East Asian NIEs, in the four other ASEAN economies and China, and the G-5 countries. The results are reported in Table 6.2.

Table 6.2 shows that the hypothesis of "no technical progress" cannot be rejected in each of the two groups of East Asian developing economies in a model with human capital explicitly distinguished as an input. Our results provide confirmation for the original findings of Kim and Lau (1995) that there has been no technical progress in the four East Asian NIEs and in addition show that there has been no measurable technical progress in the four other ASEAN economies and China.[19] As for the G-5

[19] Tests for no technical progress were also separately performed for China and four ASEAN economies. The results confirm the test results for the five economies as a group.

countries, the hypothesis that there has been no technical progress is again rejected, even with human capital explicitly distinguished as another input in the aggregate production function.[20]

Table 6.2: p-Values for Tests of the Hypothesis of No Technical Progress
(Three-Input Model with Human Capital)

	Sample			
	Full Sample for 4 NIEs and G-5		Full Sample for 4 NIEs, 4 ASEAN, China and G-5	
	$c_{iK}=0$	Level of Significance	$c_{iK}=0$	Level of Significance
4 NIEs	0.12332	0.01	0.02546	0.005
4 ASEAN + China	N.A.		0.08986	0.005
9 Developing Economies	N.A.		0.02954	
G-5	0.00000	0.01	0.00000	0.01
All Economies	0.00000		0.00000	

Note: Final specification:
$d\ln Y_t = a_K \cdot d\ln((1+c_{iK})^t K_{Ct}) + a_L \cdot d\ln L_t + B_{KK} \cdot d(\ln((1+c_{iK})^t K_{Ct}))^2/2 + B_{LL} \cdot d(\ln L_t)^2/2 + B_{KL} \cdot d[\ln((1+c_{iK})^t K_{Ct}) \cdot \ln L_t]$
where $K_{Ct} = K_t^{\lambda} H_t^{1-\lambda}$, d is the first-difference operator, K_t is the tangible capital stock, H_t is the human capital stock, and L_t is total labor hours.

(4) Accounting for Economic Growth

The final specification is estimated under the restrictions implied by the results of the tests of hypotheses of Tables 6.1a and 6.1b and the test results that there has been no measured technical progress in the two groups of East Asian developing economies. The results are reported in Table 6.3. The estimates of the rates of capital augmentation for the G-5 countries turn out to be remarkably robust to whether the four other ASEAN economies and China are included in the sample. However, the inclusion of four ASEAN economies and China raises the estimate of λ, the weight parameter for the tangible capital stock, thereby lowering the relative weight of human capital and thus the latter's relative

[20] It is also possible to test the hypothesis of no technical progress conditional on the maintained hypotheses of the meta-production function approach rather than the restricted specification. These tests have been performed separately for the three groups: G-5 countries, 4 East Asian NIEs and 5 East Asian developing economies (4 ASEAN and China). The p-values for these tests are respectively 0.00617, 0.39692 and 0.02924, also indicating that the hypothesis of no technical progress can be rejected for the G-5 countries but not for the East Asian developing economies at the 1-percent levels of significance.

contribution to the growth of the economies in the case of the fourteen economies compared to the case of only the four NIEs and G-5 countries.

Based on the estimated parameters of the final specification reported in Table 6.3, the relative contributions of tangible capital, labor, human capital, and technical progress are estimated and reported in Table 6.4.[21] In both the nine-economy and the fourteen-economy cases, tangible capital is the most important source of economic growth for the East Asian developing economies in the postwar period, accounting for between 55 percent and over 80 percent, followed by labor and then human capital. Human capital accounts for, on average, 3 percent of the postwar economic growth of the nine East Asian developing economies. The contribution rises to 6 percent in the case of only the four NIEs. In contrast, technical progress remains the most important source of economic growth for the non-Asian G-5 countries, accounting for almost 60 percent on average, followed by tangible capital, with a small contribution—between 3 and 6 percent, from labor. Human capital, surprisingly, is not an important source of growth for the G-5 countries, accounting for only between 1 and 3 percent. We speculate that it is probably due to the fact that human capital in the developed economies have reached a mature level and has been growing very slowly (especially given that the working-age populations have not been growing except in the United States). Thus, even though the marginal productivity of human capital may be substantial, the actual contribution of human capital as a source of economic growth is small because of its very low rate of growth.

Japan again occupies an intermediate position. It has, like the other G-5 countries, significant technical progress, which accounts for between 43 and 49 percent of its economic growth, but, like the

[21] In calculating the contributions to growth of each factor of input, the contribution of human capital may be decomposed into two parts: the part due to changes in average number of schooling years and the part due to changes in the working-age population. It follows from the fact that the changes in human capital H (dH=d(L'*h), where L' is the working-age population and h is average years of schooling) arise from the changes in the two factors--the changes in the average number of years of schooling (dh) and the changes in the working-age population (dL'). Thus dH = dh*L' + dL'*h, where dh*L' is the contribution due to changes in average years of education and dL'*h is the contribution due to increases in the working-age population. Since the changes in working-age population (L') is highly correlated with the

East Asian NIEs, tangible capital remains a much more important source of growth for Japan than it is for the non-Asian G-5 countries. Tangible capital and technical progress are of approximately equal importance as sources of growth for Japan in the postwar period.

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changes in labor (L) which is the employment multiplied by average work hours, we may attribute the sum of dL and dL'*h as the total contribution of the labor input to economic growth.

Table 6.3: Estimated Parameters for the Final Specification
(Three-Input Model with Human Capital)

Parameter		4 NIEs and G-5		4 NIEs, 4 ASEAN, China and G-5	
		Estimate	t-statistic	Estimate	t-statistic
a_K		0.578	2.264	0.210	1.793
a_L		0.581	3.057	0.886	5.046
B_{KK}		-0.102	-3.830	-0.091	-7.646
B_{LL}		-0.003	-0.038	-0.081	-1.583
B_{KL}		0.032	0.840	0.055	2.827
c_{iK}[1]	France	0.059	6.239	0.062	10.649
	West Germany	0.074	5.310	0.077	7.127
	Japan	0.076	4.637	0.066	6.661
	United Kingdom	0.034	3.366	0.033	3.673
	United States	0.044	3.367	0.043	4.676
$\lambda_H=(1-\lambda)$		0.275	1.859	0.084	0.940
λ		0.725	4.906	0.916	10.205
Adjusted R-squared			0.834		0.778
D.W.			1.621		1.545
No. of Observations			330		458

Note: 1. The c_{iK}'s for the East Asian developing economies are restricted to zero in accordance with the results of the tests of hypotheses.
2. Parameters for the unrestricted share equation are also estimated but not reported here.
3. Final specification:

$$d\ln Y_t = a_K \cdot d\ln((1+c_{iK})^t K_{Ct}) + a_L \cdot d\ln L_t + B_{KK}\cdot d(\ln((1+c_{iK})^t K_{Ct}))^2/2 + B_{LL}\cdot d(\ln L_t)^2/2$$
$$+ B_{KL}\cdot d[\ln((1+c_{iK})^t K_{Ct})\cdot \ln L_t],$$

where $K_{Ct} = K_t^{\lambda} H_t^{1-\lambda}$, d is the first-difference operator, K_t is the tangible capital stock, H_t is the human capital stock, and L_t is total labor hours.

Table 6.4: Growth Accounts: Contributions of the Sources of Growth
(Three-Input Model with Human Capital)

	Tangible Capital	Labor	Human Capital	Technical Progress
(1) Full Sample : 4 NIEs and G-5				
Hong Kong	62.85	31.38	5.77	0.00
South Korea	62.34	30.00	7.67	0.00
Singapore	56.50	36.36	7.14	0.00
Taiwan	70.16	23.37	6.47	0.00
Japan	40.01	8.77	1.81	49.40
Non-Asian G-5 Countries	31.15	6.22	2.92	59.71
(2) Full Sample: 4 NIEs, 4 ASEAN, China and G-5				
Hong Kong	69.37	29.08	1.55	0.00
South Korea	75.44	22.33	2.23	0.00
Singapore	59.36	38.82	1.82	0.00
Taiwan	80.83	17.37	1.80	0.00
Indonesia	77.49	17.36	5.15	0.00
Malaysia	59.48	37.68	2.83	0.00
Philippines	54.60	41.24	4.16	0.00
Thailand	73.91	22.66	3.44	0.00
China	83.75	14.12	2.13	0.00
Japan	50.44	5.70	0.56	43.30
Non-Asian G-5 Countries	37.79	3.54	0.86	57.81

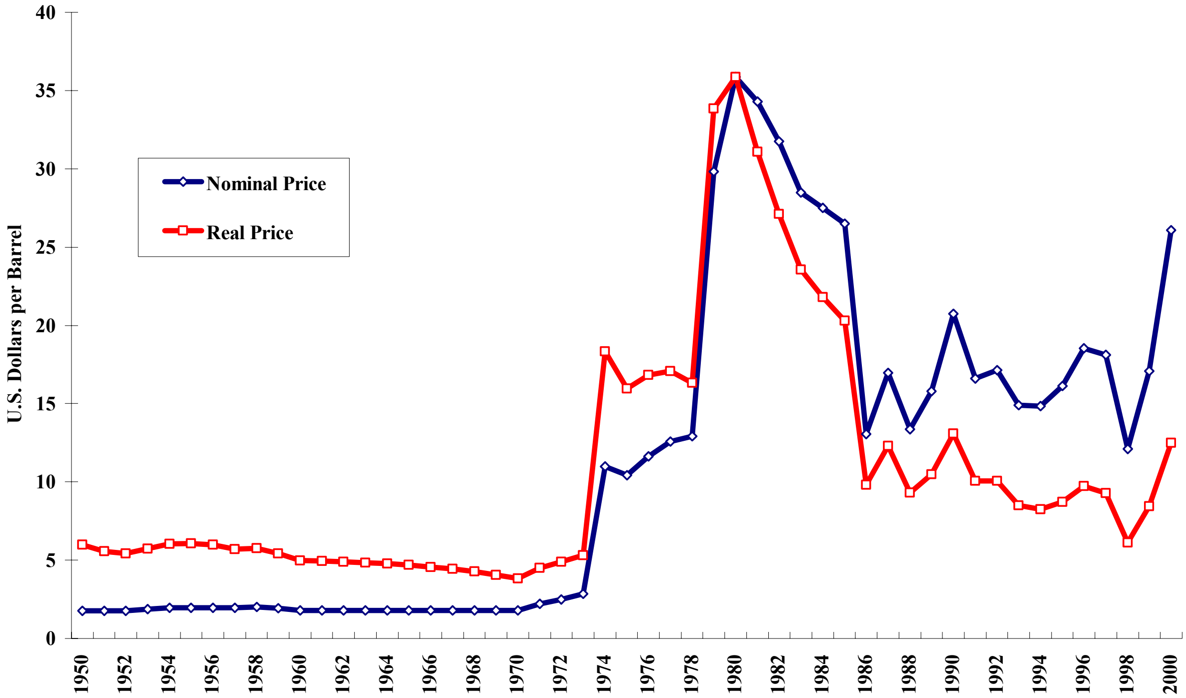
Note: The parameters are taken from Table 6.3. They have been estimated under the restrictions of $c_{iK}=0$ for all East Asian developing economies.

7. The Stability of the Capital Augmentation Rates (Has There Been Technical Progress in the East Asian Developing Economies in the More Recent Period?)

The results of Sections 5 and 6 above demonstrate that one cannot reject the hypothesis of no technical progress in the East Asian developing economies for the postwar period as a whole. However, these findings are conditional on the implicit maintained hypothesis that the rates of technical progress (more specifically, the economy- and commodity-specific augmentation rate parameters) are constant over this entire period. It is, however, entirely possible that these augmentation rates may have undergone changes during the half-century-long postwar period. In this Section we address the issue of the stability or constancy of the capital-augmentation rate parameters over time, and to the extent that the capital-augmentation rates may have undergone a change during the sample period, whether there is any evidence of positive technical progress in the East Asian developing economies in the more recent years. We allow the possibility of the capital-augmentation rates taking different values during different sub-periods, that is, we allow shifts in the rates of capital-augmentation. Increases in the capital-augmentation rates imply an acceleration of technical progress and decreases imply a slowdown.

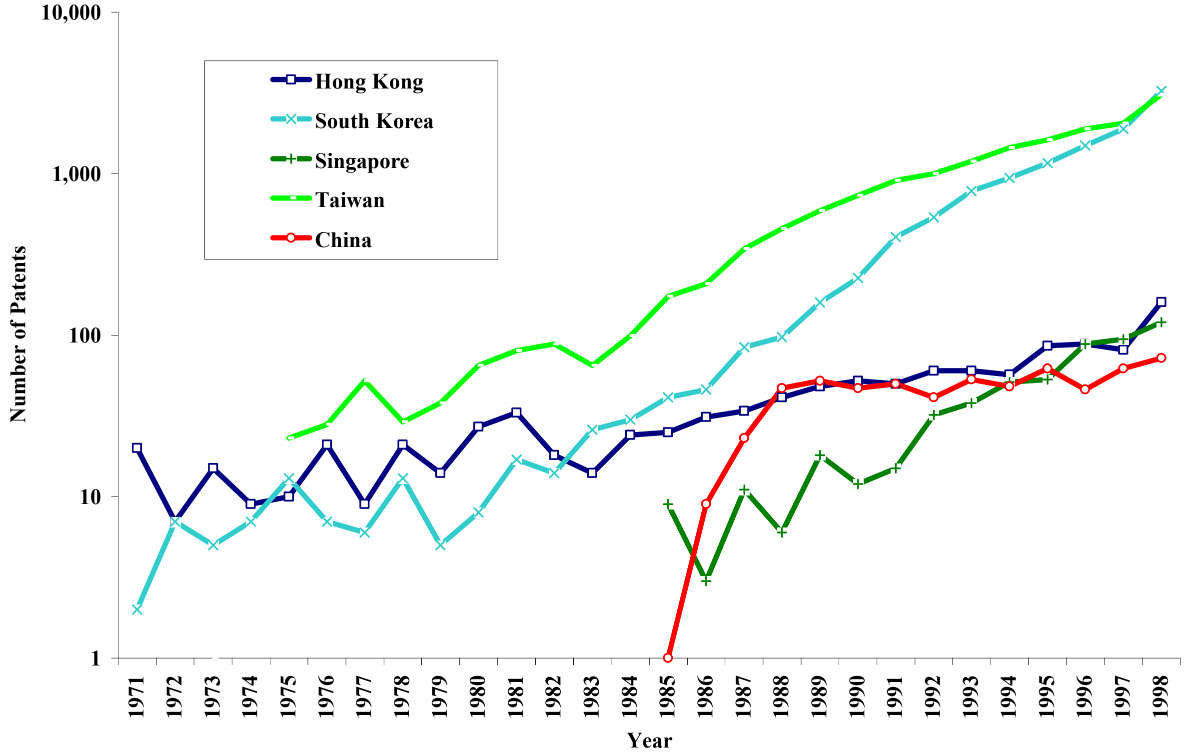
Two developments in the postwar period have the potential of causing shifts in the capital-augmentation rates in the East Asian developing economies. The first is the oil price shock--the world price of oil (both real and nominal) quadrupled in 1973-1974, reaching a peak in 1980, and remained high until 1985, when it began to decline to a more reasonable level (See Figure 7.1). During this period, the rates of economic growth slowed down worldwide. It is possible that the rates of capital-augmentation might have declined as well. The second is the rise in the levels of observed R&D activities in the East Asian developing economies—there have been numerous empirically observed cases of technological improvements in the industrial sectors of the East Asian NIEs and a huge spurt in the annual number of patents granted in the United States to the East Asian developing economies, in particular, South Korea and Taiwan, beginning in the mid-1980s (see Figure 7.2). Thus, from 1986 onwards, it is possible that the rates of capital augmentation might have risen in the East Asian NIEs, due to the decline in the real price of oil and to increased investments in R&D.

Figure 7.1: Nominal and Real Prices of Oil*



***Note: The nominal price of oil is the U.S. dollar price per barrel of United Arab Emirates Dubai Fateh petroleum, from International Monetary Fund, International Financial Statistics. The real price of oil is the nominal price deflated by the U.S. Consumer Price index (CPI) (1980=1.0).**

Figure 7.2: Number of Patents Granted Annually in the United States, Four East Asian NIEs and China



Source: U.S. Patent and Trademark Office. Patent statistics are numbers of utility patents (i.e. patents for invention) granted in the U.S. by country of origin for the period of 1963-1998.

For these reasons, the years 1974 and 1986 are selected as the years at which shifts in the capital-augmentation rates, if any, are allowed to occur (we implicitly assume that nature of the technical progress remains the same—only the capital-augmentation rates are allowed to change). Thus, two additional capital-augmentation rates are introduced for each economy, representing the additional changes to the prevailing rates of capital-augmentation for the immediately preceding sub-periods in 1974 and 1986. Let c_{iK0}, possibly zero, be the capital-augmentation rate for the ith economy for the entire sample period, and c_{iK1} and c_{iK2} be the additions (possibly zero or negative) to the rate of capital-augmentation in the ith economy beginning in the years 1974 and 1986, respectively. c_{iK1}'s are expected to be non-positive, except possibly for oil-producing countries, and c_{iK2}'s are expected to be non-negative, especially for East Asian NIEs. Statistical tests are performed to determine whether these shifts in the capital-augmentation rates are significant. There is no shift in the rate of capital-augmentation in the ith economy over time if and only if both c_{iK1} and c_{iK2} are zeroes.

In Table 7.1, the average annual rates of growth of the outputs and inputs are presented for the three sub-periods, pre-1973, 1974-1985, and post-1986, respectively.

Table 7.1: Average Annual Rates of Growth of Real Output and Inputs
(pre-1974, 1974-1985, and post-1986 sub-periods)

	Entire Sample Period	Output (Real GDP)			Tangible Capital			Total Labor Hours			Total Years of Education of the Working-Age Population[1]		
		Pre-1973	1974-1985	Post-1986	Pre-1973	1974-1985	Post-1986	Pre-1973	1974-1985	Post-1986	Pre-1973	1974-1985	Post-1986
Hong Kong	66-95	8.11	8.07	6.01	9.67	9.55	7.33	3.10	3.40	0.53	5.57	5.67	3.10
South Korea	60-95	8.94	7.64	8.48	11.86	13.43	11.48	4.14	2.83	2.76	7.70	6.41	4.15
Singapore	64-95	12.12	7.11	8.98	12.73	10.06	7.97	7.56	3.42	4.32	9.17	5.48	3.38
Taiwan	53-95	9.32	8.29	7.24	13.21	11.75	8.87	2.63	2.23	1.34	6.73	4.98	3.13
Indonesia	70-94	9.23	6.19	6.39	10.50	12.22	8.92	2.15	2.65	2.31	19.50	10.20	6.94
Malaysia	70-95	9.38	6.26	8.55	9.61	11.00	8.06	4.32	4.94	4.83	12.64	8.15	6.15
Philippines	70-95	6.29	2.71	3.47	4.48	7.78	3.18	7.36	3.53	2.96	11.52	8.07	5.09
Thailand	70-94	6.27	6.61	9.65	10.90	8.77	10.81	0.57	3.55	2.72	11.44	8.96	5.25
China	65-95	6.66	8.61	10.03	13.37	9.56	12.26	3.19	2.53	1.92	7.01	6.37	4.54
Japan	57-94	9.37	3.80	3.21	10.65	6.45	5.56	0.82	0.93	0.11	2.87	1.69	1.44
France	57-94	5.09	1.92	1.99	4.83	3.40	2.79	0.24	-1.27	0.27	2.01	2.15	1.51
West Germany	57-94	4.74	1.88	2.68	4.46	2.44	2.12	-0.01	-0.82	0.04	1.31	1.99	1.41
United Kingdom	57-94	3.25	1.69	1.95	5.06	2.91	3.07	0.17	-1.09	0.62	0.95	1.38	1.17
United States	49-94	3.62	2.58	2.55	3.54	2.94	2.03	1.29	1.52	1.22	2.51	2.07	1.35

In Table 7.2, the results of the statistical tests of the hypotheses that these additional capital-augmentation rate parameters for the three groups of economies—the East Asian NIEs, the other ASEAN economies and China, and the G-5 countries--are zeroes are presented. Table 7.2 indicates that the hypotheses of zero capital-augmentation rates for the East Asian NIEs and for the four ASEAN economies and China for the sub-periods prior to 1986 cannot be rejected at one-percent levels of significance. However, Table 7.2 also reveals that the hypotheses of zero additional capital-augmentation rates for the post-1986 sub-period can be rejected for both the four East Asian NIEs and for the other four ASEAN economies (but not for China). Thus, the empirical evidence does suggest that there has been a shift in the capital-augmentation rates in the East Asian developing economies except China around the year 1986. The capital-augmentation rates for China remain statistically insignificant for all three sub-periods whereas the capital-augmentation rates for the four NIEs and some of the four ASEAN economies turn statistically significant and positive for the sub-period since 1986. As for the G-5 countries, the hypothesis that the capital-augmentation rates remain unchanged throughout the three sub-periods cannot be rejected but the hypothesis of "no technical progress" can be rejected.

Table 7.2: p-Values for Tests of Hypotheses on the Stability of the Rates of Capital-Augmentation (Three-Input Model with Human Capital)

	Level of Significance	Pre-1973 $c_{iK0}=0$[1]	1974-1985 $c_{iK1}=0$[1]	Post-1986 $c_{iK2}=0$[1]
(1) Full Sample : 4 NIEs and G-5				
4 NIEs	0.01	0.58720	0.72308	0.00149
G-5	0.01	0.00000	0.30028	0.21305
All Economies		0.00000	0.46567	0.00774
(2) Full Sample: 4 NIEs, 4 ASEAN, China and G-5				
4 NIEs	0.005	0.45782	0.70328	0.00122
4 ASEAN + China		0.14608	0.26901	0.00006
4 ASEAN	0.004	0.11033	0.68627	0.00002
China	0.001	0.03952	0.03702	0.05631
G-5	0.01	0.0000	0.25169	0.29292
All Economies		0.0000	0.28956	0.00213

Note : 1. The rate of capital augmenation (c_{iK}) in any one year is cumulative of the rate of capital augmentation and their additions (c_{iK0}, c_{iK1} and c_{iK2}) due to the respective sub-periods in the sense that: $c_{iK} = c_{iK0} + c_{iK1} \cdot dum_{74} + c_{iK2} \cdot dum_{86}$, where dum_{74} and dum_{86} are shift-year dummies taking the value of unity for years occurring post-1974 and post-1986 respectively.

In Table 7.3, the parameter estimates corresponding to the final specification of the three-input model with shifts in the capital-augmentation rates for the East Asian developing economies except China in 1986, that is, the specification with the restrictions implied by the test results of Table 7.2 imposed, are reported. As in Section 6, the estimates of the rates of capital augmentation for the G-5 countries turn out to be remarkably robust to whether the four other ASEAN economies and China are included in the sample. We note that in the cases of both the four NIEs and the nine developing economies, the estimated rates of capital-augmentation of the East Asian NIEs in the post-1986 sub-period are comparable in order of magnitude to, if not higher than, those of the G-5 countries. Among the four ASEAN economies and China, the only one that appears to have had statistically significant technical progress is Thailand. It is probably safe to conclude that there is statistically credible empirical evidence of positive technical progress in the post-1986 sub-period for the East Asian NIEs. For the four ASEAN economies and China, the empirical evidence is much weaker except for Thailand.

However, also as in Section 6, the inclusion of four ASEAN economies and China raises significantly the estimate of λ, the weight parameter for the tangible capital stock, thereby lowering the relative weight of human capital and thus the latter's relative contribution to economic growth in the case of the fourteen economies compared to the case of only the four NIEs and G-5 countries.

Based on these parameter estimates, the growth accounts for the entire sample period as a whole are computed and reported in Table 7.4 and their breakdowns into sub-periods are presented in Tables 7.5a and 7.5b. The growth accounts in Table 7.4 are not qualitatively that different from those in Table 6.4, except that technical progress now accounts for on average perhaps 10 percent of the economic growth of the East Asian developing economies, behind tangible capital accumulation, which accounts for between 45 and 85 percent, and labor, which accounts for on average approximately a quarter. For the non-Asian G-5 countries, technical progress remains the most important source of growth, accounting for almost 60 percent and tangible capital a distant second. Japan again straddles between the East Asian economies and the non-Asian G-5 countries, with the contributions from technical progress and tangible capital being approximately equal in order of magnitude.

In contrast, the growth accounts in Tables 7.5a and 7.5b provide a very interesting picture of postwar economic growth in the East Asian developing economies. First, the growth accounts for the first two sub-periods of 1960s-1973 and 1974-1985 are very similar to comparable results in the previous Sections. However, the growth accounts for the third sub-period of 1986-1995 show that technical progress has begun to make a significant contribution to economic growth of the East Asian developing economies since the mid-1980s. The contributions of technical progress to the economic growth of the East Asian NIEs in this third sub-period average 40 percent, comparable in order of magnitude to the contributions of tangible capital. The contributions of technical progress to the economic growth of the other four ASEAN economies are significantly lower, averaging only between 15 and 20 percent, with the contributions of tangible capital averaging more than 50 percent. It is also interesting to note that the relative contribution of technical progress to Japanese economic growth for the most recent sub-period has become the most important, accounting for approximately 60 percent, with the contribution of tangible capital falling to between 30 and 40 percent. Thus, for the most recent sub-period, the relative contributions of the different sources of growth for Japan have become quite similar to those of the non-Asian G-5 countries. The G-5 countries, now including Japan, continue to have technical progress as their most important source of growth. On the whole, the picture is one in which Japan is becoming more like the non-Asian G-5 countries, the East Asian NIEs are becoming more like Japan, and the other four ASEAN economies are also becoming more like Japan, but at a slower pace. China, however, continues to exhibit tangible input-based economic growth, with tangible capital accumulation accounting for more than 80 percent.

Table 7.3: Estimated Parameters for the Final Specification
(Three-Input Model with Human Capital and Breaks in the Rates of Capital-Augmentation)

		4 NIEs and G-5		4 NIEs, 4 ASEAN, China and G-5	
Parameter		Estimate	t-statistic	Estimate	t-statistic
a_K		0.810	3.179	0.329	2.821
a_L		0.406	2.127	0.753	4.474
B_{KK}		-0.123	-3.913	-0.086	-7.156
B_{LL}		-0.041	-0.537	-0.088	-1.708
B_{KL}		0.063	1.408	0.051	2.446
c_{iK0}[1]	France	0.049	6.004	0.057	8.777
	West Germany	0.058	6.469	0.067	8.894
	Japan	0.062	4.694	0.064	6.170
	United Kingdom	0.028	5.174	0.030	6.808
	United States	0.036	4.242	0.042	6.831
c_{iK2}[1]	Hong Kong	0.056	2.607	0.073	2.691
	South Korea	0.078	2.313	0.083	2.358
	Singapore	0.045	4.016	0.056	3.510
	Taiwan	0.067	3.728	0.076	3.785
	Indonesia			0.018	0.803
	Malaysia			0.033	1.114
	Philippines			0.000	-0.001
	Thailand			0.059	2.976
λ_H=(1-λ)		0.409	3.801	0.154	1.834
λ		0.591	5.496	0.846	10.084
Adjusted R-squared			0.744		0.714
D.W.			1.762		1.670
No. of Observations			330		458

Note:

1. The c_{iK1}'s and c_{iK2}'s for the G-5 economies and the c_{iK0}'s and c_{iK1}'s for the East Asian developing economies, respectively, are restricted to zero in accordance with the results of the tests of hypotheses.
2. Parameters for the unrestricted share equation are also estimated but not reported here.
3. Final specification:

$$d\ln Y_t = a_K \cdot d\ln((1+c_{iK})^t K_{Ct}) + a_L \cdot d\ln L_t + B_{KK} \cdot d(\ln((1+c_{iK})^t K_{Ct}))^2/2 + B_{LL} \cdot d(\ln L_t)^2/2 + B_{KL} \cdot d[\ln((1+c_{iK})^t K_{Ct}) \cdot \ln L_t],$$

where $K_{Ct} = K_t^{\lambda_K} H_t^{1-\lambda_K}$, d is the first-difference operator, K_t is the tangible capital stock, H_t is the human capital stock, and L_t is total labor hours. The rate of capital augmenation (c_{iK}) in any one year is cumulative of the rate of capital augmentation and their additions (c_{iK0}, c_{iK1} and c_{iK2}) due to the respective sub-periods in the sense that: $c_{iK} = c_{iK0} + c_{iK1} \cdot dum_{74} + c_{iK2} \cdot dum_{86}$, where dum_{74} and dum_{86} are shift-year dummies taking the value of unity for years occurring post-1974 and post-1986 respectively.

Table 7.4: Growth Accounts: Contributions of the Sources of Growth (Entire Sample Period)
(Three-Input Model with Human Capital and Shifts in the Rates of Capital-Augmentation)

	Sample period	Tangible Capital	Labor	Human Capital	Technical Progress
(1) Full Sample : 4 NIEs and G-5					
Hong Kong	66-95	48.41 (8.79)	27.57 (2.44)	8.16 (4.80)	15.86
South Korea	60-95	51.23 (12.28)	24.78 (3.35)	11.59 (6.31)	12.40
Singapore	64-95	46.73(10.23)	32.43 (4.70)	10.86 (5.92)	9.99
Taiwan	53-95	58.26 (11.76)	21.61 (2.33)	9.87 (5.40)	10.27
Japan	57-94	38.89 (7.98)	9.17 (0.56)	3.24 (2.15)	48.70
Non-Asian G-5 Countries	57-94	30.13 (3.52)	7.09 (0.17)	5.21 (1.68)	57.57
(2) Full Sample : 4 NIEs, 4 ASEAN, China and G-5					
Hong Kong	66-95	56.89 (8.79)	23.65 (2.44)	2.51 (4.80)	16.94
South Korea	60-95	65.45 (12.28)	18.62 (3.35)	3.84 (6.31)	12.08
Singapore	64-95	53.10 (10.23)	33.94 (4.70)	3.23 (5.92)	9.73
Taiwan	53-95	71.26 (11.76)	15.61 (2.33)	3.15 (5.40)	9.99
Indonesia	70-94	71.20 (10.88)	14.59 (2.72)	9.38 (10.34)	4.83
Malaysia	70-95	54.22 (9.65)	32.47 (4.68)	5.12 (8.02)	8.19
Philippines	70-95	54.05 (5.40)	37.81 (3.94)	8.15 (7.41)	-0.01
Thailand	70-94	60.84 (9.68)	18.06 (2.93)	5.65 (8.00)	15.44
China	65-95	83.87 (11.63)	11.92 (2.55)	4.21 (5.99)	0.00
Japan	57-94	49.04 (7.98)	5.23 (0.56)	1.08 (2.15)	44.65
Non-Asian G-5 Countries	57-94	37.44 (3.52)	3.36 (0.17)	1.70 (1.68)	57.49

Note: The numbers in the parentheses are the average annual rates of growth of each of the inputs.

Table 7.5a: Growth Accounts: Contributions of the Sources of Growth (3 Sub-Periods)
(Three-Input Model with Human Capital and Shifts in the Rates of Capital-Augmentation)
: Full Sample for 4 NIEs and G-5

	Sample period	Tangible Capital	Labor	Human Capital	Technical Progress
(1) Pre-1973					
Hong Kong	66-73	57.58 (9.67)	32.35 (3.10)	10.07 (5.57)	0.00
South Korea	60-73	55.66 (11.58)	27.99 (4.14)	16.35 (7.70)	0.00
Singapore	64-73	48.87 (12.73)	36.87 (7.56)	14.26 (9.17)	0.00
Taiwan	53-73	65.56 (13.21)	22.20 (2.63)	12.24 (6.73)	0.00
Japan	57-73	44.02 (11.43)	9.14 (0.82)	3.24 (2.87))	43.59
Non-Asian G-5 Countries	57-73	33.94 (4.62)	9.65 (4.24)	4.42 (1.70)	51.99
(2) 1974–1985					
Hong Kong	74-85	53.79 (9.58)	36.76 (3.40)	9.46 (5.67)	0.00
South Korea	74-85	62.33 (13.28)	25.99 (2.83)	11.68 (6.41)	0.00
Singapore	74-85	56.19 (9.94)	31.86 (3.42)	11.96 (5.48)	0.00
Taiwan	74-85	65.51 (11.89)	25.04 (2.23)	9.44 (4.98)	0.00
Japan	74-85	31.26 (6.73)	14.44 (0.93)	2.83 (1.69)	51.46
Non-Asian G-5 Countries	74-85	28.49 (2.65)	-10.90 (-0.42)	7.62 (1.90)	74.79
(3) Post-1986					
Hong Kong	86-95	36.82 (7.56)	9.65 (0.53)	5.32 (3.10)	48.21
South Korea	86-95	34.82 (11.90)	19.28 (2.76)	5.26 (4.15)	40.65
Singapore	86-95	33.62 (8.50)	29.39 (4.32)	5.26 (3.38)	31.73
Taiwan	86-95	35.15 (9.01)	13.71 (1.34)	4.32 (3.13)	46.82
Japan	86-94	29.84 (4.86)	4.69 (0.11)	3.42 (1.44)	62.05
Non-Asian G-5 Countries	86-94	21.08 (2.70)	18.42 (5.37)	4.68 (1.36)	55.81

Note: The numbers in the parentheses are the average annual rates of growth of each of the inputs.

Table 7.5b: Growth Accounts: Contributions of the Sources of Growth (3 Sub-Periods)
(Three-Input Model with Human Capital and Shifts in the Rates of Capital-Augmentation)
Full Sample for 4 NIEs, 4 ASEAN, China and G-5

	Sample period	Tangible Capital	Labor	Human Capital	Technical Progress
(1) Pre–1973					
Hong Kong	66-73	68.37 (9.67)	28.50 (3.10)	3.13 (5.57)	0.00
South Korea	60-73	72.60 (11.58)	21.87 (4.14)	5.53 (7.70)	0.00
Singapore	64-73	55.59 (12.73)	40.18 (7.56)	4.22 (9.17)	0.00
Taiwan	53-73	80.63 (13.21)	15.45 (2.63)	3.91 (6.73)	0.00
Indonesia	70-73	73.09 (11.90)	9.37 (2.15)	17.54 (19.50)	0.00
Malaysia	70-73	59.97 (9.56)	29.99 (4.32)	10.05 (12.64)	0.00
Philippines	70-73	39.79 (5.12)	49.97 (7.36)	10.24 (11.51)	0.00
Thailand	70-73	82.11 (10.96)	7.67 (0.57)	10.22 (11.44)	0.00
China	65-73	85.29 (13.51)	10.36 (3.19)	4.35 (7.01)	0.00
Japan	57-73	55.01 (11.43)	4.85 (0.82)	1.06 (2.87))	39.09
Non-Asian G-5 Countries	57-73	41.50 (4.62)	6.00 (4.24)	1.43 (1.70)	51.07
(2) 1974–1985					
Hong Kong	74-85	64.31 (9.58)	32.73 (3.40)	2.96 (5.67)	0.00
South Korea	74-85	78.08 (13.28)	18.10 (2.83)	3.81 (6.41)	0.00
Singapore	74-85	64.68 (9.94)	31.72 (3.42)	3.60 (5.48)	0.00
Taiwan	74-85	78.91 (11.89)	18.12 (2.23)	2.97 (4.98)	0.00
Indonesia	74-85	77.69 (12.22)	13.55 (2.65)	8.76 (10.20)	0.00
Malaysia	74-85	61.39 (10.76)	33.61 (4.94)	5.00 (8.15)	0.00
Philippines	74-85	62.59 (7.29)	29.28 (3.53)	8.13 (8.07)	0.00
Thailand	74-85	67.53 (8.69)	25.02 (3.55)	7.46 (8.96)	0.00
China	74-85	80.46 (9.44)	14.64 (2.53)	4.90 (6.37)	0.00
Japan	74-85	40.65 (6.73)	10.22 (0.93)	0.96 (1.69)	48.17
Non-Asian G-5 Countries	74-85	36.29 (2.65)	-14.55 (-0.42)	2.53 (1.90)	75.73
(3) Post-1986					
Hong Kong	86-95	41.81 (7.56)	6.46 (0.53)	1.58 (3.10)	50.14
South Korea	86-95	44.54 (11.90)	14.98 (2.76)	1.75 (4.15)	38.73
Singapore	86-95	37.01 (8.50)	31.30 (4.32)	1.52 (3.38)	30.17
Taiwan	86-95	43.00 (9.01)	10.46 (1.34)	1.38 (3.13)	45.16
Indonesia	86-94	62.79 (8.88)	15.91 (2.31)	5.69 (6.94)	15.61
Malaysia	86-95	42.87 (8.53)	33.41 (4.83)	3.25 (6.15)	20.47
Philippines	86-95	52.18 (3.77)	41.63 (2.96)	6.23 (5.09)	-0.03
Thailand	86-94	51.01 (11.27)	13.32 (2.72)	2.36 (5.25)	33.31
China	86-95	86.39 (12.54)	10.34 (1.92)	3.27 (4.54)	0.00
Japan	86-94	38.21 (4.86)	2.47 (0.11)	1.17 (1.44)	58.14
Non-Asian G-5 Countries	86-94	27.14 (2.70)	13.83 (5.37)	1.58 (1.36)	57.45

Note: The numbers in the parentheses are the average annual rates of growth of each of the inputs.

By relaxing the assumption of constancy of the capital augmentation rates over time, we have been able to find empirical evidence of positive technical progress in some of the East Asian developing economies. For the East Asian NIEs, technical progress has become, for the sub-period since 1986, a source of economic growth that is just as important as tangible capital accumulation. For the other East Asian developing economies, tangible capital accumulation still remains the most important source of growth. The other important finding is the gradual evolution of Japanese economic growth from being predominantly tangible-input-based to technical progress-based. These results are consistent with the idea that technical progress becomes a significant source of growth only when an economy has attained a sufficient level of development, in particular, when it has accumulated sufficient tangible capital (and perhaps even human capital) relative to labor. This is in part because technical progress is primarily the result of investment in intangible capital, but because of the complementarity between tangible capital and intangible capital, investment in intangible capital becomes attractive only with sufficient complementary tangible capital in place. Thus, most economies can be expected to go through a phase of tangible-input-based growth before they graduate to technical progress- or intangible capital-based growth.

8. The Contribution of R&D Capital

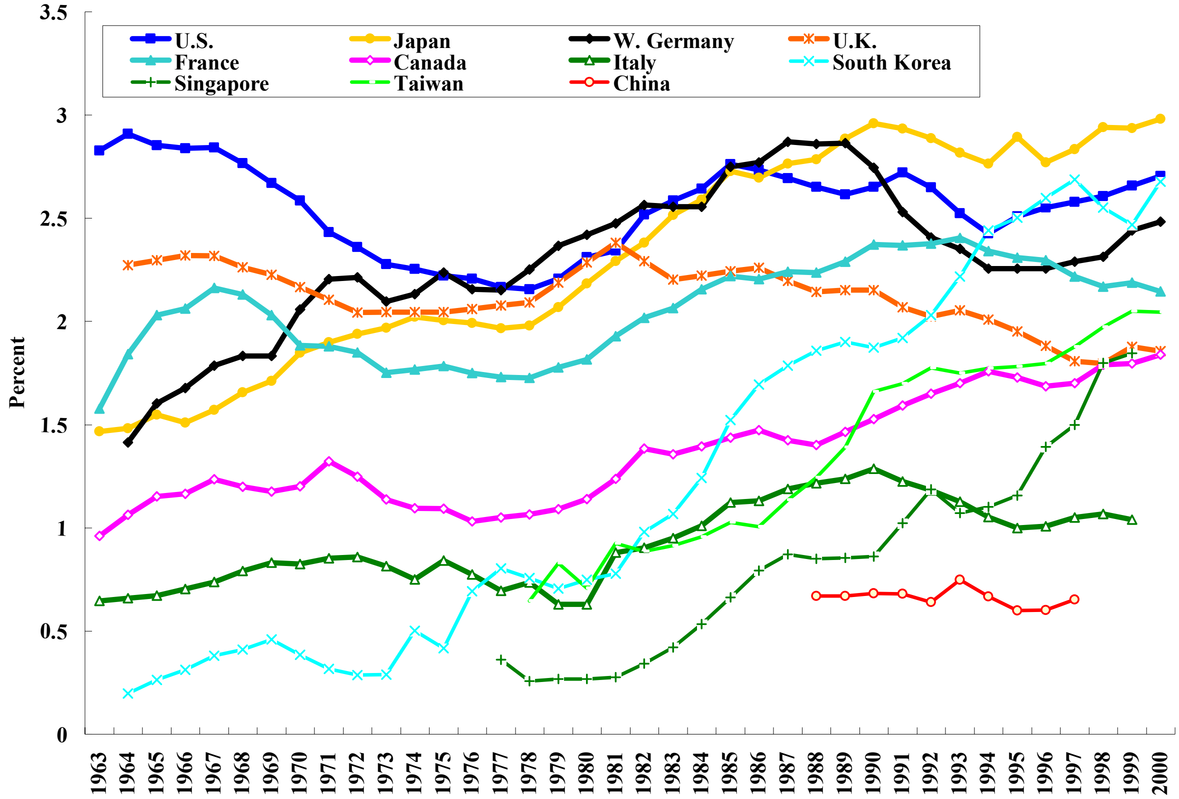
It is gratifying to find, finally, empirical evidence of positive technical progress in the East Asian NIEs in the sub-period since 1986. But where did this technical progress come from? Was it due to the increase in investment in R&D capital in the East Asian NIEs, beginning in the mid-1980s? Or was it due to something else? In this Section, the role of R&D capital, in addition to tangible capital (structures and equipment), labor, and human capital, in the growth of the three NIEs (South Korea, Singapore and Taiwan) is examined.[22] R&D capital is another important and typically unmeasured, but measurable,

[22] Time series data on aggregate R&D expenditures are too short for Hong Kong, the four ASEAN economies and China. They are therefore not included in the econometric analysis.

intangible input. The objective of introducing the R&D capital input in the meta-production function analysis is to ascertain its relative importance as a factor of production for the East Asian NIEs, especially in the more recent period during which their R&D expenditures have been rising very rapidly. In this study, R&D capital stock is measured as the cumulative R&D expenditures in constant prices, less depreciation equal to 10 percent per year, at the beginning of the calendar year.

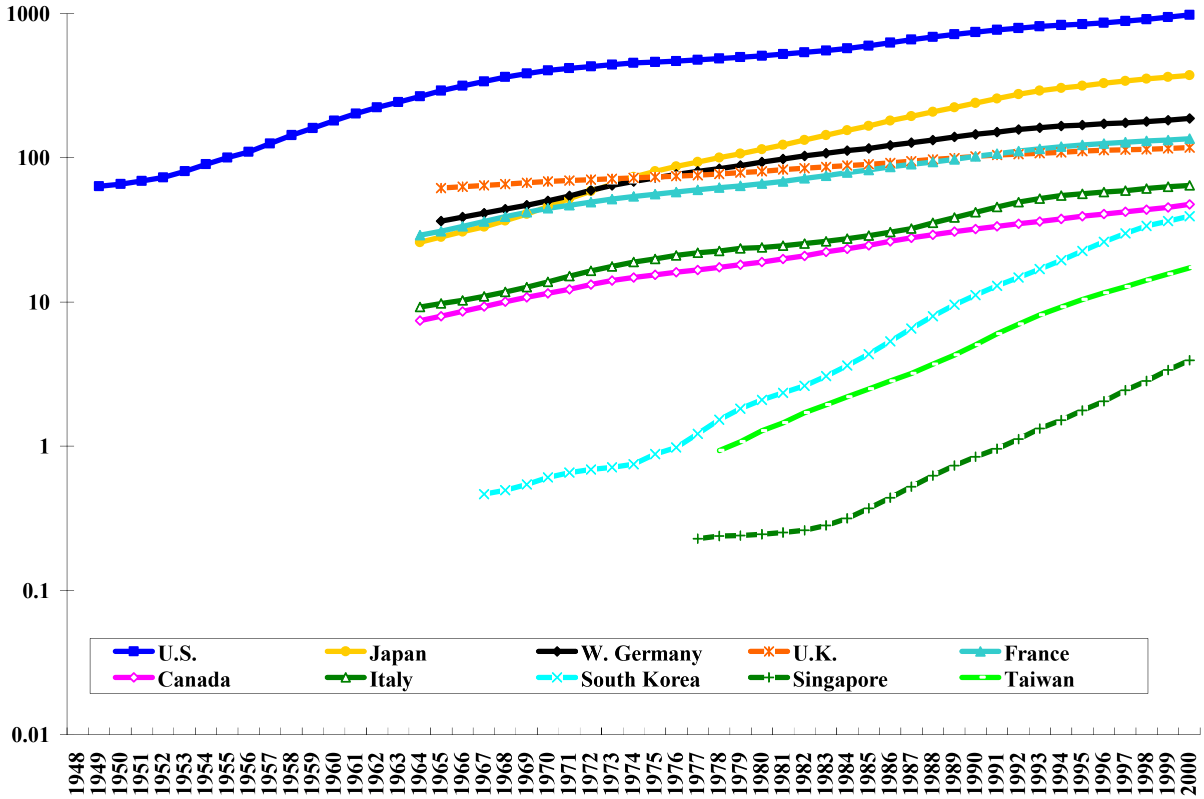
In Figure 8.1, data on R&D expenditures as a percent of GDP for the Group-of-Seven (G-7) countries (Canada, France, West Germany, Italy, Japan, the United Kingdom and the United States) and for the East Asian NIEs (and China) are presented. For the East Asian NIEs, these percentages have been rising rapidly and have reached the same order of magnitude as those of and even surpassed some of the G-7 countries. In Figure 8.2, the estimated R&D capital stocks are presented on a logarithmic scale—it is clear that the East Asian NIEs, despite their recent rapid increases in R&D expenditures, still have a great deal of catching up to do in terms of the levels of the R&D capital stocks. In Figure 8.3, the numbers of patents granted annually in the United States to applicants from the different economies are presented, again on a logarithmic scale. It is most remarkable that both South Korea and Taiwan, starting from extremely low bases, have, by the late 1990s, managed to obtain a similar number of patents each year as some of the G-7 countries. In Figure 8.4, a scatter-diagram of the annual number of patents granted and the R&D capital stock is presented for all economies in our sample on a double-logarithmic scale. The strong and positive association between the annual number of patents granted and the level of the R&D capital stock is unmistakable.

Figure 8.1: R&D Expenditures as a Percentage of GDP: G-7 Countries, 3 East Asian NIEs and China



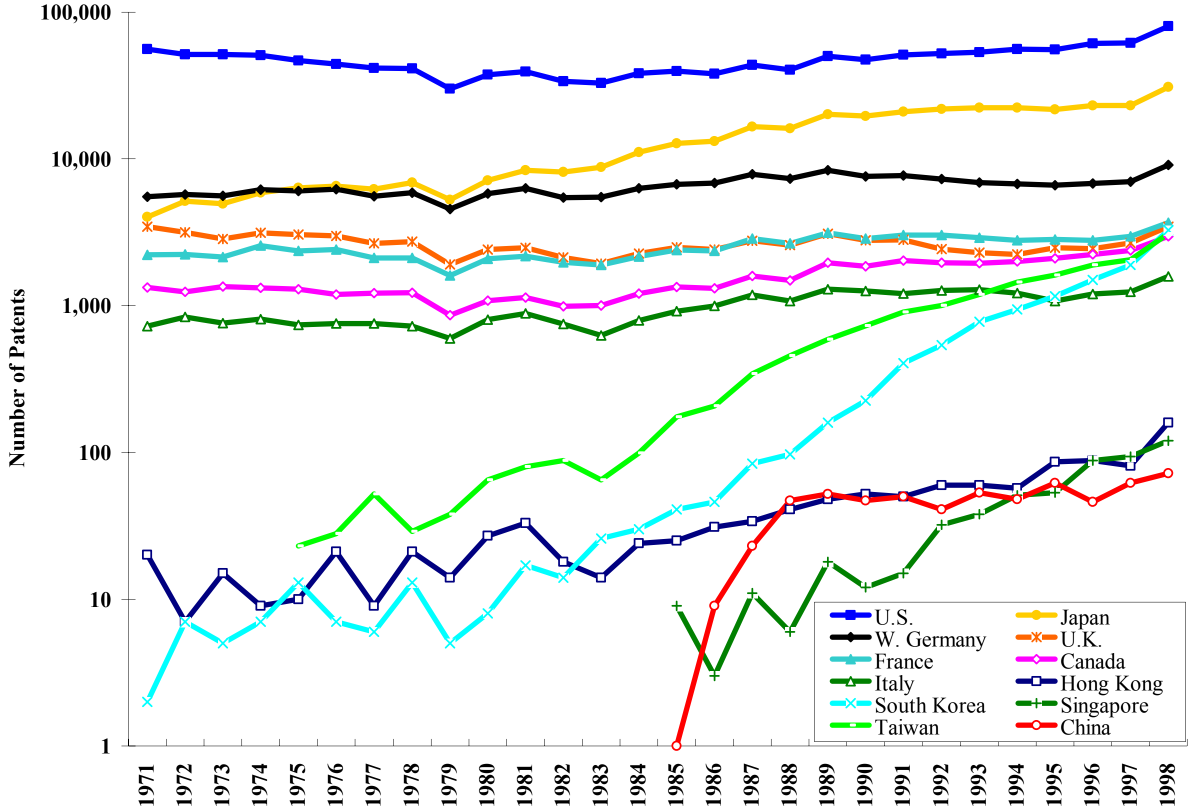
Source: Basic Science and Technology Statistics and Science and Technology Statistics, OECD for G-7, national statistical yearbooks for three NIEs and World Development Indicator for China. Refer to the discussion on data in Section 4 for details.

Figure 8.2: R&D Capital Stocks in Billions of 1980 U.S. Dollars



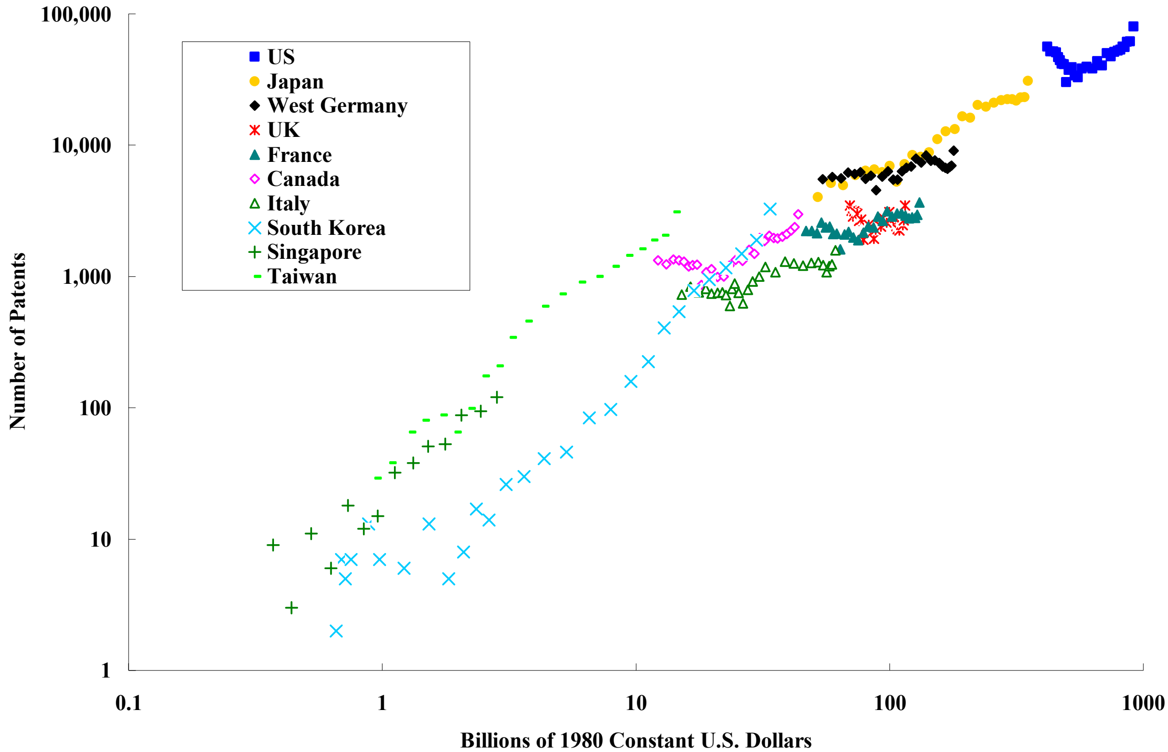
Source: R&D capital stocks are calculated based on the R&D expenditure data from Basic Science and Technology Statistics and Science and Technology Statistics, OECD for G-7 and national statistical yearbooks for three NIEs. Refer to the discussion on data in Section 4 for details.

Figure 8.3: Patents Granted Annually in the United States: G7 Countries, 4 East Asian NIEs and China



Source: U.S. Patent and Trademark Office. Patent statistics are numbers of utility patents (i.e. patents for invention) granted in the U.S. by country of origin for the period of 1963-1998.

Figure 8.4: The Number of U.S. Patents Granted Annually vs. R&D Capital Stocks



Source: Patent statistics are from U.S. Patent and Trademark Office. R&D capital stocks are calculated based on the R&D expenditure data from Basic Science and Technology Statistics and Science and Technology Statistics, OECD for G-7, and national statistical yearbooks for three NIEs. Refer to the discussion on data in Section 4 for details.

However, the annual number of patents does not translate directly into real GDP. It still remains to be demonstrated that R&D capital, as measured, has a statistically significant and positive effect on aggregate real output in the East Asian NIEs. The exercise undertaken in this Section is similar to that of Section 6, but with the explicit inclusion of both the human capital and the R&D capital inputs in the aggregate meta-production function. A four-input meta-production function model is applied to the aggregate data of the three East Asian NIEs. The sample periods are 1967-1995 for South Korea, 1977-1995 for Singapore, and 1978-1995 for Taiwan. To maximize the power of the meta-production function approach, the data of the East Asian NIEs are pooled with the data of the G-7 countries. The focus, however, is only on the East Asian NIEs. The details on the construction of the R&D capital stocks and other data used in this Section are described in Section 4. Data on the rates of growth of real output and inputs for the R&D sample periods are presented in Table 8.1. The most striking feature of Table 8.1 is the much higher rate of growth of the R&D capital stocks of the three East Asian NIEs, averaging more than 13 percent per annum, compared to an average of less than 5 percent per annum for the non-Asian G-7 countries.[23]

Table 8.1: Average Annual Rates of Growth of Real Output and Inputs (R&D Sample Periods), percent

	Sample Period	Output (Real GDP)	Tangible Capital Stock	Utilized Tangible Capital	Employment	Total Labor Hours	Average Years of Education of the Working-Age Population[1]	Total Years of Education of the Working-Age Population[1]	R&D Capital Stock	Average Share of Labor Earnings to GDP
South Korea	**67-95**	**8.81**	**13.12**	**13.35**	**3.12**	**3.42**	**3.32**	**5.93**	**14.90**	**0.39**
Singapore	**77-95**	**7.82**	**8.62**	**8.88**	**3.24**	**3.60**	**2.20**	**4.11**	**12.03**	**0.42**
Taiwan	**78-95**	**7.40**	**9.39**	**9.43**	**2.22**	**1.63**	**1.80**	**3.68**	**15.21**	**0.50**
Japan	**64-94**	**5.06**	**7.95**	**7.66**	**1.09**	**0.45**	**0.94**	**1.92**	**8.55**	**0.62**
Canada	**64-94**	**3.64**	**4.64**	**4.57**	**2.35**	**1.74**	**0.96**	**2.85**	**5.56**	**0.60**
France	**64-94**	**2.93**	**3.92**	**3.97**	**0.39**	**-0.40**	**1.30**	**2.09**	**4.82**	**0.64**
West Germany	**65-94**	**2.65**	**2.89**	**2.67**	**-0.02**	**-0.42**	**1.03**	**1.59**	**5.37**	**0.66**
Italy	**64-94**	**3.15**	**4.57**	**4.73**	**0.02**	**-0.31**	**1.34**	**1.87**	**6.10**	**0.72**
United Kingdom	**65-94**	**2.14**	**3.65**	**3.46**	**0.07**	**-0.30**	**0.89**	**1.15**	**2.00**	**0.66**
United States	**49-94**	**3.13**	**3.03**	**3.30**	**1.71**	**1.31**	**0.81**	**2.06**	**5.89**	**0.66**

Note: 1. Working-age population is defined as the number of persons in the population aged between 15 and 64, inclusive.

[23] However, one should keep in mind that the sample periods are different across economies.

(1) Tests of the Hypotheses of the Meta-Production Function Model

In principle, we should have begun by testing the same series of hypotheses that have become standard in the meta-production function approach, such as the maintained hypotheses of the meta-production function approach, the maintained hypotheses of traditional growth-accounting, the hypotheses of identical tangible capital, labor, human capital and R&D capital augmentation level parameters across economies, and hypotheses on the biases of the technical progress. However, given the relatively short time-series of R&D capital data for the East Asian NIEs, the degrees of freedom are inadequate for the full testing of a model with four explicitly distinguished inputs (tangible capital, labor, human capital and R&D capital) and time. The total number of independent parameters per economy for such a model, unrestricted, is 21, which exceeds the number of observations available for some of the NIEs.[24]

Thus, instead of testing these hypotheses, we simply take as a point of departure that the meta-production function approach is valid. Moreover, we assume that R&D capital, just like human capital, is also complementary to tangible capital and to technical progress. This implies that the aggregate meta-production function, which in the most general four-input case has the form:

(8.1) $Y_{it} = A_{i0}(t) F (A_{iK}(t)K_{it}, A_{iL}(t)L_{it}, A_{iH}(t)H_{it}, A_{iR}(t)R_{it})$,

can be specialized to the form:

(8.2) $Y_{it} = A_{i0} F (A_i(t) K_{it}^{\lambda_K} H_{it}^{\lambda_H} R_{it}^{1-\lambda_K-\lambda_H}, A_{iL}L_{it})$,

where λ_K, λ_H, and $(1-\lambda_K-\lambda_H)$ are, without loss of generality, nonnegative constants representing the relative weights of tangible capital, human capital, and R&D capital in the composite "total capital" input. In other words, we assume that tangible capital, human capital, and R&D capital together form a Cobb-Douglas aggregate of total capital that is in turn augmented by technical progress. What this means is that tangible capital, human capital, R&D capital and technical progress are all complementary to one

[24] Unrestricted, the number of independent parameters for each economy for the translog meta-production function model is given by (n+2)(n+3)/2 where n is the number of inputs explicitly distinguished, not including the time trend.

another--they enhance one another's marginal productivity. This also embodies the concepts of capital-skill complementarity[25] as well as the more general human capital-R&D capital complementarity. Finally, we assume that the commodity-augmentation level parameters are identical across economies, a hypothesis that has never been rejected in all of our meta-production function studies thus far.

(2) Has There Been Technical Progress?

We first estimate a restricted specification that imposes the restrictions implied by the assumptions discussed above, but allows the rates of augmentation of all the economies to be freely estimated. In addition, we also estimate an alternative restricted specification in which we incorporate the results of our tests of hypotheses in Section 7, namely, that the rates of capital augmentation of the developed economies are positive but constant over time, but the rates of capital augmentation of the East Asian NIEs are allowed to be different from zero only in the post-1985 period. Conditional on the validity of the restricted specifications, we proceed to test the principal hypothesis of interest: Is there positive measured technical progress in the East Asian NIEs and in the developed economies after the effects of the R&D capital input have been explicitly taken into account?

In Table 8.2 we present the results of the tests of the hypothesis of no technical progress for the four-input model. At a level of significance of 0.01, the hypothesis that there has been no technical progress in the three East Asian NIEs, in a model explicitly distinguishing human capital and R&D capital inputs, cannot be rejected for either restricted specification. In contrast, the hypothesis that there has been no technical progress in the G-7 countries is rejected. These results show that once the effects of the R&D capital input is taken into account, one can no longer find evidence of positive measured technical progress in the three East Asian NIEs, whereas there continues to be significant positive measured technical progress in the G-7 countries, including Japan, This is true of the postwar period as a whole as well as for the sub-period since 1986. Thus, we conclude that the positive measured technical

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[25] See, for example, Griliches (1969).

progress found more recently in the East Asian NIES can be mostly attributed to their investment in R&D capital.

Table 8.2: p-Values for the Tests of Hypothesis of No Technical Progress
(Four-Input Model with Human Capital and R&D Capital)

	R&D Sample for G-7 + 3 NIEs[1] c_{iK}=0, all i	R&D Sample for G-7 + 3 NIEs[1] c_{iK2}=0, all i
3 NIEs	0.01284	0.02038
G-7	0.00385	N.A.
All Economies	0.00004	N.A..

Note: 1. South Korea, Singapore and Taiwan.

2. Restricted Specification

$d\ln Y_t = a_K \cdot d\ln((1+c_{iK})^t K_{Ct}) + a_L \cdot d\ln L_t + B_{KK} \cdot d(\ln((1+c_{iK})^t K_{Ct}))^2/2 + B_{LL} \cdot d(\ln L_t)^2/2 + B_{KL} \cdot d[\ln((1+c_{iK})^t K_{Ct}) \cdot \ln L_t]$,

where $K_{Ct} = K_t^{\lambda_K} H_t^{\lambda_H} R_t^{1-\lambda_K-\lambda_H}$, $c_{iK} = c_{iK0} + c_{iK2}$, d is the first-difference operator, K_t is the tangible capital stock, H_t is the human capital stock, R_t is the R&D capital stock, and L_t is total labor hours.

(3) Accounting for Economic Growth

Next, we estimate a final specification imposing the additional restrictions that there has been no technical progress in the East Asian NIEs in the postwar period. The parameter estimates are presented in Table 8.3. One interesting feature of Table 8.3 is the relatively large weight of R&D capital in the composite total capital input compared to that of human capital. The relative weights are approximately 0.7 for tangible capital, 0.25 for R&D capital, and 0.05 for human capital. These relative weights, coupled with the relative low rates of growth of human capital, result in almost negligible contributions of human capital to the economic growth of both the East Asian NIEs and the G-7 countries during the R&D sample periods. We interpret this finding as reflecting, in part, the complementarity between human capital and R&D capital. The time series of both human capital stock and R&D capital stock are quite smooth and strongly trended, giving rise to possible multicollinearity, which may be one of the reasons why the estimate of λ_H is both small and statistically insignificant. Moreover, given the relatively longer gestation period of human capital compared to R&D capital, the latter is likely to adjust much faster to changing economic conditions than the former. Thus, aggregate real output might appear to be more sensitive to changes in R&D capital than human capital in the short and intermediate runs even though in the long run the two capital inputs are complementary.

Table 8.3: Estimated Parameters for Final Specification
(Four-Input Model with Human Capital and R&D Capital)

Parameter		G-7 + 3 NIEs Estimate	t-statistic
a_K		0.475	4.387
a_L		0.514	3.348
B_{KK}		-0.118	-9.913
B_{LL}		-0.061	-1.411
B_{KL}		0.084	4.373
c_{iK} [1]	Canada	0.022	1.932
	France	0.046	3.550
	West Germany	0.054	3.588
	Italy	0.040	3.384
	Japan	0.041	3.369
	United Kingdom	0.033	2.409
	United States	0.025	2.468
λ_K		0.686	10.472
λ_H		0.063	1.589
Adjusted R-squared			0.559
D.W.			1.364
No. of Observations			451

Note:

1. The c_{iK}'s for the East Asian developing economies are restricted to zero in accordance with the results of the tests of hypotheses.
2. Parameters for the unrestricted share equation are also estimated but not reported here.
3. Final specification:

$$d\ln Y_t = a_K \cdot d\ln((1+c_{iK})^t K_{Ct}) + a_L \cdot d\ln L_t + B_{KK} \cdot d(\ln((1+c_{iK})^t K_{Ct}))^2/2 + B_{LL} \cdot d(\ln L_t)^2/2$$
$$+ B_{KL} \cdot d[\ln((1+c_{iK})^t K_{Ct}) \cdot \ln L_t],$$

where $K_{Ct} = K_t^{\lambda_K} H_t^{\lambda_H} R_t^{1-\lambda_K-\lambda_H}$, d is the first-difference operator, K_t is the tangible capital stock, H_t is the human capital stock, R_t is the R&D capital stock, and L_t is total labor hours.

The results of the growth-accounting exercise are reported in Table 8.4. Table 8.4 shows that tangible capital is the most important source of economic growth for the East Asian NIEs in the postwar period, accounting for approximately one-half or more, followed by R&D capital, accounting for approximately one quarter, and then labor. As mentioned above, human capital accounts for a negligible percentage of the postwar economic growth of both the East Asian NIEs and the G7 countries. In contrast, technical progress remains the most important source of economic growth for the non-Asian G-7 countries, accounting for approximately 50 percent on average, followed by tangible capital and R&D capital, with a very small contribution from labor.

Table 8.4 Growth Accounts: Contributions of the Sources of Growth (Percent)
(Four-Input Model with Human Capital and R&D Capital)

	Sample Period	Tangible Capital	Labor	Human Capital	R&D Capital	Technical Progress
South Korea	67-95	60.12	14.23	1.75	23.90	0.00
Singapore	77-95	50.44	23.90	1.30	24.35	0.00
Taiwan	78-95	55.85	11.25	1.14	31.76	0.00
Japan	64-94	42.40	5.24	0.72	17.08	34.56
Non-Asian G-7 Countries	65-94	32.52	3.72	1.16	14.90	47.69

Japan, once again, occupies an intermediate position. It has had, like the other G-7 countries, significant technical progress, which accounts for approximately one-third of its economic growth, but, like the East Asian NIEs, tangible capital remains its most important source of growth, at 42 percent. However, the contribution of intangible capital as a whole (that is, the sum of the contributions of human capital, R&D capital and technical progress) to Japanese economic growth, is actually more than 50 percent, similar to those of the non-Asian G-7 countries. But the contributions of intangible capital to the economic growth of the East Asian NIEs range only between a quarter and a third—tangible capital has remained the most important source of their economic growth.

Two other points are worth observing. First, comparing Table 6.4 and Table 8.4, the explicit inclusion of the R&D capital stock in the aggregate meta-production function model reduces the percentage contribution to economic growth attributable to technical progress. In Japan, the percentage of economic growth attributable to technical progress declines from between 43 and 49 percent to less than 35 percent with the explicit inclusion of the R&D capital input. For the non-Asian developed economies, the percentage declines from between 57 and 59 percent to below 48 percent. This is to be expected, because the "residual," or the measure of our ignorance, should be reduced with the explicit introduction of additional factors of production. Second, the role of R&D capital (which we would argue subsumes the effect of human capital as well because of their complementarity) in economic growth is much higher in the three East Asian NIEs than in the G-7 countries including Japan. R&D capital, or more generally intangible capital, is found to have contributed, on average, between 20 and 32 percent of the growth of the East Asian NIEs, but less than 17 percent in the G7 countries. This may be, in part, the result of the East Asian NIEs starting from a small base of R&D capital and having undergone a very rapid growth in R&D investment since the mid-1980s. This may also reflect the fact that R&D capital is not the only important form of intangible capital. In the G-7 countries, other forms of unmeasured intangible capital may have become more important, with their effects captured by technical progress. Thus, technical progress remains the most important source of economic growth for the non-Asian developed economies even after taking into account explicitly the R&D capital input.

The explicit addition of the R&D capital variables in our aggregate meta-production function model has essentially led us full circle--back to the conclusion that there has been no technical progress in the East Asia NIEs, notwithstanding the results of Section 7 above. The positive measured technical progress found in the East Asian NIEs in Section 7 for the post-1986 period can be attributed mostly to the growth of R&D capital in these economies during this period.

9. Why Is There No Measured Technical Progress In the East Asian NIEs?

The results in the previous Sections indicate that there is no evidence of a positive technical progress in East Asian NIEs prior to the mid-1980s, despite the extraordinarily rapid growth of these economies, regardless of whether the human capital input is explicitly distinguished as an input in the aggregate production function. These results are consistent with the previous findings of Kim and Lau (1994a, 1994b, 1995 and 1996) and others. However, for the period since 1986, there is some evidence of a positive technical progress in the East Asian NIEs, even with the explicit inclusion of the human capital stock in the production function. This finding is probably regarded as good news, especially by those who simply cannot accept the idea of "no technical progress" in fast-growing economies. Yet, if the R&D capital input is explicitly distinguished in the aggregate production function, as in Section 8, there is once again no evidence of a positive technical progress in the East Asian NIEs even for the period since 1986. Why is this so?

The explanation of these seemingly paradoxical results lies in the recognition that measured technical progress is largely the reflection of the effects of investment in intangible capital that have not been explicitly included as measured inputs--that it is genuinely the "residual". The level of investment in intangible capital was very low in the East Asian NIEs compared to the developed economies. Although there was rapid accumulation of tangible capital in the East Asian NIEs since the 1960s, the investments in intangible capital such as R&D capital were relatively insignificant until the mid-1980s. In 1981, R&D expenditure as a percent of GDP averaged 0.75 percent for the three East Asian NIEs, compared to 2.29 percent for the G-5 countries. As a result of the rapid growth in investment in R&D since the mid-1980s, the average R&D expenditure-GDP ratio of the East Asian NIEs rose to 1.61 percent in 1990, compared to 2.6 percent for the G-5 countries. It has now almost approached 3 percent, comparable to the average for the developed economies. (However, the levels of R&D capital stocks of the East Asian NIEs still lag far behind the G-5 countries.) Cumulatively the investments in R&D have begun to have an impact on the aggregate real output in these East Asian NIEs in the late 1980s and early 1990s. That is why we have been able to find positive technical progress in the more recent period so long as the R&D capital input is explicitly distinguished as a factor of production.

However, investment in intangible capital in the East Asian NIEs appears to be mostly concentrated in R&D, unlike the investment in intangible capital in the developed economies. Thus, once the effects of R&D capital have been taken into account explicitly, measured technical progress disappears in the East Asian NIEs. This is not the case for the developed economies where investment in intangible capital is much more diverse and includes, in addition to R&D, advertising, brand building, goodwill, software, organization, business methods and models, etc. Thus, even after controlling for the effects of the R&D capital stock on output, we continue to find positive technical progress in the G-7 countries, even though the effects are somewhat reduced.

Another reason for the failure to find positive technical progress in the East Asian developing economies has to do with the distribution of the innovation rents that are created through the expansion of the production possibilities frontier. Often, the innovation rents are largely captured by the innovators (and tangible capital and technology providers) in the industrialized economies. These innovators, on the bases of their patents, copyrights, trade secrets, markets and know-how, are likely to have much stronger bargaining power in pricing than the enterprises in the developing economies.[26] Monopolistic pricing of capital equipment, technology licenses and critical components enable the innovators to appropriate any efficiency gains that may accrue to the adopters and users of their technology and capital equipment in the developing economies. Even with direct investments by the innovators in the developing economies, transfer pricing allows foreign direct investors to transfer most of the gains from the investee countries to the investor countries. Original equipment manufacturers (OEMs) in developing economies typically

[26] In the 1950s and 1960s, the Ministry of International Trade and Industry (MITI) of Japan played an important role in screening applications by foreign capital and technology providers for foreign direct investment (FDI) in Japan by forcing them to un-bundle and to grant licenses to Japanese firms at low license fees. It is possible that these actions of MITI could have helped lower the cost of technology transfer to Japanese firms. However, we believe that the innovation rents would still accrue to the foreign capital and technology providers because competition among the providers would be highly imperfect and monopolies based on patents, trademarks and established market positions would confer on the providers enormous bargaining power. Thus we find it more reasonable to attribute the positive technical progress in Japan to the indigenous innovative activities (including investment in R&D and product and process innovation) in 1950s and 1960s rather than to the success of MITI in managing the technology adoption process in Japan.

have only razor thin margins because they do not own the underlying intangible capital, and their value-add contents are typically low.[27] Even if they manage to achieve genuine productivity gains, their lack of bargaining power vis-à-vis their clients and customers may prevent them from benefiting financially from them. In order to be able to benefit financially in the innovations and to share in the innovation rents, indigenous R&D efforts are often necessary. Thus, even though, in principle, as the firms in the East Asian NIEs undertake the production of new products and climb up the quality ladder, one should be able to measure positive technical progress, our results, based on aggregate economy-wide data, suggest that these effects do not appear to be significant enough, especially if the effects of investment in R&D capital have been explicitly taken into account. However, in order to address this issue further, empirical studies based on more specific and narrowly-defined industry- or firm-level data will be necessary.

10. Concluding Remarks

The use of the extended meta-production function approach pooling time-series aggregate data across economies has enabled us to examine and compare the characteristics of economic growth of different groups of developed and developing economies. The rapid accumulation of tangible inputs, in particular, tangible capital, is once again identified as the major source of growth in the post-war period for the East Asian developing economies. There is, however, a new twist. Although this study confirms the earlier findings in extended sample periods of no technical progress in East Asian developing economies, when we relax the assumption of the constancy of the capital-augmentation rates, we are able to find evidence of positive measured technical progress in some of the East Asian developing economies for the sub-period since 1986. Yet if R&D capital stock is explicitly distinguished as an input in the aggregate production function, the measured technical progress disappears once again from the East Asian NIEs. Is there technical progress? Or is there not?

[27] Since the innovation rents could be captured through transfer pricing or monopolistic prices on capital goods, the actual royalty payments per se could be quite small.

It is actually both. It depends on how we interpret technical progress. If we interpret technical progress as reflecting the effects of investment in intangible capital, including R&D capital, then there is no paradox at all. First, the measured technical progress in the East Asian development economies since 1986 may be mostly attributed to investment in intangible, and more specifically R&D, capital. That is why once the effects of R&D capital are explicitly taken into account, there is no further evidence of technical progress. Second, more generally, measured technical progress is mostly the result of unmeasured investment in intangible capital, of which R&D capital is only one of many possible forms. That is why the presence of R&D capital reduces, but does not eliminate, the contributions of technical progress to the economic growth of developed economies. Because investment in R&D is likely to continue to rise in the East Asian NIES, there is every expectation that intangible capital will become an increasingly important source of growth.

Our finding of positive measured technical progress for the East Asian developing economies in the more recent sub-period of 1986-1995 is also suggestive of the role played by investment in intangible capital at different stages of economic development. Different types of measured inputs play different roles at different stages of economic growth. The study provides support for the view that tangible capital accumulation is the most important source of growth in the early stages of economic development. However, mere accumulation of tangible capital however is not sufficient for rapid economic growth--efficient allocation of tangible capital is necessary to achieve it. The major achievement of the East Asian NIEs in the postwar period is the efficient accumulation of tangible capital.

As we observed, over time, the East Asian NIEs have been becoming more like Japan, and Japan has been becoming more like the non-Asian developed economies, in terms of the sources of their economic growth. Our findings are also consistent with the historical experiences of the developed economies in the early years of their development. Abramovitz and David (1973) attribute the economic growth of the U.S. in the 19^{th} century mostly to the growth of inputs. Tostlebee (1956) studies the growth in the agricultural sector of the U.S. in 19^{th} century and finds that the most important source of growth was the growth in inputs, while total factor productivity in agriculture recorded a small but negative rate of growth. Hayami and Ogasawara (1999) attribute the Japanese economic growth between the Meiji Restoration and the World War I principally to the growth in the Japanese capital stock. These findings for developed economies in the early stages of their development as well as our own results for the East Asian economies in the post-war period suggest that economic growth in the early stages of development is generally tangible input-based rather than intangible capital- or technical progress- based. The rapid expansion of tangible inputs, including, in particular, the accumulation of tangible capital, is the major source of economic growth at the early stages. As economic development proceeds, and per capita real output and tangible capital stock begin to rise, investment in intangible capital becomes gradually more profitable because of the complementarity between tangible and intangible capital and hence more important as a potential source of economic growth.

A crucial question is whether the economic growth in the East Asian developing economies is sustainable. First, even though the rapid accumulation of both tangible capital and human capital during the past several decades has narrowed the gap between the developed economies and the East Asian NIEs, the levels of tangible and intangible capital in the NIEs, relative to their labor forces, still lag far far behind those of the developed economies. Thus, there still remains significant room for economic growth based on the growth of tangible inputs and in particular on tangible capital and human capital accumulation in the foreseeable future. Second, because of the complementarity between intangible capital and tangible capital (and human capital as well), increased investments in intangible capital can and will retard the supposed decline in the marginal productivity of tangible capital due to diminishing returns. The trend of a steadily rising ratio of investment in R&D to GDP will contribute to this cause. As our results in Sections 7 and 8 indicate, positive technical progress can be identified in some of the East Asian developing economies for the post-1986 sub-period. Moreover, this technical progress is attributable to the investment in R&D undertaken by these economies. Third, just as Japan has made the successful transition from predominantly tangible-input-based economic growth to technical progress-based economic growth, the East Asian developing economies have also begun this process, albeit each at its own pace. It is expected that the importance of tangible capital as a source of growth in the East Asian developing economies will decline slowly, to be supplanted by intangible capital. The process will take decades to complete, as it did in the case of Japan. In the interim, however, East Asian developing economies certainly have the potential to continue its robust growth, based on the accumulation of both tangible and intangible capital, for a long time to come.

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