

**An Analysis of Sources of Growth
in East Asian Economies and R&D Spillover Effects***

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The purpose of this study is to attempt to quantify the factors that have been responsible for East Asian economic performance. The approach taken here is to use a production function to decompose growth into the contributions of primary factors, including labor and capital. Often, however, growth in output cannot be fully explained by increases in these factor inputs. The residual—the part of growth not explained by the factors of production—usually reflects a more efficient use of resources or the adoption of new production technologies, in other words, improvements in total factor productivity (TFP). The estimates suggest that the R&D spillover from industrial countries to East Asian developing countries is important. The spillover from the United States is largest because it is the most important industrial country trade partner for many developing countries and because the size of its R&D stock is by far the largest among the industrial countries. This means that the R&D capital stock in the United States accounts for the largest share of the foreign R&D capital stock. An East Asian country's benefit from an industrial economy is proportional to its relative trade with that industrial country. For example, Korea and Taiwan benefit from an increase in the R&D stock of the United States, but Thailand and Malaysia benefit from an increase in that of Japan. It reflects that their trade is biased toward either the U.S. or Japan.

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1. INTRODUCTION

The purpose of this study is to attempt to quantify the factors that have been responsible for East Asian economic performance. In this way, insight can be gained into answering the question of whether comparable growth rates can be sustained in the future. The approach taken here is to use a production function to decompose growth into the contributions of primary factors, including labor and capital. Often, however, growth in output cannot be fully explained by increases in these factor inputs. The residual—the part of growth not explained by the factors of production—usually reflects a more efficient use of resources or the adoption of new production technologies, in other words, improvements in total factor productivity (TFP).

The importance of TFP to the growth process is easily demonstrated. In the short run, which in this context may be a period of several decades, high levels of growth can be achieved through the rapid accumulation of factors of production. However, in the long run, or steady state, constraints imposed by population growth, together with diminishing returns that set in as capital intensity is increased, form natural limits to growth. The only way to secure growth rates beyond these limits is to secure ongoing increases in TFP.

The various aspects of the growth experience of East Asian economies have been discussed with great fascination and controversy in a vast number of papers. Some have argued that the substantial investment boom in plants and equipment has been the source of the Asian "Growth miracles." High levels of human capital and a relatively equal distribution of income created the conditions under which government intervention stimulated investment that led to growth.¹⁾ Another, standard explanation of the success of these countries is one of export led growth.

Three different theoretical explanations have been put forward. The "New Growth Theory," proposed by Romer (1986) and Lucas (1988), stresses how factor accumulation makes growth rates endogenous so that differences in growth rates between countries may persist. There are possibilities of multi-

1) For a comprehensive discussion see World Bank (1993).

equilibrium, that is, some countries may catch up to the leader but others may get stuck on low-level equilibrium paths and may not have the opportunity to do so (Hulten, 1992). The second approach, proposed by Abramovitz (1986), emphasizes the role of catch-up in the growth process and has been examined empirically by Barro and Sala-i-Martin (1991), Dowrick and Nguyen (1989), and others. The third approach is the political economy of institutional sclerosis (Olson, 1982) which stresses the rent-seeking and anti-growth practices of special interest groups that over time lead to slower growth and differential rates of growth among different economies.

Most of the studies point to significant but varying degrees of R&D spillover across borders. Coe and Helpman (1995) found that foreign R&D made a significant contribution to the total factor productivity of 22 industrial countries. They found that the effects of foreign R&D capital are as big as those of domestic R&D capital in smaller countries, while in larger countries, the effects of domestic R&D exceed those of foreign R&D.

While the previous studies document the importance given to R&D in those countries, they did not always focus on the implications for growth in East Asian countries, with respect to the link between R&D spending and total factor productivity.

The rest of this paper is organized as follows. In section 2 we provide an analysis of the factors of growth in six East Asian countries, over the period 1971-1993, is provided. Section 3 describes the theoretical model and discusses the basic results. In this section estimates of cost elasticities with respect to labor, physical capital, human capital, and foregone capital as well as the rate of technical change for each of the countries, are also reported. Section 4 is devoted to examining the sources of output and productivity growth in each of the countries and estimates of the contributions of domestic economy and exports growth to total factor productivity growth are presented. Also, estimates of the contributions of domestic capital, labor, human capital, foreign capital and technological change to the growth of output and labor productivity in these countries are provided. In section 5, the factors that may have led to a possible convergence in labor productivity or per capita income among these economies are explored. A summary and conclusions are presented in section 6. The data used in the model are described in the appendix.

2. AN ANALYSIS OF THE FACTORS OF GROWTH IN EAST ASIAN COUNTRIES

2.1. Description of Methodology

This study employs a growth-accounting methodology to decompose output growth into contributions attributable to factor accumulation on the one hand and TFP growth on the other. In this methodology, a weighting scheme is utilized that allows the contribution of land, labor, and capital to be aggregated. As mentioned previously, the difference between output growth and the portion accounted for by the factors of production is a measure of TFP growth.

Total factor productivity growth is a residual, but the question is what does it measure? The basic answer is that it measures the contribution to output growth of the improvements in the efficiency and technology with which resources are employed. The level of TFP can be raised by adopting more advanced production techniques and by reducing distortions in the economy. For example, lowering tariff barriers, allowing flexible wage determination, and phasing out selective interventions that target certain sectors will lead to a reallocation of resources to more productive activities. Dynamic gains in efficiency, generating a permanent increase in TFP growth, may result from the elimination of (or reduction in the level of) a distortion if that distortion discouraged investment in a high productivity (potential) sector. In addition, TFP includes among other things the effects, if any, of scale economies (or diseconomies) in the aggregate, and cyclical and stochastic factors that induce a greater response in output than in factor inputs.

Note that the estimate of TFP that will be derived should be interpreted with caution, since the methodology used here does not adjust factor inputs for quality changes. For example, a unit of capital input is assumed to be the same in 1990 as it was in 1960. The implication is that the incremental effect on growth of embodied technological advancement is not attributed to capital but rather is measured as a higher level of TFP. The same measurement problem can also arise in the case of labor. As education and on-the-job

training act to improve the quality of labor, measured TFP will be enhanced. This "mismeasurement" of TFP may well be significant in the case of Singapore, a country that has experienced rapid improvements in embodied technology in the past three decades.

The methodology used here, which follows the pioneering work of Gallop and Jorgenson (1980) and Jorgenson, Gallop, and Fraumeni (1987), assumes as the translog arithmetic form²⁾ of the aggregate value-added production function (Y), using inputs capital (K), labor (L), and time (t):

$$Y = \exp[\mathbf{a}_0 + \mathbf{a}_K \ln K + \mathbf{a}_L \ln L + \mathbf{a}_t \cdot t + 1/2 \mathbf{b}_{KK} (\ln K)^2 + \mathbf{b}_{KL} \ln K \ln L + \mathbf{b}_{Kt} \ln K \cdot t + 1/2 \mathbf{b}_{LL} (\ln L)^2 + \mathbf{b}_{Lt} (\ln L) \cdot t + 1/2 \mathbf{b}_{tt} \cdot t^2] \quad (1)$$

The assumption of constant returns to scale implies that the parameters satisfy the following restrictions:

$$\begin{aligned} \mathbf{a}_K + \mathbf{a}_L &= 1 \\ \mathbf{b}_{KK} + \mathbf{b}_{KL} &= \mathbf{b}_{KL} + \mathbf{b}_{LL} = \mathbf{b}_{Kt} + \mathbf{b}_{Lt} = 0 \end{aligned} \quad (2)$$

In equilibrium, the share of the value of output that a producer is willing to pay a factor of production is equal to the elasticity of output with respect to that input. Hence,

$$\mathbf{q}_i = p_i i / p_Y Y = \mathbf{d} \ln Y / \mathbf{d} \ln i, \quad i = K, L \quad (3)$$

where, \mathbf{q}_i is equal to the value share of factor i in total output, and where P_Y and P_i denote, respectively, the current price of output and input i . Thus, both the elasticities and income shares sum to unity.

First differencing the natural logarithm of the production function in

2) The translog production function provides a theoretical justification for the use of average factor shares and log differences as a means of extending the continuous time Divisia analysis of productivity growth to data based upon discrete time periods. The translog production function may be interpreted as a second-order approximation to any given production.

equation (1) gives an expression for the growth of value added in terms of the growth of the individual factor inputs between period $g-1$ and g :

$$\ln[Y(T)/Y(T-1)] = q_K \ln[K(T)/K(T-1)] + q_L \ln[L(T)/L(T-1)] + TFP_{T-1,T} \quad (4)$$

where

$$q_i = \frac{1}{2}[q_i(T-1) + q_i(T)], \quad i = K, L$$

and where q_i denotes the average income share of factor i in total factor payments. The translog index of TFP growth between periods $g-1$ and g (denoted $TFP_{\hat{\theta}_1, \hat{\theta}}$) provides a measure of the amount by which (the log of) output would have increased had all inputs remained constant between the two time periods.

2.2. Results

Annual growth rates for output and for inputs of capital and labor for 1971-1993 are set out in Table 1. The income shares of capital and labor in nominal value added are also shown. The contribution of factor inputs to growth in output, measured by factor growth rates weighted by their income shares, is also presented in Table 1, as is the rate of growth of total factor productivity. Averages for the entire period (1971-1993) appear at the bottom.

Table 1 shows that aggregate real output increased during 1971-1993. Output growth during the period averaged more than 7.0 percent a year. Growth in the capital stock was positive throughout the period. Growth of labor inputs was positive in all periods except 1985, 1986, and 1991. The data also revealed that the income share of capital declined over the period, while that of labor increased. As mentioned previously, the declining share of capital may reflect the capital deepening that took place during this period. For the period as a whole, the average factor share accruing to capital was 38.2 percent, while the average factor share accruing to labor was 52.4 percent for Singapore.

Table 1 Contributions to Growth in Aggregate Output in East Asian Countries

	Korea	Japan	Taiwan	Singapore (61-91)	Thailand	Malaysia
Growth of Output(%)	9.7	5.1	9.7	8	7.1	7.6
Growth of Capital(%)	44.5	48	40.1	38.2	36.1	33.1
Growth of Labor(%)	50.1	47	53.9	52.4	57.1	59.1
Contribution to Growth in Value Added of						
Capital	0.047	0.056	0.031	0.043	0.034	0.028
Labor	0.026	0.022	0.025	0.027	0.035	0.036
TFP	0.024	0.029	0.027	0.018	0.019	0.016

Capital generated a positive contribution to output growth in each year of the period, accounting on average for 5.6, 4.3 and 4.7 percentage points, or more than half, of the GDP growth for Japan, Singapore and Korea. Capital's contribution was greatest from the late 1960s through the early 1970s—coinciding with the period of fastest output growth. During this period, capital contributed about 7 percentage points to the average annual growth rate. Labor's contribution to growth exhibited considerable variability, ranging from 2.2 percentage points to nearly 3.6 percentage points. On average, however, growth in the supply of labor added 2.6 percentage points to annual growth output.

Total factor productivity—which here reflects both the level of efficiency with which factors are used as well as the quality of the factors themselves—contributed 2.9, 2.4 and 1.8 percentage points, or more than one fifth of the annual growth for Japan, Korea and Singapore. Productivity growth displayed much greater variability than did the growth of factor inputs, being negative for 5 of the 31 years and ranging from minus 11 percentage points to more than (plus) 7 percentage points. In 1964 and 1985, corresponding to the years of real GDP decline, total factor productivity growth was negative.

Capital was the largest contributor to GDP growth, 28-40 percent, for the six East Asian countries and was consistently the most important factor in growth during 1969-1985. Labor made the greatest contribution in 1989 and

1990. Growth in total factor productivity accounted for the greatest share of output growth in 9 of the 31 years. Abstracting from cyclical factors, total factor productivity growth was particularly important during 1967-1974 and again from 1986 onward for the six East Asian countries.

3. R&D SPILLOVER EFFECTS AND EMPIRICAL RESULTS IN THE EAST ASIAN ECONOMIES

3.1. Theoretical Model

Griliches (1992) and Nadiri (1993) provide surveys of studies showing the importance of knowledge spillover. One of the channels through which such a spillover works is through traded goods, which is stressed in the open economy endogenous growth models as pioneered by Grossman and Helpman (1991). Coe and Helpman (1995) have shown the empirical relevance of this idea. Other studies refer to different groupings of spillovers, among advanced countries, between two countries. Some studies differ on how technological spillovers are conceived, such as the technological flow concept of Terleckyj (1980) or the technological proximity concept of Jaffe (1986). Coe and Helpman (1995) found that foreign R&D significantly contributed to total factor productivity in 22 industrial countries. They found that the effects of foreign R&D capital are as big as those of domestic R&D capital in smaller countries, while in larger countries, the effects of domestic R&D exceeds those of foreign R&D. Their empirical specification was derived from models that endogenized the process of technological change. Keller(1996) provides only a sketch of one type of model (the horizontally differentiated-inputs specification). Assume that final output y is produced according to

$$y = Ak^a d^{1-a}, \quad 0 < a < 1 \quad (5)$$

where A is a constant, k are capital services, and d is a composite input consisting of horizontally differentiated varieties $x(s)$

$$d = \left(\int_0^n x(s) ds \right)^{\frac{1}{1-a}} \quad (6)$$

Here, $n=n(t)$ is the range of intermediate inputs existing in this economy at time t (ignoring integer constraints). Because intermediates enter symmetrically, if only one unit of labor is needed to create a unit of any $x(s)$, it will be the case that l , the total labor employed in the production of intermediate goods, will be given by

$$l = n\bar{x}, \quad (7)$$

where \bar{x} is the equilibrium quantity of intermediates employed. Substituting in (5) gives

$$y = Ak^a n^{1-a} l^a. \quad (8)$$

Hence, if one defines $F = \log y - a \log k - (1-a) \log l$ as the log TFP level, one obtains that

$$\log F = \log A + a \log n \quad (9)$$

This says that the log TFP level should be positively related to the range of intermediate inputs existing at that time.

We assume that entrepreneurs invest in R&D ($g(t)$), which expands the available range of designs for new intermediate inputs: $\dot{n}(t) = ag(t)$, where a is a constant. If designs never become obsolescent, the stock of intermediate inputs available at times T is

$$n(T) = \int_{-\infty}^T \dot{n}(t) dt = a \int_{-\infty}^T r(t) dt \equiv a \mathcal{G}^d(T) \quad (10)$$

that is, it is proportional to the cumulative R&D expenditures, $S^d(T)$. Hence, for a single country, by substituting (10) in to (9), we arrive at the prediction that the log TFP level is positively related to the country's cumulative R&D expenditures

$$\log F = \mathbf{m} + \mathbf{a} \log S^d,$$

where $\mathbf{m} = \log A + \alpha \log a$. International trade among several countries allows for the importation of newly developed intermediates from abroad. If all intermediates worldwide would be tradable to the same degree, then any country's TFP level would depend solely on the world's cumulative R&D expenditures. Because the tradability of intermediates differs, though, Coe and Helpman suggest that a foreign knowledge stock variable for any country i , S_i^f , be constructed as follows:

$$S_i^f = \sum_{h \neq i} \left(\frac{m_{hi}}{m_i} S_h^d \right), \quad \forall i \quad (11)$$

Here, m_{hi} are the bilateral imports of country i from country h , and m_i are total imports of country i . Hence, the construction of the variable S_i^f weights the cumulative R&D expenditures of country i 's trading partners by their bilateral import share with country i . Coe and Helpman mention several effects trade can have, ranging from learning about new technologies and production processes to learning about new organizational methods to the direct import of goods and services developed by trade partners. In this way the specification captures the notion that the domestic economy will reap, *ceteris paribus*, more international spillover if it trades relatively more with countries which have invested heavily in R&D, and hence have large domestic knowledge stocks, S^d .³⁾

Our first specification is therefore given by

$$\log F_i = \mathbf{b}_{0i} + \mathbf{b}_1 \log S_i^d + \mathbf{b}_2 (s_i \log S_i^f) + \mathbf{e}_i, \quad \forall i \quad (12)$$

where \mathbf{e}_i is an error term. Taking this a step further, these authors argue that

3) Clearly, some of these effects are not unique to trade in goods. Foreign direct investment, for instance, can result in the same. Similarly, not all of these effects are related to the volume of trade; see below.

for a given composition of a country's trade partners, it should be the case that the domestic economy benefits more from R&D activities abroad the higher are overall imports relative to GDP; let s_i denote the import share of country i . This argument presupposes that there are some productivity effects which are tied to the volume of trade (especially some of the learning effects mentioned above).⁴⁾

Our empirical work is based on a log-linear specification that links total productivity to measures of the foreign R&D capital stock, the degree of openness to trade with industrial countries, and educational attainment.

$$\begin{aligned} \log F_i = & \mathbf{b}_{0i} + \mathbf{b}_1 \log S_i^d + \mathbf{b}_2 (s_i \log S_i^f) + \mathbf{b}_3 Open \\ & + \mathbf{b}_4 E + \mathbf{b}_5 E \log S_i^f + \mathbf{e}_i, \quad \forall i \\ & \mathbf{b}_1, \mathbf{b}_2, \mathbf{b}_3, \mathbf{b}_4, \mathbf{b}_5 > 0 \end{aligned} \quad (13)$$

where s_i is the share of imports from industrial countries in developing country GDP, $Open$ is the openness index, E is the secondary school enrollment rate. We expect that there might be important interaction between the foreign R&D capital stocks and both import shares and secondary school enrollment rates. It could be argued that foreign R&D capital affects developing countries primarily, and perhaps exclusively, indirectly through trade.

The specification of (13) differs from that used by Coe and Helpman (1995) to study R&D spillovers among North-South developing countries. There are two main differences. The first is that here we include the domestic R&D data for the East Asian countries. The second is that we include the openness index because TFP could be increased through the leaning-by-doing effects of import and exports. The third is that we include human capital. A proxy for human capital is used, namely secondary enrollment. The coefficient of $E \log S_i^f$ implies the interaction between the foreign R&D capital stocks and both import shares and secondary school enrollment rates.

4) These effects are not captured by the model as sketched above; see Grossman and Helpman (1991), Ch. 6.5, for more on this.

3.2. Empirical Results

The theoretical model presented above is more relevant to medium-term, rather than to year-to-year, developments in total factor productivity. For this reason, because the estimates for the secondary school enrollment ratio are interpolated for some years, our empirical work is mainly based on a panel made up of data for four 5-year time periods, for the two decades to 1993, for the 6 countries, although we report some results based on cross-sectional data.

We base the choice of level or change specification for our empirical work on the time series properties of the data. Pooled unit root tests on the panel data are presented in Table 2. The unit root tests indicate that the log level of total factor productivity, the log level of foreign R&D capital stocks, and the import share interacted with the foreign R&D capital stocks, are non-stationary: whereas the import share, the secondary school enrollment rate, and the enrollment rate interacted with the log level of the foreign R&D capital stocks, are stationary. These results suggest that a long-term relationship between the levels of these six variables does not exist. However, the augmented Dickey-Fuller unit root tests indicate that changes in all six of the variables are stationary, suggesting that there may exist a relationship between the changes in these variables. For this reason, we specify the equations presented in the theory section in their first difference form for purposes of estimations. In Coe and Helpman all variable —domestic and

Table 2 Unit Roots Test

	Korea	Japan	Taiwan	Singapore	Thailand	Malaysia
$\log F$	-0.31	-0.25	-0.31	-0.45	-0.27	-0.45
$\log S^d$	-0.81	-1.10	-1.25	-1.76	NA	NA
$\log S^f$	-2.0	-2.91	-2.51	-2.49	-2.56	-2.5
OPEN	-4.9	-5.10	-3.70	-4.70	-4.80	-6.1
E	-2.7	-2.5	-1.7	-1.60	-2.60	-1.7
$E \log S^f$	-1.8	-1.6	-2.6	-2.80	-3.70	-4.7

Note: F =TFP, S^d =domestic R&D stock, S^f =foreign R&D stock, Open=index of openness (Exports+Imports/GDP), E =enrollment of secondary school, NA=not available. Parenthesis is t -value. The critical value for augmented Dickey-Fuller unit root tests is -3.47 and its value without trend is -2.90.

Table 3 The Estimated Results of TFP

Variable	Korea		Japan		Taiwan		Singapore		Thailand		Malaysia	
$\log S^d$	0.035 (1.4)	0.037 (1.6)	0.101 (2.1)	0.13 (1.6)	0.039 (1.8)	0.041 (1.5)	0.01 (0.8)	0.051 (0.9)	NA		NA	
$\log S^f$	0.109 (1.7)		0.15 (1.9)		0.08 (1.1)		0.09 (1.8)		0.03 (0.4)		0.02 (0.5)	
$s_i \log S^f$		0.112 (1.8)		0.17 (2.1)		0.08 (1.4)		0.21 (1.6)		0.07 (0.8)		0.06 (0.7)
Open		0.57 (3.7)		0.45 (1.7)		0.51 (1.8)		0.63 (2.7)		0.27 (1.1)		0.31 (0.9)
E		4.04 (3.9)		3.6 (2.9)		3.8 (2.3)		2.5 (5.1)		2.1 (1.1)		1.9 (0.9)
$E \log S^f$		0.96 (2.8)		1.21 (1.7)		0.86 (1.5)		1.5 (1.1)		0.8 (0.9)		0.67 (1.9)
SEE	0.05	0.04	0.08	0.06	0.11	0.09	0.16	0.06	0.01	0.10	0.02	0.12
R^2	0.71	0.76	0.59	0.61	0.51	0.57	0.41	0.54	0.21	0.45	0.31	0.37

Note: F =TFP, S^d =domestic R&D stock, S^f =foreign R&D stock, Open=index of openness (Exports+Imports/GDP), E =enrollment of secondary school, NA=not available. Parenthesis is t -value.

foreign R&D capital stocks and total factor productivity — were non-stationary so the equations were specified in level form as pooled cointegrating equations.

We report in Table 3 estimation results based on the first difference of the equations presented in the theory section. Hypothesis tests on the equations specified in Table 3 indicated that the variances are not equal across the countries and that there are important time effects but not significant fixed effects. Accordingly, all the equations are estimated by weighted least squares to correct for unequal variance across countries and include time effects. The null hypothesis that the estimated coefficients, including the constants, are the same across all countries cannot be rejected. The estimated equation explains about 15 to 20 percent of the variance in the dependent variable. All of the estimated coefficients are significantly greater than zero with the exception of those on the change in the secondary school enrollment ratio interacted with foreign R&D capital stocks.

Equation (i) is the basic specification corresponding to equation (12) in the theory section. Equation (ii) corresponds to equation (13) and includes the

interaction of the foreign R&D capital stocks, both the import share and the secondary school enrollment ratio. A variety of specifications with the primary school enrollment ratio were tried—in addition to, and instead of, the secondary school enrollment ratio as well for groups of countries at different income levels—but in no case was the estimated coefficient positive. The effects of domestic R&D stock on TFP is insignificant in developing countries in the absence of Japan. In the case of the elasticity of the TFP with respect to domestic R&D stock, Korea's, Taiwan's, Singapore's are 0.035, 0.039, 0.01, respectively, but Japan's is 0.101. It reflects a dependence on the embodied capital and technology from foreign countries, rather than domestic R&D stocks, in developing countries.

On econometric grounds, equation (ii) is quite good. The size of the estimated elasticity on the change in foreign R&D capital, however, is implausibly large. This very large estimated elasticity turns out to reflect the offsetting interaction of the change in foreign R&D capital and the time effects. Based on equation (ii), for example, the net effect on the predicted change in total factor productivity from the positive contribution of changes in foreign R&D capital and the negative contribution from the time effects, both of which are very large relative to changes in the dependent variable, is essentially zero. That the foreign R&D capital and the time trends—which are represented by constants in the first difference specification—interact in this way is not surprising since there is a similarly strong trend in our estimates of the foreign R&D capital stock. Foreign R&D capital stock has a larger impact on total factor productivity than does domestic R&D in all of the East Asian developing countries. Changes in foreign R&D capital only affect a developing country's total factor productivity through its interaction with import shares. Given an average import share of 0.3, the average elasticity of total factor productivity, with respect to foreign R&D capital, is within the range of 0.06-0.112 in equation (ii). An average elasticity of this size is plausible on a priori grounds and is consistent with other results from the literature. For individual countries or specific time periods, the elasticity of foreign R&D capital will vary according to the level of import shares (y_i), as shown in Table 3.

Estimates of the R&D spillover from the industrial countries to the

developing countries are presented in table 4 based on equation (ii) in Table 3. The estimates suggest that the R&D spillover from industrial countries to East Asian developing countries are important. The spillovers from the United States are largest because it is the most important industrial country trade partner for many developing countries and because the size of its R&D stock is by far the largest among the industrial countries. This means that the R&D capital stock United States accounts for the largest share of the foreign R&D capital stock. For example, it raises total factor productivity, on average, for all East Asian countries by about 0.027 percent, whereas a comparable increase in the R&D capital stocks of Japan, Germany, France, and the United Kingdom raises total factor productivity in the developing countries by 0.0248 to 0.0013 percent.

There are important regional differences in the R&D spillovers. In general, countries such as Korea, Singapore and Taiwan trade more with the United States, so their productivity is most influenced by R&D in the U.S. While countries in Southeast Asia trade more with Japan, so their productivity is more influenced by R&D in Japan. For any single country, the impact on total factor productivity of a 1 percent increase in R&D capital stocks in all the industrial countries is as given in Table 4. On average for 1985-1990, a 1

Table 4 The Effect of R&D Spillover from Industrialized Countries

	U.S.A.	Japan	Germany	France	Italy	U.K.	Canada
Korea	0.036	0.021	0.007	0.002	0.0003	0.015	0.0005
Taiwan	0.037	0.025	0.008	0.003	0.0007	0.016	0.0004
Singapore	0.025	0.018	0.009	0.004	0.0002	0.018	0.0003
Thailand	0.018	0.031	0.001	0.005	0.0001	0.009	0.0002
Malaysia	0.019	0.029	0.001	0.005	0.0001	0.007	0.0001
Average for 5	0.027	0.0248	0.005	0.0038	0.00028	0.0013	0.0003

Note: Estimated elasticity of total factor productivity in the row countries with respect to the R&D capital stock in the column country. The estimated elasticities are defined as $\Delta \log F_i / \Delta \log S_k^d = (\Delta \log F_i / \Delta \log S_i) \cdot (\Delta \log S_i / \Delta \log S_k^d)$ is the R&D capital stock in the column country.

Table 5 Rates of Return in the LDC from R&D Investment in the Industrial Countries

	U.S.A .	Japan	Germany	France	Italy	U.K.	Canada
Korea	1.96	2.28	0.31	0.17	0.07	0.31	0.19
Taiwan	1.37	1.25	0.18	0.03	0.017	0.26	0.004
Singapore	1.25	1.59	0.28	0.27	0.16	0.35	0.05
Thailand	0.018	0.081	0.002	0.005	0.001	0.009	0.002
Malaysia	0.017	0.076	0.003	0.005	0.001	0.007	0.001
Average for 5	0.923	1.055	0.155	0.096	0.049	0.187	0.064

Note: The rates of return is defined as $\Delta Y_i / \Delta S_k^d = (\alpha M_{i, t-5}) \mathbf{y}_{ik} Y_i / S_i^f$, where the rates of return are the increase of the row country's output from a 100 dollar increase of the R&D capital stock of the column country.

percent increase in R&D capital stocks in the industrial countries is estimated to raise total factor productivity in Korea, Taiwan, and Singapore by 0.109, 0.08 and 0.09 percent.

The estimated rates of return, which are reported in Table 5, differ considerably across countries. The sources of these difference are apparent from the formula used to calculate the rates of return, which are defined as the increase in output in the developing countries that results from R&D investment in the industrial countries (see notes to Table 4 and 5):

$$\Delta Y_i / \Delta S_k^d = (\alpha M_{i, t-5}) \mathbf{y}_{ik} Y_i / S_i^f \quad (14)$$

where Y_i is the GDP in the country i , S_i^f is the foreign R&D capital stock, α is import share, $M_{i, t-5}$ is five year lagged imports from all the industrial countries relative to GDP, \mathbf{y}_{ik} is imports from industrial country k relative to total imports from the 22 industrial countries, S_k^d is the domestic R&D capital stock of industrial country k .

Bold symbols indicate that the variables are measured in U.S. dollars at purchasing power parties. Because the effect of industrial country k , that is the source of the R&D spillover, appears only through the relative import share

y_{ik} , the rows in Table 5 are proportional to the rows in Table A(c) in the appendix. It follows that, with all else being equal, a developing country derives larger benefits from an increase in R&D in the industrial countries with which it trades relatively more. The formula also indicates that a developing country derives larger benefits from an increase in R&D in the industrial countries, the larger is its total trade with these industrial countries. An East Asian country's benefit from a industrial economy is proportional to its relative trade with that industrial country. For example, Korea and Taiwan benefit from an increase in the R&D stock of the United States, but Thailand and Malaysia benefit from an increase in that of Japan. It reflects that their trade is biased towards either the U.S. or Japan.

4. CONCLUSION

This study has used a simple growth-accounting methodology to analyze the main determinants of six East Asian countries' growth performance over the period 1971-1993. This methodology enables one to decompose output growth into two main sources, the quality of productive factors and economic efficiency, and the increases in productivity, as measured here, raised the level of per capita GDP in the six East Asian countries' between 1971 and 1993. Furthermore, despite substantial capital deepening, relatively high growth has persisted because of the increasing contribution of TFP.

This study suggests that sustaining the high rates of growth that these six East Asian countries have traditionally experienced will require that TFP play an increasing role. However, as these six East Asian countries approach the world technology frontier, thereby exhausting their opportunities for technological catch-up and the potential for further TFP growth from this source, alternative channels for improving TFP will need to be sought. It differs from Kim and Lau's results (1996). It reflects that their study neglects the R&D spillover effect from industrial countries. Public policy will need to play a role in this endeavor. One area may be education. While there has been heavy investment in human capital in the six East Asian countries through formal education and on-the-job training, a significant gap in the level of

educational attainment remains to be closed between these six East Asian countries and the industrial world. In addition, experience in a number of other countries suggests that reducing distortions in the economy—which may arise because tax, trade, or credit policies alter relative prices faced by producers and consumers in comparison with those that would prevail in a free market—may serve to increase a country's TFP growth rate permanently by generating dynamic gains in efficiency.

The estimates suggest that the R&D spillover from industrial countries to East Asian developing countries is important. The spillover from the United States is the largest because it is the most important industrial country trade partner for many developing countries and because the size of its R&D stock is by far the largest among the industrial countries. This means that the R&D capital stock United States accounts for the largest share of the total foreign R&D capital stock. For example, it raises total factor productivity, on average, for all East Asian countries by about 0.027 percent, whereas a comparable increase in the R&D capital stocks in Japan, Germany, France, and the United Kingdom raises total factor productivity in the developing countries by 0.0248 to 0.0013 percent. There are important regional differences in the R&D spillovers. In general, countries such as Korea, Singapore and Taiwan trade more with the United States, so their productivity is most influenced by R&D in the U.S. while countries in Southeast Asia trade more with Japan, so their productivity is more influenced by R&D in Japan. For any single country, the impact on total factor productivity of a 1 percent increase in R&D capital stocks in all the industrial countries is as given in Table 4. On average for 1985-1990, a 1 percent increase in R&D capital stocks in the industrial countries is estimated to raise total factor productivity in Korea, Taiwan, and Singapore by 0.109, 0.08 and 0.09 percent, respectively.

APPENDIX

Description of the Data

The data for GDP, exports, imports, and gross investment and its components were taken from the UN *Yearbook of National Accounts* for each

country other than Taiwan. For Taiwan the data for these variables was obtained from the Yearbook of the Republic of China. The deflators for the variables mentioned are calculated by dividing the current values by constant values; all deflators are base year 1985=1. The data from the Yearbook of National Accounts was checked against the corresponding series provided in *World Tables and International Financial Statistics* (IFS). These sources were also used to update various series.

The labor input is defined as the total annual man-hours. To construct this variable we obtained data on total employment from the *Yearbook of Labor Statistics* of the ILO. Data on average hours worked per week was also obtained from this source. Total man hours worked are then calculated as the product of total employment and average hours worked per week multiplied by 50 (as a proxy for the number of weeks worked annually). Data on the compensation of employees was obtained from the *National Accounts*. The series on the hourly wage rate was constructed as the ratio of compensation of employees and total man hours worked.

The data on gross investment expenditures, in billions of the 1985 national currency for each individual country, was derived from the *Yearbook of National Account Statistics* and various issues of the *UN Statistical Yearbook*. To derive the capital stock series, disaggregated investment data on non-residential buildings, other construction, transportation equipment, and machinery and equipment, were obtained from these sources. The depreciation rates provided by Jorgenson and Yun (1993) (0.0287 for non-residential buildings, 0.0333 for other construction, 0.2113 for transportation equipment, and 0.1329 for machinery and equipment) were used to calculate the capital stock of each category by the perpetual inventory method. The estimates of the base year capital stock of each category were calculated by using the formula $K_0 = \text{INV}_0 / (d_i + g)$ where INV_0 is the base year fixed capital formation of each category, d_i is the depreciation rate of the category, and g is the average growth rate of GDP over the sample period. The non-residential capital stock was obtained by adding up these categorized capital stocks. The price of the non-residential capital stock has been calculated by using the formula $W_K = P_K * (1 + r)$, where P_K is the price deflator for non-residential fixed investment, r is the depreciation rate of non-residential capital stock

(calculated as an weighted average of individual $d's$) and r is the real interest rate, which is the nominal interest rate minus the average inflation rate calculated from the price deflator for gross fixed investment.

Human capital is measured as the average of total years of education per person and the working age population series for Korea, Japan, Taiwan, and Singapore have been obtained from Kim and Lau (1993). The human capital series for Malaysia has been generated following Kim and Lau's procedure. The data was obtained from the *International Historical Statistics*.

Foreign capital stock has been generated using the perpetual inventory method. The foreign direct investment data was obtained from the *World Directory of Investment*, and the depreciation rate and price deflator for constructing the stock of foreign capital are assumed to be the same as those used in constructing the domestic capital stock series. The benchmark value for foreign capital is estimated by the same way as for domestic capital. To avoid double counting the aggregate domestic capital stock is redefined by subtracting foreign capital stock.

The purchasing power parity (PPP) values for 1985 were obtained from Summers and Heston (1991). Those values were used to convert all data to US dollars for reasons of comparability.

The R&D capital stocks for the industrial countries, which were taken from Coe and Helpman (1993), are defined as cumulative real business sector R&D expenditures added to a calculated benchmark and depreciated at the rate of 15 percent a year. The R&D expenditure data was from the OECD's *Main Science and Technology Indicators*. The R&D expenditure data was taken from the *Report of Science Technology and Research Activity* for Korea, from the Taiwan Statistical Data Book (1997) for Taiwan, and from Dr. Sam Garrett Jones's *The Development of Science Technology Indicators in the ASEAN Region* for Singapore, Thailand and Malaysia. The secondary school enrollment ratio is defined as total secondary school enrollment divided by the total population of secondary school age. The data was from UNESCO's *Trends and Projections of Enrollment by Level of Education and by Age and UNESCO Statistical Yearbooks* (1995) thereafter.

Table A (a) Bilateral Imports Shares (Imports as a share of total imports from industrial countries, 1971-1990)

	U.S.A.	Japan	Germany	France	Italy	U.K.	Canada
Korea	0.27	0.30	0.05	0.02	0.02	0.03	0.01
Hong Kong	0.20	0.13	0.06	0.03	0.03	0.07	0.01
Malaysia	0.25	0.16	0.07	0.03	0.02	0.08	0.02
Singapore	0.26	0.38	0.06	0.04	0.03	0.06	0.01
Taiwan	0.32	0.42	0.06	0.02	0.02	0.02	0.02
Thailand	0.20	0.46	0.03	0.03	0.02	0.04	0.02

Table A (b) Imports from Industrial Countries as a Share of GDP

	1971-1975 change	1976-1980 change	1981-1985 change	1986-1990 change	1971-1990 average
Korea	0.07	-0.01	-0.01	-0.01	0.21
Hong Kong	-0.12	0.06	-0.00	0.00	0.43
Singapore	-0.01	0.26	-0.27	0.22	0.82
Malaysia	0.01	0.07	-0.04	0.19	0.26
Taiwan	0.08	0.02	-0.08	0.01	0.27
Thailand	0.01	-0.00	-0.02	0.10	0.17

Table A (c) Total Factor Productivity (TFP)

	1971-1975 change	1976-1980 change	1981-1985 change	1986-1990 change	1971-1990 average
Korea	0.11	0.09	0.06	0.21	0.117
Hong Kong	0.12	0.20	0.09	0.21	0.155
Singapore	0.07	0.04	0.08	0.15	0.085
Malaysia	0.07	0.07	-0.00	0.06	0.050
Taiwan	0.12	0.17	0.10	0.24	0.157
Thailand	0.04	0.11	0.22	0.22	0.147

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