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THE SEMI-ENDOGENOUS GROWTH MODEL FOR A DEVELOPING ECONOMY AND THE SOURCES OF GROWTH IN KOREA

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There is a widespread conception that productivity growth is the sole source of long-run growth. However, this is not the case according to the semi-endogenous growth model, which endogenizes technological change but contains the neoclassical policy prediction. We construct a semi-endogenous model for a developing economy, which introduces technological capability and costly imitation efforts. Growth accounting of the model shows that transitory factors, such as rising investment share, research intensity and educational attainment explain about 78 percent of output per worker growth in Korea. One implication of this paper is that the slowdown in the Korean economy is a shor-trun phenomenon rather than a long-run sustainable one.

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I. INTRODUCTION

Growth accounting techniques have been widely used to verify empirically whether or not the high growth in East Asia is due to a sustainable long-run factor, TFP growth. However, the theoretical foundation for this approach is not likely to be strong. Jones (1998a: 29-30) argues that:

> David (1977) notes that much of nineteenth century U.S. growth was driven by a rising investment rate and a corresponding rise in the capital-output ratio, which building on a term used by Hicks, he calls a 'grand traverse.' Clearly such a traverse is not sustainable, and, writing at the end of the nineteenth entury, one might have been tempted to predict a slowdown in future U.S. growth based on this fact. However, we know that such a prediction would have been proven

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> wrong, at least for the subsequent hundredyears. While it is correct that the rise in the investment rate and the capital output ratio ceased, the grand traverse was continued by other factors, namely the rise in educational attainment and research intensity. Perhaps when this second phase of the grand traverse comes to an end there will again be something else to continue it.

The point is that, contrary to expectation, the United States did not experience a slowdown because other transitory effects such as human capital accumulation and R&D investment replaced the role of capital accumulation that had led to the increase in growth rate above the long-run level.

According to Jones (1997), the long-run growth rate, sustainable and permanent, represents only 27 percent of economic growth in the United States during the period of 1950-93. The rest are transitory effects. This finding leads to the intuition that the earlier prediction of an East Asian slowdown loses its basis because it is quite normal that level or transitory effects play a critical role in raising growth above the long-run level. This surprising result is based on the socalled semi-endogenous growth model in which technological change is endogenized but a policy change leads to level effects rather than growth effects as does in the neoclassical model.

The question is what will happen when this new approach is applied to the growth of a developing country. Will this approach show the same prediction as Jones (1997)? If so, is the result consistent with the results of conventional growth accounting, such as Young (1994, 1995), Kim and Lau (1994), Sarel (1995), and Collins and Bosworth (1996)? These questions are examined in this paper. First, we construct a semi-endogenous growth model for developing economies by changing Jones (1997, 1998a) which is for the developed countries. We introduce the role of technological capability and costly imitation efforts, which are largely ignored in the model for developing economies. R&D intensity (imitation) effects are shor-trun sources of growth in this model, while the scale effects of labor and the effects of frontier technological change are long-run sources. Then, we decompose the sources of growth in Korea and identify the contribution of the various transitory variables to the growth in output per worker over the last three decades.

Section II establishes the argument that the increases in R&D intensity, educational attainment and investment share result in growth effects in the shor-trun and level effects in the long-run. Section III sets up the semi-endogenous growth model for developing economies. Section IV describes the data and decomposes the sources of output per worker growth in Korea. Section V summarizes the results and offers some implications.

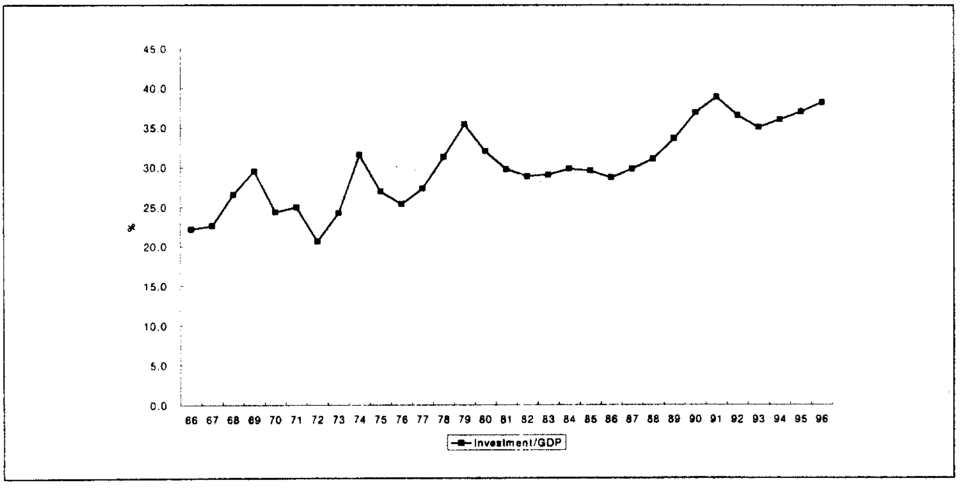
Ⅱ. GROWTH ERRECTS IN THE SHORT-RUN AND LEVEL EFFECTS IN THE LONG-RUN

Romer (1990), Segerstrom, Anant and Dinopoulos (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992) endogenize technological change to formalize the engine of growth. These models, however, are flawed by the size effect prediction that the rate of per capita growth depends on the size of the economy. These properties are empirically rejected by Jones (1995a, 1995b). A sharp increase in R&D expenditure share does not lead to the permanent increase in growth rate. Thus, Jones (1997) reformulated the idea based growth model by eliminating this unverified prediction for standard policy changes to generate level effects instead of growth effects in the long-run. He (1997: 6) names this model the semi-endogenous growth model and describes its properties as follows:

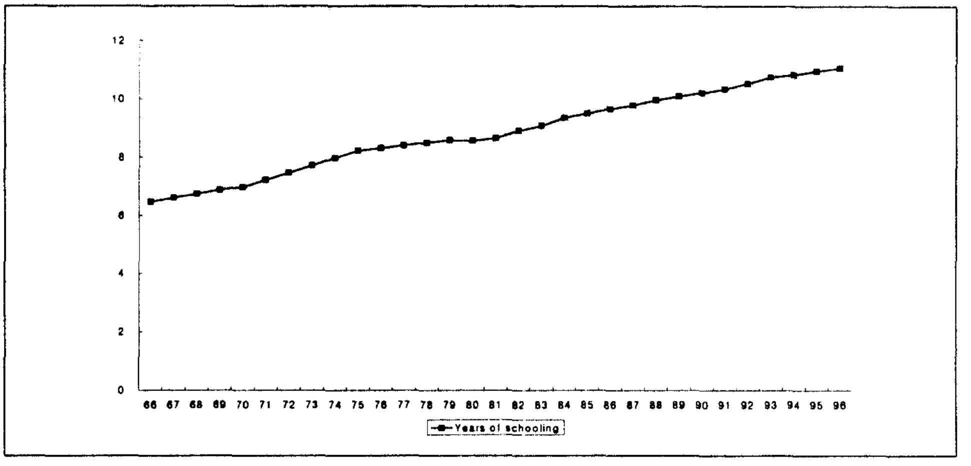
> …the reformulated model predicts a scale effect in levels, instead of growth rates. In addition, the reformulated model predicts long-run level effects instead of growth effects from standard policy changes, such as permanent subsidy to research. While policy changes have Solow like effects, the research process itself drives technological change and is endogenized, so that one might think of the reformulated model as a "semi-endogenous" growth model.

These properties of the model are also well compatible with the case of Korea. Figure 1, Figure 2 and Figure 3 show the upward trends in the investment share in GDP, the average schooling years of the employment and research efforts (R&D expenditure share in GNP and the number of researchers), respectively. These increasing trends should result in an increasing growth rate of

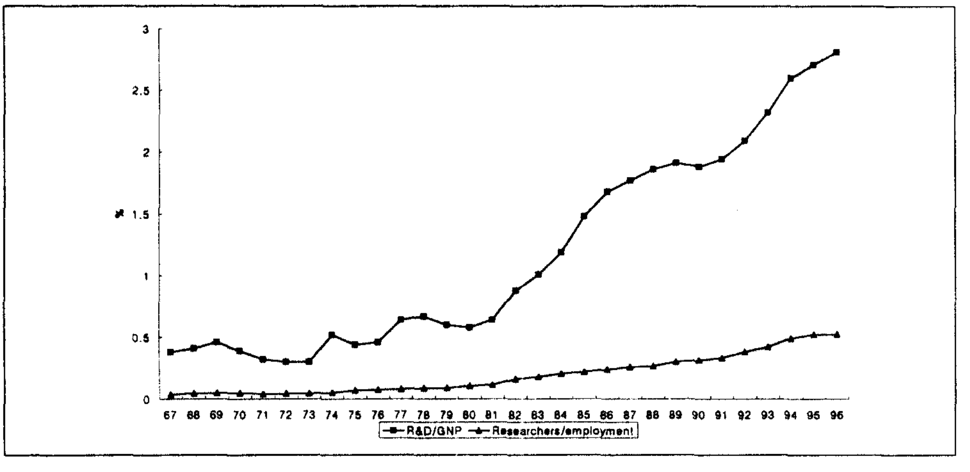
[Figure 1] Investment Share in GDP, 1966-96 (percent)



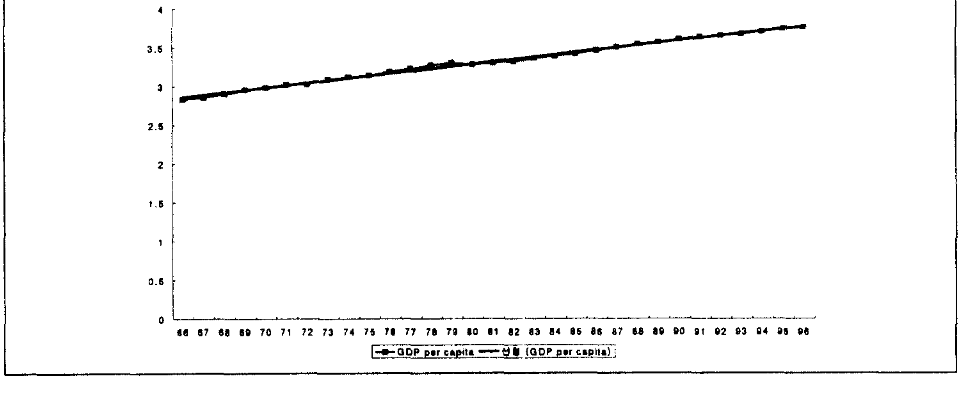
[Figure 2] Educational Attainment of Employment (years)



[Figure 3] Research Intensity, 1967-96 (percent)



[Figure 4] GDP per Capita in Korea, 1966-96 (Log scale, percent)



GDP per capita in the endogenous growth model, but this is not the case. According to Figure 4, output per worker grows almost at a constant rate. This simple exercise implies that rising research intensity, rising educational attainment and rising investment rate cause transitory effects rather than growth effects as does in the neoclassical model.

In fact, Hall and Jones (1998) and Jones (1998c) construct the model for developing economies quite differently from Jones (1997) by emphasizing human capital accumulation in developing countries as a vehicle for free technology transfer. However, the role of technological capability and costly imitation efforts in the developing countries is largely ignored. For this reason, we reformulate Jones (1997) by changing the innovative research sector to the imitating research sector, where technological capability plays a crucial role.

We define $A(t)$ as the stock of technology capability. Slightly changing Romer (1990) and Jones (1997), we endoginize growth in $A(t)$ as follows. First, we assume that growth in A is equal to the number of researchers weighted geometrically by the duplication parameter, L_A^{λ}, multiplied by the rate at which they imitate new ideas[1], δ_1.

$$dA(t)/dt = \delta_I L_A^{\lambda} \tag{1}$$

where λ is the duplication parameter between zero and unity. $\lambda < 1$ indicates that some of the ideas imitated by an individual researcher may not be new to the corresponding economy as a whole because of duplication efforts. We also assume that technological know-how in a developed economy and a developing economy in the past raises the productivity of the researchers of the latter in the present, δ_I. Namely, the stock of invention and innovation in the former and the stock of technological capability in the latter that have already accumulated ($B^{1-\phi}$, A^{ϕ}, respectively)[2] increase the rate at which new knowledge is produced.

$$\delta_I = \delta A^{\phi} B^{1-\phi} \tag{2}$$

where ϕ is the parameter for knowledge spillovers greater than zero, which indicates positive knowledge spillovers in the imitation of technology. This equation implies the advantages of backwardness: the stock of frontier technology, B, increases the productivity of the imitators (Gerschenkron 1962; Pack 1993). This specification describes the technology catch-up in successful developing economies, where barriers to technology adoption such as institutional factors are not high

[1] Note that the presence of L_A^{λ} is treated as external to the individual researcher.

[2] Note that the presence of A^{ϕ} is treated as external to the individual researcher.

(Parent and Prescott 1994).

Putting equation (2) into equation (1) produces:

$$dA(t)/dt = \delta L_A^{\lambda} A^{\phi} B^{1-\phi} \tag{3}$$

Dividing both sides of this equation by A yields:

$$d\ln A(t)/dt = \delta L_A^{\lambda}(B/A)^{1-\phi}$$

Along a balanced growth path, $d\ln A(t)\partial t = g_A$ is constant. But this growth rate will be constant if and only if the numerator and the denominator of the righthand side of the equation (4) grow at the same rate. Taking logs and derivatives of both sides of this equation gives:

$$0 = \lambda d\ln L_A(t)/dt + (1-\phi)(d\ln B(t)/dt - d\ln A(t)/dt)$$

Along a balanced growth path, the growth rate of the number of researchers must be equal to the growth rate of the population. Thus, we can get:

$$g_A = \lambda n/(1-\phi) + g_B$$

This result is different from that of Jones (1998c), in which g_A is exogenous and just equal to g_B. In this model g_A is the sum of g_B and population growth (n) weighted by λ and ϕ. Thus, the long-term growth rate of A in this model might be higher than that of Jones (1998c). This specification comes from the different definition of technology and the introduction of costly imitation efforts. We also note that the "long-run" in this model implies the period of technology catch-up required to reach the level of developed countries, and differs from that of the neoclassical model.

Ⅲ. CONSTANT GROWTH PATH IN THE SEMI-ENDOGENOUS GROWTH MODEL

The appendix describes the Romer economy as composing three sectors: the final-goods sector, the capital-goods sector and the research sector. The monopolistic research sector introduces developed designs for intermediate goods through increases in technological capability. The intermediate-goods sector purchases the design for a specific capital good from the research sector and sells to the final-goods sector. The final-goods sector produces a homogenous output, Y, using skilled labor, hL_Y (the product of human capital per worker, h, and unskilled labor, L_Y), and a collection of capital goods, x_j. Then, the production function of the representative firm is expressed as equation (A1), where A measures the range of capital goods that are available to the final-goods sector. In this section, we derive the equations of a constant and balanced growth path applying the results from the appendix.

Considering the symmetricity in the demand of capital goods ($x_j = x$), the aggregate production function in this model can be written as follows:

$$Y = A(hL_Y)^{1-\alpha}x^{\alpha}$$

Substituting equation (A6), $x = K/A$, into this function produces the familiar Cobb-Douglas form that shows labor-augmenting technology:

$$Y = K^{\alpha}(AhL_Y)^{1-\alpha}$$

This production function exhibits constant returns to the private inputs, capital, K, and skilled labor, hL_Y, which implies a perfectly competitive setup in the final goods sector, taking A as given. However, this is characterized by increasing returns at the level of the whole economy because the stock of technological capability, A, can be exploited by many units of capital and skilled labor. As emphasized by Romer (1990), this characteristic external to individuals but internal to the whole economy reflects the externality or the nonrivaly of ideas.

As does the standard neoclassical model, we assume that the population grows exponentially at some constant and exogenous rate, n. Total employment in the economy, L, can be used either to accumulate technological capability, L_A, or to produce output, L_Y. The total endowment of labor in this economy, N, is equal to total employment, L, plus the total quantity of the endowment spent accumulating skills, $l_h N$. Thus, the economy faces the following resource constraint:

$$L_A + L_Y = (1 - l_h)N \tag{7}$$

As in the standard neoclassical model, capital, K, is accumulated by forgoing consumption as follows:

$$d\ln K(t)/dt = s_K(Y/K) - d \tag{8}$$

where s_K is the investment share of output and d is some exponential rate of depreciation greater than zero. To solve for the balanced growth path in this economy, we rewrite equation (6) and (8) as follows:

$$y = k^{\alpha}$$

$$\partial \ln k(t)/\partial t = [s_K(y/k)] - (n + d + g_A)$$

where $y = Y/(AhL_Y)$, $k = K/(AhL_Y)$. Steady-state values of k and y are found when the growth rate of k is equal to zero, which produces:

$$k^*/y^* = s_K/(n + g_A + d)$$

Putting this equation into the above aggregate production function yields:

$$k^* = \xi_K^{\frac{1}{(1-\alpha)}} \tag{9}$$

$$y^* = \xi_K^{\frac{\alpha}{(1-\alpha)}} \tag{10}$$

where $\xi_K = [s_K/(n+g_A+d)]$. Rearranging equation (10), we get the steady-state value for the output per capita as follows:

$$(Y/L)^* = l_Y A^* h^* \xi_K^{\alpha(1-\alpha)} \tag{11}$$

where $l_Y = L_Y/L$. Putting the stock of technological capability along a balanced growth path (A^*)[3] into euqation (11) leads to:

$$(Y/L)^* = l_Y \xi_K^{\alpha/(1-\alpha)} (\delta/g_A)^{\lambda/\gamma} \mu e^{\psi u} l_A^{\gamma} B^* \tag{12}$$

where $l_A = L_A/L$ and $\gamma = \lambda/(1-\phi)$. This equation has some distict characteristics. First, B^* in the equation implies the advantages of a follower country. Technological change in the frontier economies leads to permanent economic growth in developing economies. Second, there is a scale effect in the model as exists in Jones (1997). Growth in output per worker is an increasing function of growth in the size of the labor force, or the speed of technological catch-up, in the economy. Finally, output per worker in the steady-state depends on the growth of labor, n, and the frontier technology, g_B. We can obtain this balanced growth path by log-differentiating equation (12) with ξ_K, u, and l_A being constant.

$$g^*(Y/L) = \gamma n + g_B \tag{13}$$

Some parts of the long-run increases in the output per worker are due to the domestic efforts to enhance technological capabilities, and the others are from the technological invention and innovation in a frontier economy. Log-differentiating this relationship with every term in equation (12), we can get the constant growth path for a developing economy, which provides the framework for the next section.

$$g(Y/L) = g(l_Y) + \alpha/(1-\alpha) g(\xi_K) + \psi \Delta u + \gamma g(l_A) + \gamma n + g_B \tag{14}$$

[3] A^* is readily calculated from equation (4) as follows:

$$A^* = [(\delta/g_A) L_A^{\lambda}]^{1/(1-\phi)} B^* = (\delta/g_A)^{1/(1-\phi)} L_A^{\lambda/(1-\phi)} B^*$$

Ⅳ. EMPIRICAL RESULTS

It is noteworthy to make a distinction between a constant growth path and a balanced growth path. Along both paths, growth rates are constant, but the former is driven by transition dynamics while the latter is associated with a steady-state. In this interpretation, the continued increases in investment in physical and human capital as well as increase in imitation efforts have led to a series of level effects that have temporarily raised the growth rate of the economy above its long-run growth rate. Each increase generates a transition path growth effect and a level effect on income. A series of increases during the last 30 years have generated a constant growth path with a growth rate higher than the long-run, sustainable one.

Using equation (14), we decompose the sources of output per worker growth. This sort of growth accounting technique is different from the traditional methodology, which uses stock variables such as K, h and A at any point in time. We employ the allocation variables such as s_K, Δu and l_A, then, identify the sources of growth along a constant growth path. The growth data for the variables in equation (26) are derived as follows. L is defined as the sum of employed $(L_Y + L_A)$ plus non-economically active population according to schooling. The data is constructed from the *Annual Report on the Economically Active Population Survey*. The data for u is calculated from the table of the employed classified by education level in the *Annual Report on the Economically Active Population Survey*. L_A data is from *The Statistical Yearbook on Science and Technology*, and L_Y is calculated by the difference between L and L_A. Expansion in frontier technology is calculated from the multifactor productivity index of the manufacturing sector in the United States (the Bureau of Labor Statistics). The others are easily observable from the *World Development Indicators* 1998, CD-ROM.

All that remains now is to obtain values of parameters such as α, ψ and γ. We assume that α is equal to 1/3, consistent with the conventional assumption in existing growth literature. Following Jones (1997), who uses the Mincerian estimation, we assume that ψ is equal to 0.06.[4] This means that an additional year of schooling raises labor productivity (output per worker) by six percent. The value of the last parameter, γ, is calculated for equation (14) to hold exactly. It results in 0.125, quite lower than the value of 0.326 in Jones (1997). Note that $\gamma = \lambda(1-\phi)$. Low λ, which means large duplication efforts in imitation research, might lead to low γ. This is quite consistent with an insight that research duplication in imitation in a developing economy is more likely to occur than that in innovation in a developed economy.

Table 1 shows the basic growth accounting results. The validity of the model

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[4] Yoo (1998) reports that ψ is equal to 0.058 and 0.041 in 1993 and 1984, respectively.

is also reported in Table 2, which presents various decomposition results according to the different values of α and ψ. The contribution of labor movement, from the production sector to the technology sector, to labor productivity growth is ignorable. A rising education attainment explains about 15% percent of labor productivity growth, which is lower than the case of the United States, about 35%. However, the contribution growth rate ($\psi \Delta u$) is higher than that of the United States. This is reasonable considering that the model set up the engine of growth from technological capability rather than human capital. Rising capital intensity is the largest contributor to economic growth in Korea, explaining about 44 percent of labor productivity growth. It can not be rejected that capital accumulation is the major source of growth in Korea.

[Table 1] Economic Growth in Korea, 1966-96

Description	Variable	Sample Value	Percent of $g(Y/L)$
Output per worker	$g(Y/L)$	0.0614	100.0
Equals:			
Effect of Labor Reallocation	$g(l_Y)$	-0.0019	-3.1
+ Capital Intensity Effect	$\alpha/(1-\alpha)g(\xi_K)$	0.0272	44.3
+ Education Attainment Effect	$\psi \Delta u$	0.0092	15.0
+ R&D Intensity (Imitation) Effect	$\gamma g(l_A)$	0.0133	21.7
+ Scale Effect of Labor Force	γn	0.0038	6.1
+ Frontier TFP growth	g_B	0.0098	16.0

Source: Author's calculations.

[Table 2] Validity of the Model(percent)

	Capital Intensity Effect	Education Attainment Effect	R&D Intensity Effect	Scale Effect
$\alpha=0.3,\ \psi=0.05$	38.0	12.5	28.6	8.1
$\alpha=0.3,\ \psi=0.06$	38.0	15.0	26.7	7.5
$\alpha=0.3,\ \psi=0.07$	38.0	17.5	24.7	7.0
$\alpha=1/3,\ \psi=0.05$	44.3	12.5	23.7	6.7
$\alpha=1/3,\ \psi=0.06$	44.3	15.0	21.7	6.1
$\alpha=1/3,\ \psi=0.07$	44.3	17.5	19.8	5.6
$\alpha=0.4,\ \psi=0.05$	59.1	12.5	12.2	3.4
$\alpha=0.4,\ \psi=0.06$	59.1	15.0	10.2	2.9
$\alpha=0.4,\ \psi=0.07$	59.1	17.5	8.3	2.3
	38.0-59.1	12.5-17.5	8.3-28.6	2.3-8.1

Notes: 1) Frontier TFP Growth Effect: 16.0%, Labor Reallocation Effect: 3.1%.
2) Author's calculations.

The second largest contributor to the constant growth rate is a rise in technological capability, whose contribution to growth records about 28 percent. This effect is more sub-categorized by the R&D intensity effect and the scale effect of the labor force. Their contributions to output per worker are about 22 and 6 percent, respectively. This result shows that rising R&D intensity (imitation efforts) plays an important role in the high growth of Korea. Interpretation of the scale effect of the labor force needs to be distinguished from that of Jones (1997). The effect means that the catching-up speed to the level of frontier technology depends on population growth.[5] Finally the frontier TFP growth, the sole source of long-run growth in Jones (1998c) and Hall and Jones (1998), explains just 16 percent of the total growth rate. It implies that free and autonomous technology transfer has a limit in explaining the high growth of developing economies. More crucial would be the domestic efforts to utilize the frontier technology stock.

What percentage of the total growth is achieved along a balanced growth path? Combining 6 percent of the scale effect and 16 percent of frontier TFP growth results in about 22 percent. The other 78 percent of growth is sustained by transitory factors. Thus, we can conclude that long-run factors do not play an important role as is seen in the case of the United States, and rather a series of transitory effects causes high growth performance in Korea.

Table 3 compares the results of this study with those of earlier growth accounting studies such as Young (1995), Kim and Lau (1994), and Collins and Bosworth (1996). It is quite interesting that all of these studies show quite similar results except Kim and Lau I. Thus, we can conclude that the specification of the model is valid.

V. SUMMARY AND IMPLICATIONS

There is a widespread conception that exogenous and autonomous technological change is the sole source of long-run growth. However, this is open to question according to the semi-endogenous growth model. We construct the model for developing economies after slightly changing Jones (1997, 1998a) by introducing the concept of technological capability and imitation efforts. The decomposition of output per worker growth in Korea shows that most growth in output per worker is sustained by transitory factors instead of longrun factors. Long-run factors, including the scale effect of the labor force explains about 22 percent of output per worker growth. The other 78 percent is explained by transitory factors, among which rising capital intensity is the largest contributor as is in

[5] This argument is not acceptable considering the experiences of large population developing economies such as India. However, note that the contribution of this effect to growth is small, about 6 percent, and that the role of infrastructure is not explicitly treated. It is certain that infrastructure such as institutional factors explains much of the variations in output per worker across developing economies.

[Table 3] Comparison with Growth Accounting Studies: Decomposition of Output per capita (percent)

	This Study	Collins and Bosworth (1996)[1]	Young (1995)[1]	Kim and Lau I	Kim and Lau II[2]
Period	1966-96	1960-94	1966-90	1960-90	1960-90
Capital share	0.3-0.4	0.35	0.297	0.564	0.35
Sources of Growth					
Capital	38.0-59.1	57.9	50.3 (45.5)[4]	98.4	61.1
Human Capital	12.5-17.5	14.0	14.3	3.2	6.4
TFP	18.3-24.1[3]	26.3	34.7(39.5)[4]	-0.0[5]	32.5[5]
R&D Intensity Effect	8.3-28.6	-	-	-	-

Source: Collins and Bosworth (1996): p.157, Young (1995): p. 660, Kim and Lau: Lau (1996) p. 75 (growth rates), Kim and Lau (1995) s. 451 (elasticity of capital).

Notes: 1) We recalculate the sources of growth in output per capita from the original results based on the decomposition of output growth.

2) We can get Kim and Lau II, when capital share is assumed to be 0.35.

3) This value is the sum of the scale effect of labor and the effect of frontier technological change.

4) This value includes the quality change of capital.

5) This value is the sum of the effects of technical progress and those of increasing returns to scale.

other growth accounting studies.

One implication of this paper would be that the economic meltdown in Korea is a short-run phenomenon rather than a long-run, sustainable one. Then, one question arises: What is accountable for the slowdown in Korea? A plausible explanation was the growth limit of rising capital intensity or diminishing returns on capital. However, we focus on the other aspect of this fact: slowdown occurred not because of diminishing returns on capital but because of the failure to find other transitory variables to replace the role of capital.

Appendix: Sectoral Description of the Romer Economy

Following Romer (1990) and Jones (1997), an economy consists of the competitive finalgoods sector, the monopolistic intermediate-goods sector and the competitive research sector. The research sector endogenizes the model through increases in technological capability. The competitive final-goods sector of an economy produces a homogenous output, Y, and the production function of the representative firm is as follows:

$$Y=(hL_Y)^{1-\alpha}\int_0^A x_j^{\alpha}dj \tag{A1}$$

Following Mankiw, Romer and Weil (1992), we assume that human capital per worker grows exponentially:

$$h=\mu e^{\psi u} \tag{A2}$$

where ψ and u denote the return to schooling and the fraction of time individuals spend accumulating skills, respectively. From equation (A2), $d\log h/d\log u=\psi$. This means that an additional year of schooling increases the wages earned by an individual proportionally. We assume the competitive market structure and normalize the price of the final output to unity. Then, the maximization problem of firms in the finalgoods sector can be summarized:

$$Max\ (hL_Y)^{1-\alpha}\int_0^A x_j^{\alpha}dj - wL_Y - \int_0^A p_j x_j\,dj \quad \text{with repect to } L_Y \text{ and } x_j$$

where p_j is the rental price for capital good j and w is the wage paid for labor. Then, the firstorder conditions are as follows:

$$w=(1-\alpha)Y/L_Y \tag{A3}$$

$$p_j=\alpha(hL_Y)^{1-\alpha}x_j^{\alpha-1} \qquad (j=1,\ 2,\ \cdots,\ A)$$

The intermediate-goods sector is characterized by monopolistic behavior. After purchasing the design for a specific capital good from the technology sector, each firm produces that capital good and sells to the final-goods sector. Assume simple production technology where one unit of raw capital can be automatically translated into one unit of the capital good. Then, the maximization problem of firms in the intermediate-goods sector can be summarized:

$$Max\ \pi_j=p_j(x_j)x_j-rx_j$$

Considering the symmetric demand functions in equation (9), the first-order condition is as follows:

$$p'(x)x + p(x) - r = 0$$

Rewriting this equation we get

$$p = r/(1-\xi_{px})$$

where ξ_{px} is the price elasticity of demand with respect to capital that equals $(\alpha-1)$ according to equation (A4). Thus, the intermediate-goods firm charges a price that is simply a markup over marginal cost,

$$p = r/\alpha$$

This means that each capital good is employed by the final-goods firms at the same price and the same amount. Therefore, each capital-goods firm earns the same profit as follows:

$$\pi = \alpha(1-\alpha)Y/A$$

Finally, the total demand for capital of the intermediate-goods firms must equal the total capital stock in the economy.

$$\int_0^A x_j d_j = K$$

Considering the symmetry in the demand for the capital goods, this equation implies

$$x = K/A \tag{A6}$$

An imitator in the research sector introduces an advanced design and sells this to an intermediategoods firm that produces the new capital good. Let P_A be the price of a new design. We can obtain the following arbitrage equation:

$$rP_A = \pi + dP_A/dt \tag{A7}$$

where r is the interest rate. This equation means that the interest earned from investing P_A in the bank is the same as the profit earned after purchasing the exclusive right plus the capital gain or loss in equilibrium. Dividing equation (A7) by P_A produces:

$$r = \pi/P_A + (dP_A/dt)/P_A$$

Along a balanced growth path, r is constant. Therefore π/P_A must be constant also, which means that π and P_A have to grow at the same rate. According to equation (A5), and P_A grow at the population growth rate, n. Thus, the price of the patent along a balanced growth path is:

$$P_A = \pi / (r - n) \tag{A8}$$

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