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9 A Time-Series Test of the Endogenous Growth Model with Human Capital

Hak K. Pyo

9.1 Introduction

The endogenous growth model developed by Romer (1986) and Lucas (1988) has focused on the role of human capital from the outset as a main source of increasing returns and divergence in growth rates between developed and underdeveloped countries. The model has been refined and extended further by Romer (1990) himself, Rebelo (1991), and Stokey (1991).

It has also been subject to empirical testing. Barro (1991) initiated it by regressing cross-country per capita income growth on a set of ancillary variables including the primary school enrollment ratio as a proxy variable for human capital. He found the initial level of human capital to be a significant determinant for economic growth. Kyriacou (1991) has constructed a cross-country human capital index from data on average school years in the labor force and school enrollment ratios. From the cross-country regression of per capita income growth, he finds the coefficient of initial human capital stock to be positive and significant but that of human capital growth to be negative and insignificant. However, Kyriacou's index is still another proxy variable limiting the validity of his empirical findings.

The convergence hypothesis implied by the Solow-type (1956) neoclassical model has been questioned by endogenous growth theories mainly in the context of a long-run growth path. Therefore, the hypothesis calls for an empirical test using time-series data rather than cross-country data. In a recent article, Lucas (1993) refers to the fact that, from 1960 to 1988, GDP per capita in South Korea grew at 6.2 percent per year, doubling the living standard every 11 years. He views the growth miracle as a productivity miracle made possible

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by the accumulation of human capital. In fact, South Korean labor productivity has been converging to West German and U.S. levels as estimated by Dollar (1991) and Szirmai and Pilat (1990), respectively. However, the latter study notes that while South Korean labor productivity increased from 11.9 percent of U.S. productivity in 1975 to 19.2 percent in 1985, it is still less than one-fifth of the U.S. level. From this point of view, the prospect for full convergence even by the most successful industrial exporter is quite uncertain and inconclusive.

The purpose of this paper is to provide an empirical test of the endogenous growth model using country-specific time-series data on human capital stocks rather than cross-country data on proxy variables. The estimates of human capital stocks by Kendrick (1969) for the United States and those by the author (Pyo 1993) for South Korea are used in the estimation of an aggregate Cobb-Douglas production function. In particular, we explicitly test the model of Romer (1990) and Rebelo (1991), which behaves just like the neoclassical model with labor and human capital augmenting technological change and which exhibits the usual constant or diminishing returns to capital accumulation, warranting a steady state growth path. We have estimated significant positive coefficients of human capital stocks for both countries. But, while diminishing returns to capital is estimated for South Korea, near-constant returns to capital is estimated for the United States. Therefore, the convergence hypothesis implied by neoclassical theory is rejected while the new growth theory with human capital is validated.

In the following section, I review alternative specifications of the endogenous growth model with human capital. Section 9.3 discusses time-series data used in the regression and presents parameter estimates of the alternative Cobb-Douglas production specifications for the United States (1940–69) and South Korea (1955–90). Section 9.4 compares the regression result with previous empirical studies in the context of the significance of human capital stocks and the convergence hypothesis. Conclusions are reported in section 9.5.

9.2 Aggregate Production Function with Human Capital

In order to examine the significance of human capital and the convergence hypothesis in the context of time-series data, let us consider the following Cobb-Douglas specification:

$$Y_t = AK_t^a L_t^b, \quad 0 < a < 1, 0 < b < 1, \tag{1}$$

where Y_t, K_t, and L_t are output, capital, and labor, respectively, and A is a technology factor. The conventional neoclassical production model assumes that A is exogenously determined and the law of diminishing marginal returns prevails.

The convergence hypothesis implied by the model can be revisited by deriving the rate of return (r) as the difference between marginal product and the depreciation rate (d):[1]

(2) $$r = aAK_t^{a-1} L_t^b - d.$$

If the growth rate of labor is exogenously given as n, the following condition must be satisfied to keep r at a constant level:

(3) $$(dK/dt)/K = bn/(1 - a),$$

which implies the steady state growth rate of capital stocks. If capital stocks are low relative to the population and, therefore, a higher rate of return prevails, then the growth rate of capital will be higher. As capital is accumulated, the rate of return will fall to the steady state level. In short, a developing economy with lower per capita capital stocks is expected to grow faster and to "converge" to the steady state achieved by advanced economies.

The new growth theory, which focuses on the role of human capital, such as the first model in Lucas (1988), Stokey (1991), and Tamura (1991) endogenizes the technology factor as follows:

(4) $$A_t = BH_t^c, \quad 0 < c < 1,$$

where H_t is the level of human capital stocks. Therefore, if H_t increases by 1 percent, A_t is assumed to increase by c percent.

Now suppose that labor input is allocated between physical output production and human capital production by xL_t and $(1 - x)L_t$, respectively. Then the production function of equation (1) can be respecified as

(5) $$Y_t = BK_t^a H_t^c (xL_t)^b.$$

In this model, endogenous growth is possible as long as there is continuous investment in human capital even if it keeps being accumulated. In other words, models of this kind introduce a critical assumption that there is no diminishing returns in the production of human capital. The assumption is embodied in the following form of the human capital production function:

(6) $$\begin{aligned} dH/dt &= j(1 - x)L_t(H_t/L_t) \\ &= j(1 - x)H_t, \end{aligned}$$

where $(1 - x)L$ is the labor input into the production of human capital and j is a productivity parameter. In addition, the productivity in human capital production is assumed to be proportional to the level of per capita human capital stocks (H_t/L_t) at time t.

Both Romer (1990) and Rebelo (1991) have shown that sustained growth can be made compatible with technologies that display constant returns to scale by assuming that there are constant returns to factors that can be accumulated.

1. See an excellent review of the convergence hypothesis by You and Chang (1991).

If physical capital and human capital are such factors ($a + c = 1$), then nonconverging growth is feasible.

Consider an alternative endogenous growth model which also departs from the assumption of exogenous technology factors but defines capital as total capital, which is the sum of physical capital and human capital.[2] Therefore, the Cobb-Douglas function is respecified as

$$(10) \qquad Y_t = A_t (K_t + H_t)^a L_t^b, \quad 0 < a < 1, 0 < b < 1.$$

Suppose the accumulation of total capital induces the accumulation of technology as follows:

$$(11) \qquad A_t = B(K_t + H_t)^c, \quad 0 < c < 1,$$

which assumes that 1 percent growth of total capital increases technology by c percent. The substitution of the above equation to into equation (10) gives

$$(12) \qquad Y_t = B(K_t + H_t)^{a+c} L_t^b.$$

The rate of return is given by

$$(13) \qquad r = (a + c)B(K_t + H_t)^{a+c-1} L^b - d.$$

If there is increasing returns to total capital ($a + c > 1$), the rate of return will increase as the capital stocks grow, as discussed in Romer (1986). This provides an explanation of why the convergence of growth rates among different economies is not universally observed, but it rules out the possibility of steady state equilibrium. Therefore, the later model of Romer (1990) and Rebelo (1991) assumes constant returns to total capital ($a + c = 1$).

Under the assumption of constant returns to capital, the rate of return will be given as constant regardless of the level of total capital stocks. In this case, the growth rate of total capital will also be constant and equal to the growth rate of per capita income. The economy is always at the steady state.

9.3 Estimation of Alternative Endogenous Growth Models with Human Capital

From a brief review of endogenous growth models with human capital, the following equations are derived for estimation from the alternative Cobb-Douglas specifications of equations (1), (5), and (12):

$$(1a) \qquad \log Y_t = \text{constant} + a \log K_t + b \log L_t + u_t,$$

$$(5a) \qquad \log Y_t = \text{constant} + a \log K_t + c \log H_t + b \log (xL_t) + u_t,$$

$$(12a) \qquad \log Y_t = \text{constant} + (a + c) \log (K_t + H_t) + b \log (L_t) + u_t.$$

2. Kendrick (1976) defines this as "total capital," which is the sum of nonhuman and human capital stocks.

First, I proceed to test $a + b = 1$ from equation (1a) to check the convergence hypothesis implied by the conventional neoclassical growth model. Second, the statistical significance of the coefficient of human capital stocks in equation (5a) is tested, and the hypothesis of constant returns to capital ($a + c = 1$) is tested. Third, the same hypothesis ($a + c = 1$) is tested from the estimation result of equation (12a). Further, if the hypothesis of constant returns to capital ($a + c = 1$) is accepted from the estimation results of equations (5a) and (12a), it may be necessary to reestimate equations (5a) and (12a) by imposing the linear constraint $a + c = 1$.

9.3.1 Data

In order to estimate a production function, we must define capital stocks and labor input. Miller (1983) distinguishes gross capital stock and net capital stock as the concepts of the capacity to produce output and the ability to produce income, respectively. I use the net concept which measures capital stocks net of depreciation since GDP, not gross output, is used as output and income.

The sample period for an empirical analysis using time-series data is naturally conditioned by the availability of human capital stock data. Kendrick (1976) has estimated human capital stocks for the United States for the period 1929–69 using a backward-looking approach.[3] The methodology is basically a cumulative accounting of past investment in human tangibles (rearing costs) and intangibles (education, health, and mobility costs). Instead of extending the data beyond 1969, the present study uses the original estimate by Kendrick to avoid possible errors in computing human capital stocks. Since Kendrick (1976) provides a consistent accounting framework for estimating both human and nonhuman capital stocks, his estimate of nonhuman capital stocks is used as the data for physical capital for the United States. Since Kendrick's estimate is available in 1958 constant prices, the U.S. GDP in 1958 constant prices has been generated from the U.S. Income and Product Accounts using GDP deflators.

For labor input data, I use "hours worked by full-time and part-time employees" (L) reported in the National Income and Product Accounts of the United States, 1929–74 for the period of 1948–69. Since the data is not available but the data for "full-time equivalent employees" (FEE) are available for the period 1929–74, I estimated hours worked for the period 1940–47 by the following regression equation for the period 1948–69, without a constant term:

$$L = \underset{(0.005)}{2.037}\text{FEE}, \quad \bar{R}^2 = 0.98,$$

3. An alternative method of estimating human capital is the present value or forward-looking approach mainly introduced by Graham and Webb (1979). This approach regards human capital as a discounted stream of future returns and estimates the present value of discounted lifetime earnings from cross-sectional data.

where the figure in parenthesis is the standard error of the estimated coefficient.

The data for South Korea's physical and human capital stocks have been estimated by the author and are available for the period 1955–90 in Pyo (1992) and Pyo (1993), respectively. The estimation of human capital stocks follows Kendrick's method closely, and the estimation of physical capital stocks combines the polynomial benchmark method and the perpetual inventory method utilizing Korea's three-time national wealth survey in 1968, 1977, and 1987. The detailed description of the estimation method and estimates by industries and types of goods are presented in Pyo (1992). The GDP data for South Korea published by the Bank of Korea is available in National Income Accounts (1984) and National Accounts (1991).

Next, in order to obtain stable estimates, I excluded a decade of the post-Depression era (1929–39) from the sample period for the estimation of the U.S. production function. For South Korea, the data for hours worked by full-time employees are available only after 1970, and those for total number of employees are available after 1955. Therefore, the period for estimation of the Korean production function for the present study is reduced to 36 years (1955–90).

The summary statistics for the basic data used for estimation are reported in table 9.1. During the post-Depression era 1940–69, the U.S. economy grew at 4.3 percent per year in real GDP terms, with the growth of physical capital (3.8 percent), human capital (3.6 percent), and employment (2.4 percent) in terms of hours worked by full-time and part-time employees.

The correlation coefficients reported in table 9.1 indicate a high degree of correlation among the U.S. GDP, physical capital stocks, and human capital stocks. The ratio of human capital stocks to total capital stocks remained rather stable, from 0.63 in 1940 to 0.62 in 1969.

The growth miracle achieved by South Korea as discussed recently by Lucas (1993) is well reflected in the growth rates of GDP (7.9 percent), physical capital (9.8 percent), and human capital (10.3 percent) reported in table 9.1. In particular, that the accumulation of human capital exceeds that of physical capital lends support to the conjecture that human capital may be an important determinant for attracting physical capital and for achieving economic growth. The ratio of human capital stocks to total capital stocks in South Korea has increased steadily from 0.47 in 1955 to 0.52 in 1990 even though it has not yet reached the U.S. level.

The convergence of South Korean productivity to the level of industrial nations is well documented in the cross-country growth accounting literature. Summers and Heston (1988) estimated that South Korea's per capita GDP in 1954 was about 10 percent of the U.S. level but reached 25 percent by 1979. Pilat (1993) reports that South Korea's labor productivity in manufacturing was only 6.4 percent of the U.S. level in 1967 but reached 26.3 percent by 1987. Dollar (1991) argues that South Korea's labor productivity in manufac-

Table 9.1 Summary Statistics for Basic Data

Statistics	United States (1940–69)	South Korea (1955–90)
Growth Rates (%)		
GDP (Y)	4.3	7.9
Physical capital (K)	3.8	9.8
Human capital (H)	3.6	10.3
Total capital ($K+H$)	3.7	10.0
Employed labor (L)	2.4	2.5
Per capita GDP (Y/L)	1.9	5.4
Per capita physical capital (K/L)	1.4	7.3
Per capita human capital (H/L)	1.2	7.8
Per capita total capital ($(K+H)/L$)	1.3	7.5
Correlation Coefficients		
r_{YK}	.98	.99
r_{YH}	.98	.99
r_{YL}	.96	.97
r_{KH}	.99	.98
r_{KL}	.92	.94
r_{HL}	.91	.97
Human capital ratio ($H/(K+H)$)	(1940) .63	(1955) .47
	(1969) .62	(1990) .52

Notes: Physical capital is defined as net nonhuman capital stocks excluding land and inventory stocks from Kendrick (1976) and Pyo (1992). Human capital is also defined as net stocks in constant prices. Employed labor is measured by hours worked by full-time and part-time employees for the United States and by total number of employees for South Korea.

turing had reached two-thirds of the West German level by 1978. All of these estimates support the catch-up or convergence hypothesis, but at the same time, they also indicate that South Korea has not yet achieved full convergence to the industrial nations level.

9.3.2 Estimation Results

The results for regressions using the ordinary least squares estimation method run on log GDP are reported in table 9.2 and table 9.3. Table 9.2 is an unrestricted version, while table 9.3 is a restricted version after imposing constant returns to all factor inputs. To account for wartime effects, a dummy variable (D) for the years 1942–45 was included in the regression for the United States. (Estimation results for U.S. data over a shorter period, 1948–69, appear in the appendix.)

Looking at the estimation results for the U.S. data, we find estimated coefficients of all three alternative models have correct signs and high significance. The degree of fitness is high, and the degree of autocorrelation is rather mild. It is interesting to note that the coefficient of human capital stocks in equation (2) and the coefficient of total capital stocks in equation (3) are significant at

Table 9.2 **Parameter Estimates of the Cobb-Douglas Production Model: Unrestricted Estimates (Dependent Variable: log GDP)**

Equation	Constant	log *K*	log *H*	log (*K*+*H*)	log *L*	*D*	$\bar{R}^2$	D-W	Auto-correlation
				United States (1940–69)					
(1)	−8.144	0.570			0.884	0.034	0.99	0.99	
	(0.611)	(0.033)			(0.071)	(0.013)			
(2)	−8.309	0.374	0.212		0.881	0.045	0.99	1.28	
	(0.581)	(0.099)	(0.102)		(0.067)	(0.013)			
(3)	−8.974			0.588	0.897	0.049	0.99	1.28	
	(0.545)			(0.032)	(0.067)	(0.013)			
				South Korea (1955–90)					
(1)	3.138	0.550			0.210		0.99	1.67	AR(1):0.974
	(6.264)	(0.298)			(0.119)				(0.087)
(2)	−0.153	0.381	0.399		0.199		0.99	1.51	AR(1):0.776
	(0.932)	(0.112)	(0.134)		(0.131)				(0.112)
(3)	−0.914			0.784	0.215		0.99	1.57	AR(1):0.766
	(0.775)			(0.050)	(0.126)				(0.106)

Notes: Standard errors in parentheses. Estimates for South Korea were obtained with the first-order autoregressive (AR(1)) adjustment on the software package Micro TSP. Parameter estimates of first-order autocorrelation coefficients with their standard errors are reported in the last column.

Table 9.3 **Parameter Estimates of the Cobb-Douglas Production Model: CRS Restricted Estimates (Dependent Variable: log GDP/*L*)**

Equation	Constant	log *K*/*L*	log *H*/*L*	log (*K*+*H*)/*L*	*D*	$\bar{R}^2$	D-W	Auto-correlation
				United States (1940–69)				
(1)	−1.396	0.883			0.128	0.95	0.85	
	(0.185)	(0.039)			(0.024)			
(2)	−1.394	0.858	0.028		0.130	0.95	0.86	
	(0.190)	(0.231)	(0.257)		(0.029)			
(3)	−2.021			0.940	0.161	0.95	1.01	
	(0.172)			(0.046)	(0.027)			
				South Korea (1955–90)				
(1)	0.110	0.647				0.99	1.56	AR(1):0.915
	(0.213)	(0.072)						(0.061)
(2)	−0.346	0.370	0.406			0.99	1.51	AR(1):0.778
	(0.142)	(0.098)	(0.129)					(0.110)
(3)	−0.918			0.784		0.99	1.57	AR(1):0.767
	(0.115)			(0.039)				(0.104)

Notes: Standard errors in parentheses. Estimates for South Korea were obtained with the first-order autoregressive (AR(1)) adjustment on the software package Micro TSP. Parameter estimates of first-order autocorrelation coefficients with their standard errors are reported in the last column.

the 5 percent significance level with a one-tail test. The estimated coefficient of labor is very high (around 0.88) and highly significant.

Note that in all three equations the hypothesis of constant returns to capital is rejected, and instead decreasing returns ($a + c < 1$) is accepted at the 5 percent significance level with a one-tail test. But, increasing returns to all factors ($a + b + c > 1$) is accepted for all three equations. Therefore, it is necessary to impose the restriction of constant returns to scale (CRS) and reestimate three equations, the results of which are reported in table 9.3.

Under the CRS restriction, the coefficient of per capita human capital is almost zero (0.028) and quite insignificant. But the estimated capital coefficient is very high with $a = 0.883$ in equation (1) and $a + c = 0.886$ in equation (2). Against the formal hypothesis of constant returns to capital ($a = 1$ or $a + c = 1$), both results reject the null hypothesis with t-values of -3.0 and -3.56, respectively, but it can be seen that they show near constant returns to capital. In particular, when capital is defined as total capital by equation (3), the estimated capital coefficient (0.94) accepts the null hypothesis ($a + c = 1$) with a t-value of -1.30. The above results partly support the hypothesis of constant returns to a broad concept of capital that includes human capital advanced by the recent models of endogenous economic growth. Barro and Sala-i-Martin (1992, 246) note that the neoclassical model requires a coefficient value of about 0.8 for a broadly defined concept of capital to fit the observed speeds of convergence from the 98-country group data. The estimated coefficient of broadly defined capital for the United States is consistent with their conjecture.

The last estimation results, reported in table 9.4, are estimates of parameters using the growth accounting equation. Benhabib and Jovanovic (1990) argue that estimation of the production function using levels is subject to all the caveats. Following this argument, Benhabib and Spiegel (1991) advance the view that, if stochastic shocks to the production function are random walks, estimating the coefficients using growth rates can overcome such difficulties.

For the U.S. results, it can be seen that the magnitude of the estimated labor coefficient has been reduced to the level of 0.46–0.50. It can be also noted that the pure neoclassical production equation (1) has produced a capital coefficient (0.63) and a labor coefficient (0.47) which are roughly consistent with the results of U.S. growth accounting. While the estimated coefficient of human capital in equation (2) is negative and insignificant, that of total capital in equation (3) is positive and significant.

Finally, it is noted that the growth accounting equation did not fit well to the South Korean data, resulting in very low degree of fitness and relatively lower t-values for the estimated coefficients.

Next, turning to the estimates from the South Korean data, table 9.2 presents significant estimated coefficients for all three equations including the coefficient of human capital stocks in equation (2) and that of total capital in equation (3). The notable difference from the U.S. results lies in the magnitude of

Table 9.4 Parameter Estimates of Growth Accounting Equations (Dependent Variable: RGDP)

Equation	Constant	*D*	R*K*	R*H*	R(*K*+*H*)	R*L*	$\bar{R}^2$	D-W
			United States (1940–69)					
(1)	−0.004	0.005	0.626			0.466	0.93	1.72
	(0.008)	(0.009)	(0.227)			(0.038)		
(2)	0.006	0.003	0.692	−0.339		0.459	0.93	1.73
	(0.016)	(0.009)	(0.236)	(0.458)		(0.039)		
(3)	−0.010	0.010			0.757	0.502	0.92	1.62
	(0.014)	(0.009)			(0.406)	(0.035)		
			South Korea (1955–90)					
(1)	0.043		0.312			0.229	0.19	1.76
	(0.015)		(0.144)			(0.123)		
(2)	0.068		0.262	−0.194		0.230	0.20	1.83
	(0.031)		(0.154)	(0.211)		(0.123)		
(3)	0.047				0.249	0.275	0.10	1.60
	(0.034)				(0.339)	(0.129)		

Notes: RGDP is defined as the growth rate of GDP: $(GDP_t - GDP_{t-1})/GDP_{t-1}$. Other variables are similarly defined.

the estimated labor coefficient and the estimated returns to scale. The estimated labor coefficients (around 0.21) are smaller than those from the U.S. data. The estimated returns to broadly defined capital is around 0.78 and the estimated returns to both broadly defined capital and labor is around 0.98–1.0. Therefore, for the South Korean data, the CRS restriction to all inputs is not necessary but is imposed to compare with the U.S. result as reported in the bottom of table 9.3. The result is almost identical to table 9.2, as it should be. It is noted that the estimated capital coefficients are smaller than those from the U.S. data.

It is important to note that the estimated coefficient for human capital from the South Korean data is around 0.4 and very significant in both the unrestricted and the restricted estimations. Therefore, it lends support to a conjecture that, for a growing economy which has not yet arrived at a long-run steady state and has not completed its productivity convergence to the industrial nation level, human capital plays the role of accumulating capital, complementing physical capital and labor rather than providing economy-wide externality as hypothesized by the endogenous growth models. The low estimates for the labor coefficient indicate that human capital is accounting partly for labor embodiment and partly for capital embodiment.

9.4 The Role of Human Capital and the Convergence Hypothesis

The estimation results of the Cobb-Douglas production function in level form using time-series data for the United States and South Korea reveal quite different results from those using cross-country data. Human capital is found to be a significant factor in aggregate production. It complements both physical capital and labor, and therefore, income growth cannot be explained by physical capital and labor only. On the other hand, the recent results of cross-country growth accounting regressions such as Kyriacou (1991) and Benhabib and Spiegel (1992) reported negative coefficients for the growth of human capital but a positive significant coefficient for the initial level of human capital stocks. Kyriacou's explanation of this puzzling result is that there could be high fixed costs in the production of human capital stocks, high opportunity costs for acquiring education in countries with low per capita human capital, and transaction, interaction, communication, and other costs when educated workers have to operate in a poorly educated environment. However, if this interpretation is correct, a developing economy can converge, or catch up, only after a certain level of human capital is endowed or created.

The difference in the magnitude of estimated capital coefficients between the U.S. data and the South Korean data provides us with a conjecture for the debate on the convergence hypothesis. The diminishing returns to capital estimated for South Korea implies that Korea started from a lower level of capital, and therefore, with a higher rate of return prevailing, the growth rate of capital has been higher. Convergence or catch-up has been occurring, as evidenced by cross-country studies of productivity comparison such as Summers and Heston (1988), Szirmai and Pilat (1990), and Dollar (1991). The accumulation of human capital is found to be an important determinant of the growth of the South Korean economy, but it has not yet arrived at a certain threshold as discussed in Azariadis and Drazen (1990) at which human capital starts providing economy-wide externality. The estimated near constant returns to broadly defined capital from the U.S. data indicates that the U.S. economy has passed the threshold and is already at a steady state.

In summary, convergence will be observed for developing economies which make use of human capital as a productive input. On the other hand, divergence will be observed between developing economies which could not make use of human capital as a productive input and developed economies which enjoy an economy-wide externality from accumulated human capital stocks. In this regard, the growth miracle of South Korea is not a miracle but the result of sustained accumulation and use of human capital. It also implies that until a converging economy's human capital reaches a certain threshold point, the externality implied by endogenous growth models cannot be expected. Until that stage, human capital will serve as a productive input rather than as a source of externality.

9.5 Conclusion

In this paper, I first estimated three Cobb-Douglas specifications of an aggregate production function suggested by the endogenous growth model with human capital. Instead of using cross-country growth data with proxy variables for human capital, the direct estimates of human capital stocks for the United States and South Korea are used for regression.

The estimation results in level form confirm the proposition that human capital plays a significant role in economic growth. However, I estimated different returns to capital between the United States and South Korea. Near-constant returns to capital estimated from the U.S. data lends support to the nonconvergence hypothesis advanced by endogenous growth models. On the other hand, decreasing returns to capital estimated from the South Korean data supports the convergence hypothesis implied by the conventional neoclassical model.

From the viewpoint of endogenous growth theory, these findings provides us with an explanation for observed divergence between rich countries and poor countries. The explanation is a conjecture that developing economies which make use of human capital as a productive input and continue to accumulate it can converge, while those which cannot may diverge. Only after the accumulation of human capital reaches a certain threshold can the broadly defined capital provide the economy with externality.

However, evidence from two-country time-series data is too fragile to test the convergence hypothesis. In addition, it can be concluded that a lot more theory and empirical evidence are required to explain why the accumulation and the utilization of human capital cannot begin in the bulk of developing countries.

Appendix

Estimation for U.S. Data, 1948–69

Table 9A.1 Parameter Estimates of the Cobb-Douglas Production Model: Unrestricted Estimates (Dependent Variable: log GDP)

Equation	Constant	log K	log H	log $(K+H)$	log L	$\bar{R}^2$	D-W
(1)	−8.264	0.592			0.873	0.99	0.87
	(0.840)	(0.040)			(0.095)		
(2)	−7.793	0.349	0.276		0.805	0.99	0.96
	(0.805)	(0.121)	(0.132)		(0.093)		
(3)	−8.164			0.632	0.794	0.99	0.93
	(0.763)			(0.038)	(0.090)		

Table 9A.2 Parameter Estimates of the Cobb-Douglas Production Model: CRS Restricted Estimates (Dependent Variable: log GDP/L)

Equation	Constant	log *K/L*	log *H/L*	log (*K*+*H*)/*L*	$\bar{R}^2$	D-W
(1)	−1.651	0.860			0.95	0.53
	(0.189)	(0.042)				
(2)	−1.672	0.326	0.564		0.96	0.72
	(0.173)	(0.243)	(0.253)			
(3)	−2.272			0.888	0.96	0.71
	(0.141)			(0.039)		

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Comment Geoffrey Carliner

The final conclusion which Hak Pyo makes in his paper is certainly correct, that evidence from time-series data on two countries is too fragile to test the convergence hypothesis. It does not require a sophisticated model to see that Korea's per capita output, physical capital stock, human capital stock, and productivity have been converging to U.S. levels with amazing speed. However the differences between the two economies are still so large that we would not want to estimate a date of convergence or overtaking, or even whether it will happen, based on the two countries' experiences over the past 35 years. It is impossible to know if Korea will be able to sustain its extraordinary rates of increase in physical and human capital, or what will happen to changes in total factor productivity as the Korean economy continues to grow.

Furthermore, the annual time-series data which Pyo uses to estimate his production functions also do not seem well suited to answering questions about convergence, since much of the movement in dependent and independent variables is due to cyclical factors rather than long-run growth. This may explain some of his results. The coefficients on human capital are not at all robust in different specifications. The increasing returns to all factors found for the United States in the unconstrained equations hardly seems consistent with low U.S. productivity growth. In any case, this finding is not repeated in the other regressions.

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Pyo observes that not all developing countries can make use of human capital as a productive input. This is supported by Helliwell (1994), who finds that high levels of human capital did not help Sri Lanka or the Philippines to grow rapidly, and low levels did not prevent Pakistan, Indonesia, and Thailand from achieving relatively high growth. Helliwell concludes that openness and investment in physical capital contributed more to rapid growth in Asia than investment in education. Perhaps inappropriate employment or education policies can sharply lower the social return on human capital.

Topel and Kim (1992) provide a more detailed look at Korean labor markets and human capital. During the 20 years they examine, the Korean economy has undergone a very rapid transformation out of agriculture into manufacturing, and from unskilled low-tech industries to higher-skilled medium and even high-tech industries. In spite of the greatly increased demand for educated labor which these shifts imply, Topel and Kim find that Korean wage differentials by education have been falling over time. This presumably is the result of the 10+ percent annual increase in the stock of human capital, estimated elsewhere by Pyo (1992). Korea's achievement in maintaining or decreasing its wage inequality while growing at a very high rate and transforming its economy is certainly remarkable.

Another recent study of Korea's path to convergence toward developed country levels of output and productivity is Young (1994). He finds that most of Korea's growth has been due to shifts from low- to high-productivity sectors, massive investment in physical and human capital, and an increase in the labor force. Although increases in total factor productivity also contributed to Korea's growth, it played a smaller role than these other factors.

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Comment Shin-ichi Fukuda

Hak K. Pyo has presented a very interesting paper. Instead of using cross-country data, Pyo used time-series data for South Korea and the United States and tested the role of human capital in economic growth. The comparison of the results for South Korea and the United States showed several differences in the role of human capital between the two countries and has several significant implications for economic development. I have four comments.

My first comment is on the over-time stability of the estimated coefficients. Assuming the Cobb-Douglas production function, the paper estimated the one-sector growth model with human capital as one of the inputs. The approach is standard. However, when we consider the economic growth of developing countries, this approach may be misleading. For example, in the case of Japan, labor-intensive textiles were one of the main products in the early stage of postwar economic growth. Thus, in this stage, the coefficient of log labor input was very large when we estimated equations (1a) and (5a). However, the share of the labor-intensive textile industry gradually declined as the Japanese economy sustained its high rate of growth. Instead, the capital-intensive steel industry and, more recently, the capital-intensive electronic and automobile industries became the main ones in the most recent stage of Japanese economic development. Thus, as a consequence of high economic growth, the coefficient of log labor input became smaller in Japan. The situation is probably quite similar in Korea, implying the possibility of biased estimations in the paper.

In fact, if we look at table 9.1, we can easily see that the growth rates of per capita physical capital and per capita human capital are very high in Korea. Of course, this result is consistent with the capital accumulation process in the one-sector growth model. However, it also implies the possibility that the leading industry in South Korea changed from a labor-intensive one to a capital-intensive one. This is a testable hypothesis, which is possibly correct. One way of testing the hypothesis is to check the time-series property of the wage-rental ratio. This is because, under a standard Cobb-Douglas production function, the wage-rental ratio is proportional to the capital-labor ratio when the factor markets are competitive.

My second comment is on human capital measurement errors. Following the method of Kendrick, the paper carefully estimated human capital stocks based on a cumulative accounting of past investment in human tangibles (rearing costs) and intangibles (education, health, and mobility costs). The estimates will be a good proxy variable for some kind of human capital. However, the estimates are not sufficient in that they have difficulty capturing accumulation of human capital through on-the-job training. In the stage of economic

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development considered here, human capital accumulation through on-the-job training is very important and deserves to be taken into account.

In addition, the estimates of human capital in the paper probably neglect the accumulation of knowledge by imitating foreign technology. In a closed economy model, we do not need to take into account this kind of human capital accumulation. However, since the export-oriented economic growth of South Korea is well known, human capital accumulation through imitating foreign technology is much more relevant in South Korea than in the United States. Thus, in comparing the role of human capital between the two countries, we have to pay more attention to different styles of human capital accumulation.

My third comment is on the econometric methods in the paper. Except for the estimates in table 9.4, Pyo ran regressions without differencing the raw data. However, it is quite possible that the levels of output, capital, and labor have unit roots. If so, the estimated t-value will be biased and the standard hypothesis test cannot be applied. In fact, if we look at the Durbin-Watson statistics in the regressions, we can easily see that they are very low in tables 9.2 and 9.3. Furthermore, the AR(1) coefficients of the disturbance terms are very close to one for South Korea, implying the high possibility of unit root problems in the analysis.

In addition to the unit root problems, the estimations in the paper may be subject to the multicollinearity problem. For example, if we look at table 9.1, we can easily see that the independent variables (i.e., physical capital, human capital, and labor input) are highly correlated with each other. If the multicollinearity problem exists, a slight change of the model specification drastically changes the estimates of the regressions. In fact, some parameter estimates of the growth accounting equations for South Korea in table 9.4 (say, a negative coefficient of human capital) are not intuitive, implying the possibility of this multicollinearity problem.

My final comment is on the accumulation of human capital. In the paper, the accumulation process is simply described by equation (6). However, the actual accumulation process of human capital will be more complicated and not automatic. The role of sophisticated government policies is likely to be very important, as is the role of exports. Allowing these elements into the analysis will make the results of the paper more fruitful and comparable to the results of other research.