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AN ANATOMY OF ECONOMIC GROWTH IN TAIWAN

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This paper revises Sedgley's model of innovation-driven endogenous growth and applies it to the case of Taiwan. The methods of empirical mode decomposition (EMD) and constrained vector error correction (VEC model or VECM) are used in the process. The EMD is used to filter out very short term fluctuations in growth, while the VECM is used to detect the various factors that affect economic growth, including human capital, public and private capital, knowledge capital and public institutions (the index of protection of property rights). It is the first attempt to include such a rich set of factors affecting economic growth at least for the studies of Taiwan.

Keywords: Economic growth; empirical mode decomposition; vector error correction.

1. Introduction

This paper revises Sedgley's model of innovation-driven endogenous growth [Sedgley (2006)] and applies it to the case of Taiwan. Besides private capital, human capital and knowledge capital, which lie at the core of innovation-driven growth, this paper incorporates public (infrastructure) capital and public institutions (security of property rights) into an analysis of the determinants of growth in Taiwan's real per capita GDP during 1970–2004. The method of constrained vector error correction model (VECM) is used in the process. It is the first attempt to include such

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a rich set of factors affecting economic growth at least for the studies of Taiwan. In addition, it involves a second novelty: in order to filter out short-term fluctuations in growth, it adopts a method called Empirical Mode Decomposition (EMD), which is a part of the Hilbert–Huang Transformation (HHT) [Huang *et al.* (1998; 2003)] and has been shown to be highly useful for the studies of both natural and biological phenomena such as the pattern of movement in ocean waves and that in heartbeats for cardiac diagnosis.

The literature on endogenous growth is very rich. It basically adds more and more dimensions to the analysis of growth besides private capital. Human capital has long been emphasized [Romer (1986); Lucas (1998)]. The importance of research and development (R&D), innovations and the associated knowledge capital has also been noticed [Grossman and Helpman (1991); Aghion and Howitt (1992)]. Still others emphasize the role of public infrastructure (government capital) and public institutions such as the degree of rule of law and political rights [Barro (1990); Barro and Sala-i-Martin (1992)].[a]

Empirically, Engelbrecht [2003] examines the cross-sectional data of the 25 economies of OECD and finds human capital measured by the average years of schooling contributes significantly to economic growth. Tallman and Wang (1994) incorporates human capital, measured similarly, into a production function and applies it to an empirical estimation of the economic growth of Taiwan in 1965–1989, and has found that human capital accumulation contributes positively and significantly to growth (about 45%) even after controlling for macroeconomic performances. Chen and Chou [1993], which investigates the differences among the growth rates of different counties in Taiwan, have also found the accumulation in human capital to be an important factor.

As for knowledge capital, Jones [1995] adopts an R&D-driven AK model to examine the pattern of growth in five OECD countries (US, France, Germany, Japan and UK) during 1950–1988.[b] His findings are (i) permanent increase in the investment rate does not bring about permanent effects on growth; its influence is no longer than 8–10 years; and (ii) the scale effect, which implies that the long-term growth rate would be equal to the ratio of R&D expenditure to GDP, is not confirmed in the estimation. He subsequently revises the model to exclude the scale effect and is able to get meaningful results for economies like the US and UK.

Sedgley [2006] similarly points to the lack of the scale effect in the US case. He generalizes Jones's [1999] model and examines the contribution of the accumulation of knowledge capital to the economic growth in the US during 1951–2000. In his paper, knowledge capital is measured by the accumulated amount of patents dating

[a]See Boldrin *et al.* [2004] for a useful survey of the literature.

[b]The AK model is a special case of Cobb–Douglas function with constant return to scale. The Cobb–Douglas function could be expressed by $Y = AK^{a}L^{1-a}$, where Y is the output, A is the total factor productivity, K is the capital, L is the labor and a is the elasticity output of capital. Let us assume that $a = 1$, then the output is a linear function of capital, that is, $Y = AK$.

back to 1851. By adopting a model of vector error correction, he finds that the contribution to growth from knowledge capital ranges from 11% to 50%, depending on the specifications.

Papers dealing with the effects of public (government) capital on growth include Aschauer [1989], which examines the US case during 1949–1985. With a generalized Cobb–Douglas production function with either constant or increasing returns to scale, he finds that (i) the output elasticity of public capital ranges from 0.36 to 0.39, (ii) the effects of non-defense capital are more significant than defense capital, and (iii) one of the main reasons of the recession in the 1970s could be the shrinking growth in public capital. Etsuro [2001] adopts various methods including the GMM (Generalized Methods of Moments), LSDV (Least Squares Dummy Variables) and LSDV-C (Corrected LSDV) to examine the contribution of public capital to growth for the period of 1963–1993 in the US and 1955–1995 for Japan. He finds that: (i) public infrastructure including roads and sewage pipes contributes significantly to economic growth; (ii) the contribution is no longer significant if public capital is broadened to include the accumulation of all government investments, and (iii) the output elasticity of public infrastructure ranges from 0.1 to 0.15.[c]

There have also been several studies on the contributions of such public institution variables as corruption to economic growth. For example, Mauro [1995; 1996] defines an index of bureaucratic efficiency which compiled from the items included in the risk rating analysis of Business International and uses one of the element in that index, namely the control of corruption, in his estimation of the effects of public institution on growth. He finds that a one standard deviation improvement in the control of corruption would raise the average investment rate (investment over GDP) by 3.3% and the average GDP growth rate by 0.8% during 1960–1985. In an alternative setting, he uses an Ethno-linguistic Fractionalization (ELF) Index, which indicate the diversity of a society, as an instrument for corruption in a two-stage least squares (2SLS) estimation of the effects and finds that the results are only marginally significant but still have the right signs.

In 2006, Gwartney *et al.* use the Economic Freedom of the World (EFW) index to measure the effects of quality of government or public institutions on growth by undertaking a cross-sectional study of 94 countries during 1980–2000. EFW index is an annual survey provided by the Canadian Fraser Institute. The index measures the size of government, legal structure and security of property rights, access to sound money, Freedom to trade internationally, and Regulation of credit, labor, and business. They find that a one unit increase in the 1980–1990 average value of EFW would raise real per capita GDP by 1.4%, and the effect becomes 0.5% for the period of 1990–2000. They also find that the causation between public institutions and growth is one-way only, with the former affecting the latter but not vice versa.

[c]See Chen [2006] for a theoretical discussion of the contribution of public capital to economic growth.

Against the background of the above studies in the literature, we will investigate the case of Taiwan in this paper. We will try to gauge whether the accumulation of knowledge capital, public capital and human capital, and the quality of public institutions would affect economic growth in that economy. In what follows, Sec. 2 will describe the theoretical model, which is a revised version of Sedgley's, as noted earlier. Section 3 will report the definition of variables and the EMD method and Sec. 4 will be the empirical results, including those from the unit root tests, co-integration and VECM. Finally, Sec. 5 will give the concluding remarks.

2. The Theoretical Model

We adopt the model of Sedgley (2006) and expand it in this article. Following the Jones (1995) functional forms which is a reduced form growth model with one factor of production, labor, Sedgley defines the production of output and that of advances in technology as follows:

$$Y_t = z_{1,t}^{1-\alpha} Q_t^{\alpha-1} \sum_{i=0}^{Q} A_t z_{2,i,t}^{\alpha}. \tag{1}$$

$$A_t - A_{t-1} = \gamma(N_{t-1}/Q_{t-1})^{\phi}, \quad \phi \leq 1. \tag{2}$$

$$Q_t = L_t^{\beta}, \quad \beta \geq 0. \tag{3}$$

In Eq. (1), Y_t is output, $z_1$and z_2 are intermediate inputs, A_t represents the level of technology, and Q_t is the number of representative firms in the economy. The parameter α is the elasticity output of input. Equation (2) describes how technology advances. There γ is the output coefficient, N_t is the amount of resources spent on R&D, and ϕ is the scale-economy coefficient. Equation (3) means that the number of representative firms is determined by the size of the working labor force.

One of the contributions of Sedgley (2006) is to explore the transitional dynamics of economic growth under capital accumulation. Let us assume $\alpha < 1$ in both Eqs. (1) and (2), and let $z_{1,t} = H_t = h_t L_t$ and $z_{2,i,t} = x_{i,t}$, where H_t is the total amount of human capital, h_t is the human capital per capita, and x_i is generated by

$$x_{i,t} = x_t = K_{i,t}/A_t. \tag{4}$$

The above equation implies the level of technology is complementary with capital stock in the sense that the higher level the technology is, the more capital accumulation is needed for the production of output.

Substituting these equations into Eq. (1), the latter could be rewritten as:

$$Y_t = C_t + I_t + N_t = H_t^{1-\alpha} Q^{\alpha-1} \sum_{i=0}^{Q} A_t x_{i,t}^{\alpha}, \tag{5}$$

where I_t stands for gross investment. From Eqs. (4) and (5), we can derive a Cobb–Douglas form of production:

$$Y_t = (A_t H_t)^{1-\alpha} K_t^{\alpha}. \tag{6}$$

Define then s_N and s_I as, respectively, the amount of final output spent on R&D and on physical capital formation:

$$N_t = s_N Y_t, \tag{7}$$

$$I_t = s_I Y_t. \tag{8}$$

And let the accumulation of capital stock be written as:

$$K_t - K_{t-1} = s_I Y_{t-1} - \delta K_{t-1}. \tag{9}$$

where δ is the rate of capital depreciation. From Eqs. (6)–(9), the steady state can be derived as:

$$g_A = g_y = \gamma(s_N Y_{t-1}/L_{t-1}^{\beta})^{\phi}/A_{t-1}. \tag{10}$$

To facilitate the exploration of the transitional dynamics, one can rewrite Eq. (6) in per capita form:

$$y_t = (K_t/L_t)^{\alpha} h_t^{1-\alpha} A_t^{1-\alpha}. \tag{11}$$

It is then postulated that human capital is determined by the average years of schooling X_t and that of working experience, E_t, according to the Mincerian specification:

$$h_t = \exp(\gamma_1 E_t + \gamma_2 X_t). \tag{12}$$

Substituting this into Eq. (11), taking the natural logarithm, and differentiating with respect to time, we can obtain an expression of transitional dynamics:

$$g_y = \alpha g_k + (1-\alpha) g_A + \gamma_1 (1-\alpha) \dot{E} + \gamma_2 (1-\alpha) \dot{X}. \tag{13}$$

Sedgley (2006) then uses this equation to analyze how various variables affect the output in such a process of transition dynamics.

In our study, we revise Eq. (1) by considering three immediate goods instead of two:

$$Y_t = z_{1,t}^{1-\alpha-\beta} z_{2,t}^{\alpha} Q_t^{\beta-1} \sum_{i=0}^{Q} \tilde{A}^{1-\alpha} z_{3,i,t}^{\beta}. \tag{14}$$

$$x_{i,t} = x_t = K_{i,t}/A_t. \tag{15}$$

It is assumed in Eq. (14) that $z_{1,t} = H_t$, $z_{2,t} = G_t$, where G_t is the capital stock of the government sector, $\widetilde{A} = B_t^{\theta} A_t$, where$B_t$ is the index of governmental institution, and $z_{3,i,t} = x_{i,t}$. The specification of Eq. (15) is the same as Eq. (4). After some substitutions, we could express Eq. (14) in a Cobb–Douglas functional per worker form:

$$y_t = A_t^{1-\alpha-\beta} k_t^{\beta} g_t^{\alpha} h_t^{1-\alpha-\beta} B_t^{\theta(1-\alpha)}, \tag{16}$$

where $k_t = K_t/L_t$, and $g_t = G_t/L_t$.

Assuming $h_t = \exp(\gamma_1 E_t)$, taking the logarithm of Eq. (16), and differentiating it with respect to time, we can obtain its transitional dynamics:

$$g_y = (1-\alpha-\beta)g_A + \beta g_k + \alpha g_g + (1-\alpha-\beta)\gamma_1 \dot{E} + \theta(1-\alpha)g_B, \tag{17}$$

where g_y is the growth rate of output per worker, g_A is that of knowledge, g_k is that of private capital stock, g_g is that of public capital stock, $\dot{E}$ is the change in human capital stock, and g_B is the growth rate of the index of institution.

Equation (17) is the empirical base of this article. As in the study of Sedgley (2006), we include human capital, knowledge capital, and private sector capital; but we have added the variable of the public capital and the index of institution. We could study the transitional dynamics of Taiwan's economic growth from Eq. (17) and investigate the impact of each variable on economic growth.

3. The Data and Methodology

3.1. *The definition of variables*

We use real GDP per capita as a proxy for real output per worker. It is obtained from the Directorate-General of Budget, Accounting and Statistics (DGBAS), Executive Yuan, R.O.C (Taiwan). The period covered is from 1970 to 2004, with the choice of the beginning year bounded by availability of data of other variables. It is expressed in constant 2001 local currency and transformed into growth rates.

In this study, we use current expenditure on R&D as a proxy for investment in knowledge capital. The data is collected from *Indicator of Science and Technology*, Taiwan. The length of data of total R&D expenditure is from 1986 to 2004, and a division into current and capital expenditures has been available only since 1999. The share of current expenditure in total R&D expenditure in these 5 years looks very stable, so we use its average, 86%, to impute the division for all other years. It is also found that a quadratic time series function fits the movement of the growth rate of R&D current expenditure pretty well during 1986–2004. A backward extrapolation then gives us all the figures back to 1951. From these figures and assuming a depreciation rate of 3% per year, as often assumed in the literature, we are able to obtain the knowledge capital stock data for 1970–2004.

Following Jones [2002], we compute human capital by the average years of schooling of the population according to $h_t = \exp(\gamma_1 E_t)$. The data is collected from the *Yearbook of Manpower Survey Statistics in Taiwan Area, R.O.C.* In the process of computation, following Hsieh [2003], we incorporate the categories of "illiterate" and "self-educated" into that of elementary school, and then assign the years of schooling as follows: 6 years for elementary, 9 years for junior high school graduates, 12 years for high school graduates, 14 years for graduates of vocational high school, and 16 years for all those receiving college or higher education. This criterion is then applied to all people who are working. It is found that the average years of schooling in 1970 was 7.4, while it increased to 11.8 in 2005.

The calculation of private capital (more accurately "business capital" as it includes that of the state-owned enterprises) and public capital (or "government capital" as it refers to the capital pertaining to the public administration of the government)[d] are largely based on the data collected in the 2004 *National Wealth Survey*, the *Multi-factor Productivity Report* (various years), and National Income Statistics (various years), all compiled by the DGBAS.

The process is quite complicated and will not be described in detail here; it is largely based on the benchmark year method for the data of 1981–2004, and the perpetual inventory method for the period prior to 1981. These methods are consistent with those given in the above-mentioned reports of the DGBAS. However, it should be noted that the System of National Accountings (SNA) in Taiwan was changed in 2001 from 1968 version to 1993 version, and while the data based on the new method in *National Wealth Survey* are traceable back to 1981, those in the *Multi-factor Productivity Report* are traceable back only to 2001. Such an inconsistency creates a certain degree of difficulty in the process of reconciliation between the items in these two reports.

The quality of public institutions in this paper is measured by the "legal structure and the protection of property rights", one of the five categories of the EFW index. The variables included in this category are judicial independence, impartial courts, protection of property rights, military interference in rule of law and the political process, integrity of the legal system, and legal enforcement of contracts.

3.2. *The EMD method*

We first transfer the variables of output per worker, various capital stocks and the index of the quality of public institutions from levels to growth rates. Empirically, the very shot-term fluctuations of the growth rate will influence the quality of the study of economic growth, which is however basically a medium- to longer-term phenomenon, so the method of Empirical Mode Decomposition or EMD [Huang *et al.* (1998)] is then applied to eliminate them from each variable individually.

The EMD is empirical, intuitive, direct, and adaptive, and based on a *posteriori* definition derived from the data. The initial stage of EMD is to separate any data into various intrinsic modes of oscillations because each data may have many different coexisting modes of oscillation at the same time. These oscillatory modes are called Intrinsic Mode Functions (IMFs) and are based on the following definitions: (i) in the whole data set, the number of extrema and the number of zero-crossings must either be equal or differ from each other at most by one; and (ii) at any point,

[d]Including public educational facilities and public hospitals.

the mean values of the envelope defined by the local maxima and of the envelope defined by the local minima are both zero. The mean value is designated as m_1, and the difference between the original data and m_1 is the first component, which would be called h_1, i.e.,

$$X(t) - m_1 = h_1. \tag{18}$$

If h_1 is not an IMF, we will do the sifting process. In the sifting process, the first component h_1 is treated as if it were the data, that is,

$$h_1 - m_{11} = h_{11}. \tag{19}$$

The sifting process would be done k times until h_{1k} is an IMF, which is assigned as c_1, then

$$h_{1(k-1)} - m_{1k} = h_{1k} = c_1. \tag{20}$$

where c_1 is the real first component which satisfies the definition of IMFs. Equation (18) could then be rewritten as

$$X(t) - c_1 = r_1. \tag{21}$$

Equation (21) will also be repeated many times until the residue, r, is less than the predetermined value of substantial consequence, or when it becomes a monotonic function from which no more IMFs can be extracted. The last residue is the trend of the data if it exists. Finally, Eq. (21) can be expressed as:

$$X(t) = \sum_{i=1}^{n} c_i + r_n. \tag{22}$$

In this analysis, the focus is on economic growth of medium- to long-term nature, so very short-run fluctuations should be purged. Thus, we purge the *first* IMF from the original data to get a new series which will be the target of analysis. It can be shown that if such very short-term fluctuations are not so purged, the results become grossly unsatisfactory. Figure 1 demonstrates the IMF of the data and Fig. 2 shows the data before and after purging first IMF by the EMD method.

4. The Empirical Analysis

4.1. *Unit root test*

We follow the procedure which was suggested by Enders [2004] in order to adopt the Augmented Dickey–Fuller (ADF) version of the unit root test for the growth rate of output per worker, knowledge capital, private capital stock, public capital stock, the changes in human capital stock, and the growth rate of the index of quality of public institutions. A brief description of each test for the null hypothesis that the series is nonstationary, is reported in Table 1.

Table 2 lists the results of the unit root tests for each variable. To take a simple example, g_y is estimated with the intercept and trend in the first stage. The estimated value ($\gamma = -1.578$) is higher than τ_τ at 5% significance level (-3.574).

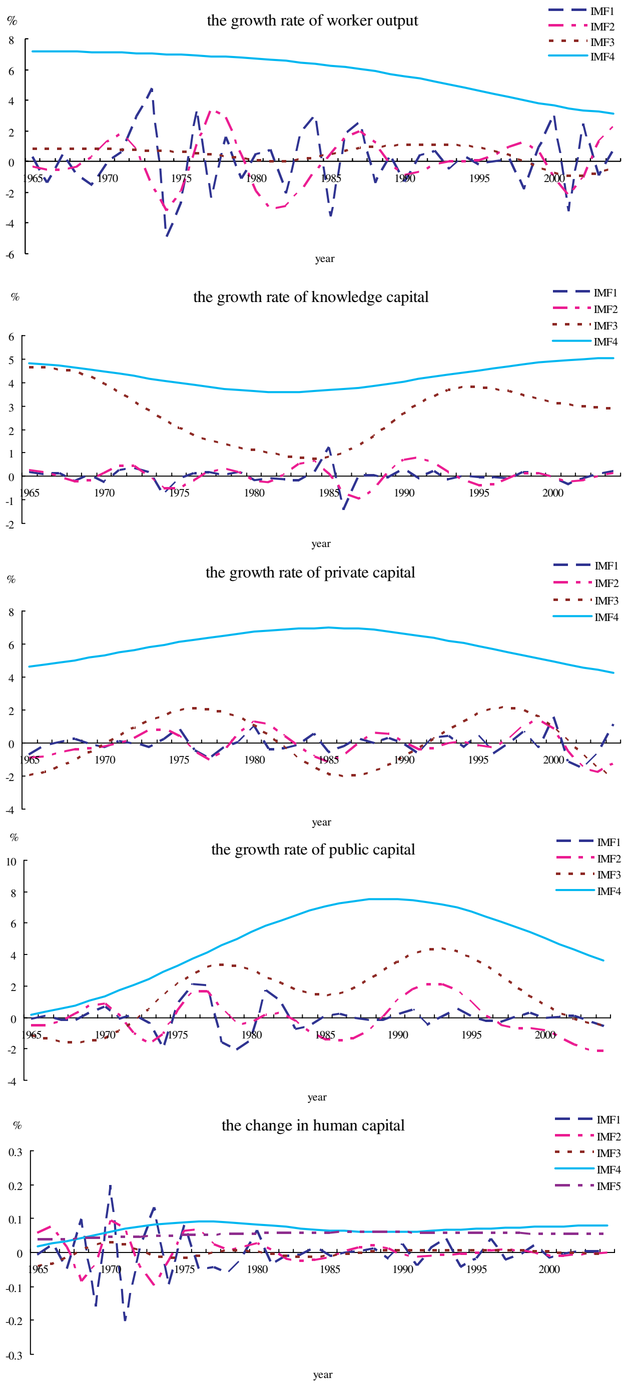

Fig. 1. The IMFs of various data.

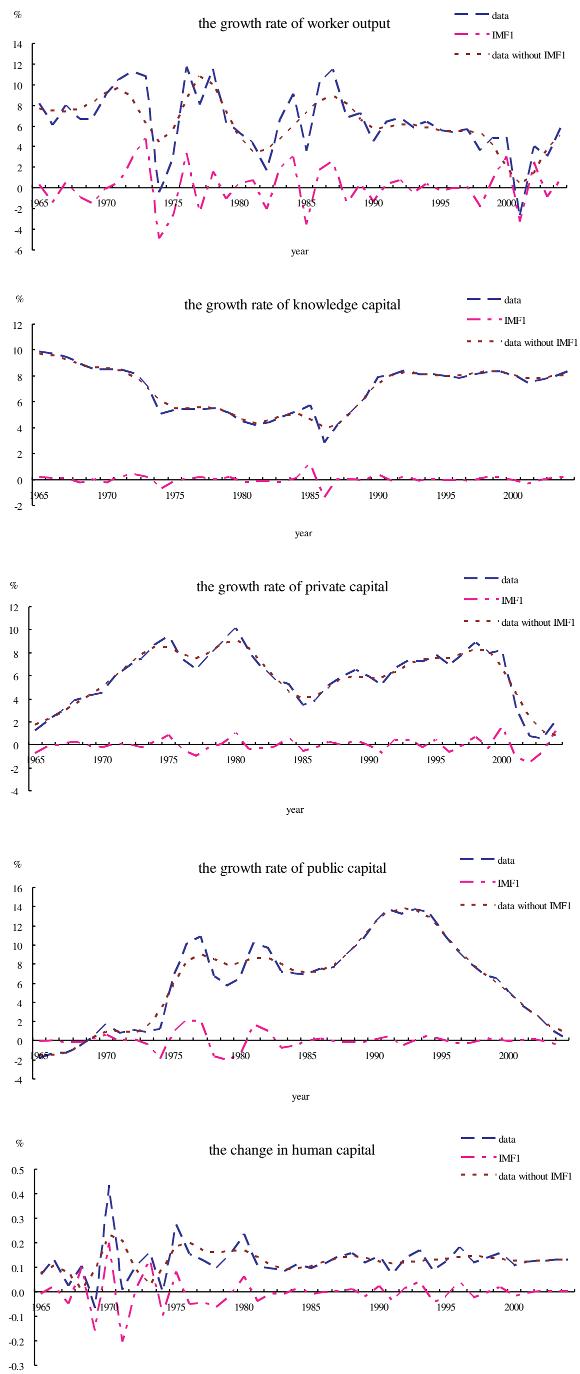

Fig. 2. The data before and after purging first IMF by the EMD method.

Table 1. The ADF unit root test.

Model	Null hypothesis	Statistics
$\Delta y_t = a_0 + \gamma y_{t-1} + a_2 t + \sum_{i=1}^{p} \beta_i \Delta y_{t-i+1} + e_t$	$\gamma = 0$	τ_τ
	$\gamma = a_2 = 0$	ϕ_3
	$\gamma = a_0 = a_2 = 0$	ϕ_2
$\Delta y_t = a_{0+} \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i+1} + e_t$	$\gamma = 0$	τ_μ
	$\gamma = a_0 = 0$	ϕ_1
$\Delta y_t = \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i+1} + e_t$	$\gamma = 0$	τ

Table 2. Unit root tests of various variables.

	τ_τ	ϕ_3	τ_μ	ϕ_1	τ
g_A	−1.578	1.412	−0.527	1.117	−1.505
g_A	−1.750	1.917	−1.207	1.365	−1.622
g_k	−1.671	1.969	−1.246	0.978	−0.944
g_g	1.629	3.483	−1.170	0.692	−0.873
$\dot{E}$	−2.172	2.398	−2.210	2.479	−0.800
g_B	−0.547	1.041	−1.359	1.001	−1.440
$d(g_y)$	-3.977^{**}				
$d(g_A)$	-10.822^{***}				
$d(g_k)$	-5.660^{***}				
$d(g_g)$	-3.614^{**}				
$d(\dot{E})$	-4.209^{**}				
$d(g_B)$	-5.522^{***}				

**, Significant at 5%; ***, significant at 1%.

It means that the null hypothesis of unit root could not be rejected. Next, we check for $\gamma = a_2 = 0$ and calculate the value of F-test, which is found to be 1.412, lower than the value of ϕ_3 at the 5% significance level (7.24), so the null hypothesis of unit root still could not be rejected in this stage. After that, we estimate g_y with drift merely, and it is found that $\gamma = -0.527$ is also higher than τ_μ at the 5% significance level (−2.968). We then do an F-test again and it is found the null hypothesis of the presence of a unit root could not be rejected. Finally, the estimation without the drift and trend again shows the presence of unit root. The nonstationarity is thus established. It would still be so even at 10% of significance.[e] The other variables in Eq. (17) including g_A, g_k, g_g, $\dot{E}$ and g_B are tested by the same procedure as above. They are all found to be nonstationary.

4.2. *The cointegration test*

After identifying these variables as I (1)s, we should check whether there exists a long-term relationship among them. Johansen's cointegration test [Johansen (1988; 1995; 1999)] is used to detect the number of cointegrating vectors. According to

[e]The non-stationarity of economic growth rate could also be found in the case of Thailand (Yoo, 2006).

Table 3. Johansen's cointegration test.

Variables	Null hypothesis	Alternative hypothesis		p-Value
g_y, g_A, g_k				
g_g, $\dot{E}$, g_{B}	Trace test			
	$\lambda = 0$	$\lambda = 6$	94.712***	0.0067
	$\lambda \leq 1$	$\lambda = 6$	59.572*	0.0549
	$\lambda \leq 2$	$\lambda = 6$	34.900	0.1536
	$\lambda \leq 3$	$\lambda = 6$	15.361	0.4274
	$\lambda \leq 4$	$\lambda = 6$	7.100	0.3152
	$\lambda \leq 5$	$\lambda = 6$	1.355	0.2860
	Maximum eigenvalue test			
	$\lambda = 0$	$\lambda = 1$	35.141*	0.0738
	$\lambda = 1$	$\lambda = 2$	24.671	0.2205
	$\lambda = 2$	$\lambda = 3$	19.539	0.1871
	$\lambda = 3$	$\lambda = 4$	8.261	0.6773
	$\lambda = 4$	$\lambda = 5$	5.746	0.3795
	$\lambda = 5$	$\lambda = 6$	1.355	0.2860

*, Significant at 10%; ***, significant at 1%.
Only 1 lag is included to obtain the result due to the small sample problem.

the trace test in Table 3, the estimated value is 94.712, so the null hypothesis that the number of cointegrating vectors is zero could be rejected at the 1% significance level (p-value = 0.0067); The null hypothesis of at most one cointegrating vector could be rejected at the 5% significance level; the rest of the null hypotheses could not be rejected even when the significance level is raised to 10%.

The results of the alternative test (maximum eigenvalue test) in Table 3 are similar: the null hypothesis of no cointegrating vector could be rejected at the 10% significance level (p-value = 0.0738); other null hypotheses could not be rejected even at the significance level of 10%.

Following the findings from the trace test and the maximum eigenvalue test, we accept that the number of cointegrating vector is 1. After that, we use the vector error correction model to analyze the relationship among these variables.

4.3. *The vector error correction model*

The estimation of VECM with and without EMD method are simultaneously demonstrated in Table 4. We normalize the cointegrating vector to 1 for an easier interpretation of the results (the impacts of $g_A, g_k, g_g, \dot{E}$ and g_{B} on growth).

The results of estimation with EMD method show that the output elasticity of knowledge capital, private capital and public capital are 0.222, 0.302 and 0.475, respectively. The output elasticity of human capital per capita is 0.198. Finally, the output elasticity of the index of public institution is 0.175, implying that improvements in public institutions would have a positive influence on Taiwan's economic growth. All of these elasticities have the expected signs and their magnitudes are broadly comparable to those found in the studies of the other economies.

Table 4. The ointegrating vector.

	g_A	g_k	g_g	$\overset{\bullet}{E}$	g_B
With EMD method					
Cointegrating vector	0.222	0.302	0.475	0.198	0.175
	(0.027)	(0.066)	(0.045)	(0.039)	(0.032)
	[8.116]	[4.571]	[10.566]	[5.100]	[5.404]
Without EMD method					
Cointegrating vector	0.145	-0.583	0.348	0.352	0.242
	(0.058)	(0.027)	(0.119)	(0.128)	(0.085)
	2.520	2.157	2.924	2.753	2.840

Standard errors inside the paretheses; t-values inside the brackets.
Only 1 lag is included to obtain the result due to the small sample problem.

On the other hand, the results of the estimation without EMD method demonstrate that the output elasticity of private capital does not have the expected signs which are introduced in the related studies, even though these results are statistically significant.

5. Conclusion

In this article, we investigate simultaneously the impact of knowledge capital, private (or business) capital, public (or government) capital, human capital, and the quality of public institutions on economic growth for Taiwan during 1970–2004. Adopting the method of VECM, we are able to find significant relationship between growth and the other variables based on the process of transitional dynamics.

Prior to the estimation, the very short-term variations of these variables are eliminated by the EMD, which is a method of adaptive decomposition originally developed for natural and engineering sciences by Huang *et al.* (2003). We adopt this procedure due to the belief that the fundamental forces underlying economic growth and productivity from the accumulation of various forms of capitals are intermediate to longer-term phenomena. Their relationship could not be properly investigated if the very short-term fluctuations are not purged. The advantages of the EMD are: (i) it is suitable for the time series data of all nature, including the nonstationary and nonlinear ones; (ii) being adaptive, it does not need priori base or particular assumption for the analysis of variation and frequency, and (iii) it has had convincingly successful performances in various cases ranging from the lifetime of bridges to the movement of waves.

According to our empirical results, the output elasticity of knowledge capital is 0.222. It is comparable to those obtained by Sedgley (2006) (0.12–0.529). The output elasticity of 0.302 for private (or business) capital obtained in this study is also comparable to those obtained in the literature.

The estimation of the output elasticity of public capital (or more precisely "public administration capital" or "government capital") in our study is 0.475. It is higher than those given in the research of Japan (0.1–0.15) by Etsuro (2001) and the US (0.36–0.39) by Aschauer (1989). Possible reasons for such differences are: (i) being an emerging economy, Taiwan could be characterized by a high productivity of public capital as it represents the availability and quality of public infrastructure; and (ii) there could be some measurement errors as the data of public capital are imputed from the *National Wealth Surveys* and the *Multi-factor Productivity Reports*, both published by the DGBAS, and the detailed items of capital defined in these two reports are somewhat different and need reconciliation as explained earlier.

The output elasticity of human capital is 0.198, broadly consistent with the results in the literature but lower than what we expected. One possible explanation is that a part of it is captured by knowledge capital. Another one is that in this study we estimate human capital only by the average years of schooling but other factors such as experience and health are not considered. More accurate estimations could be adopted in future studies.

Lastly, the output elasticity of public institution, measured by the index for "legal structure and security of property rights" is 0.175. This is lower than that (0.54) obtained by Gwartney *et al.* in the case of the US, but does have the right sign.

References

Aschauer, D. A. (1989). Is public expenditure productive? *J. Monetary Econ.*, **23**: 177–200.

Aghion, P. and Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, **60**: 323–351.

Barro, R. J. (1990). Government spending in a simple model of endogenous growth. *J. Poli. Econ.*, **98**: 103–117.

Barro, R. J. and Sala-i-Martin, X. (1992). Public finance in models of economic growth. *Rev. Econ. Stud.*, **59**: 645–661.

Boldrin, M., Chen, B. -L. and Wang, P. (2004). Introduction: A quick reference to growth theory, in *Human Capital, Trade and Public Policy in Rapidly Growing Economies: From Theory to Empirics*, M. Boldrin, B.-L. Chen and P. Wang (eds.), pp. 1–18.

Chen, B.-L. (2006). Public capital, endogenous growth and endogenous fluctuations. *J. Macroecon.*, **38**: 768–774.

Chen, B.-L. and Chou, L.-C. (in Chinese). (1993). Theoretical and empirical analysis of the differences in growth rates among Taiwan's counties. *Proceedings of the Chinese Economic Association Annual Conference*, pp. 143–165.

Enders, W. (2004). *Applied Econometric Time Series*, John Wiley & Sons, New York.

Engelbrecht, H. (2003). Human capital and economic growth: cross-section evidence for OECD countries. *Econ. Rec.*, **79**: 40–51.

Etsuro, S. (2001). Public capital and economic growth: A convergence approach. *J. Econ. Growth*, **6**: 205–227.

Grossman, G. and Helpman, E. (1991). *Innovation and Growth in the Global Economy*, MIT Press, Cambridge.

Gwartney, J. D., Holcombe, R. G. and Lawson, R. A. (2006). Institutions and the impact of investment on growth. *Int. Rev. Soc. Sci.*, **59**: 255–273.

Hsieh, L.-C. (2003). *A Re-Examination of the Effects of Human Capital on Taiwan's Economic Growth*, M.A. thesis, Tamkang University, Taiwan.

Huang, N. E., Shen, Z., Long, S. R., Wu, M. C., Shih, E. H., Zheng, Q., Tung C. C. and Liu, H. H. (1998). The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. *Proc. Royal Soc. Lond. A*, **454**: 903–95.

Huang, N. E., Wu, M. L., Qu, W., Long, S. R. and Shen, S. S. P. (2003). Applications of Hilbert-Huang transform to non-stationary financial time series analysis. *Appl. Stoch. Models Bus. Ind.*, **19**: 245–268.

Jones, C. I. (1995). R&D-based models of economic growth. *J. Political Econ.*, **103**: 759–784.

Jones, C. I. (1999). Growth with or without scale effect? *American Economic Review, Papers and Proceedings*. 139–144.

Jones, C. I. (2002). Source of US economic growth in a world of idears. *American Economic Review*, **92**: 220–239.

Johansen, S. (1988). Statistical analysis of cointegration vectors. *J. Econ Dyn. Control*, **12**: 231–254.

Johansen, S. (1995). Time series tests of endogenous growth models. *J. Quart. J. Econ.*, **110**: 495–525.

Johansen, S. (1999). Growth: with or without scale effects? *Am. Econ. Rev. Paper Proc.*, 139–144.

Lucas, R. E. (1998). On the mechanics of economic development. *J. Monetary Econ.*, **22**: 3–42.

Mauro, P. (1995). Corruption and growth. *Quart. J. Econ.*, **110**: 681–712.

Mauro, P. (1996). The effects of corruption on growth, investment, and government expenditure. in *IMF Working Paper* 96/98.

Romer, P. M. (1986). Increasing returns and long-run growth. *J. Political Econ.*, **94**: 1002–1037.

Sedgley, N. H. (2006). A time series test of innovation-driven endogenous growth. *Econ. Inquiry*, **44**: 318–32.

Tallman, E. W. and Wang, P. (1994). Human capital and endogenous growth: evidence from Taiwan. *J. Monetary Econ.* **34**: 101–124.

Yoo, S.-H. (2006). The causal relationship between electricity consumption and economic growth in the ASEAN countries. *Energy Policy*, **34**: 3573–3582.