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Convergence and Catching Up in ASEAN: A Comparative Analysis

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Abstract

The increasing diversity of average growth rates and income levels across countries has generated a large literature on testing the income convergence hypothesis. Most countries in South-East Asia, particularly the five founding ASEAN member countries (ASEAN-5), have experienced substantial economic growth, with the pace of growth having varied substantially across countries. Recent empirical studies have found evidence of several convergence clubs, in which per capita incomes have converged for selected groupings of countries and regions. This paper applies different time series tests of convergence to determine if there is a convergence club for ASEAN-5, as well as ASEAN-5 and the USA. The catching up hypothesis states that the lagging country, with low initial income and productivity levels, will tend to grow more rapidly by copying the technology of the leader country, without having to bear the associated costs of research and development. Given the important effects of technological change on growth, this paper also examines whether ASEAN-5 is catching up technologically to the USA.

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1. INTRODUCTION

The rapid rise in the economies of the East Asian and South-East Asian regions has occurred in the last three decades. As reported by the World Bank (1993), the twenty-three economies of East Asia grew at a faster average rate than all other regions in the world over the 1965-90 period. The high-performing Asian economies (HPAE) such as Japan, the Four Asian Tigers (Hong Kong, South Korea, Singapore, and Taiwan), and the three South-East Asian newly industrialising economies (Indonesia, Malaysia, and Thailand), have grown at a rate more than twice as fast as the rest of East Asia since 1960. It has been suggested that the stages of economic development in these eight HPAE followed a flying geese pattern (Kwan, 1994), which started with the miraculous growth of the Japanese economy, followed by Hong Kong, South Korea and Taiwan, and more recently by several countries from South-East Asia. Consequently, the fast-growing East Asian economies should be an ideal group of countries for which to test the convergence and catching up hypotheses. There have been several studies (for example, Young, 1992, 1995; Easterly, 1995; Fukuda and Toya, 1995) which have examined the economic growth of the Four Asian Tigers. As there has been little research regarding the countries in the South-East Asian region, this paper focuses on the five founding member countries of the Association of South-East Asian Nations (ASEAN).

ASEAN was established in 1967 with five member countries, namely Indonesia, Malaysia, the Philippines, Thailand and Singapore (hereafter referred to as ASEAN-5). The city-state Singapore was the first ASEAN-5 country to achieve the newly industrialised countries (NIC) status, while the other four member countries (hereafter referred to as ASEAN-4) are still trailing economically. An interesting question is whether Indonesia, Malaysia and Thailand (hereafter referred to as ASEAN-3), will become NIC in the manner of the Four Asian Tigers. With the empirical evidence indicating the existence of different convergence clubs and regional convergence for different nations, will there be a convergence club in the South-East Asian region?

Since the mid-1980s, ASEAN–4 has followed the path of its North-East Asian counterparts, embarking on the export-led, foreign investment-driven growth strategies. From 1986 to 1996, ASEAN-3's real gross domestic product (GDP) per capita grew at an average annual rate of 5.5–7.5 percent, but it was only 1.2 percent for the Philippines. Foreign trade encourages diffusion of new products and new technologies, while international investment brings technology and organisational improvements (see Maddison, 1995). Will ASEAN-5 be able to catch up to their technological leader, the USA, if they are able to sustain current growth rates? Will the Philippines fall behind the rest of ASEAN-5 if the growth rate remains low?

This paper examines the questions raised above using different tests of convergence and catching up, and will focus on the growth performance of the ASEAN-5 economies. As the cross section tests for the convergence and catching up hypotheses for five countries are unlikely to be robust due to the extremely small degrees of freedom, it is more appropriate to perform these tests in a time series framework. The paper is divided into five sections. Section 2 provides selected indicators for ASEAN-5 in 1996, and examines the cross section growth patterns of the ASEAN-5 countries and the USA. Section 3 outlines the time series methods used to test the convergence and catching up hypotheses. Section 4 presents the empirical results and their implications. The conclusions of the study and future research are summarised in Section 5.

2. CROSS SECTION AND TIME SERIES DATA

The formation of ASEAN can be attributed to geographical proximity and regional economic and political co-operation among its member countries. In the past thirty years, the ASEAN-5 countries that differ considerably in size, level of economic development and resource endowment have undergone profound transformations. Each country has experienced substantial industrial diversification and economic growth due to the adoption of export-oriented trade policies, the rapid flow of foreign direct investment, and sound macroeconomic policies. Selected indicators for the ASEAN-5 countries in 1996 are shown in Table 1. Among the ASEAN-5 countries, Singapore is the smallest in terms of area and population, but has the highest GDP per capita, with no foreign debt, whereas Indonesia is the largest, but also has the lowest GDP per capita and the highest external debt. The sources of rapid and sustained growth, and the shared characteristics among the ASEAN-5 countries over the past three decades, were higher levels of foreign direct investment, physical and human capital accumulation, and export growth, as well as macroeconomic stability (see Lim, 1999).

TABLE 1
Selected ASEAN-5 Indicators in 1996

Indicators	Singapore	Malaysia	Thailand	Indonesia	Philippines
Area ('000 sq. km)*	0.65	329.76	514.00	1,919.32	300.00
Population (millions)	3.04	20.57	60.00	197.05	71.90
Population Growth (%)	1.93	2.33	1.01	1.59	2.32
Real GDP (US$ billion)	66.65	67.78	116.56	105.19	35.85
Real GDP Per Capita (US$)	21,896.6	3,295.8	1,942.5	533.8	498.6
Real GDP Growth (%)	6.94	8.02	6.41	7.58	5.69
Exports (US$ billion)	124.79	78.15	55.79	49.73	20.33
Imports (US$ billion)	131.08	76.08	73.29	42.93	34.66
External Debt (US$ billion)	nil	39.78	90.82	129.03	41.21
Inflation – CPI (%)	1.38	3.49	5.81	7.97	8.41
Average Exchange Rate	1.41004	2.51594	25.3426	2342.30	26.2161

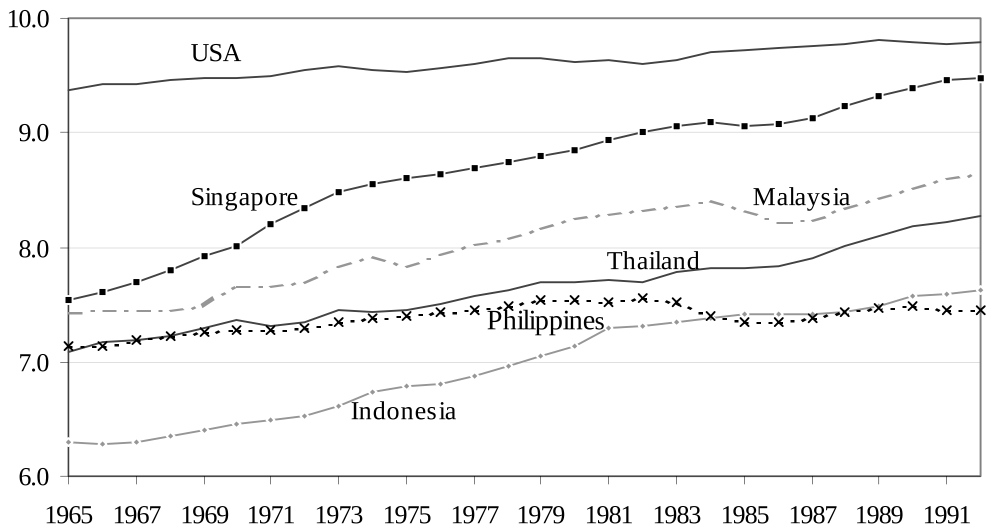
Sources: World Bank World Tables (EconData, 1998).
ASEAN (1999).

The data for the ASEAN-5 countries are extracted from the World Bank World Tables (EconData, 1998), the Penn World Table (PWT) 5.6 of Summers and Heston (1994)[1], and various statistical reports of respective local government agencies. Testing for convergence and catching up among the ASEAN-5 economies in a time series framework requires the comparative income data for these countries over extended periods. Comparative time series data for ASEAN-5 are only available from the PWT 5.6, which are limited to the post-war period from 1960 to 1992. As Singapore separated from Malaysia and became independent in 1965, any comparative study of ASEAN-5 must focus on the period since 1965.

1 The PWT 5.6 is a revised and updated version of PWT (Mark 5) prepared by Summers and Heston (1991), and has been distributed to the users since 1994 by the National Bureau of Economic Research, Cambridge, Massachusetts.

Using the data from PWT 5.6, Figure 1 plots the logarithms of real GDP per capita adjusted for changes in the terms of trade[2] (LGDP) for the ASEAN-5 countries and their technology leader, the USA, over the period 1965-92. It is evident from Figure 1 that the LGDP series for all ASEAN-5 countries, except the Philippines, are trending upwards. Singapore is the only ASEAN-5 country which has taken the lead to close the income gap with the USA. As for ASEAN-3, their individual levels of LGDP are almost parallel to that of the USA, but the gaps between ASEAN-3 and the USA appear to have narrowed slightly over the period. Intuitively, the initial level of income and its subsequent growth rate are important in determining the speed of catching up for ASEAN-3.

FIGURE 1
Logarithms of Real GDP Per Capita, 1965-92



Source: PWT 5.6.

For a better understanding of cross-country income convergence, it is useful to examine the cross-country growth patterns of the five ASEAN countries and the USA. Figure 2 shows a scatter plot of the average growth rate of real GDP per capita from 1965 to 1992[3] versus the logarithm of real GDP per capita in 1965. It is evident that all ASEAN-5 countries (excluding

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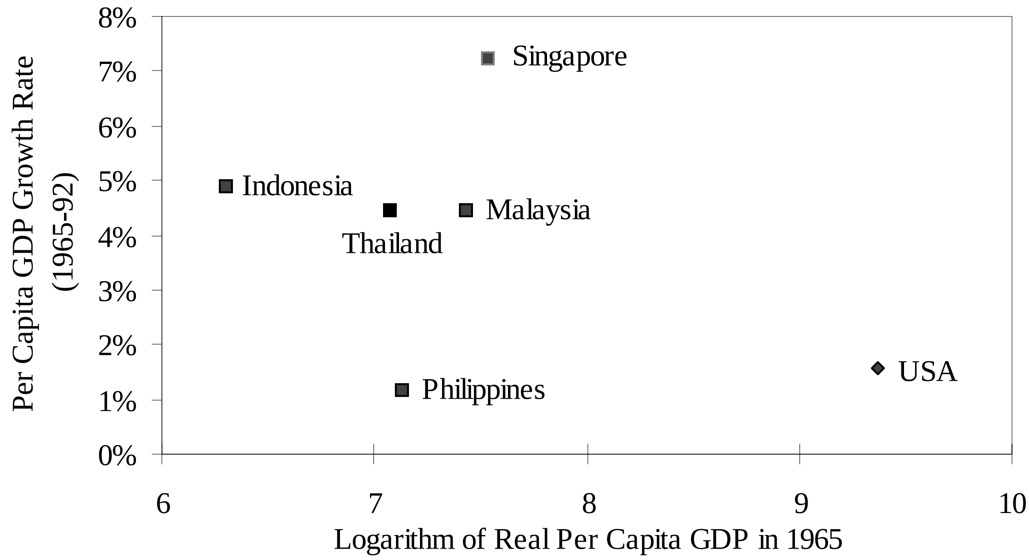
[2] As all the ASEAN-5 countries are trade dependent, it would be more appropriate to use real GDP per capita in constant dollars adjusted for the gains or losses in the terms of trade (1985 international prices for domestic absorption and current prices for exports and imports) as a measure of real income.

[3] The average growth rate of real GDP per capita in 1965-92 is computed by taking the log-difference of real GDP per capita in 1965 and 1992, and divided by the number of years (which is 27).

the Philippines) had higher per capita GDP growth and lower initial GDP levels, as compared with the USA. The higher GDP growth and initial GDP levels for Singapore, as compared with the ASEAN-4 countries, could have contributed to their success in attaining their NIC status.

FIGURE 2
Per Capita Growth Rate (1965-92) Versus Initial Per Capita GDP (1965)



Source: PWT 5.6.

Numerous studies have examined the convergence hypothesis over an extended period. There are at least three different types of convergence tests in the growth literature. The most common test of convergence is to regress the average growth rate on the initial level of real per capita output (with coefficient β) using cross section data (see Barro, 1991). A negative estimate of β is said to indicate “absolute β convergence” across countries. If other characteristics of economies such as the investment ratio, educational attainment and other policy variables are included in the growth regression, a negative estimate of β is said to indicate “conditional β convergence”. A second measure of convergence is to determine if the dispersion of real per capita income is falling over time, namely “σ convergence” (see Barro and Sala-i-Martin, 1992). In a time series framework, a third definition of convergence is to determine whether there exists a common deterministic and/or stochastic trend for different countries (see Bernard and Durlauf, 1995). In this case, convergence for a group of countries means each country has an identical long-run trend.

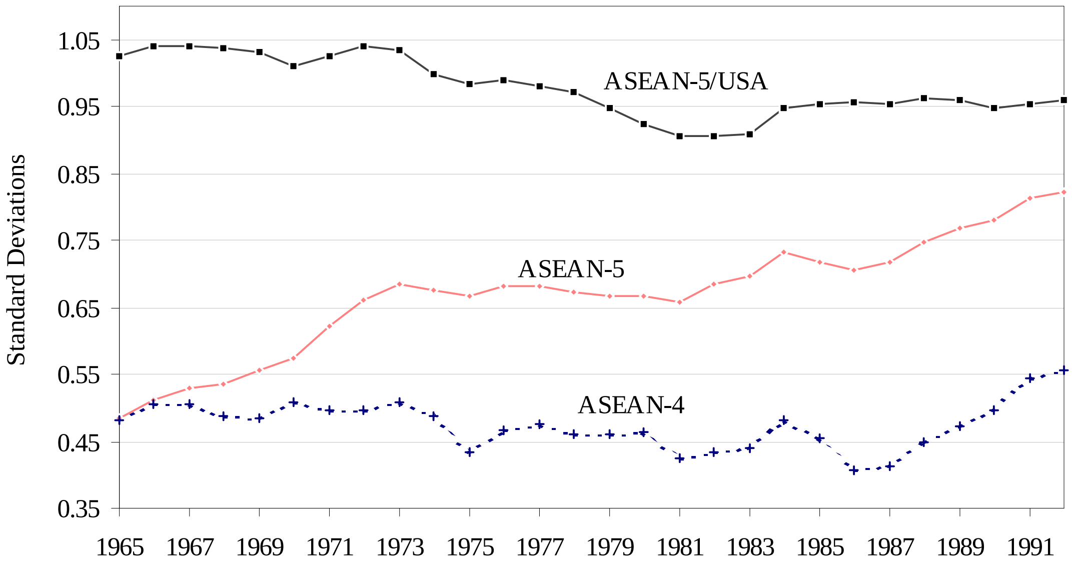
There are too few observations for serious empirical cross-section tests of β convergence for ASEAN-5, or ASEAN-5 and the USA (hereafter ASEAN-5/USA). Estimation of the β coefficient for ASEAN-5 and ASEAN-5/USA yield insignificant negative estimates at conventional levels. Inclusion of additional variables such as secondary school enrolment and the savings rate would lead to insufficient degrees of freedom, and hence is not considered.

As β convergence is a necessary but not sufficient condition for income dispersion to be reduced over time, testing for σ convergence provides a more accurate indication of income convergence across economies. In this study, the cross-country standard deviations of (the logarithms of) real GDP per capita for ASEAN-5/USA, ASEAN-5 and ASEAN-4 are computed for the 1965-92 period (see Figure 3). The results indicate the dispersion of per capita GDP for ASEAN-5 increased from a low of 0.48 in 1965 to 0.69 in 1973, remained steady around that level until 1983, and rose again to 0.82 in 1992. As Singapore has outperformed the other ASEAN-5 countries over the past three decades, it is not surprising to observe that the extent of income dispersion is reduced significantly when Singapore is excluded from the group. In fact, the income dispersion among ASEAN-4 fell gradually from 0.48 in 1965 to a low of 0.41 in 1986, before rising steadily to 0.56 in 1992. The increased income deviations for ASEAN-4 from the mid-1980s can be attributed to the outward orientation policies adopted by the ASEAN-3 countries, which has led to their rapid economic growth over the last ten years.

In the case of ASEAN-5/USA, the cross-country standard deviations fell gradually from 1.04 to 0.91 over the 1965-83 period, and remained steady at around 0.96 after 1983. The overall pattern seems to indicate a slight reduction in σ over time. Given the limitations of cross-country regressions (see for example, Bernard and Durlauf, 1996; de la Fuente, 1997; Lee et al., 1997: Lichtenberg, 1994; Quah, 1993, 1996), and the small sample size used, further research is required to determine whether the cross section growth patterns for ASEAN-5 are supported in a time series framework.

Apart from the studies of income convergence, the effects of technological catching up for ASEAN-5 are also examined. Foreign direct investment is widely acknowledged as a means of transferring foreign technology and knowledge to the host country. The ASEAN region has been a major recipient of international direct investment flows, particularly from the mid-1980s to the 1990s. This has helped to accelerate the region's economic growth, as the catching up hypothesis postulates that less advanced countries are able to increase their productivity by replacing their existing older capital stock with more modern equipment.

FIGURE 3
Standard Deviations of the Logarithm of Real GDP Per Capita, 1965-92

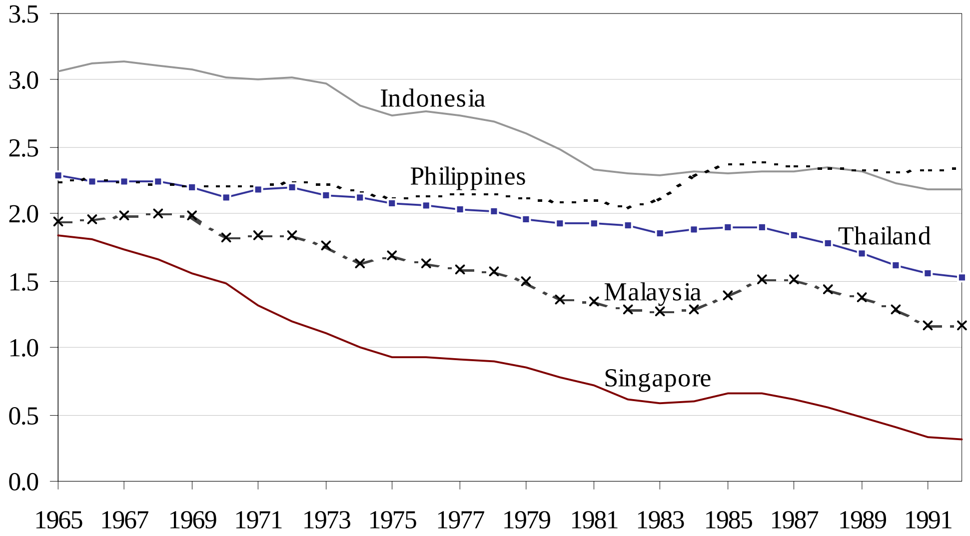


Source: These figures are computed using data from PWT 5.6.

The distance from the leader country in terms of per capita income or productivity is commonly used as a measure of catching up effects. Figure 4 depicts the log-differences of real GDP per capita between the technology leading country, the USA, and each of the ASEAN-5 countries from 1965 to 1992. It is evident from Figure 4 that the technological gaps between the USA and the five ASEAN countries have generally declined over time, except for the Philippines. The log per capita output difference between the USA and the Philippines fell from 2.24 in 1965 to a low of 2.05 in 1982, before increasing to 2.35 in 1992.

The catching up hypothesis suggests that the backward country, with low initial income and productivity, will tend to grow more rapidly by copying the technology from the leader country. An ability of the lagging country to absorb the more advanced technologies is dependent on its social capability, which involves various aspects of the country's development process. Technological catching up is often associated with innovative activities such as R&D and patenting. On the other hand, capital investment is necessary to import the more advanced technology that is embodied in the new equipment. Besides innovation and investment, the level of education also plays a crucial role in determining the technical competence of the labour force.

FIGURE 4
Logarithmic Differences in Real Per Capita GDP Between the USA and Five ASEAN Countries, 1965-92



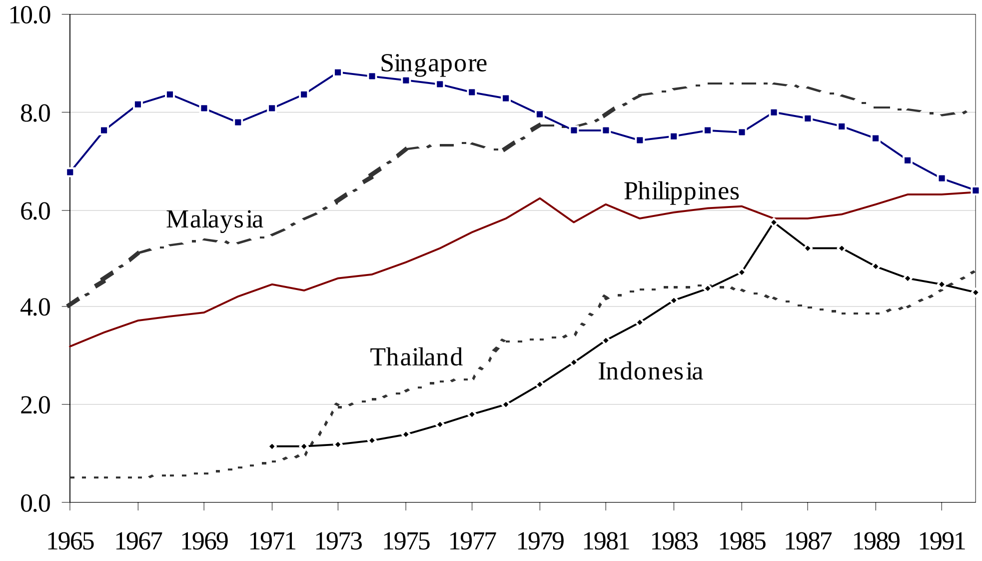
Source: PWT 5.6.

Figure 5 shows the percentage of total population enrolled in secondary education for five ASEAN countries.[4] On average, the secondary school enrolment ratios in ASEAN-5 are rising, except for Singapore. This result is rather surprising, especially as Singapore is well known to have the highest educated labour force among the ASEAN-5 countries. One possible explanation is that the data for secondary school enrolments do not include students enrolled in private schools because a complete time series is not available. In addition, there has been a substantial shift in enrolments of GCE O-level students from the traditional pre-university centres to the Institutes of Technical Education and Polytechnics, which are not included in the data. Koo (1998) found the demographic transition in each country might have a greater influence on the increase in secondary school enrolments. The author stressed that the greater supply of human resources does not necessarily imply an improved economic performance

4 Generally, the secondary school enrolment ratio is found to have a more dominant effect on a country's economic growth as compared with the primary school enrolment ratio.

unless it is linked to efficient resource use. For example, an early focus on technical and/or vocational education in Singapore has overcome a shortage in technical labour requirements.

FIGURE 5
Secondary School Enrolment Ratio for ASEAN-5, 1965-92



Sources: Statistical Yearbooks and Education Statistics from five ASEAN countries (various years).

Besides the education variable, other catching up studies have also used patents data as an indicator of innovation. For developing countries, such as those in ASEAN-5, patents data are generally not available. Alternative measures of innovation in ASEAN-5 would be the growth rates of domestic investment or government expenditure on education.

3. METHODOLOGY

This section focuses on the time series tests of the convergence and catching up hypotheses for two groups of countries discussed above, namely ASEAN-5 and ASEAN-4, over the 1965-92 period. For the convergence tests, this section applies a simple statistical test for the output trends, unit root tests (namely, the DF and ADF tests) and cointegration analysis (the Johansen test), and the Kalman filter method and cluster algorithm to the output series. In the case of catching up, the unit root tests on the output differences between two countries, and the

Verspagen (1991) model that incorporates catching up and falling behind, will be used. These time series methods are discussed briefly below.

3.1 Convergence Test

In a time series framework, a simple statistical test for converging or diverging trends of an output series, as proposed by Verspagen (1994, p. 156), is written as follows:

$$W_{it} = \ln y_{it} - \ln y_t^*, \tag{1}$$

where y_{it} is real GDP per capita for country i at time t and y_t^* is average real GDP per capita for s countries in the sample, (i.e. $y_t^* = \left(\sum_{i=1}^{s} y_{it}\right)/s$). It is assumed that for each time period, W changes according to the following process:

$$W_{it+1} = \Psi W_{it}. \tag{2}$$

If $\Psi > 1$, per capita income in country i diverges from the sample group; if $\Psi < 1$, convergence of income takes place.

Under the assumption of diminishing marginal returns, the empirical implication of the β convergence hypothesis is that countries with low initial per capita output are growing faster than those with high initial per capita output. In a time series context, this can be interpreted to mean that differences in per capita incomes among a cross section of economies will be transitory. Hence, a stochastic definition of income convergence requires per capita income disparities across countries to follow a stationary process. This study applies unit root-based tests to examine the time series properties of output differences for ASEAN-5 countries. Following Oxley and Greasley (1995), the Dickey-Fuller-type test based on the output difference between two countries, p and q, is given below:

$$y_{p,t} - y_{q,t} = \mu + \alpha t + \beta(y_{p,t-1} - y_{q,t-1}) + \sum_{j=1}^{n} \delta_j \Delta(y_{p,t-j} - y_{q,t-j}) + \varepsilon_t, \tag{3}$$

where $y_{i,t}$ is the logarithm of per capita GDP for country i (= p, q) at time t.

In a time series framework, a distinction is made between long-run convergence and convergence as catching up. The statistical tests are interpreted as follows:

1. If $y_{p,t} - y_{q,t}$ contains a unit root (i.e. $\beta = 1$), per capita GDP for countries p and q diverge over time.
2. If $y_{p,t} - y_{q,t}$ is stationary (i.e. no stochastic trend, or $\beta < 1$):
   i) $\alpha = 0$ (i.e. the absence of a deterministic trend) indicates long-run convergence between countries p and q; and
   ii) $\alpha \neq 0$ indicates catching up (or a narrowing of output differences) between countries p and q.

Clearly, the statistical tests of catching up and convergence are related as both require $y_p - y_q$ to be stationary, with the difference lying in the deterministic trend term.

Bernard and Durlauf (1995) have proposed a more stringent time series test for convergence and common trends. The notion of convergence in multivariate output is defined such that the long-term forecasts of output for all countries, $i = 1,\ldots\ldots,n$, are equal at a fixed time t (see Bernard and Durlauf, 1995, p. 99):

$$\lim_{k\to\infty} E(y_{1,t+k} - y_{i,t+k} \,|\, I_t) = 0, \qquad \forall\, i > 1, \tag{4}$$

where $y_{i,t+k}$ is the logarithm of real per capita output for country i at time t+k, and I_t is all the information available at time t.

Applying the concepts of unit roots and cointegration, their convergence test determines whether $y_{1,t+k} - y_{i,t+k}$ in equation (4) is a zero mean stationary process in a cointegration framework. Convergence in output for two countries, p and q, implies their output must be cointegrated, with cointegrating vector [1, -1]. This definition of convergence in output also implies that countries p and q must have a common time trend if their output series are trend stationary.

Countries that do not converge in output may still experience the same permanent shocks, but will differ in their long run magnitude across countries. Thus, Bernard and Durlauf (1995) proposed the tests for common trends which allows permanent shocks to have different long-run weights. For multivariate output, countries $j = 1, 2, \ldots\ldots, n$ are defined to contain a single common trend if the long-term forecasts of output are proportional at a fixed time t (see Bernard and Durlauf, 1995, pp. 99-100):

$$\lim_{k \to \infty} E(y_{1,t+k} - \alpha'_j y_{j,t+k} \mid I_t) = 0, \qquad \forall\, j > 1, \tag{5}$$

where α'_j is the vector of long-run weights for countries $j = 2, 3, \ldots\ldots, n$. In the case of two countries, p and q, they are said to have a common trend if their output series are cointegrated with vector [1, -α].

It is important to note that the concept of cointegration is used for the study of non-stationary time series, particularly a non-stationary vector autoregressive (VAR) process integrated of order one (i.e. an I(1) series). Hence, testing for convergence and common trends in a cointegration framework requires the individual output series to be integrated of order one. The following augmented Dickey-Fuller (ADF) test will be used to determine the order of integration for real GDP per capita of the ASEAN-5 countries:

$$\Delta y_{i,t} = a_0 + a_1 t + \beta y_{i,t-1} + \sum\nolimits_{j=1}^{p} \delta_j \Delta y_{i,t-j} + \varepsilon_{i,t}\,, \tag{6}$$

where $y_{i,t}$ is the logarithm of per capita output for country i, $\Delta y_{i,t}$ approximates the growth rate, t is the deterministic trend, p is the order of the autoregressive process, and $\Delta y_{i,t-j}$ is included to accommodate serial correlation in the errors.

To estimate the rank of the cointegrating matrix in a multivariate framework, the output vector process is written in the following VAR representation (see Johansen, 1991):

$$\Delta Y_t = \Gamma(L)\Delta Y_t + \Pi Y_{t-k} + \mu + \varepsilon_t\,, \tag{7}$$

where Y_t is a vector of the logarithms of real GDP per capita for the ASEAN-5 countries, Π represents the long-run relationships of the cointegrating vectors, $\Gamma(L)$ (a polynomial of order

k - 1) captures the short-run dynamics of the system, and ε_t are the independent Gaussian errors with zero mean and covariance matrix Ω.

The reduced rank (0 < rank(Π) = r < n) of the long run impact matrix is formulated as follows:

$$\Pi = \alpha\beta', \tag{8}$$

where β is the matrix of cointegrating vectors and α is the matrix of adjustment coefficients. The maximum likelihood (ML) estimators of α and β can be obtained by solving the following equation (see Johansen, 1991, pp.1553-1555):

$$\left|\lambda S_{kk} - S_{k0} S_{00}^{-1} S_{0k}\right| = 0, \tag{9}$$

where $S_{ij} = M_{ij} - M_{i1} M_{11}^{-1} M_{1j}$ denotes the residual sums of squares matrices and M_{ij} the product moment matrices (i, j = 0, k). Using the estimated eigenvalues, $\hat{\lambda}_1 > \hat{\lambda}_2 \cdots\cdots > \hat{\lambda}_k > 0$, and estimated eigenvectors, $\hat{V} = (\hat{v}_1, \hat{v}_2, \ldots\ldots, \hat{v}_k)$, normalised by $\hat{V}' S_{kk} \hat{V} = I$, yields

$$\hat{\beta} = (\hat{v}_1, \hat{v}_2, \ldots\ldots, \hat{v}_k), \tag{10}$$

$$\hat{\alpha} = S_{0k}\hat{\beta}. \tag{11}$$

Two likelihood ratio (LR) test statistics are used to test the reduced rank Π for cointegration, namely the trace and maximal eigenvalue statistics of the stochastic matrix Π. The trace statistic for testing $H_0(r)$ against H_1(unrestricted) is given by

$$J_{trace} = -T \sum_{i=r+1}^{n} \ln(1-\hat{\lambda}), \tag{12}$$

and the maximal eigenvalue statistic for testing $H_0(r)$ against $H_1(r+1)$ is given by

$$J_{\max} = -T \ln(1-\hat{\lambda}). \tag{13}$$

Applying the Johansen ML estimation method, convergence in multivariate output, as defined in equation (4), would require $r = n - 1$ (or four) cointegrating vectors for five ASEAN countries of the form [1, -1] (i.e. one common long-run trend for the individual output series in Y_t). The Johansen procedure also permits hypothesis testing of the cointegrating relations and their adjustment coefficients, using the LR test with a chi-squared distribution. This method is necessary to determine if the r cointegrating vectors are of the form [1, -1], which requires a unit restriction imposed on all the coefficients of the r cointegrating vectors.

Another time series approach to test the convergence hypothesis is the Kalman filter method, as proposed by St. Aubyn (1999), which is more powerful than the DF-type test when there is a structural break in the convergence process. Output per capita for a pair of countries, y_p and y_q, is said to converge if their difference $y_{p,t} - y_{q,t}$ converges in probability to a random variable as t tends to infinity. The Kalman filter tests are derived from the following state space model (St. Aubyn, 1999, p. 29):

$$y_{p,t} - y_{q,t} = \gamma_t + \varepsilon_t, \qquad \varepsilon_t \sim N(0, \sigma^2), \tag{14}$$

$$\gamma_t = \gamma_{t-1} + \mu_t, \qquad \mu_t \sim N(0, \Omega_t), \tag{15}$$

$$\Omega_t = \phi^2 \Omega_{t-1}, \tag{16}$$

$$\Omega_0 = \Psi^2. \tag{17}$$

Equation (14) is known as the measurement equation and (15) as the state equation. It is assumed that the variance of μ given by Ω_t in (16) is potentially time varying, but this variance will tend to zero in the long run if $|\phi| < 1$, which implies that the two output series are converging and their difference becomes an I(0) variable. The likelihood function can be constructed using the Kalman filter algorithm and the test for convergence is H_0: $\phi = 1$ against H_a: $\phi < 1$, based on the following test statistic:

$$T(\phi_{ML}) = \frac{\phi_{ML} - 1}{\sqrt{(h^{-1})_{22}}}, \tag{18}$$

where ϕ_{ML} is the ML estimator and $(h^{-1})_{22}$ is the corresponding element of the inverse of the information matrix. It is important to note that the critical values for the test statistic do not follow a standard *t*-distribution, and St. Aubyn (1999) provides a simulated distribution for testing the null hypothesis of no convergence.

The cluster algorithm proposed by Hobijn and Franses (2000) is also applied in this paper, as it provides inferences about convergence clubs for a small group of countries such as ASEAN-5. This procedure is based on the asymptotic properties of the log per capita income (y_t) disparities between *n* countries for *T* years, and the multivariate process is given by (see Hobijn and Franses, 2000, p. 61):

$$y_t = a + bt + D^* \sum_{s=0}^{t-1} v_s^* + u_t^* , \qquad (19)$$

where $y_t = [y_{1t,} \ldots, y_{nt}]' \in \Re^n$, t is a deterministic trend, v_t^* is the first difference of the $m^* \in \{0, \ldots, n\}$ common trends in y_t, and u_t^* is a zero mean vector stationary process.

This paper focuses on testing two types of convergence, namely asymptotically perfect and asymptotically relative convergence, which are defined by Hobijn and Franses (2000, pp. 64-66) as follows:

i) n^* countries are converging *asymptotically perfectly* if x_t is *zero mean stationary*;
ii) n^* countries are converging *asymptotically relatively* if x_t is *level stationary*.

The authors defined n^* as a sub-sample of *n* countries, and $x_t \equiv M_{n^*} y_t^* \in \Re^{n^*-1}$, which is assumed to have the same representation as y_t in (19), with stationary covariance, $\eta_t = [u_t' \, v_t']'$, having the following moving average (∞) representation:

$$\eta_t = \sum_{s=0}^{\infty} \Psi_s \, \varepsilon_{t-s} = \Psi(L)\varepsilon_s , \qquad (20)$$

where ε_t is an independently and identically distributed (iid) zero mean process, $E[\varepsilon_t \varepsilon_t'] = \Omega = PP'$ (using the Choleski factorisation), $\Lambda = \Psi(1)P$ and $G = \Lambda \Lambda'$.

Based on a multivariate generalisation of the stationarity test proposed by Kwiatkowski et al. (1992), Hobjin and Franses provide the following two statistics for testing whether x_t is zero mean stationary (for asymptotically perfect convergence) or level stationary (for asymptotically relative convergence):

Zero mean stationarity: $$\varpi_0 = T^{-2}\sum_{t=1}^{T} S_t' \left[\hat{G}_l\right]^{-1} S_t \,, \qquad (21)$$

Level stationarity: $$\varpi_\mu = T^{-2}\sum_{t=1}^{T} \tilde{S}_t' \left[\hat{G}_l\right]^{-1} \tilde{S}_t \,, \qquad (22)$$

where $S_t \equiv \sum_{s=1}^{t} x_s$, $\tilde{S}_t \equiv \sum_{s=1}^{t}\left(x_t - \frac{1}{T}\sum_{s=1}^{T} x_s\right)$, and $\hat{G}_l$ is a Newey-West (1987) estimator of the first k (= n^*-1) rows and columns of G. Tests for asymptotically perfect and asymptotically relative convergence of clusters i and j are applied to $x_t^{(i,j)} \equiv M_{k_i+k_j}\left[y_t^{(i)\prime}\; y_t^{(j)\prime}\right]' \in \Re^{k_i+k_j-1}$, where $y_t^{(i)}$ and $y_t^{(j)}$ are vectors of (log) real GDP per capita for countries in clusters i and j, respectively, and k_i and k_j are the numbers of countries in clusters i and j, respectively. The p-values or excess probabilities of $\varpi_0^{(i,j)}$ and $\varpi_\mu^{(i,j)}$ are denoted by $p_0^{(i,j)}$ and $p_\mu^{(i,j)}$, respectively, and the critical p-value or significance level is denoted by $p_{\min} \in (0,1)$. According to Hobijn and Franses (2000, p. 68), asymptotically perfect convergence is rejected for all pairs of clusters if no combination of i and j has $p_0^{(i,j)} > p_{\min}$. Clusters of countries that converge asymptotically perfectly will then be tested for level stationarity using the $p_\mu^{(i,j)}$ value.

3.2 Catching Up Tests

The theory of catching up effects is important in explaining the role of technological catching up in influencing modern economic growth. Given the important effects of technological change on growth, testing for technological catching up between the USA and each country of ASEAN-5 is conducted. A number of tests of the catching up hypothesis use cross section samples, such as the following dynamic model proposed by Verspagen (1991, p. 363), which incorporates both catching up and falling behind:

$$G = \ln \frac{K_{us}}{K_i}, \tag{23}$$

$$\dot{G} = a_1 + b_1 G_0 + \varepsilon_1, \tag{24}$$

$$\dot{G} = a_2 + b_2 G_0 + c_2 P + d_2 E + \varepsilon_2, \tag{25}$$

$$\dot{G} = a_3 + b_3 G_0 e^{\delta(G_0/E)} + c_3 P + \varepsilon_3, \tag{26}$$

where G is the technological gap, K_{US} and K_i are the knowledge stock of the technology leader, the USA, and lagging country i, respectively, P is the exogenous rate of knowledge growth in the lagging country, E is the variable that influences the intrinsic learning capability, the dot above the variable denotes its growth rate (or time derivative), the subscript 0 denotes initial values, and ε_i is a random disturbance with zero mean and finite variance σ_i^2. It is expected that the three variables, G_0, P and E, are inversely related to the growth rates of the technological gap ($\dot{G}$). Thus, the expected signs of the parameters are b_1, b_2, c_2, d_2, b_3, c_3, $\delta < 0$ and $a_3 > 0$ (which represents the initial value of the technology gap), while the constants a_1 and a_2 can be of either sign. A negative b_1 parameter in the simplest catching up regression (24) supports the catching up hypothesis that lagging countries have higher rates of productivity growth, thereby narrowing the technological gap.

Equation (25) is an augmentation of the simplest catching up hypothesis (24), with two additional variables, P and E. Equation (26) is based on the specification of a threshold for the initial value of the technology gap, whereby no catching up is possible if the intrinsic learning capacity is too weak or falls below some critical level. The social capability of a country to catch up is captured by the exponential term, where δ represents the intrinsic capability to assimilate knowledge spillovers. Thus, a larger δ implies a smaller technological distance effect.

Instead of using only the first and last values, Verspagen (1991) derived the growth of the technology gap using the following equation for each country over the period 1960-85:

$$G = a + \theta t + \varepsilon, \tag{27}$$

where a is a constant, t is a time trend and ε is an iid (0, σ^2) error term. The estimated θ is taken as a measure of $\dot{G}$ in equations (24)-(26).

It has been observed in the literature that many catching up studies are essentially the same as the convergence hypothesis. In a time series framework, the basic catching up hypothesis (24) is equivalent to testing for convergence, as described in equation (3) above, without a time trend and lagged dependent variables. Equation (24) is also similar to equation (2), which measures the productivity gap of a lagging country from the leader country rather than from the sample mean of the group.

Despite the small cross section sample, equation (24) is estimated for the nine Asian countries over the period 1965-92, following the method proposed by Verspagen (1991). In a time series framework, equations (24)-(26) are estimated over the same period for the five ASEAN countries, and the USA is treated as the leader country. This means that the dependent variable, $\dot{G}$, in equations (24)-(26) is taken as the first difference of G (i.e. $\dot{G}_t = G_t - G_{t-1}$), while the initial values of the technology gap (G_0) are replaced by the first lagged value of the technology gap (G_{t-1}).

4. EMPIRICAL RESULTS

All estimation and test results are derived using the Microfit 4.0 econometric software program (see Pesaran and Pesaran, 1996), except for the Kalman filter convergence test and the cluster algorithm results, which are obtained using the Gauss 3.2 program. Real GDP per capita for each country has been converted to natural logarithms (namely, LGDP).

4.1 Convergence

Using the simple statistical test of Verspagen (1994) for converging or diverging trends of the LGDP series (see equations (1) and (2)), the estimation results for ASEAN-5 and ASEAN-4 countries are reported in Table 2. Among the ASEAN-5 countries, the Philippines and Singapore are the two diverging countries, whereas ASEAN-3 converges towards the mean LGDP level. When Singapore is excluded, Indonesia becomes the only converging country in

ASEAN-4. These results indicate that the country with the fastest or lowest income growth in a group of countries generally diverges from the mean LGDP level in that group.

TABLE 2
Test Results for Divergence in ASEAN-4 and ASEAN-5

ASEAN-5	ASEAN-4($\hat{\Psi}$) 1966-92	ASEAN-5($\hat{\Psi}$) 1966-92
Indonesia	0.978	0.993
Malaysia	1.011*	0.991
Philippines	1.075*	1.067*
Singapore	–	1.024*
Thailand	1.043*	0.971

Note: * indicates LGDP of the country diverges from the sample group.

Following Oxley and Greasley (1995), the Dickey-Fuller-type test on the output difference between two countries (see equation (3)) is applied to ASEAN-5. As this test distinguishes between long-run convergence and convergence as catching up, the USA is included as a leader country to test for convergence as catching up. For annual data, an initial lag length of two is used for the ADF test. If the estimated t-statistic is insignificant, the lag length is reduced successively until a significant lag length is obtained. Table 3 documents the estimated t-values with and without a linear trend over the period 1968-92. The critical values for the DF and ADF tests with and without a linear trend over the period 1968-92 are –2.985 and –3.6027, respectively.

TABLE 3
Testing for Long-Run Convergence

Country	t-value ($\alpha = 0$) No Trend	*p*	t-value ($\alpha \neq 0$) Trend	*p*

USA				
Indonesia	-1.2143	1	-2.1129	1
Malaysia	-0.9343	0	-1.6175	0
Philippines	-1.7770	1	-2.2587	1
Singapore	-2.0365	1	-2.4651	1
Thailand	-1.1628	0	-0.9469	0
Singapore				
Indonesia	-2.5578	0	-2.1764	0
Malaysia	-2.4846	0	-2.5372	0
Philippines	-1.5882	0	-2.9381	1
Thailand	-3.5620*	0	-1.5074	0
Malaysia				
Indonesia	-1.4938	0	-2.0624	0
Philippines	-0.0879	0	-3.9460*	1
Thailand	-1.5542	0	-1.1571	0
Thailand				
Indonesia	-1.4999	0	-0.2650	0
Philippines	1.8973	0	-0.7621	0
Indonesia				
Philippines	-0.1554	0	-1.8608	0

Notes: *p* is the lag length.
* indicates significance at the 5% level.

The output differences between all pairs of countries are found to be non-stationary or diverging, except for Singapore and Thailand, and Malaysia and Philippines. In the case of Singapore and Thailand, the diagnostic tests indicate the estimates of the variances could be biased due to heteroscedasticity. Using White's heteroscedasticity-adjusted standard errors, the t-value of -2.3609 suggests no convergence in output differences between Singapore and Thailand. As for Malaysia and the Philippines, rejection of the null with $\alpha \neq 0$ implies convergence as catching up between these two countries. However, this result is not conclusive as the ADF test statistic is sensitive to the sample period used. Overall, the results indicate divergence between pairs of ASEAN-5 countries and the USA.

Before testing for convergence based on Bernard and Durlauf (1995), it is essential to determine the order of integration for each of the output series. The ADF tests are used to test for the presence of unit roots in the logarithms of real GDP per capita (LGDP) for ASEAN-5 and the USA. Tests for possible breaks in the output series, as suggested by Perron (1989), are not considered because of the small sample size and the lack of any distinct breaks observed in the per capita GDP level (see Figure 1). For annual data, an initial lag length of two is used for the ADF test. If the estimated t-statistic is insignificant, the lag length is reduced successively until a significant lag length is obtained.

The estimated t-statistics for the ADF tests are presented in Table 4. The critical values for the DF and ADF tests with and without a linear trend over the period 1968-92 are –2.985 and –3.6027, respectively. Since the null hypothesis of a unit root is not rejected for the six LGDP series, they are non-stationary. By taking first differences of the series, the test results from

TABLE 4

ADF Tests for Non-Stationarity in Levels

Variable	Period of Estimation	t-value	*p*
ILGDP	1968-92	-0.7035	0
MLGDP	1968-92	-1.7216	0
PLGDP	1968-92	-2.2673	1
SLGDP	1968-92	-2.5277	1
TLGDP	1968-92	-1.2599	0
ULGDP	1968-92	-2.7611	0

Notes: The first letter of the variable represents the country considered (i.e. I = Indonesia, M = Malaysia, P = the Philippines, S = Singapore, T = Thailand, and U = USA).
A deterministic trend is included in the ADF auxiliary regression.
p is the lag length.

Table 5 indicate that all six LGDP series are integrated of order one, except for Singapore. It is noted that the unit root test results for Singapore were sensitive to the sample period used. In this paper, the order of integration for the LGDP series for Singapore is assumed to be one, as the test statistics for the differenced series for a longer sample period were significant at the 5% level (e.g. t-statistic = -4.2209 for $p = 0$ over the 1964-92 period). Thus, the Johansen method can be used to test for the presence of cointegrating vectors or common trends.

TABLE 5
ADF Tests for Non-Stationarity in First Differences

Variable	Period of Estimation	t-value	*p*
IDLGDP	1968-92	-3.7350*	0
MDLGDP	1968-92	-4.0290*	0
PDLGDP	1968-92	-3.3901*	1
SDLGDP	1968-92	-2.4515	2
TDLGDP	1968-92	-4.4528*	0
UDLGDP	1968-92	-4.2430*	0

Notes: DLGDP denotes the first difference of LGDP.
p is the lag length.
* indicates significance at the 5% level.

The six LGDP series are tested for convergence between each country of ASEAN-5 and the USA, and ASEAN-4 and Singapore, based on the definition in Bernard and Durlauf (1995). Both the Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC) are used to determine the order of the VAR model. Overall, the test statistics and choice criteria indicate a VAR model of order one. If the LGDPs of two countries are cointegrated, the restriction [1, -1] is imposed on the cointegrating vector. Table 6 reports the trace and maximal eigenvalue statistics of the stochastic matrix (with unrestricted intercepts and no trends in the VAR) that determine the number of cointegrating vectors (*r*), and the LR test of restrictions on the cointegrating vector.

TABLE 6
Maximal Eigenvalue, Trace and LR Statistics for VAR(1) model, 1966-92

Country	Maximal Eigenvalue H_0: r = 0, H_a: r = 1	Trace H_0: r = 0, H_a: r ≥ 1	LR Test for [1, -1] vector
<u>USA</u>			
Indonesia	7.6026	8.7530	–
Malaysia	5.6239	6.9563	–
Philippines	8.2443	8.7108	–
Singapore	10.5775	14.0611	–
Thailand	6.7216	6.7245	–

Singapore			
Indonesia	11.8628	20.8608*	2.3181
Malaysia	11.5185	19.0884*	2.5904
Philippines	9.8365	11.1033	–
Thailand	10.5157	10.7544	–

Note: * denotes significance at the 5% level.

Both the trace and maximal eigenvalue statistics reject the existence of a long-run cointegrating relationship between the USA and each of the ASEAN-5 countries. In the case of Singapore and each ASEAN-4 country, the trace statistics indicate a long-run cointegrating relationship exists between Singapore and each of Indonesia and Malaysia. On the other hand, the maximal eigenvalue statistics do not reject the null hypothesis of no cointegrating relationships between Singapore and each ASEAN-4 country. If the trace statistics yield the correct inferences, the LR test of a unit restriction on each cointegrating vector is not rejected, which implies income convergence between Singapore and each of Indonesia and Malaysia. However, Cheung and Lai (1993) stress that the Johansen's LR test tends to underestimate the cointegration space in small samples, which often leads to the rejection of no cointegration under the null. In addition, the significance of the trace statistics for both Indonesia and Malaysia (see Table 6) are not robust to the sample period used. Thus, the cointegration tests are based on the maximal eigenvalue statistics, which reject income convergence between Singapore and each of Indonesia and Malaysia.

For the two groups of countries reported in Table 6, tests for the presence of a common trend are also undertaken. Both the trace and maximal eigenvalue statistics suggest the presence of at least one cointegrating vector, which indicate non-convergence of income for these two groups of countries.

As the time series tests for convergence developed by Bernard and Durlauf (1995) are rather stringent, the Kalman filter approach proposed by St. Aubyn (1999) is also applied to the income data for ASEAN-5 and the USA. Following the specifications of the state space model, equations (14) and (15) are estimated using the Gauss program provided by St. Aubyn. There are 15 pairwise combinations for these six countries, and their estimated test statistics are shown in Table 7. The non-standard critical values for the Kalman filter test, $T(\phi_{ML})$, at the 5% and 1% levels of significance are –2.479 and –3.479, respectively.[5]

In testing convergence between the USA and individual ASEAN-5 countries (the first five pairs of countries shown in Table 7), Singapore is the only country that rejects the null hypothesis of non-convergence at the 5% significance level. This suggests that the per capita incomes of the USA and Singapore have converged over time. As for the ten pairwise ASEAN-5 countries, only Malaysia, Thailand and Indonesia are found to have converged with Singapore, while the null hypothesis of non-convergence is not rejected for the remaining seven pairs of ASEAN-5 countries

The empirical evidence for income convergence between Singapore and the USA lends support to the observed high growth performance of Singapore, which has reduced substantially the income gap with the USA. In relation to the existence of an ASEAN-5 club, the convergence between Singapore and individual ASEAN-3 countries is classified as "limited convergence" (see St. Aubyn, 1999), where only a subset of a country's per capita income converges to that of a leading country, in this case, Singapore.

TABLE 7
Kalman Filter Tests for the USA and ASEAN-5, 1965-92

Country	Convergence Parameter	Test Statistic $T(\phi_{ML})$ $H_0: \phi = 1, H_a: \phi < 1$
<u>USA</u>		
Indonesia	0.9809	-1.116
Malaysia	0.9999	0.010
Philippines	1.0500	1.050
Singapore	0.9654	-2.924*
Thailand	1.0180	1.329

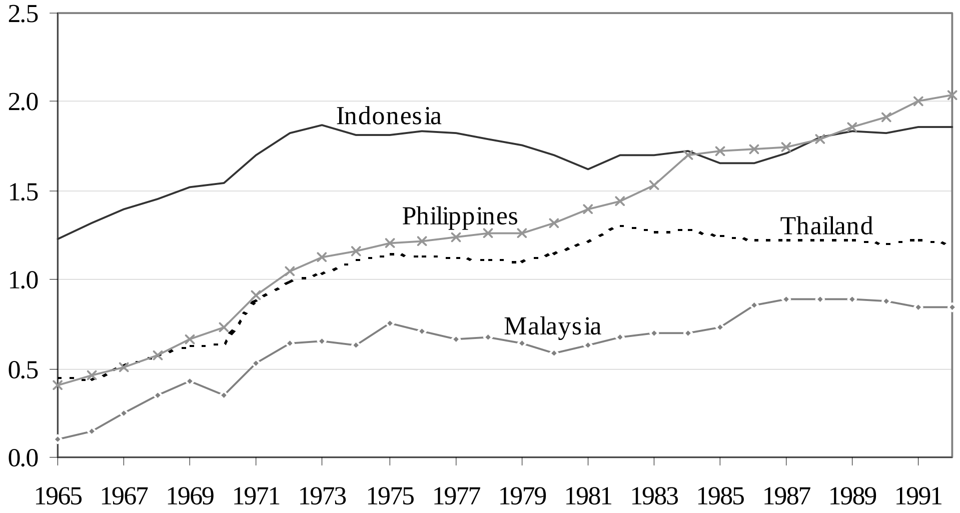
5 The non-standard critical values for the distribution of ϕ_{ML} under the null were tabulated from 1,000 replications (see St. Aubyn, 1999).

Singapore		
Indonesia	0.9607	-2.607*
Malaysia	0.9444	-4.097**
Philippines	0.9801	-1.532
Thailand	0.9175	-5.670**
Malaysia		
Indonesia	1.0050	0.269
Philippines	1.0070	0.479
Thailand	0.9977	-0.140
Thailand		
Indonesia	0.9934	-0.346
Philippines	1.0540	2.225
Indonesia		
Philippines	1.0260	1.360

Notes: * indicates significance at the 5% level.
** indicates significance at the 1% level.

These findings of income convergence between Singapore and ASEAN-3 contradict the results from the time series approach of testing output differences for stationarity using the DF and ADF tests. St. Aubyn (1999) argued that the economic definition of income convergence does not necessarily imply that the output difference between two countries is stationary. It is possible for the per capita incomes of two countries to converge, but their difference might not exhibit stationarity. These contrasting results could be explained by the definition of convergence in St. Aubyn (1999), which only requires the output difference of two countries to converge in probability to a random variable rather than to zero, as proposed by Bernard and Durlauf (1995). Despite the rising trends in income gaps between Singapore and individual ASEAN-3 countries during the early period, the log-differences for these three pairs of countries appear to have remained at a constant level from the mid-1970s onward (see Figure 6).

FIGURE 6
Logarithms of Real Per Capita GDP Differences Between Singapore and Individual ASEAN-4 Countries, 1965-92



Source: PWT 5.6.

For comparison, the cluster algorithm for testing asymptotically perfect and asymptotically relative convergence is also applied to the ASEAN-5 countries, and ASEAN-5/USA. The cluster algorithm is provided by Hobijn and Franses (2000) as a Gauss program. Before applying the cluster procedure, it is necessary to choose the critical p-value (p_{min}) and the bandwidth parameter (l) (see Section 4). According to Hobijn and Franses (2000, p. 69), a smaller p_{min} implies that a rejection of convergence under the null hypothesis is less likely, while the choice of l does not seem to have a significant effect on the number of convergence clubs found.[6] Consequently, p_{min} is set at the 1% significance level and the bandwidth for the Bartlett window (l) is set at 4. The test results are presented in Table 8.

TABLE 8
Results of Cluster Algorithm for ASEAN-5 and ASEAN-5/USA

Asymptotically Perfect Convergence (p_{min} = 0.01, l = 4)	**Asymptotically Relative Convergence** (p_{min} = 0.01, l = 4)
ASEAN-5/USA: *6 clusters*	**ASEAN-5/USA:** *3 clusters*
1. Indonesia	1. Malaysia and Thailand
2. Malaysia	2. Philippines and USA
3. Philippines	3. Singapore and Indonesia

[6] In small samples, based on the Monte Carlo results for the univariate version of the KPSS test, the choice of l is found to have a significant effect on the size of the test (see Hobijn et al., 1998).

4. Singapore
5. Thailand
6. USA

ASEAN-5: *5 clusters*

1. Indonesia
2. Malaysia
3. Philippines
4. Singapore
5. Thailand

ASEAN-5: *3 clusters*

1. Malaysia and Thailand
2. Singapore and Indonesia
3. Philippines

For ASEAN-5/USA, there are six asymptotically perfect convergence clubs with a single country in each club, and three asymptotically relative convergence clubs with two countries in each club (see Table 8). The results of asymptotically perfect and asymptotically relative convergence are the same for ASEAN-5, except for a single country (i.e. the Philippines) in an asymptotically relative convergence club when the USA is excluded. Based on the definition of asymptotically perfect convergence proposed by Hobijn and Franses (2000), there is no evidence to support the equalisation of per capita incomes in the long run, implying that none of the ASEAN-5/USA countries converges to each other. However, the results indicate the existence of three asymptotically relative convergence clubs of two countries, namely Malaysia and Thailand, Singapore and Indonesia, and the Philippines and the USA. Given the low growth performance of the Philippine economy, it is surprising to find asymptotically relative convergence between the Philippines and the USA. This could be explained by the definition of asymptotically relative convergence, which requires the income gap between two countries to be level stationary, or simply to remain stable (i.e. no catching up) over time, as in the case of the Philippines and the USA (see Figure 4).

As the samples are relatively small, the tests are also conducted with $p_{min} = 0.05$, with the bandwidth parameter ranging from 1 to 6 to examine the robustness of the results. For both ASEAN-5 and ASEAN-5/USA, an increase in the critical p-value to 0.05 does not affect the results obtained in Table 8. However, when the bandwidth parameter is reduced to 2 and below, it increases the number of asymptotically relative convergence clubs to four for both ASEAN-5 and ASEAN-5/USA. In both cases, Singapore and Indonesia do not converge to the same asymptotically relative convergence club, but each of them converges to a single country club.

Based on the cluster procedure, there is evidence to support asymptotically relative convergence between Malaysia and Thailand, and the Philippines and the USA.

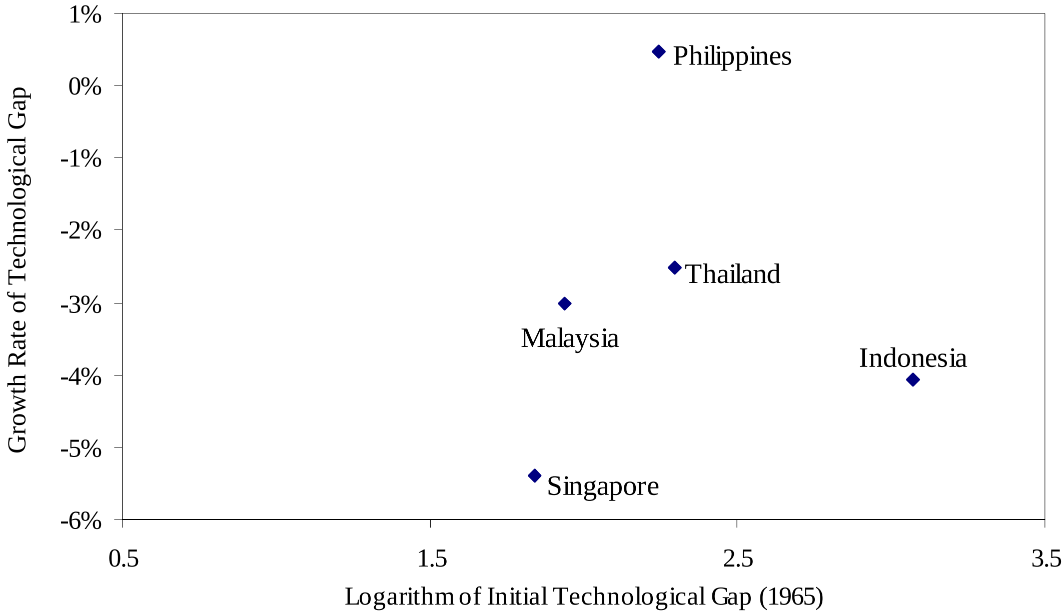
Overall, this paper finds no evidence of convergence within the ASEAN-5 countries, and within ASEAN-5/USA in a time series framework, using the unit root and cointegration techniques. In terms of limited convergence, however, the Kalman filter results support convergence between the USA and Singapore, and also between Singapore and individual ASEAN-3 countries. On the other hand, the cluster analysis indicates the existence of asymptotically relative convergence clubs for Malaysia and Thailand, and for the Philippines and the USA.

It is important to stress that the results obtained could be affected by the size of the sample. In addition, the time series methods available to test the convergence hypothesis are limited to testing the time series properties of income differences, without considering the factors that determine economic growth.

4.2 Catching Up

Although the ASEAN-5 countries have experienced tremendous economic growth, their current levels of real income per capita still lag behind that of the USA, except for Singapore (see Figure 1). Thus, it is unlikely that there would be empirical evidence of income convergence among ASEAN-4 countries and the USA. As technological progress has important effects on a country's economic growth, the catching up equation (24) is used to test for technological catching up between the ASEAN-5 countries and the USA over the period 1965-92. Real GDP per capita adjusted for changes in the terms of trade is used as a proxy for the stock of knowledge in each country. The growth rate of the technological gap for each country over the 1965-92 period is derived by regressing the technological gap (G) on a time trend (see equation (27)). In Figure 7, the initial level of the technological gap in 1965 is shown against its estimated growth rate for ASEAN-5 countries. It is evident from the scatter plot in Figure 7 that there is no significant cross section correlation between the growth rate of the technological gap and its initial level.

FIGURE 7
Technological Gap Growth Rate (1965-92) Versus Initial Level (1965)



Source: PWT 5.6.

Testing for technological catching up in a time series framework is undertaken for each of the ASEAN-5 countries and the USA. Two additional variables are included in equations (25) and (26). Verspagen (1991) used the sum of the number of patent grants per capita in the USA over the period 1960-85 as a proxy for the exogenous rate of knowledge growth due to research activity (P). However, the author has noted that patent data are not a good indicator of innovation, and that US patents are external patents for the lagging countries in the sample. As investment is an important factor in determining ASEAN-5's economic growth, the growth rate of per capita gross domestic investment (GDI) at constant prices is preferred to patent data as a proxy for P. Data for the growth rates of per capita GDI from the World Bank World Tables are only available for ASEAN-5 from 1967 onward, which restricts the estimation of equations (24)-(26) to the 1967-92 period. As for the education variable (E) that influences the intrinsic learning capability, the percentage of the population enrolled in secondary education is chosen as a proxy. Due to the unavailability of the secondary education variable prior to 1971 for Indonesia, the sample period is 1971–92.

Equations (24) and (25) were estimated using ordinary least squares, while (26) was estimated using non-linear least squares. The results of the estimated regressions are shown in Table 9.

For the basic catching up hypothesis (24), the estimated coefficients ($\hat{b}_1$) are negative for all ASEAN-5 countries, except for Thailand. Apart from Singapore, the estimated coefficients for ASEAN–4 are found to be insignificant. These results imply that, of the five ASEAN countries, only Singapore has exhibited catching up to the USA. In determining the statistical adequacy of the regression results, the Lagrange Multiplier tests indicate the presence of serial correction for the estimates of Indonesia ($\chi^2(1) = 4.1239$, with probability value 0.042), the Philippines ($\chi^2(1) = 7.1913$, with probability value 0.007), and Singapore ($\chi^2(1) = 6.8120$, with probability value 0.009) at the 5% level of significance.

Similar estimation results are obtained for the coefficient b_2 in equation (25) for Malaysia, the Philippines and Thailand. However, this coefficient has become positive and significant for Indonesia but insignificant for Singapore. Malaysia is the only country with the expected signs for all the estimated parameters, but c_3 is the only coefficient that is significant. The results indicate that the growth rates of per capita GDI have significant negative effects on the growth rates of the technological gaps for all ASEAN-5 countries, except for Singapore. On the other hand, while none of the estimated education variables is significant, the inclusion of P and E has nonetheless overcome the problem of serial correlation in the estimation of (24) for Indonesia ($\chi^2(1) = 1.4755$, with probability value 0.224), the Philippines ($\chi^2(1) = 0.2541$, with probability value 0.614), and Singapore ($\chi^2(1) = 3.2520$, with probability value 0.071).

TABLE 9
Estimation Results for the Catching Up Hypothesis

Country	Period	Parameters	
<u>Equation (24)</u>		a_1	b_1
Indonesia	1971-92	0.0863	–0.0489
		(0.8373)	(–1.2176)
Malaysia	1967-92	0.0241	–0.0346
		(0.2804)	(–0.6451)
Philippines	1967-92	0.2109	–0.0934
		(–0.9518)	(–0.9385)
Singapore	1967-92	–0.0035	–0.0575**

		(–0.1703)	(–2.8521)		
Thailand	1967-92	–0.1273	0.0499		
		(–1.7022)	(1.3327)		
<u>Equation (25)</u>		a_2	b_2	c_2	d_2
Indonesia	1971-92	–0.6678	0.2261*	–0.6638**	0.0354
		(–2.0813)	(2.1130)	(–3.5280)	(1.9686)
Malaysia	1967-92	0.1792	–0.0613	–0.4232**	–0.0119
		(0.8102)	(–0.8502)	(–8.8596)	(–0.7783)
Philippines	1967-92	0.0834	–0.0560	–0.2252**	0.0088
		(0.5408)	(–0.8222)	(–5.0705)	(1.1413)
Singapore	1967-92	–0.0609	–0.0487	–0.1358	0.0075
		(-0.4179)	(–1.4866)	(–1.3080)	(0.3626)
Thailand	1967-92	–0.1127	0.0454	–0.1826**	0.0020
		(–0.7255)	(0.6832)	(–3.3447)	(0.2309)
<u>Equation (26)</u>		a_3	b_3	c_3	δ
Indonesia	1971-92	0.2313	–0.1073	–0.4819*	–0.1721
		(0.5969)	(–0.5955)	(–2.1510)	(–1.4764)
Malaysia	1967-92	0.1491	–0.1498	–0.4167**	–1.8336**
		(1.1381)	(–1.1540)	(–8.8427)	(–3.3689)
Philippines	1967-92	0.0918	–0.0243	–0.2274**	1.0747
		(0.6130)	(–0.3850)	(–5.1585)	(0.5132)
Singapore	1967-92	0.0104	–0.0873	–0.1640	–2.8557
		(0.1845)	(–0.6036)	(–1.7003)	(–0.4941)
Thailand	1967-92	–0.0568	0.0188	–0.1856**	0.0576
		(–0.6552)	(0.4118)	(–3.4034)	(0.2407)

Notes: t-values are given in parentheses.
* indicates significance at the 5% level.
** indicates significance at the 1% level.

The results obtained from the non-linear regression model (26) do not differ significantly from (25). However, as compared with (25), a greater number of estimated parameters has the expected signs. For instance, two more countries (in addition to Malaysia), namely Indonesia and Singapore, have the correct signs. Another notable difference is that the education variable is significant for Malaysia.

Generally, countries that are more likely to catch up are those that have high levels of intrinsic learning capability and small technology distances from the technological leader (see Verspagen, 1991). In this study, Singapore is found to have the highest $\hat{\delta}$ parameter that measures the intrinsic learning capacity, followed by Malaysia and Indonesia, while the

Philippines and Thailand have incorrect, though insignificant signs. In terms of incorrect signs, Thailand is the only country that shows a persistent, though insignificant, positive correlation between the growth rate of the technological gap and its initial level in all three regressions, but the estimates are insignificant. One possible explanation is that the time lags between variables are not considered in the model. In reality, there are numerous time lags between variables, such as the creation of new knowledge and its eventual diffusion to other countries.

In comparing the specifications (24)-(26), it is clear that (24) is nested in both (25) and (26). Thus, (24) is tested against (25) and (26), with the null hypothesis $c_2 = d_2 = 0$ in (25) being tested with an F-test and $c_3 = \delta = 0$ in (26) being tested with a Wald test. The computed F and Wald statistics for the five ASEAN countries are presented in Table 10. For at least one test, the null hypothesis is rejected at the 5% level for all countries, apart from Singapore, with the results indicating that specifications (25) and (26) are preferred to (24) for ASEAN–4.

Overall, the estimation results support a negative correlation between the growth rate of the technological gap and its initial level for the ASEAN-5 countries, with the exception of Thailand. Although a significant and negative b_1 coefficient is found for Singapore, the Lagrange Multiplier tests indicate the presence of serial correlation. The results support the role of investment in reducing the technological gap between the USA and ASEAN–4. It is important to bear in mind that the samples used in this study are relatively small. As this dynamic model is formulated to explain the long run tendency of the growth path, it is difficult to accomplish this by using short run data (see Verspagen, 1991).

TABLE 10
Nested Tests for Equations (25) and (26)

Country	Period	H_0: $c_2 = d_2 = 0$	H_0: $c_3 = \delta = 0$
		Equation (25)	**Equation (26)**
Indonesia	1971-92	6.8624[0.006]	4.6394[0.098]
Malaysia	1967-92	39.2567[0.000]	84.8951[0.000]
Philippines	1967-92	15.0707[0.000]	26.6870[0.000]
Singapore	1967-92	1.4781[0.250]	2.9367[0.230]
Thailand	1967-92	5.7377[0.010]	11.6498[0.003]

Note: Probability values are given in brackets.

5 CONCLUSION

Over the past thirty years, the ASEAN-5 countries have undergone profound transformations and have grown faster (on average) than other regions in the world, excluding the high-performing North-East Asian economies. Outward orientation, such as openness to trade and foreign direct investment, and human capital investment are often cited as the two major factors which have contributed to the rapid growth in this region. Foreign trade encourages diffusion of new products and new technologies, while international investment brings technological and organisational improvements.

Based on the comparative data of real GDP per capita (adjusted for changes in the terms of trade) for the original five ASEAN countries, the Philippines had the lowest average annual growth rate of 1.2 percent over the period 1965–92. On the other hand, Singapore's average annual growth rate of 7.2 percent and initial level of real GDP per capita were the highest in ASEAN-5. As for the measure of the technological catching up, the log-difference in real GDP per capita between the USA and the Philippines was the only one in ASEAN-5 that was not reduced over the period 1965–92. This is due to the fact that the Philippines economy, on average, grew slower than that of the USA. If the growth performance of the Philippines remains at such a low level, it is likely that its economy will continue to fall behind those of the USA and other ASEAN-5 countries.

The results of the cross section tests of β convergence found a negative correlation between the average growth in income and its initial level for ASEAN-5 and ASEAN-5/USA countries, but the estimates were insignificant. Similarly, for the cross-country income deviations for ASEAN-5 and ASEAN–4, there were no reductions in income dispersion. It is important to stress that the cross section estimate of (Barro-type) β convergence has severe limitations, which prevents robust inferences from being drawn on the issue of income convergence.

In a time series framework, a number of tests for income convergence and technological catching up were undertaken. The results from the simple test of Verspagen (1994) for converging or diverging trends indicate that ASEAN-3 countries are converging, whereas only Indonesia is converging in ASEAN-4. On the other hand, the DF-type test for output differences between two countries, and the cointegration test based on the definition in Bernard and Durlauf (1995), found no evidence of income convergence among the ASEAN-5 countries, and ASEAN-5/USA. It is important to stress that the economic definition of income convergence would require more than the output difference between two series to be stationary. In terms of limited convergence, the evidence supports income convergence between the USA and Singapore, and between Singapore and individual ASEAN-3 countries. The cluster analysis provides support for asymptotically relative convergence between Malaysia and Thailand, and between the Philippines and the USA.

Based on the simple catching up hypothesis, there is no evidence of catching up by ASEAN-5 to the technology leader, with the exception of Singapore. However, the growth rate of real GDI per capita is found to have a significant effect in reducing the growth rate of the technological gap for ASEAN-4. The education variable, as approximated by secondary school enrolment, does not have a significant effect on the technological gap, except for Malaysia.

Overall, using the unit root and cointegration techniques, the time series tests for convergence do not support income convergence between pairs of ASEAN-5 countries. Despite evidence of limited convergence between Singapore and the ASEAN-3 countries, further investigation is needed to accommodate the contrasting results. Similarly, there is no evidence of technological catching up by ASEAN-5 to the technology leader, apart from Singapore, with further support regarding limited convergence with the USA. The characteristics of the data are important in determining the appropriate testing framework. Generally, the time series tests are more appropriate for the study of long-run growth behaviour. As ASEAN-5 experienced rapid and uneven economic growth over the last thirty years, the cross section tests may be superior since the data are likely to exhibit transition dynamics. However, the results do not appear to be robust due to the relatively small sample sizes. Further research on existing time series methods of testing the convergence hypothesis, examining the sample size and other relevant variables that determine economic growth are presently being investigated.

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