Is Singapore Catching Up Technologically to the USA?

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Abstract: The high growth performance of Singapore can be attributed largely to the rapid inflows of foreign direct investment (FDI). It is generally accepted that FDI brings not only additional capital to the host country, but also the transfer of advanced technology and management skills. The catch up hypothesis states that the lagging country, with low initial income and productivity levels, will tend to grow more rapidly by copying the technology from 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 examines whether Singapore is catching up technologically to the technology leader (USA). This paper applies two different time series tests of technological catching up, namely the Dickey-Fuller-type unit root test and the Verspagen model. There is evidence to suggest technological catching up by Singapore to the USA.

1. INTRODUCTION

The theory of catch up effects is important in explaining the role of technological catch up in influencing the growth processes of developing countries. Technological catch up is often associated with innovative activities such as research and development (R&D) and patenting. The catch 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, without having to bear the associated costs of R&D. In general, a less advanced country is able to increase its productivity by replacing existing older capital stock with more modern equipment, implying that capital investment is necessary to import the more advanced technology embodied in new equipment. Foreign direct investment (FDI) is another means of transferring foreign technology and knowledge to the host country. However, it is important to stress that the 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. Besides innovation and investment, the level of education also plays a crucial role in determining the technical competence of the labour force.

Over the past three decades, the dramatic growth in gross domestic product (GDP) in large parts of Asia brought economic and social transformations to many economies in the region, which helped to reduce Asia's income gap with the industrial countries. With a land area of 648 square kilometres and a population of around 3.9 million, Singapore has emerged as the fastest growing economy in the South-East Asian region. As a major recipient of international direct investment flows to developing countries, FDI has helped to accelerate Singapore's economic growth. Real GDP (in 1987 prices) of Singapore increased more than twelve-fold from S$7.5 billion to S$94.0 billion during the period 1966-96 [EconData, 1998]. Singapore's rapid economic growth has largely been attributed to a policy that promoted investment in the high growth sectors, macroeconomic stability and export-led growth, and upgrading of infrastructure and human resources, which led to its current status as a newly industrialised country. The aim of the paper is to examine whether Singapore is catching up technologically to the world leader (USA).

The plan of the paper is as follows. Section 2 outlines the methodology used to test the catching up hypothesis. Section 3 examines the data and the variables to be included in the models. Section 4 analyses the empirical results. Some concluding remarks are given in Section 5.

2. METHODOLOGY

In this paper, two different time series methods are used to test if Singapore is catching up technologically to the USA. The first method is a Dickey-Fuller-type unit root test on the output differences between two countries, while the second method applies Verspagen's [1991] model which considers both catching up or falling behind.

2.1 Unit Root Test

Theoretically, the empirical implication of the catch up and convergence hypotheses is essentially the same, whereby countries with low initial per capita productivity (or output) grow faster than those with high initial per capita productivity (or output), under the assumption of technology diffusion and imitation (or diminishing marginal returns). In a time series perspective, 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 Singapore and the USA. Following Oxley and Greasley [1995], the Dickey-Fuller-type test based on the output difference between two countries, p and q, is given below:

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

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.

The statistical tests of catching up and convergence are related as both require $y_p - y_q$ to be stationary, but the test for catching up is less stringent than convergence as it does not involve a long-run equilibrium.

2.2 Verspagen Model

Verspagen [1991] stresses that the capability of an economy to assimilate knowledge spillovers, the historical institutional framework and technological distance are crucial in the development process. If a country lags far behind the technology frontier and lacks the capability to assimilate new technology, it will fall behind rather than catch up. As most of the catch up models have not considered the possibility of falling behind, Verspagen [1991] proposed a model that incorporates both catching up and falling behind. In his model, the technology gap between two countries is defined as follows:

$$G = \ln \frac{K_{us}}{K_i}, \quad (2)$$

where G is the technological gap, and K_{US} and K_i are the knowledge stock of the technology leader (USA) and lagging country i, respectively. To accommodate the possibility of falling behind, the processes of catching up and convergence will operate only if an economy's income per capita exceeds some critical level.

Incorporating the social capability factor into equation (2), Verspagen [1991, p. 363] used the following equation to test the catch up hypothesis:

$$\dot{G} = a - bGe^{-G/\delta}, \quad (3)$$

where the dot above the variable denotes its growth rate (or time derivative). 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, so that a large δ implies a smaller technological distance effect. In this specification, there is a threshold for the initial value of the technology gap, whereby no catch up is possible if the intrinsic learning capability is too weak or falls below some critical level. This means countries that are more likely to catch up are those that have high levels of intrinsic learning capability and small technology distance from the technological leader. A negative value of the parameter b in equation (3) supports the catch up hypothesis that lagging countries have higher rates of productivity growth, thereby narrowing the technological gap.

As suggested in Verspagen [1991, p. 369], the following three equations will be estimated for Singapore and the USA:

$$\dot{G} = a_1 + b_1 G_0 + \varepsilon_1 , \quad (4)$$

$$\dot{G} = a_2 + b_2 G_0 + c_2 P + d_2 E + \varepsilon_2 , \quad (5)$$

$$\dot{G} = a_3 + b_3 G_0 e^{\delta (G_0 / E)} + c_3 P + \varepsilon_3 , \quad (6)$$

where P is the exogenous rate of knowledge growth in the lagging country, E is the variable (such as education or infrastructure) that influences the intrinsic learning capability, the subscript 0 denotes initial values, and ε_i is a random disturbance with zero mean and finite variance σ_i^2 (i = 1, 2, 3).

The simplest test for the catch up hypothesis is given by equation (4), and the parameter b_1 measures the correlation between the initial technology gap and its growth. Equation (5) is an augmentation of equation (4) with two additional variables, P and E, while equation (6) is based on the specification in equation (3). 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 take either sign.

Instead of using only the first and last values for a cross-country sample of 114 countries, Verspagen [1991] derived the growth of the technology gap using the following equation for each country over the period 1960-85:

$$G = a + \theta t + \varepsilon , \quad (7)$$

where a is a constant, t is a deterministic time trend and ε is an independently and identically distributed error term (0, σ^2). The estimated θ is taken as a measure of $\dot{G}$ in equations (4), (5) and (6).

In a time series framework, equations (4)-(6) are estimated for Singapore, and the USA is treated as the leader country. This means that the dependent variable, $\dot{G}$, in equations (4)-(6) 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 values of the technology gap (G_{t-1}).

It is essential to bear in mind that inferences from the estimated regressions (4)-(6) may be sensitive to the auxiliary assumptions of the model. Deviations from the classical assumptions will tend to bias inferences based on ordinary least squares (OLS) estimation as the standard errors will be biased. Thus, standard diagnostics to test the assumptions (and hence the statistical adequacy) of the model will be used [see McAleer, 1994]. These tests include the Lagrange multiplier (LM) tests for serial correlation, functional form misspecification, normality and heteroscedasticity.

3. DATA

Time series tests of the catch up hypothesis are applied to comparative data for Singapore and the USA from the Penn World Table 5.6 [Summers and Heston, 1994]. As Singapore separated from Malaysia in 1965, the period under study is 1965 to 1992. The distance from the leader country in terms of per capita income or productivity is commonly used as a measure of catch up effects. For empirical estimation, real GDP per capita adjusted for changes in the terms of trade is used as the proxy for the stock of knowledge in each country. Figure 1 depicts the log differences of real GDP per capita between the technology leading country (USA) and Singapore over the period 1965-92. It is evident from Figure 1 that the technological gap between these two countries has declined over time.

[Figure 1]

Regarding the measurement of the two additional variables, P and E, in equations (5) and (6), some catch up studies have used patents data as an indicator of innovation, in addition to the education variable. Verspagen [1991] also 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 noted that patents data are not a good indicator of innovation, and that US patents are external patents for the lagging countries in the sample.

In the case of Singapore, however, patents data are not available. Investment is an important factor in determining Singapore's economic growth, and capital investment facilitates the import of more advanced technology embodied in the new equipment. Thus, alternative measures of innovation would be the growth rates of domestic investment or FDI. However, FDI data for Singapore from the International Finance Statistical Yearbook [IMF] are not available prior to 1970. Bearing in mind the relatively small sample, the growth rate of per capita gross domestic investment (GDI) at constant prices is used as a proxy for *P*. Data for the growth rates of per capita GDI from the World Bank World Tables [EconData, 1998] are only available from 1967 onward, which restricts the estimation of (4)-(6) to the 1967-92 period. The percentage of the population enrolled in secondary education, which is commonly used in empirical studies as a measure of human capital, is chosen as a proxy for the variable (*E*) that influences intrinsic learning capability.

4. EMPIRICAL RESULTS

Testing for technological catching up in a time series framework is undertaken for Singapore and the USA. All estimation and test results are derived using the Microfit 4.0 econometric software program [Pesaran and Pesaran, 1996].

Following Oxley and Greasley [1995] (see equation (1)), the Dickey-Fuller-type test is used for the logarithm of per capita output difference between Singapore and the USA (LSUGDP). For annual data, an initial lag length of two is used for the augmented Dickey-Fuller (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 and critical values for 1968-92, with and without a linear deterministic trend, are presented in Table 1.

TABLE 1
ADF Tests for Convergence and Catching Up

Variable	t-value	*P*	Critical Value
No Trend			
LSUGDP ($\alpha = 0$)	-2.0365	1	-2.985
Trend			
LSUGDP ($\alpha \neq 0$)	-2.4651	1	-3.6027

Note: *p* is the lag length.

The test results for the output differences between Singapore and the USA with $\alpha = 0$ and $\alpha \neq 0$ are both insignificant at the 5% significance level, implying that neither long-run convergence nor convergence as catching up exists between Singapore and the USA. However, St. Aubyn [1996] argued that the economic definition of income convergence does not necessarily imply that the output difference between two countries is stationary.

As for the Verspagen model, equations (4) and (5) were estimated by OLS, while (6) was estimated by non-linear least squares. The results of the estimated regressions are shown in Table 2.

[Table 2]

For the basic catch up hypothesis (4), the estimated $\hat{b}_1$ is negative and significant, which implies that the Singapore economy is catching up to the USA. Standard diagnostic tests suggest the estimated model (4) is free from the problems of functional form misspecification, non-normality and heteroscedasticity, except for serial correlation. The LM test rejects the null hypothesis of no serial correlation at conventional levels of significance, which suggests that the estimates may be biased. One possible explanation is that the appropriate time lags between variables are not being 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.

Estimation results of model (5) also suggest an inverse relationship between the growth rate of the technology gap and its initial level, but the estimated $\hat{b}_2$ is insignificant at the 5% level. None of the estimated coefficients in (5) is significant. The growth rate of per capita GDI (*P*) has a negative effect on the growth rate of the technological gap, while the secondary school enrolment ratio (*E*) has a positive effect, which contradicts the economic rationale that a higher level of educated workforce (or learning capability) will lead to a narrowing of the technological gap. One possible explanation is that the secondary school enrolment ratio fails to capture the essence of intrinsic learning capability, or simply that the model (5) is misspecified. Notice that the inclusion of the *P* and *E* variables may have overcome the problem of serial correlation in the estimation of (4), but the null hypothesis of no functional form misspecification for regression (5) is rejected at the 5% level of significance.

The results obtained from the non-linear regression model (6) do not differ significantly from (5), as all estimated coefficients are insignificant at the 5% level. However, all estimated parameters in (6) have the expected signs. The education variable in (6), as approximated by secondary school enrolment, is negatively correlated with the technological gap. Diagnostic tests also indicate model (6) is free from the problems of serial correlation, functional form misspecification, non-normality and heteroscedasticity.

In comparing the specifications of (4)-(6), it is noted that (4) is nested in both (5) and (6). Thus, (4) is tested against each of (5) and (6), with the null hypothesis $c_2 = d_2 = 0$ for (5) being tested with an F-test and $c_3 = \delta = 0$ for (6) being tested with a Wald test. The computed F and Wald statistics for Singapore are presented in Table 3. For both tests, the null hypotheses are rejected at the 5% level of significance, with the results indicating that specifications (5) and (6) are preferred to (4). On the other hand, specification (6) is preferred to (5) in terms of the statistical adequacy of the model and the expected signs of the estimated parameters.

TABLE 3
Nested Tests Against Equation (4), 1967-92

Equation	Null Hypothesis	Test Statistic
(5)	H_0: $c_2 = d_2 = 0$	1.4781[0.250]
(6)	H_0: $c_3 = \delta = 0$	2.9367[0.230]

Note: Probability values are given in brackets.

5. CONCLUSION

This paper applied two different time series tests of the catch up hypothesis for Singapore and the USA. The Dickey-Fuller-type unit root test based on the definition in Oxley and Greasley [1995] found no evidence of convergence as catching up between Singapore and the USA. However, it was emphasised that the economic definition of convergence and catching up requires more than the output difference between two countries to be stationary.

On the other hand, the estimation results from the Verspagen model support a negative correlation between the growth rate of the technological gap and its initial level for Singapore. The results also indicate the potential role of domestic investment and education in reducing the technological gap between Singapore and the USA. It is important to bear in mind that the sample used in this study is relatively small. As the dynamic model is formulated to explain the long run tendency of the growth path, the use of short run data is problematic.

ACKNOWLEDGEMENTS

The first author would like to acknowledge the financial support of a Curtin Business School Research Program Funding for 1999, and the second author wishes to acknowledge the financial support of the Australian Research Council.

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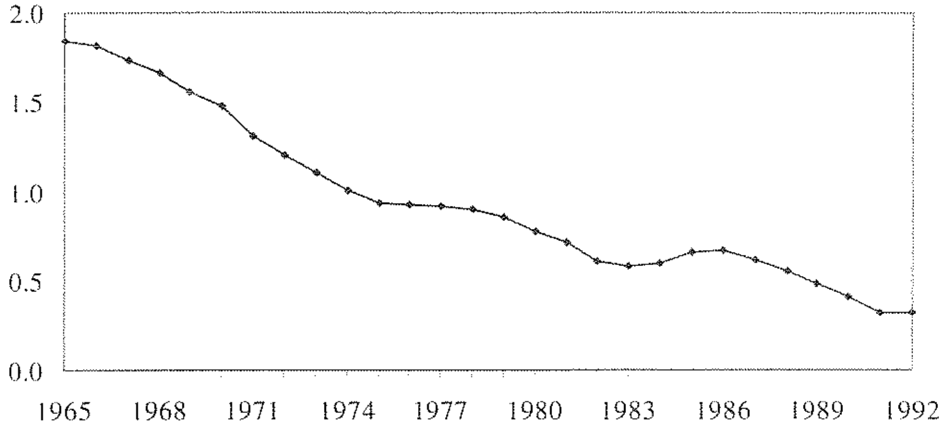
FIGURE 1
Log of Real Per Capita GDP Differences Between Singapore and the USA, 1965-92



Source: Penn World Table 5.6.

TABLE 2
Results for the Catching Up Hypothesis, 1967-92

	Equation		
Parameter	(4)	(5)	(6)
$\hat{a}_1, \hat{a}_2, \hat{a}_3$	–0.0035	–0.0609	0.0104
	(–0.1703)	(–0.4179)	(0.1845)
$\hat{b}_1, \hat{b}_2, \hat{b}_3$	–0.0575**	–0.0487	–0.0873
	(–2.8521)	(–1.4866)	(–0.6036)
$\hat{c}_2, \hat{c}_3$		–0.1358	–0.1640
		(–1.3080)	(–1.7003)
$\hat{d}_2, \hat{\delta}$		0.0075	–2.8557
		(0.3626)	(–0.4941)
$\overline{R}^2$	0.2220	0.2518	0.2551
LM Diagnostic Tests			
Serial Correlation	6.8120	3.2520	2.7393
	[0.009]	[0.071]	[0.098]
Functional Form	0.0714	6.1448	2.9728
	[0.789]	[0.013]	[0.085]
Normality	0.4434	1.1726	0.9153
	[0.801]	[0.556]	[0.633]
Heteroscedasticity	0.5143	0.0352	0.1831
	[0.473]	[0.851]	[0.669]

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