Economic Growth Centre
Working Paper Series

Growth Accounting for a Follower-Economy in a World of Ideas: The Example of Singapore

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Working Paper No: 2006/06

Growth Accounting for a Follower-Economy in a World of Ideas: The Example of Singapore

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June 2006

Abstract:

In this paper, we take another approach to accounting for the sources of Singapore's economic growth by being explicit about the channels through which Singapore, as a technological follower, benefits from international R&D spillovers. Taking into account the channels through which technology developed in the G5 countries diffuses to technological followers, we show that 57.5 percent of Singapore's real GDP per worker growth rate over the 1970-2002 period is due to multifactor productivity growth. In particular, about 52 percent of the growth is accounted for by an increase in the effectiveness of accessing ideas developed by the technology leaders through improvement in our educational quality and increase in machinery imports and foreign direct investment from the G5 countries. We also find that capital accumulation that takes the form of imports of machinery as well as foreign direct investment from the G5 countries enhances the effectiveness of technology transfer thus raising the rate of return to capital. Compared to the rate of return to capital inferred from the traditional Solow growth model with purely exogenous technological progress of 10.8 percent, taking into account the technology transfer channel raises the implied rate of return to 13 percent. (JEL classification: F43, O33, O47)

Keywords: technological diffusion, idea production function, multifactor productivity growth

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1. Introduction

Empirical work by Hall and Jones (1999) and Parente and Prescott (2000) shows that in an international cross-section of countries, the bulk of the huge differences in levels of output per worker is explained by differences in multifactor productivity. Klenow and Rodríguez-Clare (1997) further show that differences in multifactor productivity growth rates play an even greater role in explaining differences in the growth rates of income per capita across countries. A theoretical framework that carries these predictions is one with a group of innovating countries (technology leaders) constantly pushing forward the world technology frontier through its investment in research and development (R&D) and the rest of the world (technological followers) potentially benefiting through international R&D spillovers. Coe, Helpman and Hoffmaister (1997) and Hejazi and Safarian (1999) show empirically that how much any single follower-economy benefits from international R&D spillovers depends on its distance from the frontier, its stock of human capital as well as its integration with the technology leaders through trade and foreign direct investment. Nelson and Phelps (1966) is a seminal paper presenting such a theoretical framework while Barro and Sala-i-Martin (1997) provides a more micro-foundation-based treatment of innovation and technological diffusion.

Given the empirical findings in these international cross-sectional studies, it is surprising that growth accounting done by Tsao (1985) and Young (1992, 1995) for Singapore, the second fastest-growing economy over the 1960-2000 period in the sample of 112 countries compiled by Barro and Sala-i-Martin (2004, chapter 12), finds a very small contribution of multifactor productivity growth to the rapid growth of income per capita. For example, according to Young (1995, Table VI), the percentage of total real GDP growth over the period 1966-1990 that is explained by multifactor productivity growth is only 2 percent. This is a puzzle because Singapore is very open to trade with the G5 countries and is also a major recipient of foreign direct investment flows from the G5 countries. Over the years, educational quality has also been steadily improving. According to the insights that have been gained from international cross-sectional studies, Singapore’s close integration to the world’s technology leaders through trade and foreign direct investment should have boosted its multifactor productivity growth. If one accepts these international cross-sectional findings, one would have to conclude that there must have been offsetting inefficiencies in Singapore to block the adoption of new ideas from abroad despite its economic openness and increase in human capital. Otherwise, one would have to doubt the reliability of these international cross-sectional findings about the importance of educational quality and international linkages between follower-economies and technological leaders in the transmission of ideas.

The traditional growth accounting methodology that Tsao and Young apply was originally developed by Solow (1957) to study the U.S. economy, which is a technology *leader*. In this paper, we take another approach to accounting for the sources of Singapore's economic growth by being explicit about the channels through which Singapore, as a technological *follower*, benefits from international R&D spillovers. Our approach builds upon the work of Jones (2002), who explicitly incorporates a production function for ideas in accounting for U.S. economic growth, where ideas are created by the research scientists and engineers in the G5 countries and are immediately disseminated to each of the G5 countries. In the case of a follower-economy, however, we need to explicitly incorporate the process of technological diffusion. Taking into account the channels through which technology developed in the G5 countries diffuses to technological followers, we show that 57.5 percent of Singapore's real GDP per worker growth rate over the 1970-2002 period is due to multifactor productivity growth, a finding that is consistent with the findings from international cross-sectional studies regarding the sources of growth. In particular, about 52 percent of the growth is accounted for by an increase in the effectiveness of accessing ideas developed by the technology leaders through improvement in our educational quality and increase in machinery imports and foreign direct investment from the G5 countries. Another finding is that capital accumulation that takes the form of imports of machinery as well as foreign direct investment from the G5 countries enhances the effectiveness of technology transfer thus raising the rate of return to capital. Compared to the rate of return to capital inferred from the traditional Solow growth model with purely exogenous technological progress of 10.8 percent, we find that taking into account the technology transfer channel raises the implied rate of return to 13 percent for the period 1971-2002.

The rest of the paper is organized as follows. We set up the theoretical model in section 2. Then in section 3, we conduct the quantitative analysis. Section 4 concludes.

2. Setup of the Model

We incorporate the Coe, Helpman, and Hoffmaister's (1997) technology spillover channels into the Jones (2002) growth accounting framework, with an additional channel via G5 foreign direct investment identified by Hejazi and Safarian (1999) as empirically important.

The goods production function is given by

$$Y_t = A_t^{\sigma} K_t^{\alpha} H_{Yt}^{1-\alpha}, \tag{1}$$

where σ =1-α, so multifactor productivity is measured in Harrod-neutral terms as in Jones (2002), H_{Yt} is the effective workforce, and A_t is the stock of ideas adopted by the follower-economy. Capital K_t accumulates according to

$$\dot{K}_t = s_{Kt} Y_t - dK_t, \qquad K_0 > 0, \tag{2}$$

where s_{Kt} is the savings or investment rate, d is the depreciation rate, and K_0 is the initial capital stock. Effective workforce H_{Yt} is given by

$$H_{Yt} = h_t L_{Yt}, \tag{3}$$

where h_t is human capital per person, and L_{Yt} is labor employed in producing output. Human capital of workers is influenced by the amount of time spent accumulating human capital, l_{ht}:

$$h_t = e^{\psi l_{ht}}, \qquad \psi > 0. \tag{4}$$

We assume that the labor force of the follower-economy is growing at the rate of n:

$$N_t = N_0 e^{nt}, \qquad N_0 > 0. \tag{5}$$

The labor resource constraint faced by the follower-economy is given by

$$L_{At} + L_{Yt} = L_t = (1 - l_{ht}) N_t, \tag{6}$$

where L_t denotes total employment, L_{At} denotes labor employed in research activities (being Research Scientists and Engineers, *RSE*'s), and $l_A \equiv \frac{L_A}{L}$ is defined to be the research intensity, and $l_Y \equiv \frac{L_Y}{L}$.

Note that the above equations (1) to (6) also apply to the leader-economy (which we take to be the G5 countries in our empirical work). To avoid confusion, we will cap the variables with a ~ when such variables pertain to the leader-economy. For example, the growth rate of the labor force of the leader-economy is denoted by $\tilde{n}$.

We define output per effective worker as

$$y_t^E \equiv \frac{Y_t}{A_t H_{Yt}}.$$

It can be readily shown that the steady-state output per effective worker is given by

$$y^{E*} = \left[\frac{s_K}{n + g(AH_Y) + d}\right]^{\frac{\alpha}{1-\alpha}},$$

where the growth rate of $A_t H_{Yt}$ is written as $g(A_t H_{Yt}) = g(A_t) + g(H_{Yt}) = \frac{\dot{A}_t}{A_t} + \psi \frac{dl_{ht}}{dt}$. It can also be shown that

$$g(y_t^E) \equiv \frac{\dot{y}_t^E}{y_t^E} = \alpha\nu\left[\left(\frac{y^{E*}}{y_t^E}\right)^{\frac{1}{\alpha}} - 1\right],$$

where the speed of convergence $\nu \equiv (1-\alpha)(n + g(AH_Y) + d)$. A first-order Taylor series expansion around $\frac{y^{E*}}{y_t^E} = 1$ gives

$$g(y_t^E) = \nu\left(\frac{y^{E*}}{y_t^E} - 1\right).$$

Noting that $y_t \equiv \frac{Y_t}{L_t} = A_t h_t L_t y_t^E$ for a follower-economy, and using the preceding four equations, we obtain

$$g(y_t) = \alpha[g(A_t) + \psi \frac{dl_{ht}}{dt} - n - d] + \frac{(1-\alpha) s_K^{\frac{\alpha}{1-\alpha}} [n + g(A_t) + \psi \frac{dl_{ht}}{dt} + d]^{1-\frac{\alpha}{1-\alpha}}}{\frac{y_t}{A_t h_t}} . \qquad (7)$$

We make several ceteris paribus inferences from (7) about the determinants of real GDP per worker growth. First, we observe that an increase in the investment rate s_K will raise $g(y_t)$. Second, we observe that $g(y_t)$ is increasing in the state variables A_t and h_t. Third, we observe that a sufficient though not a necessary condition for an increase in $g(A_t)$ and/or $\frac{dl_{ht}}{dt}$ to raise $g(y_t)$ is that $\alpha \leq 0.5$. Hence to understand the influences on growth of per worker income, it is necessary to understand the determinants of $g(A_t)$ for the follower-economy.

Before we develop the determinants of $g(A_t)$ for a follower-economy, we shall take a preliminary look at some key data for Singapore. Figure 1 shows the average decadal growth rates of real per capita GDP and real GDP per worker for Singapore from 1961 to 2000. It is useful to differentiate these two growth rates as population and total employment could be growing at different rates due, say, to changes in labor force participation rate. As a reference point, we have also drawn a line corresponding to a real per capita GDP growth rate of 1.8 percent, which is the mean value for the growth rate of real per capita GDP for the 112 countries with available data from 1960 to 2000 reported in Barro and Sala-i-Martin (2004). Interestingly, 1.8 percent is also the average growth rate of real per capita GDP of the U.S. economy over the past 125 years reported in Jones (2002).

[Figure 1: Real Growth Rates]

From Figure 1, we observe that Singapore's average growth rates in the earlier decades were higher than in the later decades. However, the growth rates in the 1980s and the 1990s do not suggest a rapid convergence to that of U.S. long-run growth rate. Motivated by (7), we check whether there are increases in the decadal averages of the investment rate s_K, and change in educational attainment dl_h, which could prevent a rapid convergence to the U.S. long-run growth rate. These are depicted in Figure 2.

[Figure 2: Decadal Averages of Investment Rate and Change in Educational Attainment]

From Figure 2, we observe that there was an increase in average decadal s_K from the 1960s to 1970s and a decline from the 1970s down to the 1990s. In contrast, there was a steady increase in dl_h over the past four decades. According to (7), if $\alpha \leq 0.5$, this steady increase in average educational attainment will unambiguously lead to a steady increase in $g(y)$, holding other things constant.

Figure 3 shows the natural logarithm of multifactor productivity $\ln A$. The plot of $\ln A$ suggests that the growth rate of multifactor productivity is rather stable over the past four decades. We proceed to test whether the growth rate of multifactor productivity, $g(A)$, can statistically be considered a constant in Appendix 1. The results in Appendix 1 show that the constancy of $g(A)$ cannot be rejected using a simple student-t test and that $g(A)$ is stationary using the Dickey-Fuller test for unit root. There is no problem of serial correlation in the error term. Hence, the augmented version of the Dickey-Fuller test is not required. Based on these statistical tests, we conclude that $g(A)$ can be considered a constant for our empirical analysis in section 3. We show later that the constancy of $g(A)$ is the result of the increase in educational quality and increase in imports of machinery and foreign direct investment from the G5 countries, leading to shifts in the steady-state distance to frontier. Note, however, that in deriving the key equations in the theoretical model of this section, we do not need to restrict $g(A)$ to be constant.

[Figure 3: Multifactor Productivity in Singapore]

Now we proceed to endogenize the evolution of A_t. We begin by defining the effective world research effort $\tilde{H}_{At}$ as

$$\tilde{H}_{At} = \sum_{i=1}^{M} L_{Ait} \, , \tag{8}$$

where i indexes each of the G5 economies. The number of *RSE*'s in a follower-economy such as that of Singapore is insignificant compared to the combined number in G5 economies and hence makes a negligible contribution to the effective world research effort.[1]

The stock of ideas adopted by the follower-economy advances according to

$$\dot{A}_t = \delta \tilde{H}_{At}^{\lambda} A_t^{\phi} E_t^{\beta} \left(\frac{G5MT_t}{Y_t} \right)^{\mu} \left(\frac{G5FDI_t}{K_t} \right)^{\kappa}, \qquad A_0 > 0, \tag{9}$$

where $\tilde{H}_{At}$ is effective world research effort, which is given by the sum of research scientists and engineers in G5, $\delta > 0$, $0 < \lambda \leq 1$, $\phi < 1$ and can be positive or negative, $\beta > 0$, $\mu > 0$, $\kappa > 0$, $G5MT_t$ is imports of machinery and transport equipment from G5, $G5FDI_t$ is the stock of foreign direct investment from G5, E_t is tertiary enrollment to employment ratio, and A_0 is the initial level of technology. As Jones (2002) noted, allowing λ to vary between zero and one allows for the possibility of duplication of research findings by research scientists while allowing $\phi < 1$ leaves open two possibilities: that past research increases the current flow of new ideas ($\phi > 0$) and decreases it ($\phi < 0$). Note that we have used the symbol ~ to cap variables pertaining to the combined G5 economies. We have introduced three channels of improving A_t in the small open follower-economy: the quality of learning captured by E_t, the linkage to advanced imported technology through machinery import captured by $\frac{G5MT_t}{Y_t}$, and the quality of capital stock captured by $\frac{G5FDI_t}{K_t}$. Figure 4 shows time plots of these three channels of idea transmission for the case of Singapore.

[Figure 4: Decadal Averages of Idea Transmission Channels]

From Figure 4, we observe that the linkage to advanced imported technology both through machinery import as well as through foreign direct investment from G5 countries has steadily increased while the quality of learning began to increase more significantly

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[1] For example, in 2002, Singapore had 23,101 *RSE*'s, about 0.95% of the combined number in G5 economies.

in the 1980s and the 1990s. The quantitative contribution of these three channels of idea transmission to Singapore's growth will be presented in section 3.

These three channels apply to technological followers, and determine how effectively ideas created at the world technology frontier by the technological leaders are transmitted to and adopted by the followers. The evolution of the frontier stock of ideas T_t is described by

$$\dot{T}_t = \delta \tilde{H}_{At}^{\lambda} T_t^{\phi}, \qquad T_0 > 0,$$

which is the form of the idea production function given in Jones (2002) for a technology leader. Hence, the growth rate of ideas of the leader-economy at the frontier is given by

$$g(T_t) \equiv \frac{\dot{T}_t}{T_t} = \delta \tilde{H}_{At}^{\lambda} T_t^{\phi-1}. \tag{10}$$

Using (10), we re-write (9) to get

$$g(A_t) \equiv \frac{\dot{A}_t}{A_t} = g(T_t)\left(\frac{T_t}{A_t}\right)^{1-\phi} E_t^{\beta} \left(\frac{G5MT_t}{Y_t}\right)^{\mu} \left(\frac{G5FDI_t}{K_t}\right)^{\kappa}, \qquad A_0 > 0. \tag{11}$$

In this set-up, the stock of ideas adopted by the follower-economy grows faster when the frontier stock of ideas is growing faster, when the follower-economy is further away from the frontier[2], and when the three channels of idea transmission are stronger. As the follower-economy advances toward the frontier, reflected in a smaller distance to frontier, $\frac{T_t}{A_t}$, its growth rate of multifactor productivity diminishes, holding other things constant. It is important to note that while the average years of schooling l_h affects human capital accumulation and hence output, it is the quality of learning captured by the tertiary enrollment to employment ratio E which influences the growth rate of adopted ideas.

Definition 1

The steady-state distance to frontier is defined to be the stock of ideas in the leader-economy relative to the stock of ideas adopted by the follower-economy when $g(A_t)$ =

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[2] Recall that $\phi < 1$, as assumed earlier. In fact, later in the empirical studies, we will find that $\phi < 0$, which is also the case found in Jones (2002).

$g(T_t)$ (which are not necessarily constant), and when E, $\frac{G5MT}{Y}$, and $\frac{G5FDI}{K}$ are held constant, and it is given by

$$\left(\frac{T}{A}\right)^{*} = E^{\frac{-\beta}{1-\phi}} \left(\frac{G5MT}{Y}\right)^{\frac{-\mu}{1-\phi}} \left(\frac{G5FDI}{K}\right)^{\frac{-\kappa}{1-\phi}} \quad . \tag{12}$$

Hence, the steady-state distance to frontier is negatively related to the quality of learning as well as the linkage to imported technology through capital imports and foreign direct investment from the leader-economy. In the convergence to the steady-state distance to frontier, the growth rate of ideas adopted in the follower-economy will slow down; however, the pace of decline may be offset if there are increases in the strength of the three channels of idea transmission as such increases effectively reduce the steady-state distance to frontier $\left(\frac{T}{A}\right)^{*}$. Figure 4 shows that the tertiary enrollment to employment ratio, the share of capital imports from G5 countries as a ratio to GDP, and the share of G5 foreign direct investment stock to total capital stock have all been rising especially in the past two decades thus reducing the steady-state distance to frontier $\left(\frac{T}{A}\right)^{*}$. Using (11) and (12) and holding E, $\frac{G5MT}{Y}$, and $\frac{G5FDI}{K}$ constant, we obtain

$$\frac{g(A_t)}{g(T_t)} = \left[\frac{\left(\frac{T_t}{A_t}\right)}{\left(\frac{T}{A}\right)^{*}}\right]^{1-\phi} \text{, or}$$

$$\frac{g(A_t)}{g(T_t)} = \left[1 + \frac{\left(\frac{T_t}{A_t}\right) - \left(\frac{T}{A}\right)^{*}}{\left(\frac{T}{A}\right)^{*}}\right]^{1-\phi} \quad . \tag{13}$$

Jones (2002) found $g(T_t)$ to have been approximately constant from 1950 to 1993 so if $\left(\frac{T}{A}\right)^{*}$ is also declining steadily due to a steady increase in educational quality and linkage to the G5 through capital imports and foreign direct investment (see (12)), $g(A_t)$ would be approximately constant and greater than $g(T_t)$. A linearization of (13) around the steady state gives

$$g(A_t) = g(T_t) + (1-\phi)\left[\frac{\left(\frac{T_t}{A_t}\right)}{\left(\frac{T}{A}\right)^*} - 1\right] g(T_t)\,. \tag{14}$$

Proposition 1

Given $\phi < 1$, the growth rate of ideas in a follower-economy, $g(A_t)$,

(i) is positively related to the growth rate of ideas in the leader-economy, $g(T_t)$,

(ii) is positively related to its distance to frontier, $\frac{T_t}{A_t}$,

(iii) is negatively related to its steady-state distance to frontier, $\left(\frac{T}{A}\right)^*$,

(iv) is positively related to the three channels of idea transmission, namely the quality of learning, E, the linkage to imported technology through capital import, $\frac{G5MT}{Y}$, and the quality of capital stock, $\frac{G5FDI}{K}$, through their influence on the steady-state distance to frontier, and

(v) is higher than the leader-economy's $g(T_t)$ if its current distance to frontier is further than its steady-state distance to frontier.

Rewriting (1) in terms of output per worker gives

$$y_t \equiv \frac{Y_t}{L_t} = \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}} l_{Yt} h_t A_t^{\frac{\sigma}{1-\alpha}}\,. \tag{15}$$

Using (2) and (9), (15) can be rewritten as

$$y_t = \left(\frac{s_{Kt}}{n_t + g(k_t) + d}\right)^{\frac{\alpha}{1-\alpha}} l_{Yt} h_t \left(\frac{\delta}{g(A_t)}\right)^{\frac{\gamma}{\lambda}} \tilde{H}_{At}^{\gamma} \left[E_t^{\beta} \left(\frac{G5MT_t}{Y_t}\right)^{\mu} \left(\frac{G5FDI_t}{K_t}\right)^{\kappa}\right]^{\frac{\gamma}{\lambda}}, \tag{16}$$

where $k \equiv \frac{K}{L}$, and $\gamma \equiv \frac{\sigma}{1-\alpha}\frac{\lambda}{1-\phi}$. Note that in the derivation of (16), we do not have to restrict the growth rates $g(k_t)$ and $g(A_t)$ to be constant.[3] Along a steady-state balanced-growth path where the capital-output ratio (K_t / Y_t), l_{Yt}, h_t, $g(A_t)$, E_t, $\frac{G5MT_t}{Y_t}$, $\frac{G5FDI_t}{K_t}$, and G5 research intensity $\tilde{l}_{At}$ are all constant, the growth rate of output per worker is

$$g(y) = \gamma\tilde{n}\,, \tag{17}$$

where $\tilde{n}$ is the exogenous growth rate of the combined labor force of the G5 economies. In a world of ideas, the follower-economy's balanced-growth path is driven by the labor force growth in the G5 economies where ideas spread out. However, its growth outside the balanced-growth path will be influenced by its capital intensity, distance to frontier, and the three channels facilitating the spillover of ideas, namely, the quality of learning and the linkage to advanced imported technology through capital import and foreign direct investment from G5.

3. Quantitative Analysis

Based on the theoretical model developed in the previous section, we are now equipped to conduct a growth accounting exercise for a follower-economy in a world of ideas. We will use the data for Singapore and examine whether the three channels of idea transmission are quantitatively important in explaining the growth rate of the stock of adopted ideas, or equivalently, multifactor productivity.

We will briefly describe the data sources and construction of data series, discuss some of the key variables, and report the results of our growth accounting exercises. We first report results for our baseline case where the capital coefficient, α, is equal to 1/3 and then results based upon different values of α. Finally, we conduct a quantitative analysis of the implied rates of return to capital.

3.1. Data Sources and Data Construction

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[3] Jones (2002) assumes that the stocks *K* and *A* grow at constant rates as his focus is on the constant growth path of the U.S. economy. The derivation of (10) in Jones (2002) actually does not require constant growth rates in *K* and *A*. Our derivation of (16) without such restrictions is provided in Appendix 2.

The data used are obtained from and computed based on various sources.

Singapore

Population. Data on Singapore's population is obtained from the Singapore Department of Statistics at http://www.singstat.gov.sg. The data presented in the website are mid-year estimates.

Employment. Population Censuses 1970, 1980, 1990, and 2000 provide data for 1957, 1970, 1980, 1995, and 2000. *Report on the Labor Force Survey of Singapore* provides data from 1973 to 1999 and *Report on Labor Force in Singapore* provides data from 2001 to 2002, excluding those reported by the various censuses. Missing observations are log-linearly interpolated.

GDP. Data on Singapore's real GDP at 1995 prices is taken from the Singapore Department of Statistics at http://www.singstat.gov.sg. Real GDP per capita at 1995 prices is derived by dividing the above series by the population. Real GDP per worker at 1995 prices is derived by dividing real GDP by the number of employed workers. Nominal GDP is taken from http://www.singstat.gov.sg. We have also divided the nominal GDP by the real GDP at 1995 prices to obtain the GDP deflator with base year in 1995.

Imports of Machinery and Transport Equipment from G5 nations. *Singapore External Trade Statistics* provides data from 1958 to 1974, *Singapore Trade Statistics Imports and Exports* provides data from 1975 to 1990, and the Singstat Time Series (STS) available from the Singapore Department of Statistics provides data from 1991 to 2002. The data correspond to category 7 of the Standard International Trade Classification (SITC). The price index is constructed from nominal (current prices) and real (in 1995 prices) machinery and transport equipment components of Gross Fixed Capital Formation (GFCF) from the Singstat Time Series available from the Singapore Department of Statistics. Real imports of machinery and transport equipment from G5 are then obtained by dividing the nominal imports by the constructed price index.

Foreign Direct Equity Investment. Data for stock of foreign direct equity investment in Singapore by country of origin (G5 countries, Netherlands, and European Union) are obtained from the Singapore Department of Statistics for the years 1970 to 1979, with that of 1980 to 2001 taken from *Foreign Equity Investment in Singapore*.

France’s data for 1970 to 1987, and 1990 to 1993 are not available. We estimate them by adopting the following procedure (with details available upon request in a spreadsheet): Foreign direct equity investment from France is a fraction of the difference between the sum of Japan, U.S., European Union less Netherlands, and foreign direct equity investment from G4 countries (that is, excluding France). France’s share of the difference is computed for 1988, 1989, and 1994 to 2002. For 1970 to 1987, its share is assumed to be the same as that of 1988. For 1990 to 1993, its share is log-linearly interpolated. Based on these shares, we estimate France’s foreign direct equity investment for 1970 to 1987, and 1990 to 1993. Nominal stock values of foreign direct equity investment from G5 are obtained and divided by the nominal values of total capital stock estimated and described below.

Educational Attainment. The average number of years of schooling for residents aged 25 and above is obtained from Barro and Lee (2000) for years 1960, 1965, 1970, and 1975 and from the *Yearbook of Statistics* for years 1980, and 1985 to 2003. Log-linear interpolation is carried out for years where such data are unavailable.

Tertiary Enrollment. Data are obtained from the *Yearbook of Statistics*. Data on enrollment in institutes of higher learning (IHL) combined are available for 1960 to 1992. From 1993 onwards, figures for polytechnics, the National Institute of Education, and the universities are available.

Gross Fixed Capital Formation and Increase in Stocks. These are obtained from the SingStat Time Series (STS), available from the Singapore Department of Statistics. The base year is 1995. Data on various asset classes of Gross Fixed Capital Formation (GFCF) are also obtained from *Economic Survey of Singapore* for data since 1993 and *Singapore System of National Accounts 1995* for earlier years.

Data Pertaining to Depreciation. Let Gross Fixed Capital Formation (GFCF) as a whole be x_t, and the GFCF of asset class i be x_{it}, where t denotes year. Straight-line depreciation is assumed for the various asset classes, as in OECD (2001). Hence, depreciation rate of asset class i, d_i, is the reciprocal of the average service life of asset class i. The average service lives of Residential Buildings (80 years), Non-Residential Buildings (40 years), Other Construction and Works (40 years), Transport Equipment (15 years) (assumed to be the simple average of Ships and Boats (20 years), Aircraft (15 years), and Road Vehicles (10 years)), and Machinery and Equipment (15 years) are supplied by the Singapore Department of Statistics in OECD (2001, page 98). We first compute the average proportion of GFCF on asset class *i* by the following:

$$\bar{x}_i = \frac{1}{T}\sum_{t=1}^{T}\frac{x_{it}}{x_t},$$

where *T* is the total number of years in the period considered.

The weighted depreciation rate is computed as follows:

$$d = \sum_i \bar{x}_i d_i .$$

Construction of capital stock series. The steps taken are:

1. Real figures for Gross fixed capital formation (GFCF) and increase in stocks (IIS) are obtained from the Singstat Time Series (STS) available from the Singapore Department of Statistics. The base year is 1995. Real gross investment is obtained by adding up real GFCF and IIS.

2. An initial net real capital stock figure is computed by the following: $K(0) = \dfrac{I(0)(1+g)}{g+d}$, where g is the growth rate of gross investment and d is the depreciation rate of capital stock as computed above. Note that g is computed by running a regression of the natural logarithm of gross investment on an intercept and trend term. The coefficient of the trend term indicates the growth rate of gross investment.

3. Subsequent net real capital stock figures are computed by the following: $K(t) = (1-d)K(t-1) + I(t)$, where all figures used are in real terms.

4. The above method of computing the net real capital stock is based on Park (1995, page 590) and Gong, Greiner and Semmler (2004, pages 158-159).

<u>G5 nations</u>

Research Scientists and Engineers. Data prior to 1993 are taken from Jones (2002). To extend Jones' series beyond 1993, we use data from OECD (2005). Missing observations for Germany (1994) and the U.S. (1986, 1988, 1990, 1992, 1994, 1996, 1998) are log-linearly interpolated. Data for U.K. from 1999 to 2002 are estimated from Higher Education Statistical Agency (1998/99 to 2002/03) and OECD (2006, Table 6). Based on these (estimated) data, we sum up the *RSE*'s of G5 countries and compute the annual growth rates of combined G5 *RSE*'s from 1994 to 2002. We then use these growth rates to extend Jones' G5 *RSE*'s to cover 1994 to 2002. Details are given in a spreadsheet available upon request.

Labor Force. The data are taken from Bureau of Labor Statistics (2006), also available at http://www.bls.gov/fls.

3.2. Key Variables

We will consider three overlapping periods in Table 1. The first period from 1970 to 2002 gives the widest coverage where data for all variables are available. Data on foreign direct investment are only available from 1970 to 2002 while data on G5 *RSE*'s are only available from 1960 to 2002. The second period from 1966 to 1990 is the period of study used in Young (1992, 1995). The third period 1970 to 1990 corresponds closest to that of Young (1992, 1995) when we incorporate the channels of idea transmission since data on foreign direct investment are not available before 1970. Table 1 shows the average annual growth rates of some key variables for the different sample periods. Our baseline model takes the case of output elasticity of capital $\alpha = 1/3$, which is consistent with a follower-economy in a world of ideas. The justification is that α itself is a feature of technology and in a world where technological followers adopt the ideas created by technological leaders, the value of α should be approximately the same in all countries. (Jones (2005) endogenously derives the shape of the production function and shows that if the distribution of ideas is Pareto, the global production function is Cobb-Douglas.) This is the view taken by Gollin (2002) who shows that countries with high measured capital shares in national income might nevertheless have the same α when account is taken of the prevalence of self-employment in these high capital share countries. He argues that for a number of reasons, the labor income of the self-employed is often treated incorrectly as capital income. Once corrections are made, he argues that α is stable both across time and across countries. A 1993 Singapore Department of Statistics paper showed that Singapore's share of self employed in total employment was about 13 to 14 percent in the 1980s compared to 9 percent in the U.K. and U.S. As a robustness check, we also report results of our growth accounting exercises for $\alpha = 0.53$ (the value used by Young (1992) under the assumption that perfect competition and constant returns to scale hold so that the measured average capital share in national income can be taken to be equal to α) as well as the values of α calculated by Kee (2004) under the assumption of imperfect competition and non-constant returns to scale to capital and labor.

[Table 1: Average Annual Growth Rates]

From Table 1, we observe that the growth rate of real GDP per worker was about 4 percent from 1970 to 2002, multifactor productivity growth rate was an average of 2.31 percent, average educational attainment grew at 1.04 percent, and the growth rate of capital-output ratio for the same period was an average of 1.32 percent. The average growth rate of G5 *RSE*'s, the engine of frontier ideas, was 2.96 percent from 1970 to 2002. The three channels of idea transmission were growing significantly: the quality of learning (which is measured by tertiary enrollment to employment ratio) registered an average growth rate of 3.48 percent from 1970 to 2002; G5 machinery imports to output ratio, 3.51 percent; and G5 FDI stock to total capital stock ratio, 2.94 percent. We have also computed the growth rate of the interaction of G5 machinery imports to output ratio and G5 FDI stock to total capital stock ratio because this interaction term will be useful when we do the growth accounting incorporating the idea transmission channels later.

The numbers for the other two periods are given in Table 1 and similar comparisons can be made. It is interesting to note that from 1966 to 1990 (corresponding to the period studied by Young (1992, 1995)) the multifactor productivity had an average growth rate of 3.32 percent,[4] a not insignificant number.

3.3. Growth Accounting in a Framework of Idea Transmission

This section will conduct a growth accounting exercise for Singapore, incorporating the channels of idea transmission. We use (2) and (4) to rewrite (16) as

$$y_t = \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}} l_{Yt} e^{\psi l_{ht}} \left(\frac{\delta}{g(A_t)}\right)^{\frac{\gamma}{\lambda}} \tilde{H}^{\gamma}_{At} [E_t^{\beta} (\frac{G5MT_t}{Y_t})^{\mu} (\frac{G5FDI_t}{K_t})^{\kappa}]^{\frac{\gamma}{\lambda}} . \tag{18}$$

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[4] If we assume $\alpha = 0.53$ instead of $\alpha = 1/3$, the average growth rate of multifactor productivity, calculated as the residual in (15) and corresponding to the term, $A^{\frac{\sigma}{1-\alpha}}$, from 1966 to 1990 is 2.70 percent, which is still not insignificant.

Taking natural logarithm and differentiating with respect to time, and using (8), we have

$$\begin{aligned} g(y_t) &= \frac{\alpha}{1-\alpha} g(\frac{K_t}{Y_t}) + g(l_{Yt}) + \frac{\gamma}{\lambda} g(g(A_t)) + \psi \Delta l_{ht} + \gamma g(\tilde{l}_{At}) + \gamma \tilde{m} \\ &\quad + \frac{\beta}{1-\phi} g(E_t) + \frac{\mu}{1-\phi} g(\frac{G5MT_t}{Y_t}) + \frac{\kappa}{1-\phi} g(\frac{G5FDI_t}{K_t}). \end{aligned} \tag{19}$$

For Singapore, the share of employed workers engaged in R&D is about one percent in 2002 so $l_Y = 0.99$, which is close to unity. Our analysis will proceed under the approximation that $l_A = 0$ and $l_Y = 1$. We also take the interaction term, $\frac{G5MT}{Y} . \frac{G5FDI}{K}$, to represent the effectiveness of idea transmission from the G5 countries through machine imports and foreign direct investment. When a multinational corporation set up by a G5 country in Singapore imports machinery from its home country, it is empirically difficult to disentangle the separate knowledge transmission effects of machinery imports and foreign direct investment. Thus, we assume that $\mu = \kappa = \eta$ in (18) and (19). As pointed out before, we tested whether $g(A)$ can statistically be considered a constant in Appendix 1. The test results confirm that $g(A)$ is stationary and that $g(g(A_t))$ is not statistically different from zero. Therefore, in the growth accounting exercise to follow, we will take $g(g(A_t)) = 0$. Hence, the growth accounting equation for Singapore can be simplified to

$$\begin{aligned} g(y_t) &= \frac{\alpha}{1-\alpha} g(\frac{K_t}{Y_t}) + \psi \Delta l_{ht} + \gamma g(\tilde{l}_{At}) + \gamma \tilde{m} \\ &\quad + \frac{\beta}{1-\phi} g(E_t) + \frac{\eta}{1-\phi} g(\frac{G5MT_t}{Y_t} . \frac{G5FDI_t}{K_t}). \end{aligned} \tag{20}$$

In our growth accounting exercise, we take $\alpha = 1/3$ to be our baseline case. We take the return to schooling parameter $\psi = 0.07$, the same value used in Jones (2002), based on evidence from the literature of the labor market. To conduct the growth accounting exercise, we will need to empirically estimate three parameter values: γ, $\frac{\beta}{1-\phi}$ and $\frac{\eta}{1-\phi}$. (Since Jones (2002) assumed immediate dissemination of ideas, he only had to econometrically estimate one parameter, namely, γ.) The detailed regression results are given in Appendix 3. The approach adopted here of first obtaining values for multifactor productivity as a residual in the usual way, and then proceeding to use the residuals in a regression equation to estimate the coefficients in an idea production function was first used in an important paper by Griliches (1973). Griliches (1973) made R&D capital the main input in his idea production function whereas Jones (2002) made the number of research scientists and engineers the main input. Our approach builds on the Jones' formulation but goes on further to incorporate the channels for technological diffusion. We point out that as we go from the baseline case of $\alpha = 1/3$ to alternative values of α, we recalculate multifactor productivity as the residual in (15) using different values of α, and econometrically re-estimate γ, $\frac{\beta}{1-\phi}$ and $\frac{\eta}{1-\phi}$ accordingly. The actual estimated values of the parameters used in each case are noted in Tables 2 to 5.

Assuming $\alpha = 1/3$, our baseline case, Table 2 provides the breakdown in contributions to growth. We only consider two periods, namely 1970 to 2002, and 1970 to 1990, since foreign direct investment data are available from 1970 onwards.

[Table 2: Accounting for Singapore's Growth with Transmission Channels (α = 1/3)]

From Table 2, we see that the portion of unexplained growth is -2.29 percent for the period 1970 to 2002. The negative unexplained residual implies that there is over-explanation of growth based upon the contributions of all the terms appearing on the right-hand-side of (20). Using this residual to make an adjustment, we can say that the idea transmission channels help to account for 33.74 + 20.36 – 2.29 = 51.81 percent of $g(y)$ for the period 1970 to 2002. Similarly, for the period 1970 to 1990, after making the adjustment for over-explanation, the transmission channels account for 45.19 percent of $g(y)$. It is noteworthy that the quality of learning, measured by tertiary enrollment to employment ratio, is the most important contributor to $g(y)$, commanding a share of 33.74 percent for the period 1970 to 2002, and a share of 29.46 percent for the period from 1970 to 1990. This finding gives support to the Nelson-Phelps (1966) hypothesis that higher education is valuable in helping technological followers to copy ideas from technological leaders. In Appendix 4, Table A6 presents the results for two sub-periods:

1970 to 1984 and 1984 to 2002.[5] Over there, we observe that the role of educational quality in assimilating ideas from abroad gains more prominence in the later period: 24.73 percent in the earlier period and 47.16 percent in the later period. That is, the closer the economy is to the world technology frontier, the more important higher education is as a contributor to effective technology diffusion from technological leader to follower. This result is consistent with the findings of Aghion, et al. (2005, p. 2) that "the closer a U.S. state is to the technological frontier at the beginning of the current period, the more important `high brow' education---that is, education oriented toward research at the frontier of technology---will be as a source of productivity growth."

Are the results robust to a change in the value of α? Table 3 assumes $\alpha = 0.53$. Compared to Table 2, Table 3 shows a greater contribution of capital intensity to growth, which is about 37.35 percent for the period 1970 to 2002, and 51.74 percent from 1970 to 1990. Nevertheless, the contribution of higher learning to growth through boosting multifactor productivity remains huge at 36.13 percent and 31.54 percent, respectively, for the period 1970 to 2002, and 1970 to 1990. With this new value of $\alpha = 0.53$, the portion of unexplained growth is -16.19 percent and -30.35 percent, respectively, for the two periods. The huge (negative) residual, especially for the period 1970 to 1990, suggests that α may have been set too high at 0.53 and that the true value should be closer to 1/3 as is appropriate for a follower-economy in a world of idea transmission.

[Table 3: Accounting for Singapore's Growth with Transmission Channels ($\alpha = 0.53$)]

Next, as another robustness test, we use the values of α calculated for Singapore by Kee (2004) based upon departures from perfect competition and constant returns to scale to capital and labor. Table 6 in Kee (2004) gives a primal estimate of a price markup equal to 1.33 and a primal estimate of returns to scale to capital and labor equal to 0.87 for the aggregate economy. Table 2 in Kee (2004) also estimates an average labor share in total value added of 0.47 for the aggregate economy from 1970 to 2001. Using

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[5] Tables A6 to A9 in Appendix 4 provide the growth accounting for two sub-periods: 1970 to 1984, and 1984 to 2002. The assumptions for these tables correspond to those in Tables 2 to 5.

these estimates, the output elasticity of labor is equal to 0.47 x 1.33 = 0.6251. Supposing that the assumption on constant returns to scale to capital and labor is retained but imperfect competition prevails, the output elasticity of capital α is equal to 1 - 0.6251 = 0.3749. This value of α will be used in Table 4. If we assume the returns to scale coefficient is equal to 0.87 and imperfect competition also prevails, the output elasticity of capital α is equal to 0.87 – 0.6251 = 0.2449. Our Table 5 will assume an output elasticity of labor of 0.6251 and an output elasticity of capital of 0.2449.

[Table 4: Accounting for Singapore's Growth with Transmission Channels (α = 0.3749)]

From Table 4, we observe that the portion of unexplained real GDP per worker growth is small, -4.15 percent for the period 1970-2002, while the learning effect is an important transmission channel for the follower-economy of Singapore, explaining 33.78 percent of $g(y)$. Again, the results are consistent with those reported in the earlier tables.

Now, relaxing the assumption of constant returns to scale to capital and labor requires amendments of some key equations in the model. The goods production function (1) is amended to

$$Y_t = A_t^{\sigma} K_t^{\alpha} H_{Yt}^{\chi}, \tag{21}$$

where $\sigma \neq 1 - \alpha$, $\alpha + \chi < 1$, and $\sigma = \chi$. The growth accounting equation (20) is amended to

$$\begin{aligned} g(y_t) = {} & \frac{\alpha}{1-\alpha} g(\frac{K_t}{Y_t}) + \frac{\chi}{1-\alpha} \psi \Delta l_{ht} + \frac{\sigma}{1-\alpha} \gamma g(\tilde{l}_{At}) + \frac{\sigma}{1-\alpha} \gamma \tilde{m} \\ & + \frac{\beta}{1-\phi} g(E_t) + \frac{\eta}{1-\phi} g(\frac{G5MT_t}{Y_t} . \frac{G5FDI_t}{K_t}) + \frac{\alpha + \chi - 1}{1-\alpha} g(L_t). \end{aligned} \tag{22}$$

Table 5 shows the results with these new assumptions. The unexplained portion of growth is now a small positive number, 1.94 percent, for the period 1970 to 2002. With decreasing returns to scale to capital and labor, employment growth now brings about a decrease in $g(y)$. The employment growth effect explains -15.96 percent of real GDP per worker growth for the period 1970 to 2002. Multifactor productivity growth now plays a very huge role to overcome the negative employment growth effect, contributing to 81.83 percent of real GDP per worker growth.[6]

[Table 5: Accounting for Singapore's Growth with Transmission Channels (α = 0.2449)]

3.4. Implications for the Rate of Return to Capital

This sub-section will discuss the theoretical implications for the rate of return to capital for a follower-economy in a world of ideas, and provide a quantitative breakdown of the components of the rate of return to capital. We take α = 1/3 to be the baseline case but will also present results under different assumptions about the value of α as a robustness test.

The rate of return to capital is not just the direct marginal product of capital (MPK) in our model because an additional unit of capital will also affect the accumulation of the stock of ideas for the follower-economy through two idea transmission channels: linkage to advanced technology via machinery imports, and quality of capital stock via foreign direct investment from G5 countries. The channel of quality of learning is assumed not to be affected by a change in *K*. Differentiating the goods production function (1) with respect to *K*, we have

$$\frac{dY}{dK} = \frac{\alpha Y}{K} + \frac{(1-\alpha)Y}{A}\frac{dA}{dK}\text{, or,}$$

$$\frac{dY}{dK} = \frac{\alpha Y}{K} + \frac{(1-\alpha)Y}{K} \times$$

$$\left[\frac{\partial \ln A}{\partial \ln\left(\frac{G5MT}{Y}\right)} \frac{1}{\frac{\partial \ln K}{\partial \ln\left(\frac{G5MT}{Y}\right)}} + \frac{\partial \ln A}{\partial \ln\left(\frac{G5FDI}{K}\right)} \frac{1}{\frac{\partial \ln K}{\partial \ln\left(\frac{G5FDI}{K}\right)}} \right]. \tag{23}$$

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[6] This is the sum of the contribution of G5 R&D intensity effect (6.15%), scale effect of G5 labor force (4.32%), learning effect (39.41%) and linkage to G5 via capital imports and foreign direct investment (31.95%).

From (23), we see that the association of an increase in *K* with imports of machinery and transport equipment from G5 countries and with G5 foreign direct investment will facilitate the transmission of ideas, raising *A* and consequently the rate of return to capital. This indirect effect will add on to the direct MPK effect. Note that this indirect effect may diminish as *K* increases further as the term in squared brackets in (23) is multiplied to *Y*/*K*, which could be decreasing in *K*. In other words, for a follower-economy, the extra lift to the rate of return to capital provided by the two idea transmission channels could be temporary and not permanent.

How do we break down the components of the rate of return to capital quantitatively using (23)? Note that using the definition of *g*(*A*), we may rewrite (9) as

$$\ln A_t = \frac{1}{1-\phi}\ln\frac{\delta}{g(A_t)} + \frac{\lambda}{1-\phi}\ln\tilde{H}_{At} + \frac{\beta}{1-\phi}\ln E_t + \frac{\mu}{1-\phi}\ln\frac{G5MT_t}{Y_t} + \frac{\kappa}{1-\phi}\ln\frac{G5FDI_t}{K_t}\ .$$

Hence,

$$\frac{\partial \ln A}{\partial \ln\left(\frac{G5MT}{Y}\right)} = \frac{\mu}{1-\phi}\text{, and}$$

$$\frac{\partial \ln A}{\partial \ln\left(\frac{G5FDI}{K}\right)} = \frac{\kappa}{1-\phi}\ .$$

In our empirical studies, we have estimates for $\frac{\mu}{1-\phi}$ and $\frac{\kappa}{1-\phi}$, where $\mu = \kappa = \eta$. Next, we need to compute the percentage change in *K* corresponding to the percentage change in $\frac{G5MT}{Y}$ and $\frac{G5FDI}{K}$, respectively, for each year. The empirical version of (23) is then given by

$$\frac{dY}{dK} = \frac{\alpha Y}{K} + \frac{(1-\alpha)Y}{K}.\frac{\eta}{1-\phi}\left[\frac{1}{\frac{\frac{\Delta K}{K}}{\frac{\Delta G5m}{G5m}}} + \frac{1}{\frac{\frac{\Delta K}{K}}{\frac{\Delta G5f}{G5f}}}\right]. \qquad (24)$$

For the case of non-constant returns to scale in the goods production function, (24) is amended to

$$\frac{dY}{dK}=\frac{\alpha Y}{K}+\frac{\chi Y}{K}.\frac{\eta}{1-\phi}\left[\frac{1}{\frac{\frac{\Delta K}{K}}{\frac{\Delta G5m}{G5m}}}+\frac{1}{\frac{\frac{\Delta K}{K}}{\frac{\Delta G5f}{G5f}}}\right]. \tag{25}$$

To abstract from business cycle movements, we apply Hodrick-Prescott filters to the empirical components of (24) and (25). Figure 5 shows the Hodrick-Prescott filtered MPK's: the first term of (24) which is without transmission channels, and the entire right-hand side of (24) with transmission channels, for the baseline case of α = 1/3. We observe that the rate of return to capital did diminish in the 1970s; however, with the influence of idea transmission channels incorporated, the rate of return to capital was higher than the conventionally calculated rate of return to capital based on exogenous technological progress throughout the period under study.

[Figure 5: HP-Filtered MPK's (α = 1/3)]

Table 6 shows a breakdown of the various components of the rate of return to capital for the 1970s, 1980s, 1990s and for the whole period 1971-2002. We see that the idea transmission effect accounted for about 20.02 percent of the total rate of return to capital in the 1970s. Their contribution was smaller in the 1990s, about 12.96 percent. For the entire period, it is 16.61 percent. Equivalently, for the period 1971-2002, including the idea transmission mechanism raises the rate of return to capital by about 0.0215/0.1080 = 19.91 percent. Compared to the rate of return to capital inferred from the traditional Solow growth model with purely exogenous technological progress of 10.8 percent, we find that taking into account the technology transfer channel raises the implied rate of return to 13 percent for the period 1971-2002.

[Table 6: Breakdown of Rate of Return to Capital (α =1/3)]

Will the results be changed if we assume $\alpha = 0.53$? Figure 6 shows that the rates of return to capital with and without transmission channels are close to each other; nevertheless, the one with the idea transmission channels is higher. The contribution by the idea transmission effect accounted for about 3.49 percent to 5.73 percent of the total rate of return to capital for the three decades shown in Table 7.

[Figure 6: HP-Filtered MPK's ($\alpha = 0.53$)]

[Table 7: Breakdown of Rate of Return to Capital ($\alpha = 0.53$)]

Next, we consider the case where there is imperfect competition while retaining the assumption of constant returns to scale. Figure 7 shows a higher rate of return to capital when transmission channels are incorporated, consistent with Figure 5 and Figure 6. Table 8 shows that the contribution of the idea transmission effect was about 10.26 percent to 16.12 percent for the three decades.

[Figure 7: HP-Filtered MPK's ($\alpha = 0.3749$)]

[Table 8: Breakdown of Rate of Return to Capital ($\alpha = 0.3749$)]

Lastly, we consider the case of imperfect competition and non-constant returns to scale to capital and labor. The results are robust. Figure 8 shows a much higher rate of return to capital with transmission channels. In fact, the idea transmission effect accounted for 37.72 percent of the total rate of return to capital in the 1970s, and 26.49 percent in the 1990s, as given in Table 9.

[Figure 8: HP-Filtered MPK's ($\alpha = 0.2449$)]

[Table 9: Breakdown of Rate of Return to Capital ($\alpha = 0.2449$)]

4. Conclusion

Our quantitative exercise shows that physical and human capital investments can explain only 42.5 percent of Singapore's real GDP per worker growth rate over the 1970-

2002 period. By estimating the production of ideas in the G5 countries following the lead of Jones (2002) and being explicit about the channels through which these ideas get implemented in Singapore following the lead of Coe, Helpman and Hoffmaister (1997) and Hejazi and Safarian (1999), we show that the quality of education as well as imports of machinery and foreign direct investment from the G5 countries, by increasing the effectiveness of accessing ideas from abroad, account for 51.8 percent of the growth of Singapore's real GDP per worker. Our finding from the growth accounting exercise for a follower-economy of Singapore, the second fastest-growing economy over the 1960-2000 period in the 112-country sample of Barro and Sala-i-Martin (2004), that 57.5 percent of growth in its standard of living is due to multifactor productivity growth is consistent with the finding from international cross-sectional studies that it is mainly the difference in multifactor productivity growth rates that explains the difference in growth rates of real per capita GDP.

Our findings raise the question why Tsao (1985) and Young (1992, 1995) found such low multifactor productivity growth for Singapore. An explanation that Hsieh (2002) has offered is that the official statistics have substantially overstated the growth of capital since his use of the dual approach gave an estimate of multifactor productivity growth for Singapore of 2.2 percent per year for the period 1972-90 compared to Young's 0.2 percent for 1966-1990. We have found, using the most recent data from the Singapore Department of Statistics currently available to the public, that there is, in fact, a far larger role played by multifactor productivity growth in explaining Singapore's real GDP per worker growth. Moreover, we are able to show that the sources of multifactor productivity growth come from factors that growth theories and empirics in the past two decades have shown to be very important, namely, educational quality and effective links to the world's technological leaders through trade and foreign direct investment.

Our study also highlights an essential difference between a follower-economy and a technology leader. Jones (2002) found that the assumption that ideas produced by world's research efforts are immediately disseminated to the U.S. economy is a good one. This assumption, however, does not hold for a follower-economy like Singapore where the channels for technological diffusion take center stage. In theory, for a given level of educational quality and strength of international linkage via trade and foreign direct investment, there is a multifactor productivity catch-up if a follower-economy is initially far away from its steady-state distance to frontier so multifactor productivity growth gradually declines as a follower-economy becomes richer. One finding of our paper is that the strength of the channels of idea transmission in Singapore has been rising steadily thus reducing the steady-state distance to frontier. The result is that there have been new and higher transition paths of multifactor productivity so that the growth rate of multifactor productivity has remained roughly unchanged. So Singapore's real GDP growth has been stable because its multifactor productivity growth has been stable.

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Table 1: Average Annual Growth Rates

Growth Rate of	Variable	70-02 Average	66-90 Average	70-90 Average
Real GDP per worker	$g(y)$	0.039752	0.048007	0.039195
Capital-output ratio	$g(K/Y)$	0.013168	0.011536	0.017984
Human capital	$g(h)$	0.010388	0.009322	0.009910
Multifactor productivity	$g(A)$	0.023090	0.033155	0.020454
G5 R&D labor	$g(\tilde{H}_A)$	0.029598	0.034383	0.034412
G5 labor force	$g(\tilde{n})$	0.012656	0.013829	0.014040
Share of G5 labor in R&D	$g(\tilde{l}_A)$	0.018016	0.021441	0.021539
Change in average years of schooling	Δl_h	0.147111	0.132400	0.140699
Tertiary enrollment to employment ratio	$g(E)$	0.034750	0.017594	0.029911
G5 machinery imports-output ratio	$g(\frac{G5MT}{Y})$	0.035067	0.074508	0.063291
G5 FDI stock-total capital stock ratio	$g(\frac{G5FDI}{K})$	0.029376		0.022858
Interaction of *G5MT_Y* and *G5FDI_K*	$g(\frac{G5MT}{Y}.\frac{G5FDI}{K})$	0.054243		0.073360

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables.

Table 2: Accounting for Singapore's Growth with Transmission Channels (α = 1/3)

Description	**Variable**	**70-02 Average**	**70-90 Average**
Growth rate of real GDP per worker equals:	$g(y)$	0.039752 (100.00%)	0.039195 (100.00%)
Capital intensity effect	$\frac{\alpha}{1-\alpha} g(\frac{K}{Y})$	0.006584 (16.56%)	0.008992 (22.94%)
Educational attainment effect	$\psi \Delta l_h$	0.010298 (25.90%)	0.009849 (25.13%)
G5 R&D intensity effect	$\gamma g(\tilde{l}_A)$	0.001337 (3.36%)	0.001598 (4.08%)
Scale effect of G5 labor force	$\gamma \tilde{m}$	0.000939 (2.36%)	0.001042 (2.66%)
Tertiary enrollment to employment ratio learning effect	$\frac{\beta}{1-\phi} g(E)$	0.013414 (33.74%)	0.011547 (29.46%)
G5 machinery imports and FDI transmission effect	$\frac{\eta}{1-\phi} g(\frac{G5MT}{Y} . \frac{G5FDI}{K})$	0.008092 (20.36%)	0.010944 (27.92%)
Unexplained		**-2.29%**	**-12.19%**

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables. Note: We have assumed γ = 0.074213, the estimated value in specification (2) in Table A2 of Appendix 3. We have also assumed $\frac{\beta}{1-\phi}$ = 0.38603, and $\frac{\eta}{1-\phi}$ = 0.149179, values estimated when λ is set to 1.

Table 3: Accounting for Singapore's Growth with Transmission Channels (α = 0.53)

Description	**Variable**	**70-02 Average**	**70-90 Average**
Growth rate of real GDP per worker equals:	$g(y)$	0.039752 (100.00%)	0.039195 (100.00%)
Capital intensity effect	$\frac{\alpha}{1-\alpha} g(\frac{K}{Y})$	0.014849 (37.35%)	0.020279 (51.74%)
Educational attainment effect	$\psi \Delta l_h$	0.010298 (25.90%)	0.009849 (25.13%)
G5 R&D intensity effect	$\gamma g(\tilde{l}_A)$	0.001320 (3.32%)	0.001578 (4.03%)
Scale effect of G5 labor force	$\gamma \tilde{n}$	0.000927 (2.33%)	0.001029 (2.62%)
Tertiary enrollment to employment ratio learning effect	$\frac{\beta}{1-\phi} g(E)$	0.014363 (36.13%)	0.012363 (31.54%)
G5 machinery imports and FDI transmission effect	$\frac{\eta}{1-\phi} g(\frac{G5MT}{Y} . \frac{G5FDI}{K})$	0.004432 (11.15%)	0.005994 (15.29%)
Unexplained		**-16.19%**	**-30.35%**

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables. Note: We have assumed γ = 0.073259, the estimated value in specification (2) in Table A3 of Appendix 3. We have also assumed $\frac{\beta}{1-\phi}$ = 0.41333, and $\frac{\eta}{1-\phi}$ = 0.081702, values estimated when λ is set to 1.

Table 4: Accounting for Singapore's Growth with Transmission Channels (α = 0.3749)

Description	**Variable**	**70-02 Average**	**70-90 Average**
Growth rate of real GDP per person equals:	$g(y)$	0.039752 (100.00%)	0.039195 (100.00%)
Capital intensity effect	$\frac{\alpha}{1-\alpha} g(\frac{K}{Y})$	0.007897 (19.87%)	0.010786 (27.52%)
Educational attainment effect	$\psi \Delta l_h$	0.010298 (25.90%)	0.009849 (25.13%)
G5 R&D intensity effect	$\gamma g(\tilde{l}_A)$	0.001367 (3.44%)	0.001635 (4.17%)
Scale effect of G5 labor force	$\gamma \tilde{m}$	0.000961 (2.42%)	0.001066 (2.72%)
Tertiary enrollment to employment ratio learning effect	$\frac{\beta}{1-\phi} g(E)$	0.013427 (33.78%)	0.011557 (29.49%)
G5 machinery imports and FDI transmission effect	$\frac{\eta}{1-\phi} g(\frac{G5MT}{Y} . \frac{G5FDI}{K})$	0.007453 (18.75%)	0.010080 (25.72%)
Unexplained		**-4.15%**	**-14.74%**

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables. Note: We have assumed γ = 0.075904, the estimated value in specification (2) in Table A4 of Appendix 3. We have also assumed $\frac{\beta}{1-\phi}$ = 0.386391, and $\frac{\eta}{1-\phi}$ = 0.1374, values estimated when λ is set to 1.

Table 5: Accounting for Singapore's Growth with Transmission Channels (α = 0.2449)

Description	**Variable**	**70-02 Average**	**70-90 Average**
Growth rate of real GDP per person equals:	$g(y)$	0.039752 (100.00%)	0.039195 (100.00%)
Capital intensity effect	$\frac{\alpha}{1-\alpha} g(\frac{K}{Y})$	0.004271 (10.74%)	0.005833 (14.88%)
Educational attainment effect	$\frac{\chi}{1-\alpha} \psi \Delta l_h$	0.008525 (21.44%)	0.008153 (20.80%)
G5 R&D intensity effect	$\frac{\sigma}{1-\alpha} \gamma g(\tilde{l}_A)$	0.002446 (6.15%)	0.002924 (7.46%)
Scale effect of G5 labor force	$\frac{\sigma}{1-\alpha} \gamma \tilde{n}$	0.001718 (4.32%)	0.001906 (4.86%)
Tertiary enrollment to employment ratio learning effect	$\frac{\beta}{1-\phi} g(E)$	0.015667 (39.41%)	0.013485 (34.41%)
G5 machinery imports and FDI transmission effect	$\frac{\eta}{1-\phi} g(\frac{G5MT}{Y} . \frac{G5FDI}{K})$	0.012700 (31.95%)	0.017176 (43.82%)
Employment effect	$\frac{\alpha+\chi-1}{1-\alpha} g(L)$	-0.00634 (-15.96%)	-0.00766 (-19.55%)
Unexplained		**1.94%**	**-6.69%**

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables. Note: We have assumed γ = 0.164006, the estimated value in specification (2) in Table A5 of Appendix 3. We have also assumed $\frac{\beta}{1-\phi}$ = 0.544604, and $\frac{\eta}{1-\phi}$ = 0.282822, values estimated when λ is set to 1.

Table 6: Breakdown of Rate of Return to Capital (α = 1/3)

	71-79 Average	80-89 Average	90-99 Average	71-02 Average
Total	0.1527 (100%)	0.1186 (100%)	0.1197 (100%)	0.1295 (100%)
Direct MPK	0.1222 (79.98%)	0.1007 (84.87%)	0.1042 (87.04%)	0.1080 (83.39%)
G5 Machinery Imports and FDI Transmission Effect	0.0306 (20.02%)	0.0179 (15.13%)	0.0155 (12.96%)	0.0215 (16.61%)

Source: Computed based on data from Singapore Department of Statistics.

Note: We have assumed $\frac{\eta}{1-\phi}$ = 0.149179, which is estimated when λ is set to 1.

Table 7: Breakdown of Rate of Return to Capital (α = 0.53)

	71-79 Average	80-89 Average	90-99 Average	71-02 Average
Total	0.2060 (100%)	0.1670 (100%)	0.1717 (100%)	0.1800 (100%)
Direct MPK	0.1942 (94.27%)	0.1601 (95.85%)	0.1657 (96.51%)	0.1717 (95.39%)
G5 Machinery Imports and FDI Transmission Effect	0.0118 (5.73%)	0.0069 (4.15%)	0.0060 (3.49%)	0.0083 (4.61%)

Source: Computed based on data from Singapore Department of Statistics.

Note: We have assumed $\frac{\eta}{1-\phi}$ = 0.081702, which is estimated when λ is set to 1.

Table 8: Breakdown of Rate of Return to Capital: (α = 0.3749)

	71-79 Average	80-89 Average	90-99 Average	71-02 Average
Total	0.1638 (100%)	0.1287 (100%)	0.1306 (100%)	0.1400 (100%)
Direct MPK	0.1374 (83.88%)	0.1132 (87.96%)	0.1172 (89.74%)	0.1214 (86.74%)
G5 Machinery Imports and FDI Transmission Effect	0.0264 (16.12%)	0.0155 (12.04%)	0.0134 (10.26%)	0.0186 (13.26%)

Source: Computed based on data from Singapore Department of Statistics.

Note: We have assumed $\frac{\eta}{1-\phi}$ = 0.1374, which is estimated when λ is set to 1.

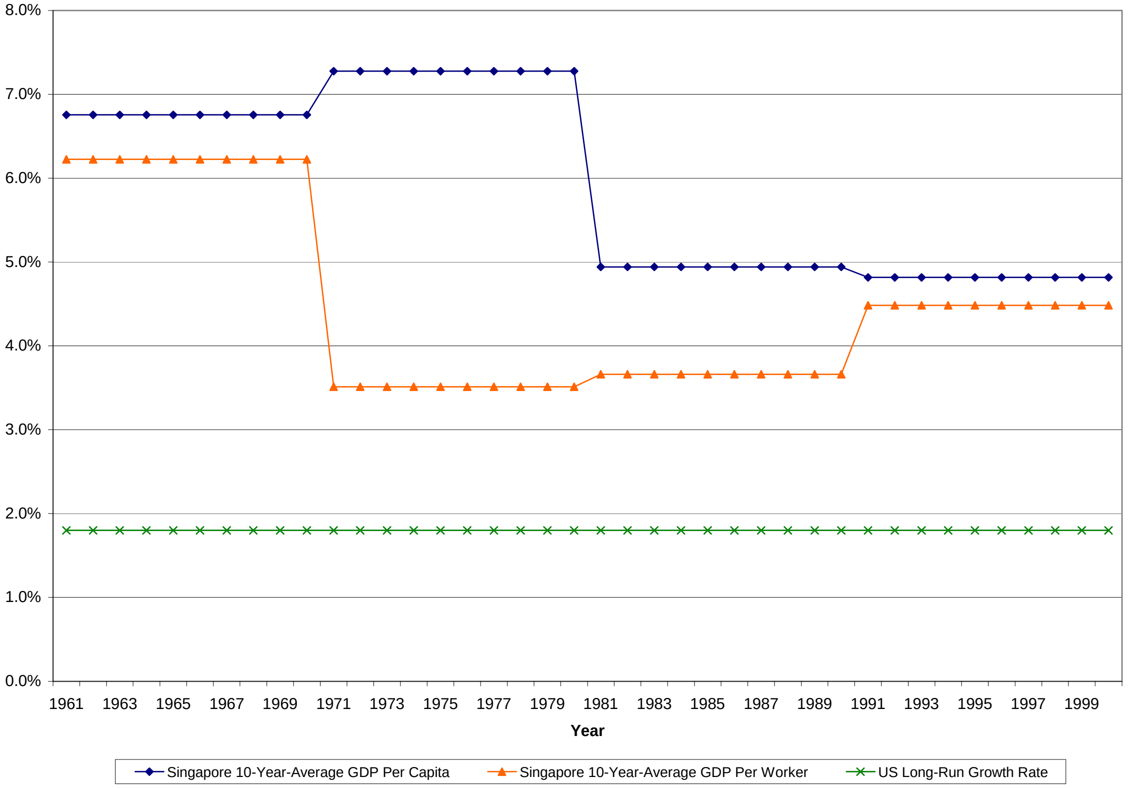
Table 9: Breakdown of Rate of Return to Capital (α = 0.2449)

	71-79 Average	80-89 Average	90-99 Average	71-02 Average
Total	0.1441 (100%)	0.10.59 (100%)	0.1042 (100%)	0.1175 (100%)
Direct MPK	0.0898 (62.28%)	0.0740 (69.87%)	0.0766 (73.51%)	0.0793 (67.48%)
G5 Machinery Imports and FDI Transmission Effect	0.0544 (37.72%)	0.0319 (30.13%)	0.0276 (26.49)	0.0382 (32.52%)

Source: Computed based on data from Singapore Department of Statistics.

Note: We have assumed $\frac{\eta}{1-\phi}$ = 0.282822, which is estimated when λ is set to 1.

Figure 1: Real Growth Rates

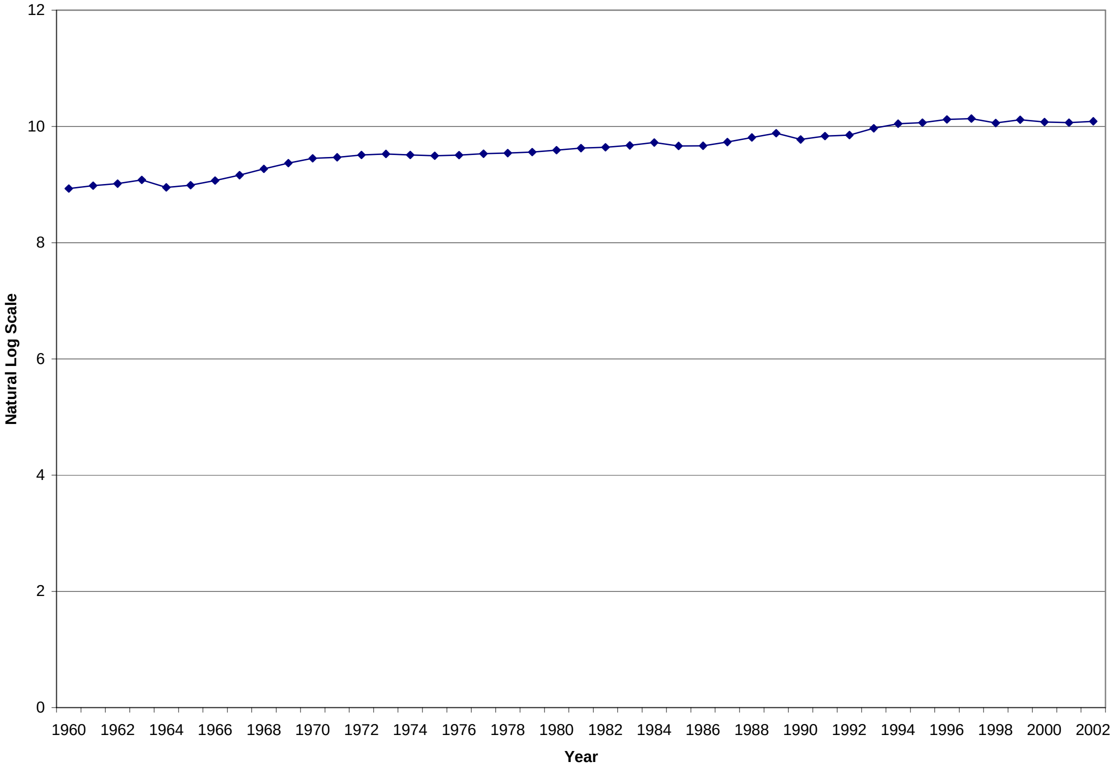


Source: Computed based on data from Singapore Department of Statistics.
Note: Jones (2002) pointed out that the average annual growth rate of per capita GDP for U.S. over the last 125 years has been a steady 1.8 percent per year. Barro and Sala-i-Martin (2004, chapter 12) reported a mean growth rate of 1.8 percent per year for a sample of 112 countries from 1960 to 2000.

Figure 2: Decadal Averages of Investment Rate and Change in Educational Attainment

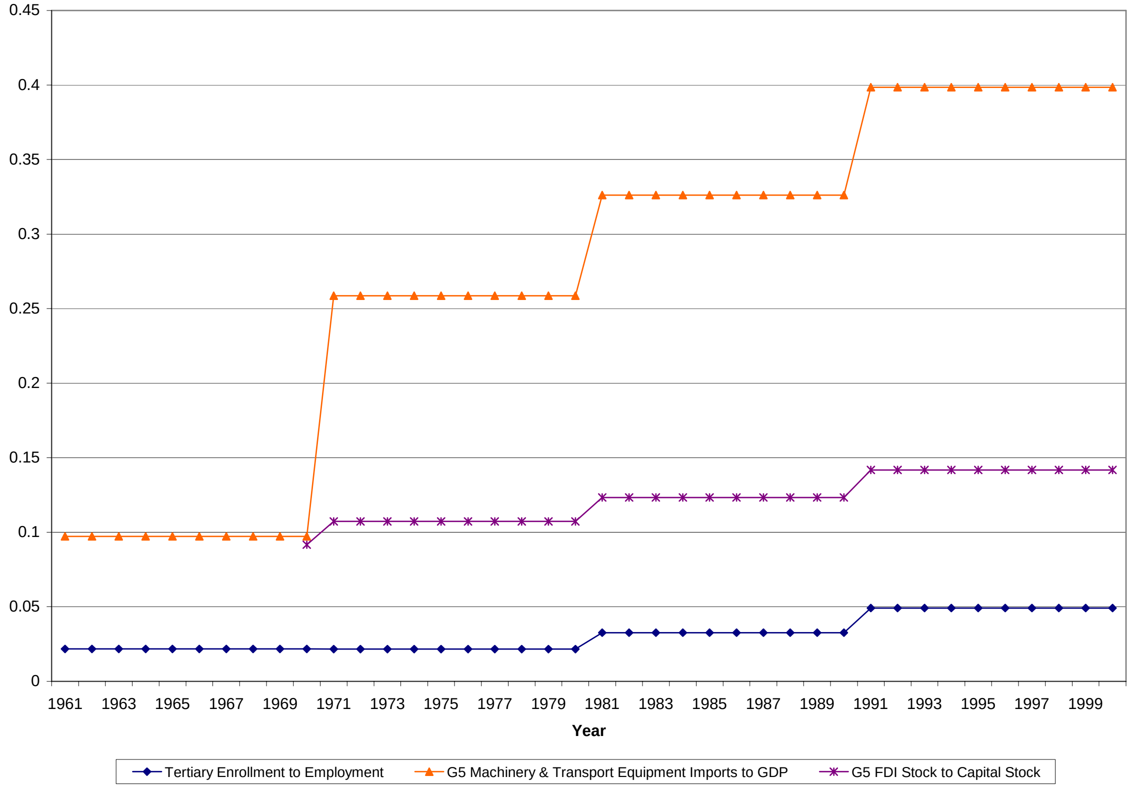
Source: Computed based on data from Singapore Department of Statistics
Note: The vertical scales for the 2 variables in Figure 2 are different. For the change in educational attainment, it is the increase in number of years of schooling. For instance, the average years of schooling increase by 0.2 year or 2.4 months per annum in the 1990s. For the investment rate, the vertical scale represents a fraction. For instance, 0.3 means 30%.

Figure 3: Multifactor Productivity in Singapore



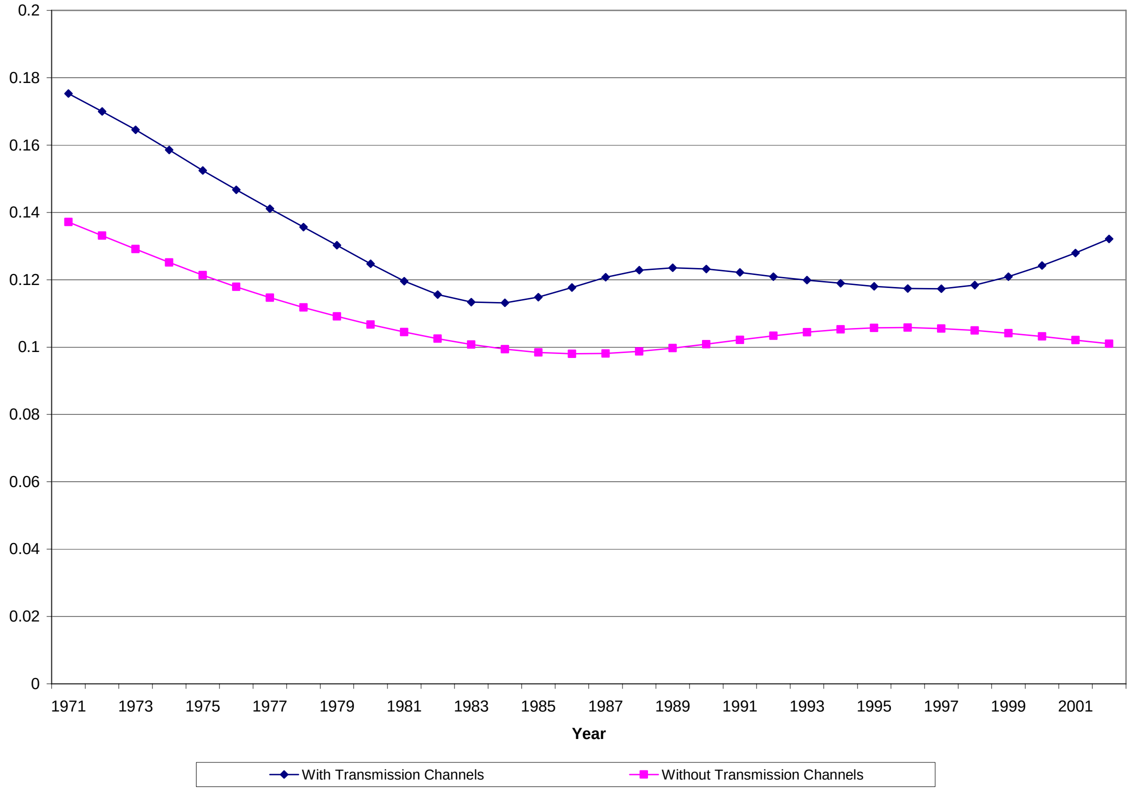
Source: Computed based on data from Singapore Department of Statistics. Multifactor productivity is computed as the residual in $Y_t / L_t = \left(\frac{K_t}{Y_t} \right)^{\frac{\alpha}{1-\alpha}} l_{Yt} h_t A_t^{\frac{\sigma}{1-\alpha}}$, assuming $\sigma = 1 - \alpha$, α = 1/3, and l_Y = 1, and corresponds to the term, $A_t^{\frac{\sigma}{1-\alpha}}$.

Figure 4: Decadal Averages of Idea Transmission Channels



Source: Computed based on data from Singapore Department of Statistics

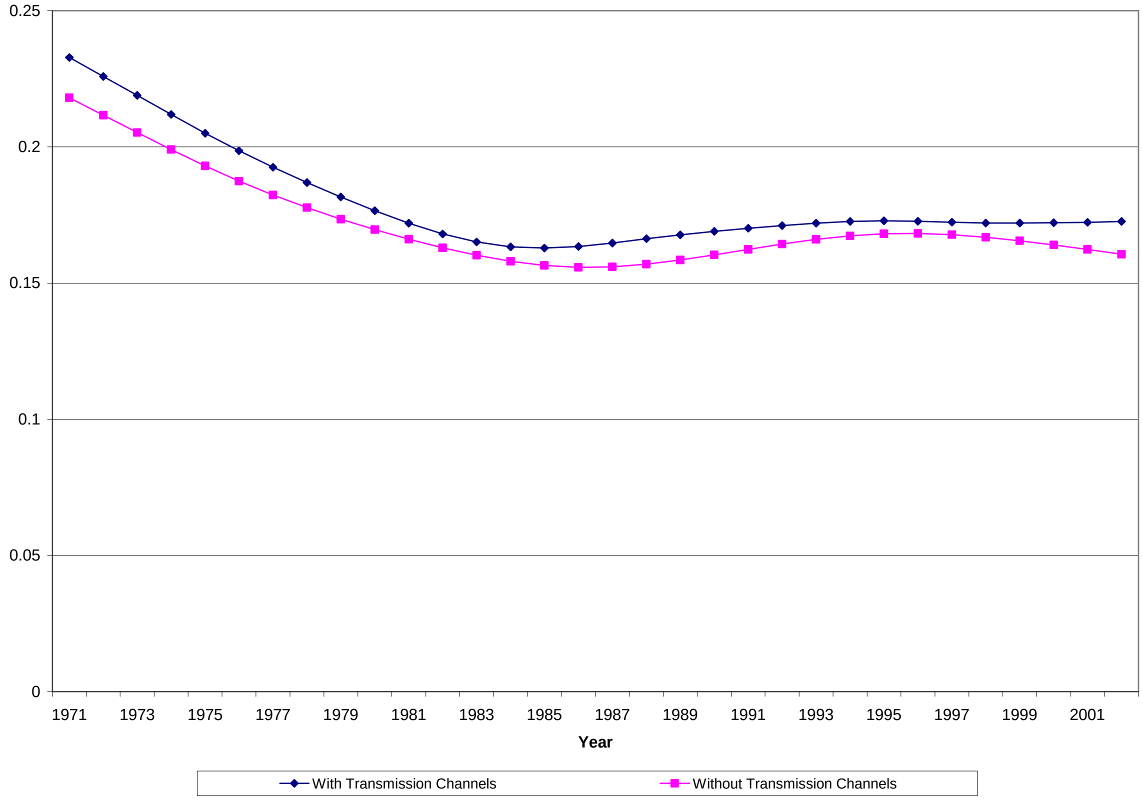
Figure 5: HP-Filtered MPK's (α = 1/3)



Source: Computed based on data from Singapore Department of Statistics.

Note: We have assumed $\frac{\eta}{1-\phi}$ = 0.149179, which is estimated when λ is set to 1.

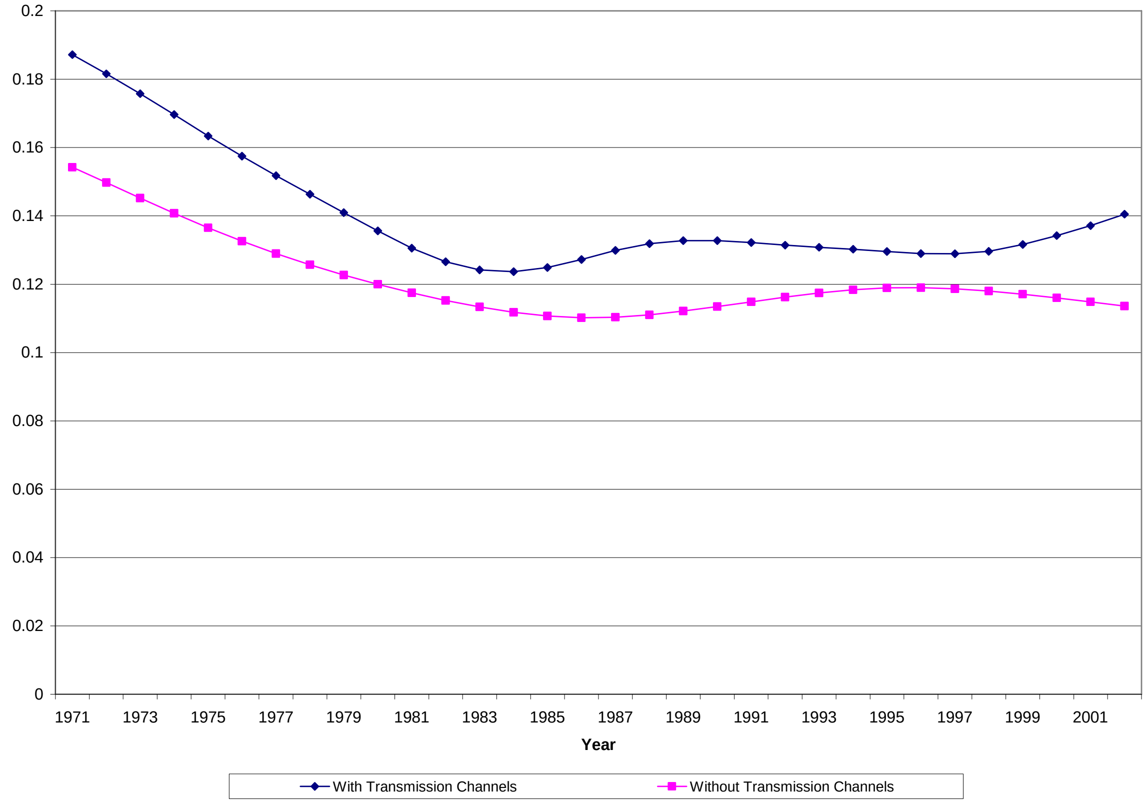
Figure 6: HP-Filtered MPK's ($\alpha = 0.53$)



Source: Computed based on data from Singapore Department of Statistics.

Note: We have assumed $\frac{\eta}{1-\phi}$ = 0.081702, which is estimated when λ is set to 1.

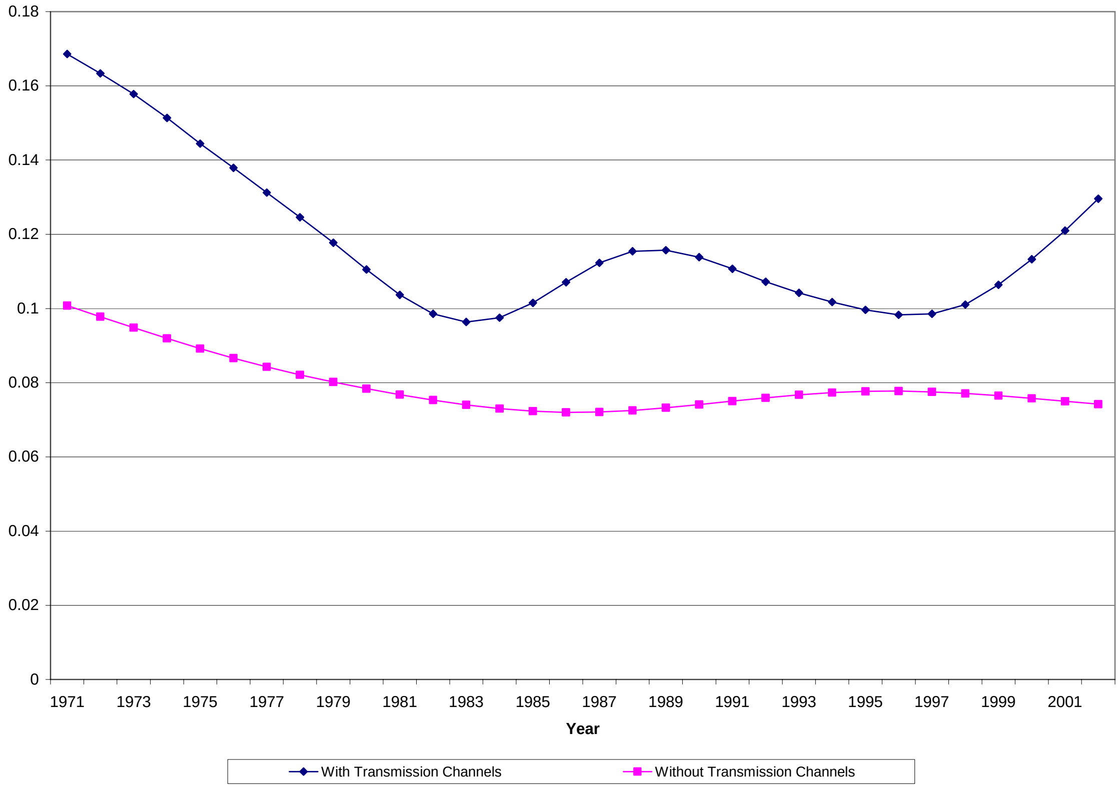
Figure 7: HP-Filtered MPK’s ($\alpha = 0.3749$)



Source: Computed based on data from Singapore Department of Statistics.

Note: We have assumed $\frac{\eta}{1-\phi}$ = 0.1374, which is estimated when λ is set to 1.

Figure 8: HP-Filtered MPK's ($\alpha = 0.2449$)



Source: Computed based on data from Singapore Department of Statistics.

Note: We have assumed $\frac{\eta}{1-\phi}$ = 0.282822, which is estimated when λ is set to 1.

Appendix 1: Statistical Tests on $g(g(A))$ and $g(A)$

This appendix provides statistical evidence to justify the assumption that $g(A)$ is a constant for the growth accounting exercise in section 3. To check for constancy of $g(A)$, we first conduct a simple student-t test on $g(g(A)$. To check whether $g(A)$ is stationary, we conduct unit root tests.

Using Stata's command *ttest*, based on the assumption that the underlying distribution is asymptotically normal, a simple student-t test on $g(g(A))$ for the period from 1962 to 2002 gives:

Observations:	41
Mean:	1.021898
Standard Error:	1.46294

H_0: Mean of $g(g(A)) = 0$
H_1: Mean of $g(g(A)) \neq 0$
$t = 0.6985$
$P > |t| = 0.4889$

Hence we do not reject the null hypothesis that the mean of $g(g(A)) = 0$ even at 10% level of significance. In other words, we infer that $g(A)$ can be considered a constant.

Next, using Stata's command *dfuller*, we perform the (Augmented) Dickey-Fuller tests for unit root on $g(A)$ for the period 1961 to 2002. The results are presented in Table A1.

Based on the t-ratios on the last lag of difference for the separate regressions, we conclude that the problem of serial correlation is absent. Hence, the Dickey Fuller test is appropriate. Given a test statistic of -5.676, we can reject the null hypothesis that there is unit root at 1% level of significance. Although not necessary, for the sake of completeness, Table A1 also shows the results of the Augmented Dickey-Fuller tests for lags of up to 3 periods. The results confirm that $g(A)$ is stationary.

We have also conducted statistical tests for the period 1970 to 2002 and the conclusion remains the same. Detailed results are available upon request.

Table A1: (Augmented) Dickey-Fuller Tests on $g(A)$

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value	MacKinnon approximate p-value	t-Ratio on Last Lag of Difference
Lags(0)	-5.676***	-3.641	-2.955	-2.611	0.0000	
Lags(1)	-3.873***	-3.648	-2.958	-2.612	0.0022	-0.31
Lags(2)	-3.568**	-3.655	-2.961	-2.613	0.0064	0.67
Lags(3)	-3.523**	-3.662	-2.964	-2.614	0.0074	0.84

Note: *, **, and *** denote 10%, 5%, and 1% level of significance, respectively.

Appendix 2: Mathematical Derivation of (16)

From (2), we have

$$\frac{K_t}{Y_t} = \frac{s_{Kt}}{\frac{\dot{K}_t}{K_t} + d} = \frac{s_{Kt}}{n_t + g(k_t) + d},$$

where $k_t = K_t/L_t$. Noting (9), we have

$$g(A_t) \equiv \frac{\dot{A}_t}{A_t} = \delta \tilde{H}_{At}^{\lambda} A_t^{\phi-1} E_t^{\beta} \left(\frac{G5MT_t}{Y_t}\right)^{\mu} \left(\frac{G5FDI_t}{K_t}\right)^{\kappa}.$$

Putting A_t as the subject, we have

$$A_t = \left(\frac{\delta}{g(A_t)}\right)^{\frac{1}{1-\phi}} \tilde{H}_{At}^{\frac{\lambda}{1-\phi}} E_t^{\frac{\beta}{1-\phi}} \left(\frac{G5MT_t}{Y_t}\right)^{\frac{\mu}{1-\phi}} \left(\frac{G5FDI_t}{K_t}\right)^{\frac{\kappa}{1-\phi}}, \text{ or}$$

$$A_t = \left(\frac{\delta}{g(A_t)}\right)^{\frac{\gamma}{\lambda}} \tilde{H}_{At}^{\gamma} E_t^{\frac{\beta\gamma}{\lambda}} \left(\frac{G5MT_t}{Y_t}\right)^{\frac{\mu\gamma}{\lambda}} \left(\frac{G5FDI_t}{K_t}\right)^{\frac{\kappa\gamma}{\lambda}},$$

where we have used $\gamma = \frac{\sigma}{1-\alpha}.\frac{\lambda}{1-\phi}$ and $\sigma = 1-\alpha$. Substituting the above expressions for $\frac{K_t}{Y_t}$ and A_t into (15), we get (16). Hence, the derivation does not require constant growth rates in K and A.

Appendix 3: Regression Results

This appendix gives details on the estimation of (9) under different assumptions. The coefficients estimated are used in the growth accounting exercises. Following Jones (2002), let the unobserved actual stock of ideas be A and the observed or measured multifactor productivity be B. Suppose

$$\ln B_t = \ln A_t + \varepsilon_t ,$$

where ε_t is a stationary disturbance term. The discrete version of (9) with $\mu = \kappa = \eta$ is

$$\frac{\Delta A_{t+1}}{A_t} = \delta \left(\frac{\tilde{H}_{At}}{A_t^{\frac{1}{\lambda}}} \right)^{\lambda} E_t^{\beta} \left(\frac{G5MT_t}{Y_t} . \frac{G5FDI_t}{K_t} \right)^{\eta} .$$

Next, we log-linearize the above around a path where B_t and $\tilde{H}_{At}$ are growing at constant rates, and express in terms of the measured multifactor productivity:

$$\Delta \ln B_{t+1} \approx \beta_0 + \lambda g(B)[\ln \tilde{H}_{At} + \frac{\beta}{\lambda} \ln E_t + \frac{\eta}{\lambda} \ln(\frac{G5MT_t}{Y_t} . \frac{G5FDI_t}{K_t}) - \frac{1}{\gamma} \ln B_t] + \pi_{t+1} ,$$

where $\beta_0 \equiv g(B)(1 - \ln(\frac{g(B)}{\delta}))$ is a constant, and $\pi_{t+1} \equiv \Delta\varepsilon_{t+1} + \frac{\lambda g(B)}{\lambda} \varepsilon_t$ is an error term. We have 4 sub-cases: setting λ free, fixing $\lambda = 1$, 0.5, and 0.25. Hence we have a total of 4 specifications. Table A2 presents the results for these 4 specifications under the assumption of $\alpha = 1/3$. Table A3 takes the assumption of $\alpha = 0.53$. Table A4 assumes a price markup of 1.33 and constant returns to scale, implying $\alpha = 0.3749$. Table A5 further assumes a returns to scale parameter of 0.87, implying $\alpha = 0.2449$.

The results from Tables A2 to A5 show that γ is statistically significant when λ is set to 1, 0.5, or 0.25, and for different assumptions on α. When λ is set free, the significance of γ cannot be established because the delta-method of computing the standard error involves a square root of a negative number. Furthermore, when λ is set free, the estimated λ is greater than unity, inconsistent with the theory. Hence, we prefer the case of $\lambda = 1$ and the associated estimated coefficients are used in the growth accounting exercises which are presented in the main text. Note also that β is at least moderately significant for most cases in Tables A2 to A5 when λ is set to 1, 0.5, or 0.25.

Table A2: Log-Linearized Estimation of (9), 1970-2002, $\alpha = 1/3$

	Specification where $\alpha = 1/3$			
	(1)	(2)	(3)	(4)
λ	10.0614 (8.414)	1	0.5	0.25
$g(B)$	0.0231	0.0231	0.0231	0.0231
γ	0.8578	0.0742 (0.035)	0.0368 (0.0171)	0.0184 (0.008)
ϕ	-10.729 (6.462)	-12.475 (6.273)	-12.571 (6.287)	-12.619 (6.294)
β	-0.4720 (6.172)	5.2016 (3.223)	5.5147 (3.231)	5.6712 (3.234)
η	-0.7629 (3.046)	2.0101 (1.631)	2.1632 (1.635)	2.2397 (1.637)
R^2	0.1837	0.1663	0.1493	0.1444

Note: Numbers within parentheses are standard errors, computed using the delta-method. When λ is set free, the standard error for γ cannot be computed because it involves a square root of a negative number.

Table A3: Log-Linearized Estimation of (9), 1970-2002, $\alpha = 0.53$

	Specification where $\alpha = 0.53$			
	(1)	(2)	(3)	(4)
λ	15.1487 (17.264)	1	0.5	0.25
$g(B)$	0.0159	0.0159	0.0159	0.0159
γ	1.3307	0.0733 (0.035)	0.0363 (0.017)	0.0298 (0.018)
ϕ	-10.384 (7.111)	-12.650 (6.514)	-12.770 (6.522)	-7.3875 (5.052)
β	-2.9445 (11.214)	5.6421 (3.9733)	6.0972 (3.978)	2.7796 (3.082)
η	-2.9286 (5.596)	1.1152 (2.625)	1.3296 (2.628)	0.7687 (2.036)
R^2	0.1653	0.1323	0.1388	0.0925

Note: Numbers within parentheses are standard errors, computed using the delta-method. When λ is set free, the standard error for γ cannot be computed in specification (1) because it involves a square root of a negative number.

Table A4: Log-Linearized Estimation of (9), 1970-2002, $\alpha = 0.3749$

	Specification where $\alpha = 0.3749$			
Parameter	(1)	(2)	(3)	(4)
λ	10.503 (9.412)	1	0.5	0.25
$g(B)$	0.0219	0.0219	0.0219	0.0219
γ	0.9305	0.0759 (0.035)	0.0377 (0.018)	0.0188 (0.009)
ϕ	-10.288 (6.435)	-12.175 (6.160)	-12.274 (6.171)	-12.324 (6.177)
β	-0.8772 (6.733)	5.0905 (3.225)	5.4045 (3.231)	5.5615 (3.234)
η	-1.0773 (3.322)	1.8102 (1.691)	1.9621 (1.694)	2.0381 (1.696)
R^2	0.1770	0.1547	0.1435	0.1409

Note: Numbers within parentheses are standard errors, computed using the delta-method. When λ is set free, the standard error for γ cannot be computed because it involves a square root of a negative number.

Table A5: Log-Linearized Estimation of (9), 1970-2002, $\alpha = 0.2449$

	Specification where $\alpha = 0.2449$			
Parameter	(1)	(2)	(3)	(4)
λ	7.9268 (4.901)	1	0.5	0.25
$g(B)$	0.0404	0.0404	0.0404	0.0404
γ	1.3004	0.1640 (0.093)	0.0820 (0.047)	0.0410 (0.024)
ϕ	-5.0957 (3.411)	-5.0973 (3.469)	-5.0974 (3.487)	-5.0975 (3.496)
β	-0.4050 (3.667)	3.3206 (2.593)	3.5896 (2.606)	3.7240 (2.613)
η	-0.1995 (1.915)	1.7245 (1.370)	1.8633 (1.377)	1.9328 (1.380)
R^2	0.1833	0.2066	0.1460	0.1233

Note: Numbers within parentheses are standard errors, computed using the delta-method. When λ is set free, the standard error for γ cannot be computed because it involves a square root of a negative number.

Appendix 4: Growth Accounting for Different Sub-Periods

Table A6: Accounting for Singapore's Growth with Transmission Channels ($\alpha = 1/3$)

Description	**Variable**	**70-84 Average**	**84-02 Average**
Growth rate of real GDP per worker equals:	$g(y)$	0.046197 (100.00%)	0.036612 (100.00%)
Capital intensity effect	$\frac{\alpha}{1-\alpha} g(\frac{K}{Y})$	0.013133 (28.43%)	0.001651 (4.51%)
Educational attainment effect	$\psi \Delta l_h$	0.008582 (18.58%)	0.011875 (32.44%)
G5 R&D intensity effect	$\gamma g(\tilde{l}_A)$	0.001590 (3.44%)	0.001113 (3.04%)
Scale effect of G5 labor force	$\gamma \tilde{n}$	0.001063 (2.30%)	0.000843 (2.30%)
Tertiary enrollment to employment ratio learning effect	$\frac{\beta}{1-\phi} g(E)$	0.011425 (24.73%)	0.017266 (47.16%)
G5 machinery imports and FDI transmission effect	$\frac{\eta}{1-\phi} g(\frac{G5MT}{Y} . \frac{G5FDI}{K})$	0.009933 (21.50%)	0.005372 (14.67%)
Unexplained		**1.02%**	**-4.12%**

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables.
Note: We have assumed γ = 0.074213, the estimated value in specification (2) in Table A2 of Appendix 3. We have also assumed $\frac{\beta}{1-\phi}$ = 0.38603, and $\frac{\eta}{1-\phi}$ = 0.149179, values estimated when λ is set to 1.

Table A7: Accounting for Singapore's Growth with Transmission Channels (α = 0.53)

Description	**Variable**	**70-84 Average**	**84-02 Average**
Growth rate of real GDP per worker equals:	$g(y)$	0.046197 (100.00%)	0.036612 (100.00%)
Capital intensity effect	$\frac{\alpha}{1-\alpha} g(\frac{K}{Y})$	0.029619 (64.11%)	0.003723 (10.17%)
Educational attainment effect	$\psi \Delta l_h$	0.008582 (18.58%)	0.011875 (32.44%)
G5 R&D intensity effect	$\gamma g(\tilde{l}_A)$	0.001570 (3.40%)	0.001099 (3.00%)
Scale effect of G5 labor force	$\gamma \tilde{n}$	0.001049 (2.27%)	0.000833 (2.27%)
Tertiary enrollment to employment ratio learning effect	$\frac{\beta}{1-\phi} g(E)$	0.012233 (26.48%)	0.018487 (50.49%)
G5 machinery imports and FDI transmission effect	$\frac{\eta}{1-\phi} g(\frac{G5MT}{Y} . \frac{G5FDI}{K})$	0.00544 (11.78%)	0.002942 (8.04%)
Unexplained		**-26.62%**	**-6.41%**

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables. Note: We have assumed γ = 0.073259, the estimated value in specification (2) in Table A3 of Appendix 3. We have also assumed $\frac{\beta}{1-\phi}$ = 0.41333, and $\frac{\eta}{1-\phi}$ = 0.081702, values estimated when λ is set to 1.

Table A8: Accounting for Singapore's Growth with Transmission Channels (α = 0.3749)

Description	Variable	70-84 Average	84-02 Average
Growth rate of real GDP per worker equals:	$g(y)$	0.046197 (100.00%)	0.036612 (100.00%)
Capital intensity effect	$\frac{\alpha}{1-\alpha} g(\frac{K}{Y})$	0.015753 (34.10%)	0.001980 (5.41%)
Educational attainment effect	$\psi \Delta l_h$	0.008582 (18.58%)	0.011875 (32.44%)
G5 R&D intensity effect	$\gamma g(\tilde{l}_A)$	0.001626 (3.52%)	0.001138 (3.11%)
Scale effect of G5 labor force	$\gamma \tilde{n}$	0.001087 (2.35%)	0.000863 (2.36%)
Tertiary enrollment to employment ratio learning effect	$\frac{\beta}{1-\phi} g(E)$	0.011436 (24.76%)	0.017282 (47.20%)
G5 machinery imports and FDI transmission effect	$\frac{\eta}{1-\phi} g(\frac{G5MT}{Y} . \frac{G5FDI}{K})$	0.009148 (19.80%)	0.004947 (13.51%)
Unexplained		**-3.11%**	**-4.03%**

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables. Note: We have assumed γ = 0.075904, the estimated value in specification (2) in Table A4 of Appendix 3. We have also assumed $\frac{\beta}{1-\phi}$ = 0.386391, and $\frac{\eta}{1-\phi}$ = 0.1374, values estimated when λ is set to 1.

Table A9: Accounting for Singapore's Growth with Transmission Channels (α = 0.2449)

Description	Variable	70-84 Average	84-02 Average
Growth rate of real GDP per worker equals:	$g(y)$	0.046197 (100.00%)	0.036612 (100.00%)
Capital intensity effect	$\frac{\alpha}{1-\alpha} g(\frac{K}{Y})$	0.008519 (18.44%)	0.001071 (2.92%)
Educational attainment effect	$\frac{\chi}{1-\alpha} \psi \Delta l_h$	0.007104 (15.38%)	0.009831 (26.85%)
G5 R&D intensity effect	$\frac{\sigma}{1-\alpha} \gamma g(\tilde{l}_A)$	0.002909 (6.30%)	0.002036 (5.56%)
Scale effect of G5 labor force	$\frac{\sigma}{1-\alpha} \gamma \tilde{m}$	0.001945 (4.21%)	0.001543 (4.21%)
Tertiary enrollment to employment ratio learning effect	$\frac{\beta}{1-\phi} g(E)$	0.013344 (28.88%)	0.020164 (55.08%)
G5 machinery imports and FDI transmission effect	$\frac{\eta}{1-\phi} g(\frac{G5MT}{Y} . \frac{G5FDI}{K})$	0.015589 (33.74%)	0.00843 (23.03%)
Employment effect	$\frac{\alpha+\chi-1}{1-\alpha} g(L)$	-0.00741 (-16.04%)	-0.00523 (-14.27%)
Unexplained		**9.08%**	**-3.38%**

Source: Various, as described in section 3.1. A tilde ~ is used to denote G5 variables.
Note: We have assumed γ = 0.164006, the estimated value in specification (2) in Table A5 of Appendix 3. We have also assumed $\frac{\beta}{1-\phi}$ = 0.544604, and $\frac{\eta}{1-\phi}$ = 0.282822, values estimated when λ is set to 1.