FEATURE ARTICLE

Singapore's Productivity Puzzle: Estimating Singapore's Total Factor Productivity Growth Using the Dual Method

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INTRODUCTION

Conventional estimates of Singapore's total factor productivity (TFP) growth point to a "productivity puzzle". TFP growth in Singapore has been low throughout the past decades, despite an improving education profile for the population, increasing investments in research and development (R&D) and rising capital inflows. Moreover, this phenomenon appears unique to Singapore. Estimates of TFP growth in Hong Kong, another small open economy, are significantly higher.

To shed some light on this puzzle, we calculate TFP growth in Singapore and Hong Kong over the period 1997-2009 using an alternative, "dual" methodology introduced in the East Asian context by Hsieh (2002). This is mathematically equivalent to the primal method used in conventional estimates, but measures TFP directly rather than as a residual. We find that in Singapore's case, dual estimates of TFP growth in the 1997-2009 period are higher than corresponding primal estimates. This divergence between dual and primal TFP growth is much smaller in Hong Kong. Also, the improvements in TFP (as measured through the dual method) in both Singapore and Hong Kong have been driven by robust growth in the real rental price of capital. Growth in real wages has been much more sluggish, especially when adjusted for the composition of the labour force.

MOTIVATION

The Concept and Significance of Total Factor Productivity

Total factor productivity is defined as the variable which accounts for changes in economic output not due to changes in factor inputs. In the Solow growth model (Solow, 1957), this is represented as part of the economy's "aggregate production function":

$$Y = AL^{S_L} K^{S_K} \qquad (1)$$

Where:

Y is output or GDP;
A is TFP;
K and L are capital and labour inputs respectively; and
S_K and S_L are the income shares of capital and labour respectively.

In the Solow formulation, an increase in A (*ceteris paribus*) leads to an increase in output. Many economists interpret this growth in A as TFP or technical improvements that allow for GDP growth without any corresponding increase in labour or capital.[2] This could be through any type of improvements in underlying technology, such as an improvement in production methodology (Howitt and Aghion, 1998) or a decrease in per unit costs (Harberger, 1998).

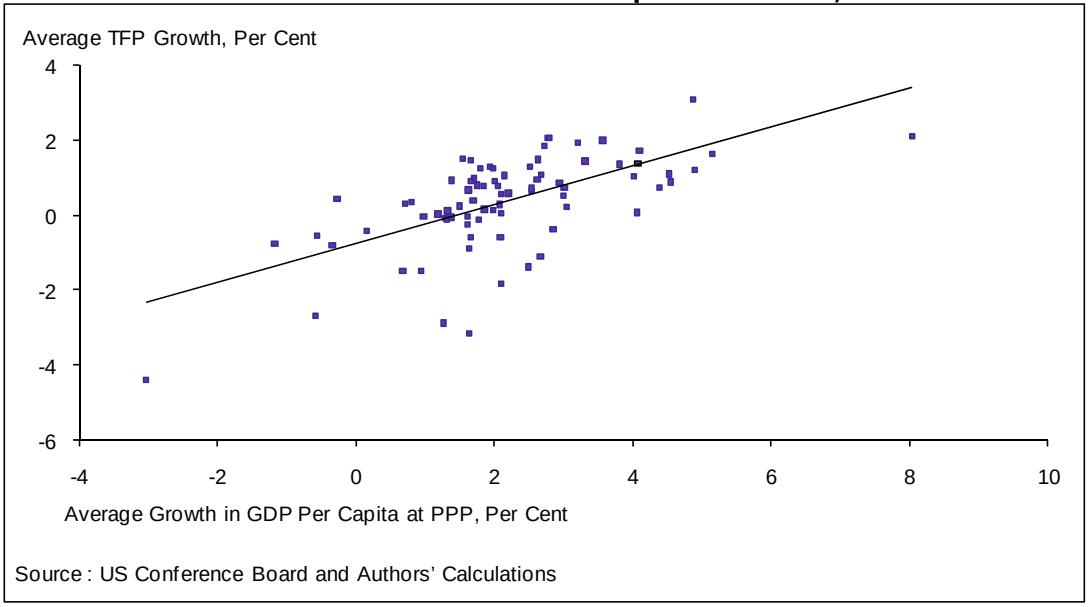
[1] We thank Thia Jang Ping, Yip Chun Seng, Toh Mun Heng, Cheong Wei Yang, Yong Yik Wei, Albert Hu, Dominic Soon and participants at the Economic and Social Research Network [ESRN] June 2010 seminar for helpful comments and suggestions. Any remaining error belongs to the authors.

[2] However, some economists argue that changes in TFP can also be attributed to factors not captured by the Solow aggregate production function such as externalities, economies of scale, and investment-specific technical change etc. These include Romer (1986), Greenwood, Hercowitz and Krusell (1997) and Lucas (1988).

Several empirical studies also link variations in TFP to differences in cross-country economic outcomes. For example, Islam (1995), Hall and Jones (1999) and Easterly and Levine (2000) all find that TFP has a statistically significant impact on income, after controlling for many other factors that affect income. In fact, Klenow and Rodriguez-Clare (1999) find that roughly 90 per cent of country differences in GDP per capita growth can be attributable to differences in TFP growth.

We illustrate this in Exhibit 1, using data from the Conference Board for 79 countries in the 1990-2008 period. There is a statistically significant positive relationship between TFP growth and per capita GDP growth, indicating that over this 18 year period, economies with higher TFP growth have enjoyed higher GDP per capita growth.

Exhibit 1: Correlation between TFP Growth & Per Capita GDP Growth, 1990-2008



Source : US Conference Board and Authors' Calculations

The Primal Method of Calculating TFP

Traditionally, TFP is measured through the "primal" method, which follows directly from the aggregate production function in Equation (1). This approach measures TFP as a residual after accounting for all observable drivers of growth, i.e. the difference in the growth of real output and the weighted growth of real inputs, with the shares being the payments to the respective factors of production. This method is employed by several national statistical agencies, including the Singapore Department of Statistics (DOS), which provides official estimates of Singapore's TFP growth. As per the primal method, a generalised expression of TFP growth is:[3]

$$\Delta TFP = \Delta Y - S_L \Delta L - S_K \Delta K \qquad (2)^4$$

Estimates of Singapore's TFP growth, using different primal specifications, consistently reveal Singapore's TFP growth over the past four decades to be low. TFP growth in Singapore has also been lower than in Hong Kong, despite both being small open economies (Exhibit 2).[5] This is puzzling because one would expect an economy with an increasingly well-educated labour force, flexible factor markets, considerable R&D investments and abundant foreign investment to enjoy strong technological progress and

[3] Δ indicates growth rates.

[4] In the following sections, we will show that our dual estimates are "quality adjusted." Hence, the corresponding primal expression should also adjust capital and labour inputs for quality, i.e. estimates of capital and labour inputs should take into account the contribution of differentiated types of capital and labour respectively.

[5] The studies presented in Exhibit 2 all use the primal method, but with different specifications. For instance, Young (1995) takes into account the contribution of differentiated types of capital and labour. On the other hand, Kim and Lau (1994) and DOS' official estimates rely on aggregated factor input data which are not quality-adjusted. The various studies also make different assumptions on areas such as capital and labour utilisation and returns to scale.

productivity gains (Svyerson, 2010 & Kose et al., 2009). However, this has not been the case in Singapore. In fact, Young (1995) argues that nearly all of Singapore's growth in the period of 1966-1990 was driven by factor accumulation, concluding that TFP growth in Singapore was "next to nil" over this period.

Exhibit 2: Historical Primal Estimates of TFP Growth in Singapore

	Period	Annual Growth (Per Cent)	
		Singapore	Hong Kong
Young (1995)	1966-90	0.2	2.3
Kim and Lau (1994)	1966-90	0.4	2.0
Bosworth and Collins (1997)	1960-94	1.5	NA
Marti (1996)	1970-90	1.4	2.4
Singapore Department of Statistics	1974-90	0.7	NA

Source: Felipe (2000) and DOS

This puzzle persists even in recent periods. DOS estimates that Singapore's non-quality adjusted TFP grew by an average of 0.1 per cent per annum from 1997 to 2009, significantly lower than our estimates of Hong Kong's non-quality adjusted TFP growth of 1.4 per cent per annum (Exhibit 3). Similarly, the Monetary Authority of Singapore (MAS) estimates that Singapore's quality-adjusted TFP growth, adjusted for improvements in information and communications technology (ICT) and labour quality, was 0.2 per cent per annum in the 2000-2009 period (MAS, 2010). While the pattern of fluctuations in Singapore's TFP (as calculated by DOS) is broadly similar to Hong Kong's, Hong Kong's TFP growth exceeds Singapore's in many periods. This divergence explains why GDP growth rates in both economies have been similar, despite larger contributions from factor inputs in Singapore (Exhibit 4a and 4b).

Exhibit 3: TFP Growth in Singapore and Hong Kong (Primal - Growth Accounting)

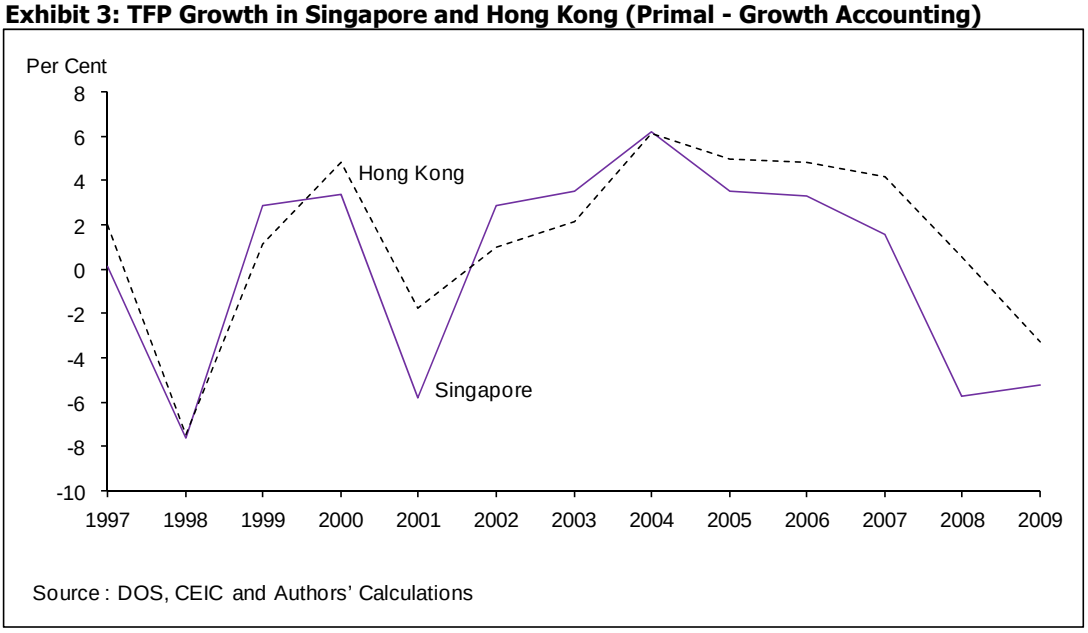


Exhibit 4a: Factor Accumulation and Output Growth in Singapore

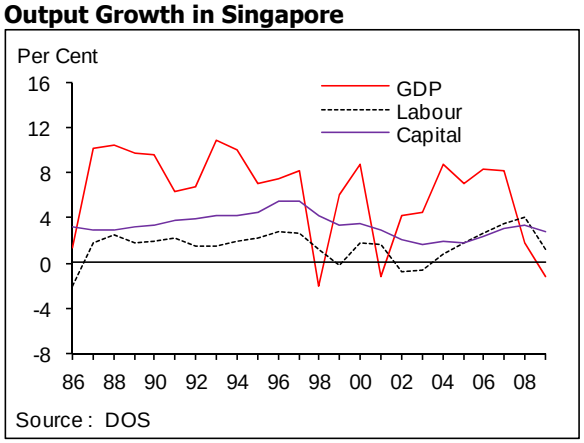
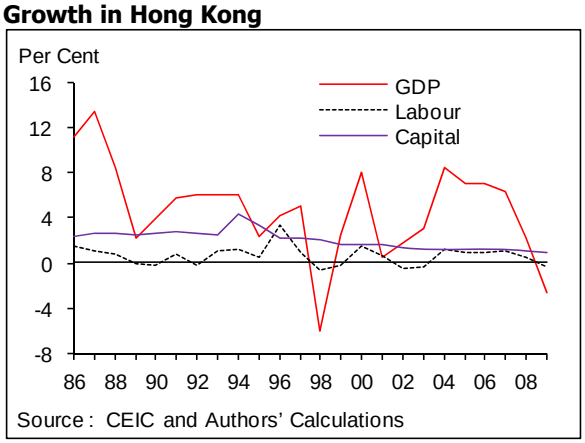


Exhibit 4b: Factor Accumulation and Output Growth in Hong Kong



Overall, Singapore's weak TFP growth over the past few decades is puzzling, especially in comparison with Hong Kong, a similarly small open economy. Unfortunately, the primal estimates described above measure TFP as a residual, and do not allow us to gain much further insight into TFP growth.

METHODOLOGY

To investigate this puzzle, we estimate an alternative "dual" measure of TFP growth in Singapore and Hong Kong over the period 1997-2009. This dual method was first applied to these economies by Hsieh (2002). It is mathematically equivalent to the primal method and measures TFP growth directly as:

$$\Delta TFP_{Dual} = S_L \Delta w + S_K \Delta r \qquad (3)$$

Where:

Δw refers to the growth rate of real wages, and
Δr refers to the growth rate of the real rental price of capital.[6]

The changes in real wages and rental prices of capital are assumed to reflect underlying changes in the productivity of these factor inputs, assuming equilibrium in factor markets. In this case, wages would reflect workers' marginal productivity, and rental prices of capital would reflect the marginal productivity of capital.

The dual estimates rely on "quality-adjusted" changes in real wages and real rental rates of capital.[7] In other words, these estimates adjust for quality improvements by using the share of payments of each factor input to weight changes in the real price of the input. As such, the quality-adjusted estimates of factor prices change only if there are corresponding changes in the real returns to given types of capital and labour. Conceptually, the quality-adjusted dual TFP estimates only measure quality improvements which have a permanent impact on real returns to factor inputs, and exclude once-off changes in real returns due to compositional changes in factor input types.[8] We discuss the real price changes of labour and capital in turn.

[6] For a detailed derivation of the equivalence, please see Hsieh (2002)

[7] We use the GDP deflator to estimate real wages and the real rental price of capital. This is consistent with Hsieh's (2002) methodology, and also allows consistency across both payments to labour and payments to capital, instead of using the CPI for labour and the PPI for capital. While the GDP deflator and CPI inflation generally display similar growth trends, we note that the former is more volatile than the latter. This may not be surprising in Singapore's case, as much of its economic output is export oriented. As such, output-related prices may differ from the consumption basket used to construct CPI prices.

[8] For example, average real wages in an economy may increase because the average worker is better educated, without any increase in wages for the given labour types. Such one-time increases in average returns due to changes in the composition of labour or capital are excluded in the quality-adjusted estimate of TFP growth. Only quality improvements to each given labour or capital type that have been translated into increases in real returns are captured in the quality-adjusted TFP growth.

Real Wages

We measure quality-adjusted changes in real wages through growth in wages of a given type (or quality) of labour across time. This is expressed by the following equation:

$$\Delta w = \sum S_{L\,i} \Delta w_i \qquad (4)$$

Where:

Δw_i refers to the change in real median wage for a given type of labour i, and
S_{Li} refers to the share of total wages of labour type i.

We obtain data on median wages and employment for the labour force in Singapore from the Ministry of Manpower (MOM). This is categorised by education attainment (degree, polytechnic and secondary and below).[9] We calculate the share of payments to each type of worker, S_{Li}, as the product of the median wage and the number of employees in each category, divided by the total payments to labour. In Hong Kong, we obtain data on employment and median monthly earnings (with bonus) for nine occupation types from the CEIC database.[10] We obtain the share of payments to each type of worker in a manner similar to Singapore.

Over the 1997-2009 period, real median incomes have grown weakly or declined in both Singapore and Hong Kong for different representative labour types (Exhibits 5a and 5b). For example, degree holders in Singapore and professionals in Hong Kong enjoyed modest or limited increases in income in the 2005–2007 period compared to previous periods.

Exhibit 5a: Changes in Singapore Resident's Real Median Incomes by Education Profile

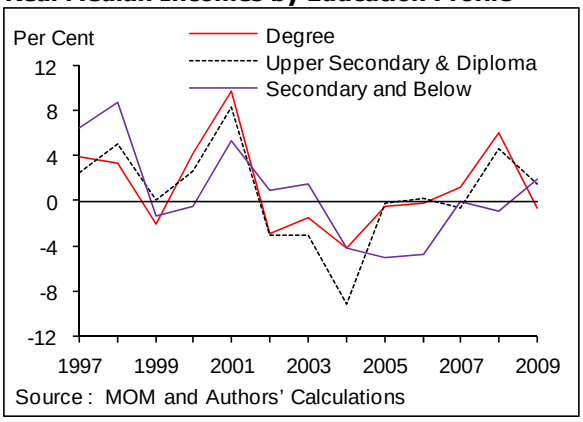
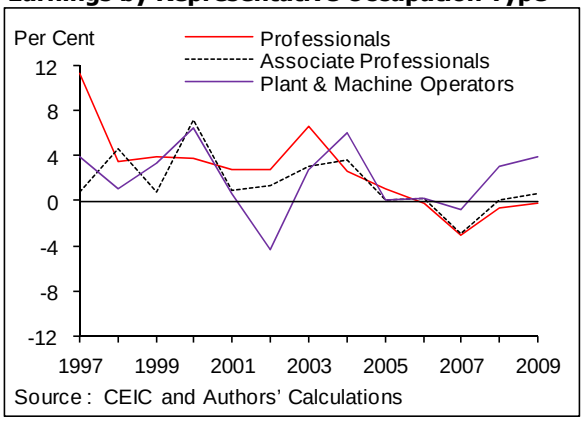


Exhibit 5b: Changes in Hong Kong Real Median Earnings by Representative Occupation Type



This weak or declining growth in real median incomes has occurred in tandem with increases in the shares of polytechnic and degree holders in the employed populations of both Singapore and Hong Kong (Exhibit 6). Many economists treat improvements in education profile as a proxy for improvements in labour quality, as they assume that the more education a worker has, the more human capital he or she has (Romer, 2006). However, based on our estimates, these improvements in education profile have not translated to increases in quality-adjusted real wages (Δw) in Singapore or Hong King. In fact, we see a moderation in quality-adjusted real wage growth over the 1997-2009 period for both economies (Exhibit 7). This suggests that labour quality improvements, as measured by real wage growth, may have started to plateau in Singapore and Hong Kong, even though the average worker may be more educated.

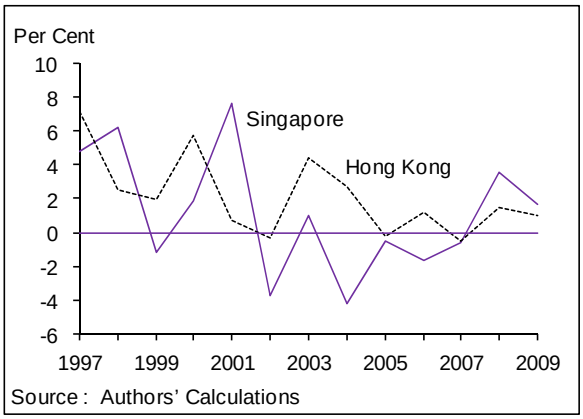
[9] We rely on linear interpolation to deal with missing data, similar to Hsieh (2002) and Young (1998).
[10] The nine types are "managers and administrators," "professionals," "associate professionals," "clerks," "service & shop sales workers," "craft and related workers," "plant & machine operators and assemblers," "elementary occupations," and "other occupations."

Exhibit 6: Labour Force Education Attainment (Per Cent)

Education Attainment	Share of Total Employed		
	1996	2002	2009
Singapore (Residents only)			
Degree	0.11	0.19	0.27
Upper Secondary and Polytechnic Diploma	0.19	0.23	0.25
Secondary and Below	0.69	0.59	0.48
Hong Kong			
Degree	0.11	0.17	0.23
Polytechnic (Tertiary non-degree)	0.09	0.10	0.09
Secondary and Below	0.79	0.73	0.68

Source: MOM, CEIC

Exhibit 7: Estimates of Δw



From Exhibit 7, we observe that quality-adjusted real wages grew by 2.5 per cent per annum in the 1997-2002 period in Singapore, but fell by 0.1 per cent per annum in the 2003-2009 period. Similarly, Hong Kong's real wages grew by 3.0 per cent per annum in the 1997-2002 period, but this growth moderated to 1.5 per cent per annum in the 2003–2009 period. The contribution of wage growth to total factor productivity was therefore weaker in the second half of the 1997-2009 period, compared to the first half for both economies.

This issue of wage stagnation has been discussed extensively in Singapore's context. Some observers argue that it is due to Singapore's foreign labour policies. In particular, the recent increase in foreign labour supply may have depressed local wages, especially for workers with secondary education and below.[11] Nevertheless, regardless of the cause, weak growth in real wages is a significant contributor to Singapore's low TFP growth.[12]

Returning to Exhibit 7, we see that Hong Kong experienced stronger increases in real wages compared to Singapore over the 1997–2009 period. This is consistent with Hong Kong's higher labour productivity growth (measured by growth in real value-added (VA) per worker), which is 2.2 per cent per annum, compared to Singapore's 1.2 per cent growth over the same period (Exhibits 8a and 8b).[13] While both Hong Kong and Singapore have large service sectors, this divergence in VA per worker may be due to Hong Kong's specialisation in high-value services such as financial services, and transport and communication which have high labour productivity growth. Estimates of industry-specific labour productivity growth show that Hong Kong is indeed outpacing Singapore in these sectors (Exhibits 8a and 8b). This is also borne out by industry-specific studies of Singapore and Hong Kong.[14]

[11] The Straits Times, 18 May 2010, "World country, but not First World wages?"
[12] Cyclicality in weekly hours worked could be one omitted factor that affects real wage growth. However, we note that weekly hours worked in Singapore did not fluctuate significantly over the period 1996-2009, especially when measured on an annual basis.
[13] This assumes that improvements in labour productivity are commensurate with real wage improvements.
[14] For example, case study research by Lee and Shepherd (2006) shows that Singapore's air transport sector uses more labour per unit of capital than Hong Kong. This suggests that labour productivity in that sector is lower in Singapore.

Exhibit 8a: Labour Productivity Growth in Singapore

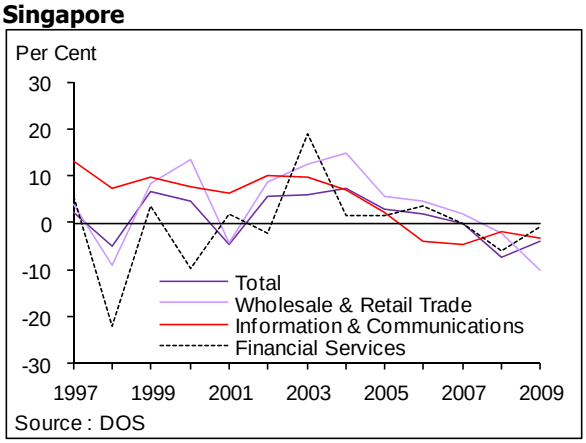
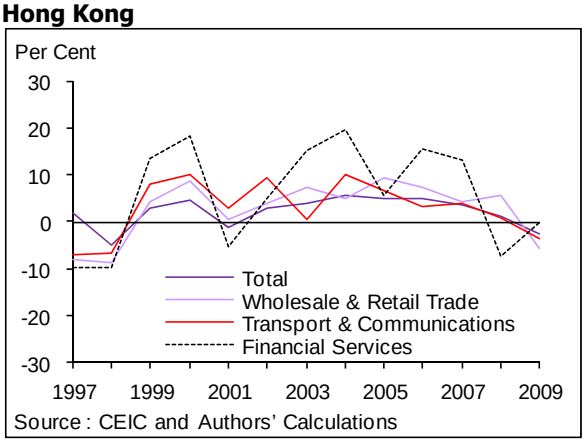


Exhibit 8b: Labour Productivity Growth in Hong Kong



Real Rental Price of Capital

We next calculate the contribution of growth in the real rental price of capital according to the standard Hall-Jorgenson (1967) formula:

$$r_j = \frac{p_j^k}{p}(i - \pi_k + \partial_j) \qquad (5)$$

Where:

r_j is the real rental price of capital type j,
p is the GDP deflator,
p^k_j is the GFCF deflator of capital type j,
i is the nominal interest rate,
π_k is the GFCF inflation rate, and
δ_j is the depreciation rate of capital good j.

Similar to the quality-adjusted real wage, we estimate the quality-adjusted real rental price of capital, based on the following equation[15]

$$\Delta r = \sum S_{Kj} \Delta r_j \qquad (6)$$

Where:

S_{Kj} refers to the share of total rental of capital type j, and
Δr_j refers to the change in the real rental price for a given type of capital j, and r_j is calculated as per Equation (5)

We estimate the share of payments to each type of capital, S_{Kj}, by taking the product of the nominal rental price of capital of type j and the capital stock of type j, and dividing this by the total payments to capital. We take the depreciation rates from Hulten and Wykoff (1981) (Exhibit 9).

[15] Singapore's investment data is categorised into residential buildings, non-residential buildings, other construction, transport equipment and machinery and equipment. To calculate capital stock in Hong Kong, we use the standard perpetual inventory method with geometric depreciation, assuming that the growth rate of investment before the beginning of the investment series is the average growth rate in the first 10 years the data are available. We do this by two categories – building and construction, and machinery equipment and computer services. We distribute the costs of ownership (the third component of Hong Kong's GFCF data) across these two categories according to the proportions of their value. The depreciation rates for these two categories are an average of those shown in Exhibit 9.

Exhibit 9: Depreciation Rates for Various Capital Types (Per Cent)

Residential buildings	Non-residential Buildings	Other Construction	Transport equipment	Machinery and equipment
1.3	2.9	2.1	18.2	13.8

A key component of the rental price formula is the real interest rate or $i - \pi_k$. For our estimates, our primary measure of real interest rates is the earnings-price (E-P) ratio, which is the earnings per share divided by price per share of all listed firms on the respective stock exchanges. This is the same measure used by Hsieh (2002), and has the advantages of being a market-determined, tax-adjusted measure of the return to capital. However, this measure only captures the returns to capital reported by listed firms, which are assumed to be representative of all firms in the economy.

Singapore's E-P ratio has been relatively stable except during the recent financial crisis when a sharp fall in equity prices raised it to 11 per cent in 2008. Hong Kong's E-P ratio has exhibited similar trends to Singapore's, although the 2008 increase is not as accentuated (Exhibit 10). Conceptually, such consistent increases in returns to capital are surprising in newly industrialised economies such as Singapore and Hong Kong, as significant capital accumulation has taken place in past decades, and diminishing returns to investment should have set in. In part, this could be due to the assumption that the return to capital of listed firms is representative of all returns in the economy, which is likely to be an overstatement. Nevertheless, robust returns to capital have led to continued investment growth in Singapore and Hong Kong. This is observed in Singapore's and Hong Kong's FDI inflows, which have continued on an upward trend, even in recent years (Exhibit 11). [16]

Exhibit 10: Singapore and Hong Kong Earnings-to-Price Ratios

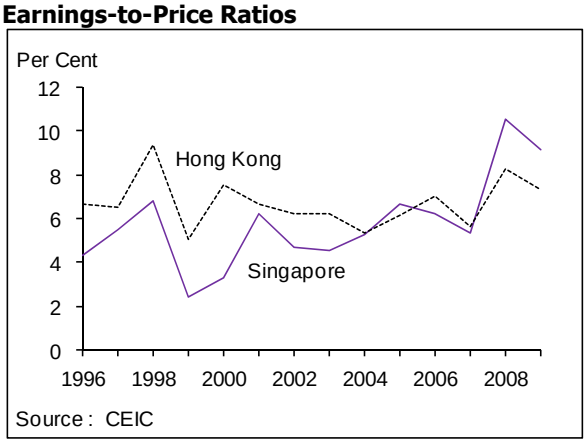
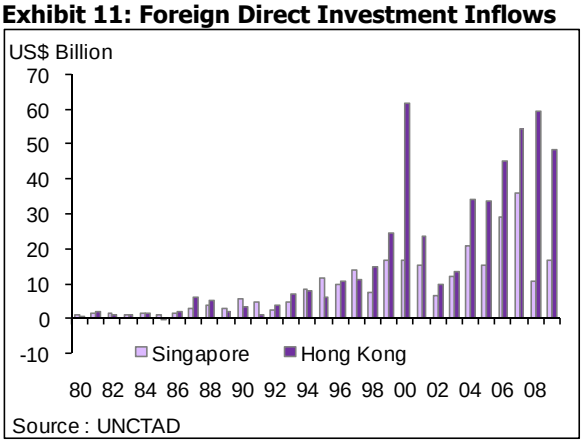
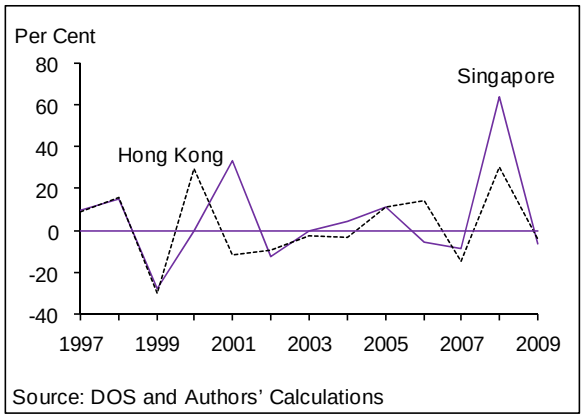


Exhibit 11: Foreign Direct Investment Inflows



[16] An alternative measure of the real interest rate ($i - \pi_k$), also used by Hsieh (2002), is the lending rate of each economy less ex-post asset price inflation. However, this does not adjust for tax rates on capital investment, and Young (1998) argues that this limitation has a significant impact on estimates of the real return on capital. Moreover, since Hong Kong does not have an autonomous monetary policy, and Singapore targets its exchange rate, both economies' lending rates may not fully reflect fluctuations in the cost of credit to firms. Due to these limitations, we use the E-P ratio as our primary measure of the return to capital.

Exhibit 12: Estimates of Δr



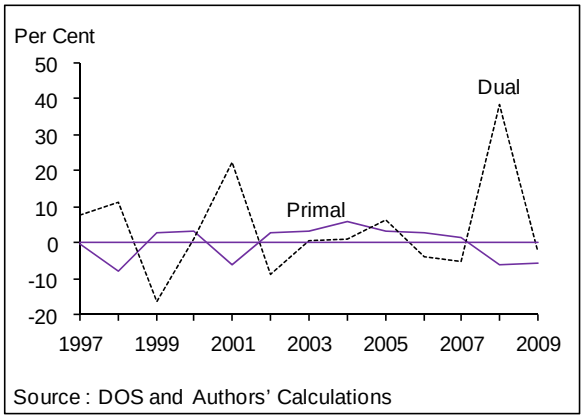
Source: DOS and Authors' Calculations

Singapore's and Hong Kong's real rental price of capital, based on the E-P ratio, exhibited similar growth trends in the 1997-2009 period. Both series tracked each other relatively closely until 2008 when Singapore's real rental price of capital spiked due to an increase in the E-P ratio and relative prices of building and construction-related capital (Exhibit 12).

KEY RESULTS

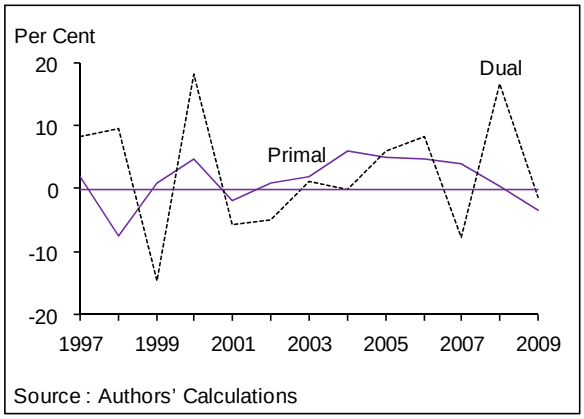
We sum our estimates of real wage growth and the real rental price of capital as in Equation (3) to obtain dual estimates of TFP growth, with wage and capital shares as weights. [17] We present dual TFP growth estimates in comparison with the primal estimates in Exhibits 13a and 13b, and summarise our findings in Exhibit 14.

Exhibit 13a: Singapore's Primal and Dual TFP Growth Estimates



Source : DOS and Authors' Calculations

Exhibit 13b: Hong Kong's Primal and Dual TFP Growth Estimates



Source : Authors' Calculations

Exhibit 14: Dual Estimates of TFP Growth

Dual Estimates	Period	Assumed Labour Share	Annual Growth Rate (CAGR Per Cent)			
			Rental Price of Capital	Wages	Dual TFP	Primal TFP (Growth Accounting)*
EP Ratio	**Singapore**					
	1997-2002	0.42	1.22	2.52	2.09	-0.78
	2003-2009	0.42	6.50	-0.14	4.09	0.94
	1997-2009	0.42	4.03	1.08	3.16	0.14
	Hong Kong					
	1997-2002	0.48	-1.47	2.97	1.12	-0.12
	2003-2009	0.48	3.81	1.50	2.92	2.73
	1997-2009	0.48	1.34	2.18	2.09	1.41

Source: *DOS' estimates for Singapore, authors' calculations for Hong Kong

[17] We use the average wage share from Singapore's national accounts (1980-2009) for the share of payments to labour, and attribute residual payments to capital. For Hong Kong, estimates of wage share in nominal GDP were discontinued in 2002. Assuming the share is relatively stable over time, we average the longest available time-series (1980-2002), which is 0.48 as an estimate of Hong Kong's wage share. The share of capital follows as 0.52.

Our dual estimates provide us with a number of insights. First, the "puzzle" of low TFP growth in Singapore does not seem to manifest in the dual method, as the dual TFP growth estimated for Singapore over the period 1997-2009 is 3.2 per cent per annum, which is higher than the 0.1 per cent per annum growth estimated by DOS using the primal method. While DOS' primal estimates are not quality-adjusted and hence may not be directly comparable to our dual estimates, Hsieh (2002) observes similar results – his dual estimates of TFP growth for Singapore were also significantly higher than Young's (1995) quality-adjusted primal estimates.

On the other hand, our dual TFP growth estimate for Hong Kong for the period of 1997–2009, at 2.2 per cent per annum, is relatively closer to our primal estimate of 1.4 per cent. This is also the case according to Hsieh's (2002) estimates, reinforcing the TFP growth puzzle as somewhat unique to Singapore. The divergence in TFP growth between Hong Kong and Singapore is smaller in the dual method than in the primal method. This is due to the similar trends exhibited by Singapore's and Hong Kong's factor prices over the 1997–2009 period. Also, for Hong Kong and Singapore, both the primal and dual measures indicate that TFP growth was stronger in the later period of 2003-2009 compared to 1997-2002.

The key factor driving the strong dual estimates in both Singapore and Hong Kong is the rental price of capital. This is because of two factors. First, both Singapore and Hong Kong observed a spike in overall asset prices in 2008, especially in the area of real estate investment. Second, by using the E-P ratio as the measure of real interest rates, we assume that listed firms are representative of all firms in the economy. This may lead to an overestimate of the rental price of capital for the economy, as listed firms may enjoy stronger growth in earnings than non-listed firms. Moreover, both these factors could be especially relevant in Singapore, where residential real estate investment has been a large share of total investment in recent years. [18]

CONCLUSION

In conclusion, we find that the dual estimates of TFP growth for the period of 1997-2009 are higher than corresponding primal estimates for Singapore. This is in line with Hsieh's (2002) findings for the 1973-1990 period, and suggests that Singapore's TFP growth has been better than "next-to-nil." However, rather than focussing on the divergence between the primal and dual estimates, our view is that the dual method offers an alternative perspective on Singapore's TFP growth, and is a useful complement to the primal method. In particular, from the dual method, we can see that the contribution of real wage growth to TFP growth has fallen significantly over time, with growth in real wages being negative over the 2003-2009 period. This trend of weaker wage growth is also seen in Hong Kong, but to a smaller degree. This suggests that improvements in the actual quality of labour have been limited, despite improvements in education profile. A possible reason for the moderation in wage growth is the relaxation of Singapore's foreign manpower policies in earlier years. Nevertheless, this moderation was observed even in the late 1990s and early 2000s, and is consistent with the general weakness in Singapore's labour productivity (VA per worker) figures, especially when compared to Hong Kong.

On the other hand, returns to capital have increased over time in Singapore and Hong Kong, even though the increase has been much sharper in Singapore. The strong growth in the real rental price of capital in the later part of the sample period has contributed to the increase in TFP in both economies. This is due to higher asset prices, especially in real estate investment. There is also the possibility that the use of the E-P ratio as our measure of real interest rates overestimates the rental price of capital.

[18] Some researchers argue that residential capital should be excluded from estimates of net capital stock as it does not contribute significantly to production. We retain it for two reasons. First, residential capital provides a stream of rental income, a non-trivial form of production in Singapore's case. Second, retaining residential capital facilitates comparison between Singapore and Hong Kong, since Hong Kong does not release separate estimates of residential and non-residential construction in its GFCF data. Nonetheless, excluding estimates of residential capital stock from total capital stock in Singapore lowers the dual TFP estimate to 2.3 per cent from 3.2 per cent.

We end by stressing the need to further our understanding of TFP growth, as it is an important driver of economic growth. Both the primal and dual TFP estimates are important parts of the overall productivity growth puzzle, as they measure productivity growth using different types of data. Neither measure should be considered superior to the other, and both should be studied more carefully and thoroughly in order to provide us with further insights on Singapore's economic growth.

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