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Abstract

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Keywords

Conundrum, Economic, Miracle, Manufacturing, Growth, without, TFP, Growth

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THE CONUNDRUM OF ECONOMIC MIRACLE: MANUFACTURING GROWTH WITHOUT TFP GROWTH

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ABSTRACT

The findings of low or even negative total factor productivity (TFP) growth in Singapore's manufacturing industries by Young (1995) and many others has been a controversial issue in view of its crucial role in the future sustainability of Singaporean manufacturing. This paper applies the varying coefficients frontier model to re-examine productivity growth in Singapore's manufacturing at the 3-digit industry level over the period 1970–1997. The results indicate that Singapore's manufacturing has on average experienced a –0.8 percent TFP growth per annum although the extent of TFP growth improved slightly in the 1990s. The decomposition of TFP growth into technical efficiency change and technological progress, found technological regress is responsible for the negative TFP growth. Factor accumulation remains the principal contributor to the economic miracle of Singapore's manufacturing industries.

JEL Classifications: O47, O53
Keywords: Singapore, Varying Coefficients Frontier Model, Manufacturing, Total Factor Productivity Growth, Technical Efficiency Change, Technological Progress
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INTRODUCTION

The manufacturing sector of Singapore on average accounted for a quarter of the overall gross domestic production (GDP) and sustained rates of output growth by more than 9 percent a year encompassing the period from 1970 to 1997, making it one of the most rapidly growing manufacturing sectors in the world. More specifically, of the major clusters within the sector, the electric and non-electrical machinery industries have grown annually by 18.2 and 11.1 percent, respectively, and both shared as high as 43 percent of the manufacturing output during the same period. Although theoretical and empirical findings that total factor productivity (TFP) growth is crucial in terms of maintaining output growth are widespread, it is difficult to draw any consensus about the role of TFP growth in the development of Singapore's manufacturing sector from the existing literature.

Regardless of different sample periods covered, data sources and adjustments, the findings of the growth-accounting based TFP studies on Singapore's manufacturing sector vary extensively from study to study (see Table 5).[1] Tsao (1985), for instance, argued that the miraculous output growth in Singapore's manufacturing was not associated with high TFP growth in the 1970s. Tsao claimed that its TFP level grew by 0.08 percent per annum stemming from the annual TFP growth rates of –1.18 percent for the period 1970–73 and of 0.71 percent for 1973–79. Young (1995) even suggested that Singapore's manufacturing sector experienced an annual TFP growth rate of –1.0 percent during the 1970–90 period. In contrast to Tsao (1985) and Young (1995), Rao and Lee (1995) found the manufacturing sector enjoyed TFP growth of 3.2 percent a year for the period 1987–94. Likewise, Koh et al. (2002) estimated that TFP growth for the overall manufacturing sector was 2.7 percent on an annual basis over the period 1975–98. For more empirical studies on East Asian manufacturing TFP growth, refer to a survey by Sun (2005).

The aim of this paper is to identify the sources of output growth for 25 Singapore's manufacturing industries, using the varying coefficients frontier model and panel data at the 3-digit industry level over the period 1970 to 1997.[2] As opposed to the conventional stochastic frontier approach, the paper presents evidence of variations in the response coefficients of labor and capital inputs. Next, this paper decomposes TFP growth into technological progress and technical efficiency and the general notion that high-tech firms will reach the production frontier more quickly than low-tech firms will be also examined.

The remainder of the paper is organised as follows. Section 2 discusses the varying coefficients frontier model to measure TFP growth. Section 3 briefly describes the sources of data, variables construction and adjustments. Section 4 presents empirical results and analyses the sources of output and TFP growth and examines the interaction between technological progress and technical efficiency change. It also conducts a sensitivity analysis to consolidate the findings of this study and compares the results with earlier studies. Summary and concluding remarks are made in section 5. The Appendix provides the decomposition analysis.

EMPIRICAL MODEL

This paper estimates the production frontier utilising the varying coefficients frontier model proposed by Swamy (1970) and Kalirajan and Obwona (1994). On the premise that all industries have equal opportunity to access best-practice technology, a Cobb-Douglas production technology is assumed for Singapore's manufacturing at the 3-digit industry level,

$$\ln Y_i = \beta_{0i} + \beta_{1i} \ln L_i + \beta_{2i} \ln K_i, \quad i = 1, \ldots, N, \tag{1}$$

where Y_i denotes the output level of ith industry measured by value added, L is the labor input measured by number of employees adjusted for quality improvement, K_i is capital input measured by the level of capital stock. The varying intercept is β_{0i}. β_{1i} and β_{2i} are the response coefficients of labor and capital inputs, respectively. Equation (1) expresses that the estimated response coefficients are unique to each individual firm. Put differently, the response production coefficients vary from firm to firm according to firm-specific characteristics.

Nevertheless, the estimation of equation (1) cannot be carried out without further assumptions imposed on the random coefficients because the number of intercepts and coefficients ($MN + N$) to be estimated exceeds the number of observations (N). To solve the difficulty, it is assumed that all the varying response coefficients are deviated from its mean in order to obtain the estimates of the coefficients, $\beta_{0i} = \bar{\beta}_0 + u_{0i}$ and $\beta_{mi} = \bar{\beta}_m + u_{mi}$, $m = 1,2$. Then, equation (1) can be rewritten as this is,

$$\ln Y_i = \bar{\beta}_0 + \bar{\beta}_1 \ln L_i + \bar{\beta}_2 \ln K_i + v_i, \tag{2}$$

where $v_i = u_{0i} + u_{1i}\ln L_i + u_{2i}\ln K_i$, $E(v_i)=0$ for all i, $Cov(v_i, v_j)=0$ for $i \neq j$, and $Var(v_i) = \sigma_{u00} + \sigma_{u11}(\ln L_i)^2 + \sigma_{u22}(\ln K_i)^2$. To find the estimates of $\bar{\beta}$, ordinary least squares (OLS) gives an unbiased but inefficient estimator. If $Var(v_i)$ were known, the best linear unbiased estimator (BLUE) could be derived by generalised least squares (GLS). Following Hildreth and Houck's (1968) procedure, the mean response coefficients $\bar{\beta}$'s can be estimated under some specific assumptions of $Var(v_i)$. As for the individual response coefficients β_{mi}'s, Griffiths (1972) presents the actual firm-specific and input-specific response coefficient estimator for the ith observation.

According to Kalirajan and Obwona (1994), there are two implications of equation (1). First, technical efficiency is achieved by adopting the best available techniques which involve the efficient use of inputs. Therefore, the sources of technical efficiency stem from the efficient use of each input which contributes individually to technical efficiency and any other firm-specific intrinsic characteristics which are not explicitly included may produce a combined contribution over and above the individual contributions. The former can be measured by the magnitudes of varying slope coefficients β_{mi}'s and the latter can be obtained by the varying intercept term.

Second, the highest magnitude of each response coefficient and the intercept constitute the production coefficients of the potential production function. These production frontier coefficients, β^*'s, are chosen in such a way as to reflect the production responses following the adoption of 'best practice' techniques. Assume β^*_m is the highest response coefficient of the mth input for all firms, that is, $\beta^*_m = \max_i\{\beta_{mi}\}$, $m = 0,\ldots,M$ and $i = 1,\ldots,N$. Then, the potential frontier output for each firm can be expressed by

$$\ln Y_i^* = \beta_0^* + \sum_{m=1}^{M} \beta_m^* \ln X_{mi}, \quad i = 1,\ldots,N. \tag{3}$$

DATA SOURCES AND VARIABLES CONSTRUCTIONS

The data of Singapore's manufacturing industries used in this paper are obtained from the United Nations Industrial Development Organization (UNIDO) Industrial Statistics Database. It contains the annual data of 3-digit manufacturing industries on valued-added, number of employees and gross fixed capital formation (GFCF). Since manufacturing value added and GFCF are measured at current prices in local currencies in the UNIDO database, it is necessary to deflate those variables into constant prices. The use of local currencies for manufacturing value added and GFCF avoids the adverse influences of exchange rate fluctuations, which may mislead the decomposition of output growth. The construction of GDP and GFCF deflators can be derived using the nominal and real values of GDP and GFCF, which are available from *dX* for Windows 3.0, EconData. Alternatively, the data required for GDP and GFCF deflators are available from the publications of the Singaporean national accounts.

The capital stock of each industry is estimated by the conventional perpetual inventory method, $K_t = K_{t-1}(1-\delta) + I_{t-1}$, where K_t and K_{t-1} are capital stocks at time t and t–1; δ is the rate of depreciation; I_{t-1} is the real gross investment or more precisely GFCF carried out at time t–1. If the growth rate of GFCF (g) is assumed stable over time, the initial capital stock can be constructed by the initial GFCF divided by the sum of the depreciation rate and the average real growth rate of GFCF in the first ten years of the sample period, i.e., $K_0 = GFCF_0/(g+\delta)$, where $GFCF_0$ is the initial gross fixed capital formation and g is the average real growth rate of GFCF at the *manufacturing* level in the first ten years.[3] Due to lack of detailed components of GFCF data, a simple average depreciation rate (δ) of 0.1768 is adopted from Jorgenson's (1990) estimates to depreciate Singapore's manufacturing capital stocks. The depreciation rate of 0.1768 is computed from four depreciation rates of capital subinputs: non-residential building (0.0361), machinery and equipment (0.1048), transport equipment (0.2935), and office equipment (0.2729), where land is excluded from the construction of capital stock.

Moreover, to capture the quality improvement embodied in labor input due to an increasing number of well-educated employees, the labor input is calculated as the number of employees multiplied with one plus the labor quality adjustment index over time. This effectively scales up the number of employees in later years when workers become better educated. For Singapore's manufacturing sector, the average annual labor quality adjustment index is 1.6 percent according to Young (1995). Similarly, the paper adjusts the quality improvement embodied in capital input (GFCF) using the capital quality adjustment index of 0.5 percent suggested by Young (1995).[4]

EMPIRICAL RESULTS AND INTERPRETATIONS

To realize the development of individual industries over the past few decades, it is informative to present their shares in the overall manufacturing sector prior to further discussion. Table 1 shows the average shares of individual industries in Singapore's manufacturing sector over the period 1970–97. Three dominant industries with the highest share over the sample period were electric machinery with 24.4 percent, non-electrical machinery with 18.5 percent and transport equipment with 8.7 percent. They accounted for approximately 52 percent of total manufacturing output during 1970–97 and over 60 percent during the recent period 1995–97. Given such a high share of output contributed by the three leading industries, it is evident they would heavily influence the extent of TFP growth estimate of the overall manufacturing sector.

Table 1. The Average Shares of Individual Industries in the Overall Manufacturing in Singapore, 1970–1997 (percent)

	1970–79	1980–84	1985–89	1990–94	1995–97	1970–97
311 Food products	4.6	3.4	3.1	2.6	2.6	3.1
313 Beverages	1.7	1.4	1.4	1.1	0.8	1.2
314 Tobacco	1.1	0.8	0.6	0.6	0.2	0.6
321 Textiles	2.7	1.2	0.6	0.5	0.2	0.9
322 Wearing apparel	3.2	3.3	3.0	1.8	0.7	2.2
323 Leather products	0.2	0.1	0.1	0.1	0.1	0.1
324 Footwear	0.3	0.2	0.1	0.1	0.0	0.1
331 Wood products	3.7	1.5	0.6	0.3	0.2	1.0
332 Furniture	0.7	1.1	1.0	0.7	0.6	0.8
341 Paper and product	1.1	1.3	1.6	1.5	1.3	1.4
342 Printing and publishing	3.8	4.0	4.2	4.7	4.4	4.3
351 Industrial chemicals	1.4	1.6	5.6	3.8	1.8	3.0
352 Other chemicals	3.6	4.4	5.5	5.6	7.7	5.6
353+354 Petroleum & Miscellaneous petroleum	15.9	14.9	6.5	7.1	5.1	8.9
355 Rubber Products	2.2	0.8	0.4	0.3	0.3	0.7
356 Plastic Products	1.5	2.0	2.2	2.8	2.5	2.3
361+362 Pottery, Glass and product	0.4	0.3	0.1	0.3	0.5	0.3
369 Other non-metallic mineral	2.6	2.9	1.6	1.6	1.5	1.9
371 Iron and steel	1.7	1.3	1.0	0.7	0.4	0.9
372 Non-ferrous metals	0.3	0.3	0.3	0.3	0.1	0.3
381 Fabricated metal products	4.9	6.3	6.0	6.4	6.0	6.0

382 Non-electrical machinery	7.2	9.4	9.9	24.2	30.6	18.5

Table 1. (*continued*)

383 Electric machinery	18.6	23.9	33.8	23.0	22.7	24.4
384 Transport equipment	12.9	10.7	7.8	7.5	7.1	8.7
385 Professional equipment	1.9	1.4	1.8	1.8	2.1	1.8
390 Other manufactured products	1.4	1.3	1.3	0.7	0.5	1.0

Notes: 1. Due to rounding, figures above may not add up precisely.
2. The average share is calculated by the sum of value added of each industry divided by the sum of manufacturing value added over the period at constant 1990 prices, that is, $(y_i^t + y_i^{t-1})/(Y^t + Y^{t-1})$, not a simple average share.

Source: UNIDO database and author's calculation.

Table 2 presents the estimates of frontier and mean coefficients of production function for Singapore's manufacturing sector. It is interesting to note that certain variations in the labor coefficients occurred from the start of the sample period until the late 1980s. By contrast, there were some variations in the capital coefficients from the mid-1980s. The rationale for this outcome is that on the one hand, manufacturing industries in Singapore applied labor inputs differently in the early 1970s but similarly since the late 1980s. On the other hand, the application of capital inputs was increasingly diverse after the mid-1980s. Furthermore, the returns to scale, that is, sum of the coefficients of labor and capital inputs, on the basis of estimated frontier coefficients were between 0.974 in 1979 and 1.122 in 1985.

Table 2. Estimates of Frontier and Mean Coefficients of Production Function for Singapore's Manufacturing Sector, 1970–1997

Year	Range of actual response coefficients: Minimal varying coefficients			Frontier coefficients (maximal)			Mean coefficients		
	Constant	Labor	Capital	Constant	Labor	Capital	Constant	Labor	Capital
1970	3.469	0.420	0.596	4.408	0.496	0.596	3.960	0.458	0.596
1971	4.173	0.493	0.529	5.364	0.507	0.529	4.726	0.500	0.529
1972	4.789	0.561	0.464	5.499	0.611	0.464	5.136	0.585	0.464
1973	4.795	0.537	0.478	5.234	0.537	0.518	5.008	0.537	0.498
1974	4.381	0.509	0.503	5.203	0.509	0.522	4.804	0.509	0.513
1975	3.809	0.490	0.532	5.217	0.490	0.532	4.565	0.490	0.532
1976	5.189	0.537	0.455	6.156	0.555	0.455	5.626	0.546	0.455
1977	4.764	0.397	0.542	5.476	0.455	0.542	5.125	0.429	0.542
1978	4.319	0.319	0.610	4.788	0.395	0.610	4.540	0.359	0.610
1979	3.708	0.244	0.680	4.452	0.294	0.680	4.099	0.271	0.680
1980	3.393	0.340	0.653	3.978	0.390	0.653	3.646	0.364	0.653
1981	3.418	0.325	0.644	4.118	0.407	0.644	3.771	0.369	0.644
1982	3.726	0.473	0.544	4.307	0.576	0.544	3.975	0.519	0.544
1983	3.540	0.366	0.617	3.791	0.482	0.617	3.649	0.418	0.617
1984	2.634	0.296	0.696	2.860	0.412	0.696	2.741	0.353	0.696
1985	1.605	0.335	0.728	2.235	0.387	0.735	1.912	0.361	0.732
1986	1.602	0.280	0.761	2.134	0.343	0.761	1.860	0.309	0.761
1987	2.032	0.278	0.746	2.585	0.318	0.753	2.319	0.298	0.750

1988	2.486	0.298	0.711	3.085	0.310	0.734	2.817	0.304	0.723
1989	3.078	0.328	0.674	3.600	0.341	0.691	3.316	0.335	0.682

Table 2. (*continued*)

1990	3.654	0.398	0.618	3.748	0.398	0.660	3.695	0.398	0.634
1991	2.205	0.339	0.716	3.084	0.339	0.716	2.591	0.339	0.716
1992	3.042	0.404	0.643	3.332	0.404	0.672	3.181	0.404	0.657
1993	2.595	0.388	0.670	2.906	0.388	0.703	2.755	0.388	0.686
1994	2.224	0.358	0.704	2.379	0.358	0.745	2.304	0.358	0.725
1995	2.811	0.415	0.649	3.069	0.415	0.686	2.923	0.415	0.665
1996	3.986	0.521	0.532	4.254	0.521	0.573	4.122	0.521	0.553
1997	4.215	0.534	0.515	4.503	0.534	0.555	4.360	0.534	0.536
Average	3.416	0.399	0.615	3.992	0.435	0.628	3.697	0.417	0.621

Notes: 1. The minimal varying coefficients denote the lowest estimated coefficients among industries and the frontier coefficients are the largest coefficients among industries according to the specification of the model.
2. All varying coefficients are averaged to obtain 'mean coefficients'.

Source: The empirical estimation is carried out using the computer program *TERAN* developed by Kalirajan and Obwona (1994).

SOURCES OF OUTPUT GROWTH

Table 3 shows the decomposition of output growth for Singapore's manufacturing industries over the 1970–97 period. The highest average annual output growth occurred in the non-electrical machinery, with 18.2 percent, followed by professional equipment with 15.9 percent, and plastic products with 11.8 percent. Conversely, sizeable negative output growth occurred in several traditional industries, such as wood, footwear, and rubber. Except for the footwear, wood and textiles industries, most industries experienced positive as well as substantial input growth.

Although the average annual output growth of 9.4 percent for the Singaporean manufacturing sector between 1970 and 1997 was a remarkable performance, it was realised by utilising more resources due to extraordinary annual input growth of 10.2 percent. The result implies that the level of TFP in Singapore fell by 0.8 percent per annum. Irrespective of negative TFP growth, it is incorrect to conclude that all Singaporean manufacturing industries experienced no growth in TFP. In fact, Table 3 shows that 11 of 23 industries improved TFP; in particular, the professional equipment industry achieved the highest annual TFP growth rate of 3.5 percent, followed by textiles and other manufactured products.

Theoretical interpretation for the decline in TFP is that manufacturing industries in Singapore used more resources over time in order to maintain the same amount of output. Or, given the same amount of inputs, the Singaporean manufacturers produced less output over time. In fact, the finding of negative TFP growth of 0.8 percent per year in Singapore's manufacturing sector is not unusual in the literature on similar studies. Tsao (1985) also finds little evidence of TFP growth (0.08 percent) in Singapore's manufacturing industries between 1970 and 1979. Moreover, the result of this study is consistent with Young (1995), who suggested that Singapore's manufacturing sector experienced an average annual TFP growth rate of −1.0 percent during the 1970–90 period. Young (1992) further explained that manufacturing industries in Singapore always adopted the most advanced technology, which might have led to productivity loss at the outset before they efficiently managed new technology.[5] If the process of adopting new technology persisted in Singapore over the past three decades, the full benefits of applying new technology might not have been entirely realised due to the lack of a learning-by-doing effect.[6]

Through the above empirical analysis, the paper attempts to identify four major factors driving down TFP growth in Singapore's manufacturing sector.[7] First, TFP growth for Singapore's manufacturing sector over the 1970–75 period was severely affected by external shocks, for example, the oil crisis, leading to a significant TFP decline of 5.8 percent per annum. The surge in energy prices directed technological innovation to saving energy rather than to increasing productivity. If this five-year period is excluded, the average annual TFP growth rate between 1975 and 1997 becomes a *positive* 0.4 percent. Hence, it is believed that the choice of sample period is vital for TFP growth estimates in Singapore's manufacturing sector and this may help explain why Tsao (1985) and Young (1995) obtain lower TFP growth estimates because they include the 1970–75 period.

Table 3. Decomposition of Output Growth in the Manufacturing of Singapore, 1970–97 (percent)

	Output growth	Input growth	TFPG	TP	TE ch.
311 Food products	5.5	5.4	0.1	–1.2	1.3
313 Beverages	3.7	4.7	–1.1	–1.1	0.0
321 Textiles	0.5	–1.4	1.9	–1.1	3.0
322 Wearing apparel	3.9	4.3	–0.4	–0.9	0.5
323 Leather products	5.3	3.8	1.5	–1.0	2.5
324 Footwear	–2.0	–2.7	0.8	–0.9	1.7
331 Wood products	–2.7	–2.5	–0.3	–1.1	0.8
332 Furniture	7.2	8.8	–1.7	–1.0	–0.7
341 Paper and products	9.2	8.3	0.9	–1.1	2.0
342 Printing and publishing	8.7	7.8	0.9	–1.1	2.0
351 Industrial chemicals	9.5	9.9	–0.4	–1.4	1.0
355 Rubber products	–1.5	0.3	–1.8	–1.0	–0.7
356 Plastic products	11.8	12.4	–0.6	–1.1	0.5
361 +362 Pottery, glass and product	7.0	5.9	1.0	–1.1	2.2
369 Other non-metallic mineral	7.7	6.7	1.0	–1.1	2.1
371 Iron and steel	3.6	6.0	–2.4	–1.2	–1.2
372 Non-ferrous metals	2.3	4.2	–1.9	–1.2	–0.7
381 Fabricated metal products	8.4	10.3	–1.9	–1.1	–0.8
382 Non-electrical machinery	18.2	18.1	0.1	–1.0	1.1
383 Electric machinery	11.1	14.3	–3.2	–1.0	–2.2
384 Transport equipment	6.8	7.6	–0.8	–1.1	0.3
385 Professional equipment	15.9	12.4	3.5	–1.2	4.7
390 Other manufactured products	2.7	1.2	1.6	–1.1	2.7
300 Manufacturing	9.4	10.2	–0.8	–1.1	0.3

Notes: 1. Due to rounding, figures above may not add up.
2. TFPG, TE ch. and TP denote total factor productivity growth, technical efficiency change and technological progress, respectively.

Source: Author's calculation based on frontier coefficients in Table 2

Second, industries that experienced TFP decline and had higher shares in the manufacturing sector, such as electric machinery, fabricated metal products, and transport equipment, were probably responsible for the negative TFP growth. For example, if the average annual TFP growth (–3.2 percent) of the electric machinery industry with about a 25 percent share could be raised to zero or positive, it would increase the overall manufacturing sector's TFP growth estimate by 0.8 percentage points per annum.

Third, it is argued that the true depreciation rate of capital stock in Singapore's manufacturing sector may be higher than the figure of 0.1768 suggested by Jorgenson (1990). If the depreciation rate turned out to be higher, the TFP growth estimate would improve slightly. Conversely, TFP growth estimate will be lower if the labor (capital) quality adjustment index turned out to be higher due to a growing number of better-educated workers (the use of modern capital) in Singapore.

Fourth, in contrast to Hong Kong's laissez faire policy, the Singaporean government has been actively participating in economic activities and providing many schemes, grants, and tax concessions to promote investment as documented by Huff (1999) and Ermisch and Huff (1999). Nevertheless, excess investment may have resulted in a lower rate of capacity utilization, indicating an overestimation of capital input and understatement of TFP growth in Singapore.

Although discounting the above factors may have the effect of converting Singapore's TFP growth rate from negative to slight positive growth, it would have not brought it into line with that of other East Asian manufacturing sectors and therefore supports the finding of this study that the spectacular output growth in Singapore's manufacturing was mainly driven by factor accumulation rather than TFP growth.

DECOMPOSITION OF TFP GROWTH – HIGH-TECH VERSUS LOW-TECH INDUSTRIES

The traditional concept of treating TFP growth synonymously with technological progress used in growth accounting has narrowed the nature of TFP and ignored the importance of technical efficiency pertaining to the industry and firm's organization and effective use of available resources. To distinguish the difference, it is claimed that technological progress is measured by a shift in the production frontier, and the distance between actual output and potential output, or the production frontier, is traditionally referred to as technical inefficiency. Stated differently, TFP growth not only explicitly captures the technological progress but also reflects the improvement in using available resources and technology. The details of TFP decomposition is presented in the Appendix.

Regardless of the fact that eleven industries experienced positive TFP growth during 1970–97, the overall manufacturing sector experienced a 0.8 percent TFP decline on an annual basis. On analyzing the contribution of the components to TFP growth, a decline of 1.1 percent in technological progress was deemed to be the main cause for the negative TFP growth.[8] As for technological progress, all 23 industries uniformly experienced negative technological progress, varying from –0.9 percent per annum in the wearing apparel and footwear industries to –1.4 percent in industrial chemicals. In terms of technical efficiency change, there were only six industries with technical efficiency deterioration, especially, the electric machinery industry with the highest technical efficiency decline of 2.2 percent a year.

Intuitively, high-tech industries are often associated with high TFP growth, yet such empirical comparison has rarely been carried out in the literature. This paper compares high-tech with low-tech industries to examine two hypotheses. The first is that high-tech industries have higher TFP growth than low-tech ones. The second is that the sources of TFP growth for high-tech industries stem from technological progress, whereas those for low-tech industries come from technical efficiency improvement.

In the literature, there is no precise definition regarding the classification of high-tech and low-tech industries. Therefore, on the basis of capital-labor ratio, low-tech industries defined in this study are textiles, wearing apparel, leather products, footwear, wood products, and furniture, also known as labor-intensive or traditional industries.[9] Although the capital-labor ratio for chemicals, petroleum, and iron and steel industries are generally among the highest, these industries are usually characterised as heavy instead of high-tech industries. Based on the nature of technology rather than capital-labor ratio, this study classifies the non-electrical machinery, electric machinery, and professional equipment industries as high-tech.

TFP growth estimates for low-tech industries ranged from −1.7 (furniture) to 1.9 (textiles) percent per year. As the highest (3.5 percent) and lowest (–3.2 percent) TFP growth estimates were recorded in two of high-tech industries, namely, professional equipment and electric machinery, the first hypothesis is rejected for Singapore's manufacturing industries.[10] In terms of the sources of TFP growth, a similar extent of technological regress was evident across both high-tech and low-tech industries. Thus, preliminary analysis rejects the hypothesis that TFP growth in high-tech industries largely emanated from technological progress. Nevertheless, due to significant technical efficiency improvement in the textiles, leather, and footwear industries, the hypothesis of Singapore's low-tech industries gaining TFP growth from technical efficiency improvement is confirmed.

SENSITIVITY ANALYSIS

Concerns about the poor results for Singapore's manufacturing raise a number of questions regarding the choice of labor quality adjustment index (1.6 percent per annum) and capital depreciation rate (0.1768). To test the robustness of the TFP growth estimates for Singapore's manufacturing industries, several sensitivity tests using three capital depreciation rates (0.20, 0.25, and 0.30) and labor quality improvement indices (1 percent, 0.5 and 0, per annum) have been carried out in Table 4. The tests can alleviate criticisms that a constant depreciation rate is used, based on an average of the depreciation rates used by Jorgenson, and that the depreciation rate may be increasing over time because there are much higher depreciation rates for more modern (and high-tech) capital.

Table 4. Sensitivity Analysis of TFP Growth Estimates in Singapore's Manufacturing, 1970–97 (percent)

Labor quality indices	Depreciation rates	Output growth	Input growth	TFPG	TP	TE ch.
1.6	**17.68**	**9.4**	**10.2**	**−0.8**	**−1.1**	**0.3**
	20	9.4	10.1	−0.7	−1.1	0.3
	25	9.4	9.9	−0.6	−1.1	0.5
	30	9.4	9.8	−0.5	−1.0	0.6
1.0	17.68	9.4	9.9	−0.5	−1.1	0.6
	20	9.4	9.8	−0.4	−1.1	0.6
	25	9.4	9.6	−0.3	−1.1	0.8
	30	9.4	9.5	−0.1	−1.0	0.9
0.5	17.68	9.4	9.6	−0.2	−1.1	0.8
	20	9.4	9.5	−0.2	−1.1	0.9
	25	9.4	9.4	0.0	−1.1	1.0
	30	9.4	9.2	0.1	−1.0	1.2
0	17.68	9.4	9.3	0.0	−1.1	1.1
	20	9.4	9.2	0.1	−1.1	1.2
	25	9.4	9.1	0.3	−1.1	1.3
	30	9.4	9.0	0.4	−1.0	1.4

Notes: 1. 'TE ch.' and 'TP' denote technical efficiency change and technological progress, respectively.
2. Due to rounding, figures above may not add up.
3. The results above are derived based on the estimated frontier coefficients in Table 2

It is also evident that an increase in capital depreciation rate and decrease in labor quality index generate a positive impact on the TFP growth estimates for Singapore.[11] However, the impact generated by different scenarios appears to be insignificant unless the extreme capital depreciation rate (0.3) and labor quality adjustment index (0 percent) are selected. Even this could only raise average annual TFP growth from a negative estimate of –0.8 percent to a slight positive 0.4 percent which remains insignificant compared to other manufacturing sectors in East Asia.[12]

REVIEW OF EARLIER TFP STUDIES

The studies by Rao and Lee (1995) and Mahadevan and Kalirajan (2000) coincidently exclude the 1984–87 period of economic recession. After estimating TFP growth for two separate periods, their results contradict each other. Rao and Lee (1995) indicate that Singapore's manufacturing sector experienced –0.4 percent TFP growth over the 1976–84 period whereas Mahadevan and Kalirajan (2000) arrived an average annual TFP growth of 0.92 percent for the same period. The results remain inconsistent over the 1987–94 period, that is, 3.2 percent in Rao and Lee (1995) versus –0.52 percent in Mahadevan and Kalirajan (2000).

Table 5 shows a comparison of TFP studies for Singapore's manufacturing industries. The estimated annual TFP growth rates for the overall manufacturing sector range from –0.8 percent in this study to 2.8 percent in Leung (1997). The TFP growth estimates at the industry level vary widely across these studies. According to Tsao (1985), Wong and Gan (1994) and this study, the electrical machinery industry, regarded as a high-tech one, experienced negative TFP growth. By contrast, it gained substantial TFP progress according to Leung (1997) and Bloch and Tang (1999). Inconsistencies in TFP growth estimates also appear in other industries, for example, the leather and industrial chemicals.

Table 5. Studies of TFP for Manufacturing Industries in Singapore (percent)

	This study	Tsao (1985)	Wong and Gan (1994)	Leung (1997)	Bloch and Tang (1999)	Koh et al. (2002)
	1970–97	1970–79	1981–90	1983–93	1975–94	1975–98
	TFPG	TFPG	TFPG	TFPG	Tech ch.	TFPG
311 Food products	0.10	0.62	1.51	3.0	n.a.	–0.4
313 Beverages	–1.10	1.73	–2.14	–1.0	n.a.	as food
314 Tobacco	n.a.	3.22	11.22	–1.3	4.85	as food
321 Textiles	1.90	–3.23	–5.21	4.8	n.a.	2.6
322 Wearing apparel	–0.40	–2.11	2.05	1.6	–0.94	0.6
323 Leather products	1.50	–3.06	–4.67	3.0	0.27	–0.4
324 Footwear	0.80	–9.91	0.49	5.8	5.61	as leather
331 Wood products	–0.30	–6.57	–4.59	5.3	0.29	1.8
332 Furniture	–1.70	–2.44	–2.01	3.3	n.a.	n.a.
341 Paper and products	0.90	2.18	–3.97	3.4	–4.78	1.9
342 Printing and publish.	0.90	–1.36	0.35	–1.2	0.07	1.4
351 Industrial chemicals	–0.40	–0.24	–2.99	2.4	4.03	0.8

Table 5. (*continued*)

352 Other chemicals	n.a.	4.80	2.48	7.3[d]	−5.61	as chemical
353 Petroleum refineries	n.a.	n.a.	n.a.	2.6	0.73	0.3
354 Miscellaneous petrol.	n.a.	1.49	2.64	n.a.	as petrol.	as petrol
355 Rubber products	−1.80	−1.57	−4.65	3.0	−0.82	2.5
356 Plastic products	−0.60	−3.16	−6.07	4.5	−7.46	as above
361 Pottery, china, earth.	1.00	−3.03	−19.67[b]	−3.0	n.a.	1.2
362 Glass and products	as pottery	as pottery	as pottery	as pottery	n.a.	as pottery
369 Other non-metallic	1.00	−1.7[a]	−4.71[c]	4.1[e]	n.a.	as pottery
371 Iron and steel	−2.40	3.41	−0.77	0.6	1.17	0.9
372 Non-ferrous metals	−1.90	−13.87	2.81	0.8	n.a.	as iron
381 Fabricated metal	−1.90	−3.59	−3.35	3.8	−3.46	1.0
382 Non-electrical mach.	0.10	−3.28	−2.32	4.3	0.22	4.0
383 Electric machinery	−3.20	−0.04	−0.54	3.8[f]	6.54	3.7
384 Transport equipment	−0.80	1.27	5.56	3.7	0.00	4.8
385 Professional equip.	3.50	n.a.	0.39	2.3	−2.46	6.6
390 Other manufactured	1.60	n.a.	n.a.	0.8	−8.14	n.a.
300 Manufacturing	−0.80	0.08	1.60	2.8	n.a.	2.7

Notes: 1. (a) This is a simple average of the annual TFP growth rates for the concrete, structural clay and cement products, which were −0.0536, −0.0563, −0.0378 respectively. (b) This figure is from Wong (1993) because it is not reported in Wong and Gan (1994). However, these TFP growth estimates are derived from the same author. (c) The average annual TFP growth rates for the concrete, structural clay and cement products were 0.1072, −0.0554, 0.0468 respectively. (d) This estimate is for the pharmaceutical industry. (e) The average annual TFP growth rates for the bricks/ tiles, cement and concrete product industries were 0.049, 0.099, and 0.022 respectively. (f) This includes the electronics industry, which had an average annual TFP growth rate of 0.008.

2. In addition, Bloch and Tang (1999) use conventional growth accounting to estimate TFP growth for the 19 industries, which is available in Table 1, p. 700.

Sources: The result of Leung (1997) is from p. 526, Table 1, Bloch and Tang (1999) from p. 700, Table 1, Tsao (1985) from p. 29, Table 1, Wong and Gan (1994) from p. 182, Table 2, and Bloch and Tang (1999) from p. 700, Table 1, Koh et al. (2002) from p. 263, Table 4.

SUMMARY, CONCLUSION, AND POLICY IMPLICATIONS

This paper has investigated the sources of output growth for 25 Singapore's manufacturing industries, applying the varying coefficients frontier model and a panel data set from the UNIDO Industrial Statistics Database at the 3-digit industry level. This paper finds no evidence of TFP growth in Singapore's manufacturing sector and concludes that Singapore experienced a negative TFP growth rate of −0.8 percent per year over the period 1970–97, suggesting that the spectacular output growth in Singapore's manufacturing was mainly driven by factor accumulation rather than TFP growth. Although the study tentatively identifies that the inclusion of the 1970–75 period and industries with large TFP declines and higher shares in manufacturing, such as electric machinery, have a detrimental impact on overall TFP growth, discounting these two factors would have not brought it into line with that of other East Asian manufacturing sectors.

The comparison between high-tech and low-tech industries reveals that high-tech industries did not associate with higher TFP growth. In terms of the sources of TFP growth, the paper rejects the hypothesis that TFP growth in high-tech industries largely emanated from technological progress but confirms that the hypothesis of Singapore's low-tech industries gaining TFP growth from technical efficiency improvement. Moreover, by disaggregating TFP growth into technical efficiency change and technological progress across industries, the study holds technological decline responsible for the negative TFP growth in Singapore. Finally, in unison with Tsao (1985) and Young (1995), the conclusion emerging from this study indicates that though TFP growth in Singapore was negligible the extent of TFP decline abated in recent years.

From the policy perspective, the two components of TFP growth are analytically distinct and may have quite different policy implications (Nishimizu and Page, 1982). On the one hand, high rates of technological progress can coexist with deteriorating technical efficiency. On the other hand, low rates of technological progress can also coexist with high improvements in technical efficiency.

Literature emphasizes that technological progress is the backbone of economic growth. Policy makers therefore tend to adopt various measures to induce investment in research and development (R&D) in order to promote technical progress. While implementing such policy measures, industries that have a high R&D component are usually given financial priority over industries with a low R&D component, even though the latter constitutes an essential part of the economy in many countries. These kinds of policy decisions are based on the following reasons: first, policy makers erroneously think that once the technology is identified, entrepreneurs will use them effectively; second, the growth of high-tech industries is more technology-driven than that of low-tech industries; and third, high-tech industries are more effective in using the chosen technology than low-tech industries.

However, a number of theoretical models on technology adoption argue that after firms adopt a new technology, not all of the expertise in the old technology transfers to the new technology, and there is a period of technology-specific learning (Hornstein and Krusell, 1996; Greenwood and Yorukoglu, 1997). Focusing heavily on technological progress but ignoring possible improvement in technical efficiency may result in lower TFP growth because it may take some time for firms to reap the full potential of the new technology. If the technology has not been used to its full potential, introducing new technologies or upgrading the existing technology is wasteful (Kalirajan et al., 1996).

ENDNOTES

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1. Despite its wide popularity, growth accounting has been seriously questioned as an appropriate means of explaining the role of technological progress in the East Asian economic miracle. In contrast to Krugman's and Young's hypothesis, Chen (1997) considers the concept of TFP growth in detail and asserts that it should not be regarded as technological change because TFP growth on the basis of growth accounting is defined as disembodied, exogenous and Hick-neutral technological change. Rodrik (1998) has particular concerns about the assumption of an elasticity of substitution between labor and capital of one for East Asian economies. If the true elasticity of substitution is less than one, this implies that technical change is no longer Hicks-neutral and TFP growth is underestimated. Likewise, Felipe (1999) argues that an important part of technological progress is embodied in the factors of production, so that conventional TFP growth may not be convincing in terms of accounting for technological progress in East Asian economies and predicting their future.
2. As for the sample period examined in this paper, it is from 1970 to 1997 mainly due to availability of data set collected in January 2001.
3. If the average real growth rates of GFCF were chosen from individual 3-digit manufacturing industries, in some cases the initial capital stock could become negative due to the dramatic fluctuations of GFCF in several 3-digit industries. The average annual real growth rate of GFCF in the initial ten years for the Singapore's (1970–80) manufacturing sector was 0.0840. Note that the average annual growth rate of GFCF is geometric *not* logarithmic.
4. The outcome of the quality adjustment can be easily worked out. For example, the adjustment for capital input will raise the growth of capital input; subsequently it reduces the degree of TFP growth slightly. The magnitude of reduction in TFP growth due to the quality adjustments for labor and capital inputs is therefore interpreted as 'embodied technological change'.
5. This proposition has been recently examined by Huggett and Ospina (2001). From annual plant-level data in the Colombian manufacturing sector, they find evidence that a large investment in equipment will simultaneously reduce TFP growth by 3~9 percent.
6. Young (1992, pp. 38–43) provides his bounded learning-by-doing model to reconcile the results for Singapore.
7. A number of studies, including Tsao (1985), Toh and Low (1996), and Swee and Low (1996), have provided other interpretations for the low estimated TFP growth in Singapore.
8. If the 1970–75 period is excluded, this study suggests deterioration in technical efficiency was the main cause of low TFP growth in Singapore over the 1975–97 period. This outcome is consistent with the finding of Mahadevan and Kalirajan (2000).
9. For instance, R&D expenditure ratio is also a good indicator in defining high-tech and low-tech industries; yet, such data are unavailable in the UNIDO database.
10. Wong and Gan (1994) also find that the high-tech industries such as electrical machinery and electronic products, and industrial machinery experienced TFP decline by 0.54 percent and 2.32 percent, respectively.
11. In addition, it is observed that when the capital depreciation rate is fixed, say, 0.20, an increase in labor quality adjustment index only alters technical efficiency improvement but not technological progress because the calculation of technological progress is based on the initial capital and labor input.

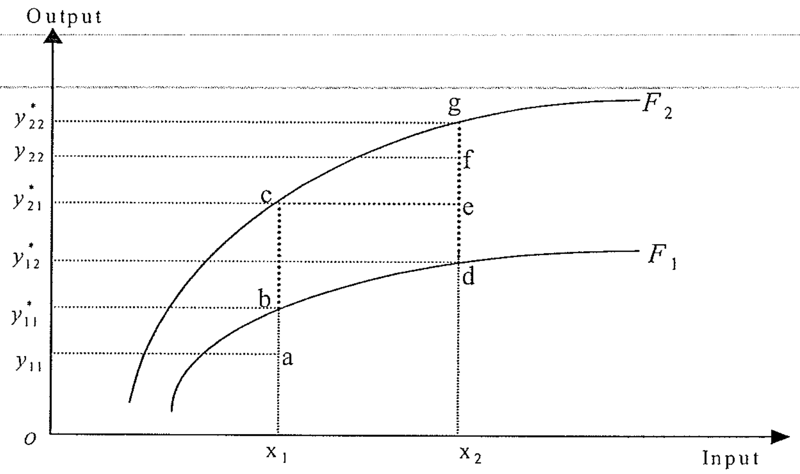
12. The sensitivity analysis clearly shows that a larger labor quality adjustment index generates higher input growth resulting in lower TFP growth. On the other hand, a larger capital depreciation rate creates higher TFP growth because of less capital input.

APPENDIX

The conventional Solow residual or growth accounting does not distinguish between the effects of technical efficiency change and technological progress. Following the rationales introduced by Nishimizu and Page (1982), TFP growth can be decomposed into two components, technological progress and technical efficiency change. Figure A.1 demonstrates the decomposition of output growth into technological progress, technical efficiency change and input growth.

Figure A.1

The Decomposition of Output Growth with Technical Inefficiency



In Figure A.1, F_1 and F_2 refer to the potential production frontiers at periods, T_1 and T_2, i.e., the efficient production technologies, from which maximum potential outputs are estimated from equation (3). The x_1 and x_2 (in logarithms) are the levels of inputs and y_{ij} (in logarithm) is the output level, where i denotes technology (or production frontier) and j represents the level of inputs. Finally, the asterisk (*) denotes that firms efficiently operate on the production frontier. According to Figure 1, the decomposition of output growth ($y_{22} - y_{11}$) into input growth, a movement towards production frontier and a shift in production frontier can be described as follows.

Output growth = $y_{22} - y_{11} = \overline{ab} + \overline{bc} + \overline{ef} = \overline{ab} + \overline{bc} + (\overline{eg} - \overline{fg}) = (\overline{ab} - \overline{fg}) + \overline{bc} + \overline{eg}$

$= [(y^*_{11} - y_{11}) - (y^*_{22} - y_{22})] + (y^*_{21} - y^*_{11}) + (y^*_{22} - y^*_{21})$

$= (TE_2 - TE_1) + (\Delta TP) + (\Delta Y_x)$

= (*change in technical efficiency*) + (*technological progress at* x_1) + (*input growth from* x_1 *to* x_2 *with production technology* F_2),

where the distance between frontier output (y^*_{11}) and actual output (y_{11}) indicates that firms do not efficiently operate on the production frontier and the loss in outputs is due to technical inefficiency measured as '*a movement towards or away from production frontier*'. The gap ($y^*_{21} - y^*_{11}$) implies that using the same amount of input (x_1) but different technologies (F_1 and F_2) the increase in output is attributed to the technological progress measured as '*a shift in production frontier*', i.e., vertically shifting up. The gap between y^*_{22} and y^*_{21} stems from using the same technology (F_2) but with different levels of inputs, x_1 and x_2, namely, output growth due to the increase in inputs. The decomposition framework has shown the important role played by technical efficiency in determining TFP growth.

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