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Total factor productivity growth accounting in the construction industry of Singapore

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Total factor productivity (TFP) determines long-term economic growth and is a comprehensive industry-level productivity measure. This paper proposes Jorgenson's method as an appropriate TFP measurement for the construction industry. The method is less restrictive than the conventional Chau's approach, as it does not impose the Hick Neutral Technical Change assumption. Jorgenson's method is then applied to estimate TFP growth in the construction industry of Singapore over 1984–1998. TFP growth is found down by 1.37% per annum over this period, indicating that the performance of TFP in the construction industry lags behind the rest of economy. TFP growth is also found to be fluctuating over time and tends to move in tandem with construction business cycle.

As a monitor progress towards TFP achievement, factors influencing TFP growth in the construction industry of Singapore over 1984–1997 are identified. Totally, seven factors are found to be significantly related to TFP growth. Among them, Economies of scale, R&D by the industry, investment allowance granted and labour union are leading contributors to TFP growth; while foreign worker, construction accidents and pre-cast are major hampers.

The general methodology presented in this study can be applied to other countries. Future studies are required to find appropriate indicators for factors unquantified.

Keywords: total factor productivity, growth accounting, Singapore, translog production function, indicators

Introduction

In the construction industry, three productivity concepts are currently adopted. They are labour productivity (LP), multi-factor productivity (MFP), and total factor productivity (TFP). LP is usually measured as value-added per worker and MFP is measured as value-added labour capital productivity.¹ LP and MFP are misleading when applied to measure construction industry-level productivity performance, because materials role in productivity improvement is ignored (CIDB, 1992; Chau, 1988). Recognized as a more comprehensive indicator than LP and MFP to evaluate efficiency in the use of resources, TFP has become a key consideration for Singapore's economy in general.

Theoretically, TFP growth is the rate at which the production frontier is shifting over time, due to advances

in knowledge and improvements in organization (Oulton and O'Mahony, 1994). TFP growth is measured as the difference between growth of output and the growth of total input, where the latter is the sum of weighted growth rates of labour, capital and intermediate inputs (Jorgenson *et al.*, 1987). Due to the lack of data, most of the works are limited on MFP. The world's major statistical agencies such as the US Bureau of Labour Statistics and the Department Statistics of Singapore publish MFP indices only at the national and industry levels. Using value-added production function, Tan (2000) estimated the MFP growth of Singapore's construction industry. However, using the MFP concept to measure industry-level productivity is inappropriate although it is an appropriate measure for productivity at aggregate level (Jorgenson *et al.*, 1987; Oulton and O'Mahony, 1994). Many economists (Wolff, 1981; Gollop 1985) agree that when measuring industry-level productivity, all factor inputs should be included as

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they work together to produce one common output. Jorgenson *et al.* (1987) further tested that there is no existence of a value-added function at the industry level.

Owing to data limitations, only a few studies of TFP in the construction industry have been done and they tend to use indirect ways. Among them, the most established approach is by Chau and Walker (1988; Chau, 1993). Their approaches are to measure TFP indirectly from construction cost and price data by assuming Hicks Neutral Technical change. Under the assumption, biases of productivity growth with respect to all three inputs are equal to zero. However, the existence of bias in technology change made Chau's neutral technology change assumption restrictive (Jorgenson *et al.*, 1987). Therefore, it is imperative to propose or develop a less restrictive TFP measurement for the construction industry.

In recent years, the government of Singapore has recognized TFP as a determinant of long-term economic growth and set a target of attaining MFP growth rate of 2% per annum (DOS, 1997). As an important sector of the economy, the construction industry should contribute its fair share to achieving this national target. To monitor the progress towards this goal, significant factors affecting TFP growth in the construction industry of Singapore need to be identified and analysed.

Objectives of the study

The objectives of this paper are:

1. To propose an appropriate, less restrictive TFP measurement for the construction industry and apply it to estimate TFP growth of the construction industry of Singapore.
2. To identify theoretical factors and select significant ones that affect TFP growth of the construction industry of Singapore.
3. To investigate the trend of TFP growth and analyse significant factors affecting TFP growth in the construction industry of Singapore.

Methodology

Jorgenson's (Jorgenson *et al.*, 1987) method is introduced and a comparison between Jorgenson's method and Chau's approach (Chau and Walker, 1988; Chau, 1993) is conducted. Essentially, Jorgenson's method is applied to calculate TFP growth in the construction industry of Singapore. In order to identify significant factors that affect TFP growth of the construction industry of Singapore, three steps are involved. First, a comprehensive search of theoretical factors influencing TFP growth in the construction industry is conducted. Second, a list of influencing factors or their proxies is

abstracted from statistical resources to create the time-series data set. Finally, using the calculated TFP growth as the dependent variable, and the influencing factors as independent variables, the STEPWISE procedure is used to select the statistically significant indicators.

The appropriate measurement of TFP for the construction industry

Building on the pioneer works of Solow (1957) and Denison (1967), Jorgenson *et al.* (1987) developed a production function based TFP measurement. It assumes that for each industry, there exists a transcendental logarithmic (translog) production function, giving output as a function of intermediate input, capital input, labour input and time.

$$Z = F(X, K, L, T) \quad (1)$$

Where Z is the quantity of output, X, K, L are the quantity of the intermediate, capital and labour inputs, and T is time.

Rates of productivity growth can be defined as rates of growth of output with respect to time, holding intermediate input, capital input and labour input constant. Under the condition of constant returns to scale and producer equilibrium, the average growth rate of TFP can be expressed as the growth rate of output less the sum of weighted average of growth rate of intermediate, capital and labour inputs:

$$\begin{aligned} \bar{V}_T = & [\ln Z(T) - \ln Z(T-1)] - \bar{V}_X[\ln X(T) - \\ & \ln X(T-1)] - \bar{V}_K[\ln K(T) - \ln K(T-1)] - \\ & \bar{V}_L[\ln L(T) - \ln L(T-1)] \end{aligned} \quad (2)$$

Where

$$\begin{aligned} \bar{V}_X &= \frac{1}{2}[V_X(T) + V_X(T-1)] \\ \bar{V}_K &= \frac{1}{2}[V_K(T) + V_K(T-1)] \\ \bar{V}_L &= \frac{1}{2}[V_L(T) + V_L(T-1)] \\ \bar{V}_T &= \frac{1}{2}[V_T(T) + V_T(T-1)] \\ V_X &= \frac{p_X X}{qZ} \quad V_K = \frac{p_K K}{qZ} \quad V_L = \frac{p_L L}{qZ} \end{aligned}$$

Where, $\bar{V}_X, \bar{V}_K, \bar{V}_L$ represents the respective shares of intermediate, capital and labour input averaged over time T and $T-1$, while q, p_X, p_K, p_L denote the prices of the output and intermediate, capital and labour inputs.

Equation 2 can be represented as:

$$\begin{aligned} \Delta \ln(TFP) = & \Delta \ln(Z) - \bar{V}_X \Delta \ln(X) - \bar{V}_K \Delta \ln(K) \\ & - \bar{V}_L \Delta \ln(L) \end{aligned} \quad (3)$$

Where Δ is the difference between a variable at time T and $T-1$: For example,

$$\Delta \ln(Z) = \ln Z(T) - \ln Z(T-1)$$

Each input can be defined as a translog function of its individual inputs. Under constant returns to scale and producer equilibrium, the growth rate of each input can be expressed as a weighted average of growth rates of individual input, with weights given by average value shares:

$$\ln X(T) - \ln X(T-1) = \sum \bar{V}_{Xi} [\ln X_i(T) - \ln X_i(T-1)] \quad (4)$$

$$\ln K(T) - \ln K(T-1) = \sum \bar{V}_{Kj} [\ln K_j(T) - \ln K_j(T-1)] \quad (5)$$

$$\ln L(T) - \ln L(T-1) = \sum \bar{V}_{Li} [\ln L_i(T) - \ln L_i(T-1)] \quad (6)$$

While in Chau's approach, TFP is defined as:

$$T = \frac{Q_0}{g(Q_1, Q_2, \dots, Q_n)} \quad (7)$$

Where $g(Q_1, Q_2, \dots, Q_n)$ is an input aggregator function and is assumed to be linearly homogeneous and continuously differentiable. Under the assumption of Hicks Neutral Technical and constant return to scale and using the Divisia index, TFP growth is expressed as:

2

$$\Delta(\ln T)_t = \sum_{i=1}^n \bar{s}_{it} \Delta(\ln P_{it}) - \Delta(\ln P_o)_t \quad (8)$$

Where the Δ sign denotes the difference in the value of the corresponding variable between two successive periods and the bar sign denotes the average of the same two successive periods, P_o is the price of output and the P_{it} the price of i th input.

In contrast to Chau's approach, Jorgenson's method does not impose the assumption of Hicks Neutral Technology Change (Jorgenson *et al.*, 1987). Jorgenson's method defines output as a function of the intermediate input, capital input, labour input and time $Q = F(X, K, L, T)$; while Chau's method is based on the existence of an aggregate input function $g(Q_1, Q_2, \dots, Q_n)$, in which aggregate output depends on the intermediate, capital and labour inputs and is independent of the level of technology T . A quantity aggregate input is equivalent to assumption of Hicks neutrality of technology change. The existence of biases of productivity growth made the Chau's assumption vulnerable. Thus, a more appropriate TFP measurement for the construction industry is that of Jorgenson's (1987).

Review of factors affecting TFP in the construction industry

Little study has been done on factors influencing construction industry-level TFP growth. As TFP growth is a relevant measure of technological change, it is necessary to review factors identified as technology

progress in LP growth accounting studies. Meanwhile, because factors influencing productivity growth highly interacted (National Research Council, 1979; and Fabricant, 1983), it is also necessary to review those factors interacting to technological change. Furthermore, conventional productivity growth accounting was built on exogenous growth theory, which has been greatly challenged by the new endogenous growth theory in recent years. Hence, it is also necessary to review the impact of the new growth theory on the productivity accounting studies.

In macroeconomics, Denison (1972) classified three main sources of productivity growth: (i) economies of scale; (ii) shifts in resources allocation; (iii) and growth of knowledge. Griliches (1980) attributed part of Denison's residual to investment in R&D activities. In the construction area, factors identified as affecting LP growth include: (1) capital – labour ratio; (2) composition of output; (3) increase in the corporate share in contract construction; (4) labour quality; (5) economies of scale; (6) introduction of new techniques in building; (7) the substitution of labour-saving building materials for others; (8) percentage of union (Dacy, 1965; Stokes, 1981; Allen, 1985).

Technology, capital and education interact in productivity growth. Technical progress must often be incorporated into new tangible capital goods and used by appropriately trained labour, if it is to be effective (Oulton and O'Mahony, 1994). Meanwhile, through learning by doing, workers invent new ideas to improve the machine itself (Valdés, 1999). R&D activity is in turn influenced by the country's education level.

The new endogenous growth theories incorporate the determinants of growth into the production model. Romer (1986) emphasizes the public knowledge, suggesting spillovers from R&D expenditure. Lucas (1988) emphasizes the role of human capital. The new growth theories are important because they provide new explanation on residuals problem in old productivity growth accounting theories. According to Valdés (1999) it is reasonable to integrate both the new and old growth theories in the future theory of production of technology.

Theoretical factors influencing TFP growth in the construction industry of Singapore

The factors explained here are those which theory indicates have an influence on TFP growth of the construction industry. They have been derived from a thorough literature review.

Composition of output

An index of weighted value-share of each sector in the construction industry can be derived as an indicator to

reflect the change in the composition of construction products. The weights are given by the average TFP of each sector. Another factor is the ratio of new construction to maintenance and repair construction works.

Technology progress

Technology progress involves two aspects: advances in knowledge and rate of diffusion of new knowledge. Advances in knowledge come from two sources: organized R&D activity and informal R&D through job-practice (Kendrick, 1981). To measure organized R&D activity, R&D expenditure in construction industry per construction output is used as an indicator. In addition, construction technology change is also affected by technology progress of the country as a whole. Ratio of aggregate of domestic R&D expenditure to GDP in Singapore is used as another indicator. Meanwhile there is likely to be substantial innovation through job practice (Young, 1993; and De Long and Summers, 1992). As better-educated people develop new ideas more easily, the educational level in the construction industry is used as proxy to measure innovation through job-practice. Education level will be discussed under quality of labour.

New knowledge can be diffused through modernizing capital goods or through international technology transfer. Because innovations are often embodied in new plant and equipment, the average age of real fixed-capital stock in the construction industry is used to measure the rate of diffusion of knowledge in the industry. However, such data were seldom available in Singapore. Factors affecting rate of capital formation such as government allowance on taxation of capital expenditure, energy price, and inflation rate will be discussed later. International technology transfer is viewed as reflecting the narrowing 'technological gap' between developed industries and developing industry as a result of 'catch up' (Kendrick, 1981). Usually, the technology transfer is measured in terms of money of technology purchased by the recipient country (Lall, 1982). However, this measure would omit an indirect channel such as reference to publications and would not reflect the effectiveness (Ofori, 1994). Therefore, so far it is difficult to measure international technology transfer.

Quality of labour

To measure labour quality, an index is developed. Labour force is cross-classified by type of sex, age and education. Under the assumption that a worker's pay reflect their marginal productivity, the index then can be developed as the sum of weighted value-share of each type of worker, with weights given by their median

weekly earnings correspondingly. Meanwhile, percentage of certified workers is used as an indicator to reflect workers' skill employed in the construction industry of Singapore. Besides, the construction industry of Singapore employs a large number of unskilled foreign workers, which has been identified as an important factor leading to low construction productivity. The proportion of foreign worker in total workforce is used as an indicator to evaluate the effect of foreign worker in TFP growth.

Quality of materials

Utilization of new materials that are of better quality and easier to work with will contribute to productivity growth (Chau, 1993). Use of prefabrication components has been transferring some labour to off-site. In Singapore, the concepts of prefabrication and buildable-design have been promoted by the Construction Industry Development Board (CIDB) since 1992 to enhance the industry's productivity. Generally, a positive correlation between buildability and productivity exists, (CIDB, 1992). Hence, the prefabrication level and buildable score of the industry can be used as proxies to estimate materials quality. As the overall buildable score of the industry was only available after 1992 and the prefabrication level is not recorded in Singapore, the pre-cast level is used as a proxy. Pre-cast level is estimated as the percentage of cement used in pre-cast concrete over total consumption of cement in the industry.

Economies of scale

Allen's (1985) study shows that there is a positive relationship between average hours per establishment and productivity. However, the economies of scale in the construction industry are limited due to the labour-intensive characteristic and non-standard products of construction industry (Ofori, 1990). Nevertheless, for the purpose of testing, economies of scale are still taken as a potential factor influencing TFP. To quantify economies of scale, the factors that can be used as proxies include: changes in number of employee per firm, output per employee by different sizes of firm. In Singapore, these types of data are only available from 1996. Instead, construction output per capita is employed as an indicator of economies of scale.

Government regulations

Government plays both positive and negative roles in productivity growth. In Singapore, the government has launched many schemes to improve productivity in the construction industry. Since March 1984, the Investment

Allowance Scheme was introduced by the CIDB to help local contractors improve their competitiveness through mechanization. Other schemes include the Preferential Margin to promote international technology transfer and skills training for construction workers. To quantify government's positive role in productivity growth, total grant to CIDB (%) over the size of the construction industry of Singapore is used as efficiency indicator to evaluate the government performance in TFP growth. Besides, investment allowance granted by CIDB to contractors, R&D grants to contractors are also used as indicators. To measure the government's negative effect on TFP growth, the proportion of capital used to meet health, safety, and environmental regulations for non-productive purpose in the total real stock of capital can be used as proxies. However, these kinds of data cannot be easily gathered.

Cyclical factors

Cyclical factors affecting TFP include energy prices and inflation rate. Sharp increase in energy prices has a negative effect on productivity growth (Kendrick, 1981). Steep rise in energy price renders some existing energy-intensive capital goods uneconomical and obsolete, which leads to a slow down in the rate of capital formation. Inflation can impede productivity (Levitan, 1984). It discourages capital formation and exacerbates future uncertainties. It postpones innovative investment.

Industrial relation and policies

Work rules and motivation policies can affect construction productivity. The indicators include: (1) percentage of union and percentage of contract that: (2) allow the establishment of labour-management committees; (3) allow for incentive wage payment; (4) allow for subcontracting. According to Allen's study (1985), decline in percentage of union will cause decline in productivity. In Singapore, the data available is percentage of union.

Construction accident

Accidents on site cause productivity to fall as the site activities disrupted will lead to a delay in progress. Data on industrial accidents are needed.

Other factors

The residual factors include changes in the legal, institutional and social environment and changes in exports.

Data

Data for the calculation of TFP growth of the Singapore construction industry

Estimation of TFP is from 1984 1Q to 1998 4Q, with total of 60 quarterly records involved. The period starts from 1984 because data for most factors are only available after 1984. The study period ends in 1998 because *Survey of Construction Industry 1998* was the latest series, whereby the coefficient of intermediate input and output is acquired. To compute the TFP growth by Eq.2, data required are translog index of real output growth $\ln Z$, translog indices of real intermediate $\ln X$, capital $\ln K$ and labour growth $\ln L$ and average value share of intermediate \bar{V}_X , capital \bar{V}_K and labour input \bar{V}_L .

Translog index of output growth

In Singapore, 'progress payment certified' was used to estimate construction output. However, this measure does not include the construction works carried out by developer/owner himself and the value of related architectural service. A more accurate measure of construction gross output is from the Singapore I-O table. As *the Singapore I-O Table* (DOS, 1978; 1983; 1988; 1990) is published only every five years and it assumes that the economic structure during the benchmark years remains stable, to obtain the gross output value between the benchmark year, three steps are involved. First, coefficients or ratio of value-added and output on benchmark year were computed from *Singapore I-O Table*, *Census of the Construction Industry 1996* (CIDB, 1998) and *Survey of the construction industry 1998* (BCA, 2000). Second the coefficients between benchmark years can be developed by interpolation. Third outputs are calculated by dividing the valued-added by the coefficients. The output should be valued in the producer's prices. Adjustment to nominal gross output is needed to exclude all indirect taxes and intra-industry purchase. To get the real output growth, the nominal output are deflated by tender price index.

Translog index of intermediate input growth

From Eq.3, translog index of intermediate input growth is aggregate growth of its individual components. The primary sources for the individual components are *COMMODITY ANALYSIS OF PURCHASES FROM DOMESTIC PRODUCTION*, and *COMMODITY ANALYSIS OF RETAINED IMPORTS*, in *Singapore I-O Table*. The Singapore I-O table allows two types of intermediate input to be distinguished: (1) materials purchased; (2) non-industrial services. To get the real value of each component, for materials, building materials price index are used as deflators; for non-industrial

services, GDP deflators of each industry are used as deflators.

Translog index of capital growth

Theoretically, quantity of capital input should be measured in terms of capital services provided. In reality, such data are seldom recorded. The alternative method assumes that the services provided by a durable good are proportional to initial investment in this good. Value of net fixed assets, published on *Singapore Corporate Sector: Size Composition and Financial Structure* (DOS 1992), *Singapore Corporate Sector 1986–1995* (DOS, 1998), *Singapore Corporate Sector 1986–1995* (DOS, 2000), is used as an approximate to capital stock. Two types of fixed asset are distinguished: machinery and equipment; land and building. As data on net fixed assets are available in aggregate level, a survey was conducted to decompose and estimate the proportion of each category in the composition of fixed assets. Results from 20 respondings construction firms indicates that land and buildings constitute about 24.5% (mean value) of all net fixed assets. Thus, 24.5% of net fixed assets is attributed to land and buildings and Property Price Index (all types of properties) is used to deflate the real property proportion of net fixed assets; and the rest 73.5% is attributed to machinery and equipment, and Domestic Supply Price Index for Machinery and Transport Equipment is used as the deflator.

Translog index of labour growth

Labour input is measured by quarterly hours worked, which is computed as the product of number of workers employed, weekly hours worked, and weeks worked per quarter. Workers are cross-classified by age, sex, and education. Totally 72 categories of workers are identified (six age group, two sex group and six education levels). Numbers of workers employed, cross-classified by age–sex–education are obtained from employment matrices of construction labour force. The main data source is *profile of the labour force of Singapore 1983–1994* (Ministry of Labour, 1995). For the year 1995–1998, the main data source is *Report on the labour force survey of Singapore* (Ministry of Labour, 1995; 1996; 1997; 1998). Weekly hours worked by each category of workers are from *TREND* data on average weekly hours worked by industry annually. Quarterly hours worked for each group of workers are assumed to be 12 weeks for all groups of workers (divide the 48 weeks for annual hours worked by 4).

Value share of intermediate, capital and labour input

Under the condition for producer's equilibrium, the sum of the value intermediate, capital and labour is equal to value of output. Value share of intermediate, capital and labour input is derived in benchmark year are from

Singapore Input–Output Table, and between benchmark years using interpolation.

Data for the selection of statistically significant indicators

Theoretical factors have to be transferred into statistical indicators in order to gather data. A list of the statistical indicators and data sources is presented on Table 1. Among the 22 indicators listed in Table 1, 14 indicators can be quantified or available in the case of the construction industry of Singapore. Because the calculated TFP growth is in log value, data for each indicator were also transformed to log growth rate. Data put into STEPWISE procedure were actually chosen from 1984 1Q to 1997 4Q because the four quarters in 1988 were kept for test purpose.² Thus totally 55 datasets were involved. Translog growth of TFP was taken as the dependent variable and translog growth of 14 factors were taken as independent variables to run STEPWISE.

Results

A sample of detailed account of calculation of quarterly translog index of TFP growth is presented in Table 2. To make sense, the translog index of TFP growth was transformed into real TFP growth, then to normal TFP index. The TFP trend of the construction industry of Singapore over the period of 1984 1Q–1998 4Q is shown in Figure 1.

When a significance level was set at 5%, 10% and 15%, two, five and seven factors were selected correspondingly. R^2 reached maximum when the significance level was set to 15% and hence its result is chosen as the final one. Results of the STEPWISE procedure when significance level is 10% are shown in Table 3. The results of the STEPWISE procedure of significance level 15% are shown in Table 4. As shown in Table 4, totally seven indicators are found significantly related to TFP growth for the construction industry of Singapore. They are:

1. Output per capita (OPC)
2. Foreign worker's proportion (FWP)
3. Pre-cast level (PL)
4. R&D expenditure per million contract awarded (RDPCA)
5. Percentage union (PU)
6. Industrial Accident numbers (IAN)
7. Investment allowance granted (IAG)

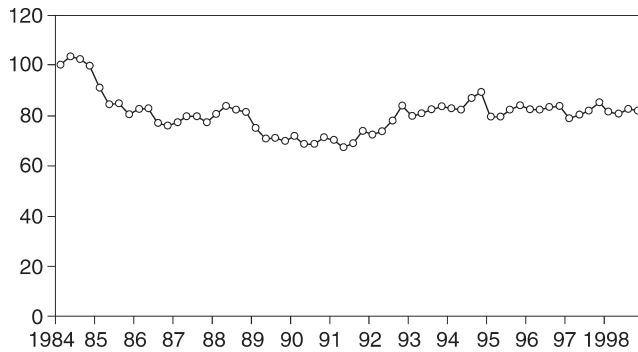
It was found that the actual significance value for the each factor fell within 10% (Table 4). Those that did not meet the significance level 15% are: composition of output, Domestic R&D expenditure per million GDP,

Table 1 Theoretical factor, statistical indicators and data sources

Theoretical factors		Statistical indicators	Data sources
Composition of output	Index of composition of output		Labour productivity by type of work from CIDB annual report; Value share of each type of work from progress payment certified by construction industry from TREND
Technology progress	Ratio of new construction to repair and maintenance works		Dataset recorded is not long enough
	R&D in construction per million contract awarded		CIDB annual report; National survey of R & D expenditure & manpower; National Survey Of R & D In Singapore.
	Domestic R&D per Million GDP		National survey of R & D expenditure & manpower; National Survey Of R & D In Singapore.
Labour quality	The average age of real fixed capital stock employed in construction industry		N/A
	Rate of international technology transfer		N/A
	Index of labour quality, by age-sex-education		See Translog index of labour growth above
	Foreign worker's proportion in total labour force		CIDB construction manpower report 1987; construction industry manpower survey by CIDB
Materials quality	Certified worker's proportion in total labour force		Construction industry manpower survey by CIDB; CIDB annual report; CIDB economics report
	Pre-cast level		Precast level from CIDB annual report; TREND: total consumption of cement for precast concrete; CIDB economics report: TOTAL CEMENT DEMAND; TREND:
Economies of scale	Buildable score		Dataset recorded is not long enough
	Output per capita		Data on output see translog index of output growth above; capita is number of labour employed from construction industry. Data is from TREND: employed person aged 15 and over by construction industry, annual.
Government regulations	Investment allowance granted		CIDB annual report
	Efficiency indicators of the CIDB (now BCA) – Total granted to CIDB (now BCA)(%)/contract awarded		CIDB annual report
Cyclical factors	Energy price (oil)		TREND: Domestic Price Index – petroleum product refined
	Inflation rate		Inflation rate is computed as growth rate of consumer price index. TREND: Consumer price index
Industrial relation polices	Percentage of contract that establish of labour management committees		N/A
	Percentage of contract that allow for incentive wage payment		N/A
	Percentage of contract that allow for subcontracting		N/A
Irregular factors	Percentage of union		Memberships of employee's trade Unions by sector at year end, from Singapore yearbook of labour statistics and Singapore yearbook of manpower statistics
	Number of industrial accidents		Industrial accidents by number and industry, from Singapore yearbook of labour statistics and Singapore yearbook of manpower statistics
Other factors	Such as social and institutional change		N/A

Table 2 Sample of detailed account of calculation of TFP growth

	$\Delta \ln Z$	$\Delta \ln X$	$\Delta \ln K$	$\Delta \ln L$	$\Delta \bar{V}_X$	$\Delta \bar{V}_K$	$\Delta \bar{V}_L$	$\Delta \ln TFP$	$\frac{\Delta TFP}{TFP}$	TFP index
1984 1Q										100.00
1984 2Q	0.04562	0.04870	0.03786	-0.09156	0.57055	0.18798	0.24147	0.03282	0.03337	103.34
1984 3Q	0.01370	0.02220	0.04073	0.01079	0.56846	0.18803	0.24351	-0.00921	-0.00916	102.39
1984 4Q	-0.02830	-0.01814	0.04434	0.00299	0.56638	0.18807	0.24555	-0.02710	-0.02673	99.65
1985 Q1	-0.11702	-0.03414	-0.00535	-0.02080	0.56430	0.18810	0.24760	-0.09160	-0.08753	90.93
1985 Q2	-0.13946	-0.12262	0.00440	0.00346	0.56221	0.18813	0.24965	-0.07221	-0.06966	84.60
1985 Q3	0.00047	-0.00500	0.01652	-0.01015	0.56013	0.18815	0.25171	0.00272	0.00272	84.83
1985 Q4	-0.11061	-0.10967	0.00961	-0.00941	0.55805	0.18817	0.25378	-0.04883	-0.04766	80.78

**Figure 1** TFP index of the construction industry of Singapore over 1984 1Q–1998 4Q (1984 1Q = 100)**Table 3** STEPWISE result: coefficients, t-value and Sig.*t* of selected significant factors (significance level = 10%)

Independent variables	Coefficients	t-value	Sig. <i>t</i>
(Constant)	-7.762E-03	-3.982	0.000
OPC	0.429	17.390	0.000
FWP	-0.122	-3.294	0.002
PL	-6.345E-02	2.041	0.047
RDPCA	1.396E-02	2.197	0.033
PU	1.529E-02	1.983	0.053

$R^2 = 0.894$; adjusted $R^2 = 0.883$.

Final parameter: Number of residuals = 54; Standard error = 1.3856675E-02.

percentage of certified worker in the construction industry, total granted to CIDB over size of the industry, energy price, consumer price index (inflation rate) and labour quality index.

Discussions

TFP trend

The trend of the TFP index of the construction industry of Singapore during 1984 1Q–1998 4Q is shown in Figure 1. The TFP index fell from 1984 to 1989 and rose in the early 1990s and dropped after 1994 to a

Table 4 STEPWISE results: coefficients, t-value and Sig.*t* of selected significant factors (dependent variable: TFP growth, significance level = 15%)

Independent variables	Coefficients	t-value	Sig. <i>t</i>
(Constant)	-7.986E-03	-4.276	0.000
OPC	0.424	17.853	0.000
FWP	-0.111	-2.974	0.005
PL	-7.635E-02	-2.477	0.017
RDPCA	1.079E-02	1.732	0.090
PU	1.535E-02	2.075	0.043
IAN	-3.795E-02	-2.062	0.045
IAR	9.914E-03	1.964	0.056

$R^2 = 0.907$; adjusted $R^2 = 0.893$.

Final parameter: Number of residuals = 54; Standard error = 1.3261850E-02.

constant level. On average, TFP growth dropped 1.37% per annum over the entire period, 1984–1998. For short periods, average TFP growth is -5.85% per annum over 1984–1989, 2.74% p.a. over 1989–1994, -0.91% p.a. over 1994–1998. The downward tendency of TFP accords with the trend of MFP calculated by Tan (2000) for the construction industry of Singapore during this period. The TFP trend was found fluctuating over time. It is consistent with Oulton and O'Mahony's (1994) conclusion about UK's industrial TFP growth that there is little persistence in growth rates of productivity, even over long periods.

To investigate what cause TFP growth trend to fluctuate, Fabricant's Law (1942) was tested. Under Fabricant's Law, in every short or long period, there is a significant and positive correlation between LP growth and output growth; and there is also a significant and positive correlation between TFP growth and output growth.³ On average, TFP growth tends to be high when output growth is high. These empirical regularities have been confirmed by different industries, countries and time periods (Oulton and O'Mahony, 1994). To test whether Fabricant's Law holds for the construction industry of Singapore, a correlation study between TFP growth and output growth was conducted. To further

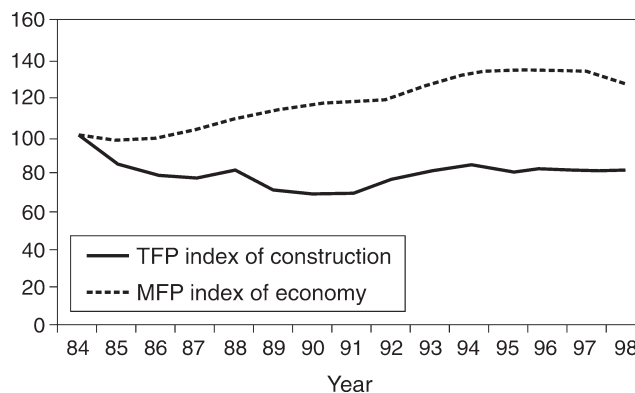
Table 5 Correlation coefficients and *t* ratios (in brackets) between growth of TFP ($\Delta \ln \text{TEP}$) and growth of output, intermediate input, capital input and labour input

Period	$\Delta \ln Z$	$\Delta \ln X$	$\Delta \ln K$	$\Delta \ln L$
Long periods 1984–1998	0.414 (<i>t</i> ratio = 14.005)	0.367 (<i>t</i> = 9.294)	−0.0534 (<i>t</i> = −0.641)	−0.263 (<i>t</i> = −1.150)
Short period 1984–1987	0.478 (6.923)	0.416 (3.913)	−0.0339 (−0.175)	−0.596 (−1.555)
1988–1991	0.502 (4.513)	0.344 (2.170)	−0.413 (−2.114*)	−0.749 (−2.051*)
1991–1994	0.449 (12.373)	0.422 (8.450)	−0.361 (−1.285)	−1.090 (−0.884)
1995–1998	0.384 (9.099)	0.297 (5.395)	−0.395 (−1.811)	−0.0686 (−0.087)

study the pattern of TFP growth, correlation studies between TFP growth and growth of inputs were also conducted. The correlation coefficients and *t* ratios (in Parentheses) between TFP growth and the growth of output, growth of intermediate, capital and labour are presented in Table 5. It indicates that in every period, short or long, TFP growth in the construction industry of Singapore is indeed significantly and positively correlated with the growth of output. It suggests that TFP growth tends to move closely with the growth of output. Thus, the cyclical behaviour of TFP growth was due to the growth of construction output, which is greatly affected by the construction business cycle.

Another important finding from the correlation study (Table 5) is that there is a significant and positive correlation between TFP growth and intermediate input growth over the short and long periods; But the correlations between TFP growth and capital input growth, labour input growth are insignificant except in the short term, 1988–1991. Therefore, it reinforced the view that the materials input plays an important role in TFP growth of the construction industry. Hence, when measuring productivity in construction, intermediate input should be incorporated. It also suggests that technological diffusion from manufacturing industry to construction industry through materials is an important contributor to the TFP growth of the construction industry. On the other hand, insignificant correlation between TFP growth and capital suggests that the technology incorporated in machinery and equipment utilized in construction is generally low.

As discussed in the introduction, MFP is an appropriate productivity measure at the aggregate level. It reflects overall technology change in a country. Therefore, MFP growth at Singapore's economy as a whole was used to compare with TFP growth of the construction industry. The trends were depicted on a yearly basis as shown in Figure 2. It shows that the overall trend of TFP growth in the construction industry of Singapore was down while overall MFP growth of Singapore was up during 1984–1998. It suggests that technology progress in the construction industry of Singapore has lagged considerably behind technology progress of rest of the economy.

**Figure 2** TFP index of the construction industry of Singapore and MFP index of economy of Singapore during 1984–1998, (1984 = 100)

This study did not compare the MFP and TFP trend of the construction industry in Singapore as:

- I. According to Jorgenson *et al.*, the value-added production function does not exist at the sector level. Hence, MFP is not appropriate to be used to measure industrial productivity performance.
- II. MFP and TFP concepts are not comparable. The former measures how efficient the industry uses technology to transform capital and labour input into value added; while the latter measures how efficient the industry uses technology to transform capital, labour and intermediate input into output. The technology that MFP covers is different from that of the TFP.
- III. The relationship of MFP growth and TFP growth is a complex one. This study does not agree with Chau (1993) in his analysis of the pattern of TFP growth and MFP growth (i.e. VATFP) of Hong Kong's building industry. From the observation that the growth rate of the VATFP trend was about twice that of the TFP trend, he inferred that intermediate inputs have played an important role in the growth in productive efficiency of Hong Kong's building industry. This conclusion is not always true.

Referring to the equations to calculate MFP growth and TFP growth:

$$\begin{aligned}\Delta \ln MFP &= \Delta \ln V - \bar{V}_{VK} \Delta \ln K - \bar{V}_{VL} \Delta \ln L \\ \Delta \ln TFP &= \Delta \ln Z - \bar{V}_K \Delta \ln K - \bar{V}_L \Delta \ln L - \bar{V}_X \Delta \ln X\end{aligned}$$

The difference of $\Delta \ln MFP$ and $\Delta \ln TFP$ can be expressed as:

$$\begin{aligned}\Delta \ln MFP - \Delta \ln TFP &= [\Delta \ln V - \Delta \ln Z] \\ &\quad - [\bar{V}_{VK} - \bar{V}_K] \Delta \ln K \\ &\quad - [\bar{V}_{VL} - \bar{V}_L] \Delta \ln L + \bar{V}_X \Delta \ln X\end{aligned}$$

From the above equation, MFP growth can be higher than TFP growth even in the case when intermediate input growth is negative.

Significant factors

Although not all of the influencing factors can be quantified or have available data, it should not affect the validity of the selection of statistically significant factors too much. Three reasons are given here. First, the *R*-square of the seven significant factors is 0.893, which means that about 90% of TFP growth can be explained by the seven factors. Second, for each factor, at least one proxy is available (See Table 1).⁴ Third, some factors like average age of capital stock are not available in Singapore, but they are available in other countries such as the UK and the USA.

The coefficients of the significant factors on log rate of TFP growth are given in Table 4. To interpret the coefficient, for example, if log growth of output per capita increases by 1%, log growth of TFP will increase by 0.424%. The result proves that economies of scale (output per capita) is an important factor affecting TFP growth in the construction industry. It is against the view by Ofori (1990) that there are little economies of scale in the construction industry, but consistent with a recent analysis on the economic growth of Singapore (Monetary Authority of Singapore, 2000).

Heavy reliance on unskilled foreign workers has been regarded a primary cause for low labour productivity in the construction industry of Singapore (CIDB, 1992; and Construction 21, 1998). As shown in Table 4, when log growth of foreign worker's proportion increases by 1%, it will cause log growth of TFP to fall by 0.111%. Therefore, it is evident that a large number of unskilled foreign workers not only caused low LP but also led TFP to decline in the construction industry of Singapore.

As shown in Table 4, if log growth of R&D per million contract awarded increases by 1%, TFP growth will increase by 0.0108%. As R&D is a primary indicator of technology progress, it substantiates that technical progress is a significant factor for enhancing TFP growth in the construction industry.

Another two factors have been found to be significant. They are percentage of union and construction accident number. It suggests that unionization will facilitate TFP growth (coefficient 0.0154), while construction accident will hamper TFP growth (coefficient -0.038). It is consistent with the case of Singapore: the safety performance in the construction industry has remained poor. This study validates the importance of safety management, which is identified by the Construction 21 Committee (1998) of Singapore as one of areas of focus to improve productivity.

Investment allowance granted is another factor found to be significantly related to TFP growth. It shows that 1% log growth in investment allowance granted will contribute to an increase in log growth of TFP by 0.01%. As the main purpose of this allowance is to accelerate the pace of mechanization in the construction industry, by encouraging contractors to invest in new-generation equipment which would contribute to higher productivity.

Among the seven significant indicators, the one found to have controversial signs of coefficient is pre-cast level. According to theory, pre-cast level is expected to have a positive relationship with TFP growth but the reverse was obtained. This departure from theory can be explained by two reasons: (1) currently the cost of pre-fabrication is more expensive than casting on site; (2) the initial investment is high while the demand for prefabrication is low. There is no economy of scale benefit for prefabrication in Singapore at the present development stage. For those seven indicators that did not fall within the significance level of 15%, it does not necessarily reduce their theoretical importance. Factors selected by the statistical analysis may change over time if different periods are studied.

Conclusion

Jorgenson *et al.*'s (1987) TFP measurement has been presented as the appropriate method to compute TFP growth for the construction industry. Within this framework, TFP growth is computed as the difference between output growth and the weighted growth of intermediate, capital and labour inputs. This paper has shown that Jorgenson's method is more realistic and less restrictive than Chau's approach as it does not impose assumption of Hick Neutral Technology Change.

TFP growth of the construction industry of Singapore lagged behind the rest of economy over 1984–1998. On the average, the estimated growth rate of TFP over this period was down by 1.37% per annum. The general trend of TFP growth was found to be fluctuating over time and was significantly correlated with output growth. Thus the time series of TFP growth tends to move in

tandem with construction business cycle. Meanwhile, TFP growth was also found to be significantly and positively correlated with the growth of intermediate inputs. This suggests that materials play an important role in TFP growth in the construction industry and that technological diffusion from the manufacturing industry to the construction industry through the use of materials is an important contributor to the TFP growth of construction industry.

Economies of scale, R&D in construction industry, investment allowance granted and labour union were the factors found to be major contributors to the growth of TFP in the construction industry of Singapore over the study period of 1984–1997; while heavy reliance on foreign workers, use of pre-cast component, increase in construction accidents were factor hampering to TFP growth.

As TFP is a better indicator than LP and MFP to evaluate the construction industry's efficiency in the use of resources, the Department of Statistics (DOS) in Singapore should begin to compile data on TFP growth in the construction industry. Future studies need to quantify factors such as the effect of international technology transfer and social and institutional change.

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Notes

1. Although most economists made no distinction between using term 'MFP' and 'TFP', this study strictly refers to 'MFP' as value-added labour capital measure. Chau (1993) calls MFP as value-added TFP. On the other hand, Oulton and O'Mahony (1994) refer to TFP as 'MFP'.
2. To develop a regression model, it is necessary to keep the last four quarters of 1988 for the purpose of testing the model. Regression modelling is another task associated with this paper. This paper will not address the test.
3. The original Fabricant Law observes that there is a significant and positive correlation between LP growth and output growth. Oulton and O'Mahony (1994) extend this law to TFP growth and output growth.
4. For example, although data on ratio of new construction works to repair works are not available, they will not affect the result too much because indicators of composition of output can partly cover it. Besides, although indicators such as average age of fixed asset is not available in Singapore, such data are available in the UK and the USA. One of the purposes of this study is to provide a framework that can be employed to other countries.

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