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Malmquist indices of total factor productivity changes in the Australian construction industry

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Construction is an important industry and forms a vital part of national economics in the world. Factors affecting the productivity of the construction industry should be measured appropriately to reflect its development situation and economic performance. The Malmquist index method with a novel decomposition technique is employed to estimate the total factor productivity of the Australian construction industry during the period 1990–2007 and to analyse the factors affecting the technological change in the industry. Research results exemplified by two input variables and one output variable elaborate how construction technology, pure technical efficiency and scale economy take effect in the change of construction productivity. In addition, based on temporal and spatial comparisons, the analysis for construction productivities reveals their changes over time and across the country. Proposals and recommendations are expected to be beneficial for policy making and strategic decisions to improve the performance of the Australian construction industry.

Keywords: Australia, construction industry, data analysis envelopment, Malmquist total factor productivity.

Introduction

The construction industry as the fifth largest industry in Australia is vital to its economic development. The industry enables infrastructure development for every sector. In the meantime, the construction industry keeps developing and extending its business by means of further heavy investment in constructing its own facilities. Thus national and regional economic development relies on infrastructure contributed by the construction industry. The construction industry has also created large numbers of job opportunities for citizens in Australia. For example, it employed about 936 000 people (being the equal of 9% of the Australian workforce) at June quarter 2007 (ABS, 2008a).

Productivity is a technical concept which refers to a ratio of output to input, a measure of efficiency. When referring to a single input, like labour or capital, the notion of productivity that may be expressed as a partial measure is called partial productivity. When more than one input, such as labour and capital, are taken into account, the problem that arises is how to weight each factor in the quotient. Total factor productivity (TFP) is an attempt to measure productivity taking into account all factors of production, which do not just contain a labour or capital variable.

Previous studies have focused on measuring TFP in the construction industry. Tan (2000) took advantage of the Tornqvist index method that could integrate respectively input and output variables to measure the total factor productivity of Singapore's construction industry. Zhi *et al.* (2003) measured the total factor productivity change in the construction industry of Singapore during 1984–1997 and investigated the change trend. Crawford and Vogl (2006) discussed the relative merits of measuring total factor productivity and single productivities and the fields where these productivities were often used, including policy making and economic research. In recent years, the Malmquist index has gained in popularity as a measure of TFP change. Yet few papers took advantage of the Malmquist index method to evaluate levels of the construction industry.

The main objective of this study is to measure the total factor productivity changes of Australian states' construction industries from 1990 to 2007 by means of the Malmquist index. The Malmquist index with a novel decomposition method is beneficial for obtaining

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economically meaningful sources of productivity changes with best practice production technologies. This paper reviews the research progress of data envelopment analysis (DEA), displaying the widespread use of Malmquist indices in the next section. A full account of practice implications for Malmquist indices will also be presented. Each factor contributing to total factor productivity and factors impacting on construction technical changes at the national and state levels are analysed and compared with the performance of construction productivity in Australia. The final section summarizes the conclusions generated from this research.

The development of data envelopment analysis

Data envelopment analysis as a non-parametric method in operational research and economics, based on the economic notion of Pareto optimality, aims to determine the efficiency of a decision making unit (DMU) by the projection of variables of inputs and outputs in geometric figures. Charnes *et al.* (1978) first introduced the non-parametric method according to the ideas of Farrell (1957), calculating relative values about efficiency by means of linear programming under constant returns to scale (CRS). This method was named as the CCR model using the initials of the three authors of Chares *et al.* (1978). Yet the CCR model has its own limitations and faults, and specifically it is unable to judge whether scale inefficiency or technical inefficiency results in final inefficiency. The BCC model presented by Banker *et al.* (1984) and also abbreviated from the authors' names is applicable to technologies of variable returns to scale (VRS). It could further explain the result of efficiency analysis by distinguishing between technical and scale inefficiencies through estimating pure technical efficiency at the given scale of operations.

The Malmquist index calculated using distance functions is a bilateral index that can be used to compare the production technology of two economies. It is named after a Swedish economist and statistician, Sten Malmquist, who published a quantity index for use in consumption analysis, comparing the distances from two vectors to any indifference curve in the manner of measuring radial scale in 1953. It is also called the Malmquist productivity index. The Malmquist theory was introduced for production analysis by Caves *et al.* (1982). Färe *et al.* (1994) specified an output-based Malmquist productivity change index as the geometric mean of two indices from period t and period t+1. The Malmquist productivity change was decomposed into a component measuring technical efficiency change and

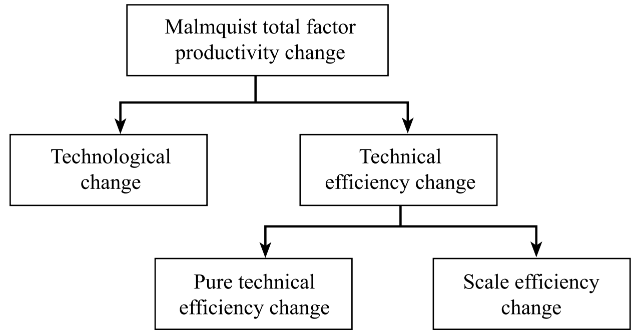

Figure 1 Traditional Malmquist productivity decomposition

the other component measuring technological change. These two terms are calculated on the benchmark technologies satisfying CRS. In addition, technical efficiency change can be further decomposed into pure technical efficiency change and scale efficiency change under VRS. This traditional Malmquist productivity decomposition technique is presented in Figure 1.

Grifell-Tatjé and Lovell (1996) indicated that the Malmquist index has several advantages, one of which is that it does not require input or output price, relative to other productivity indices. Furthermore, the index does not require the profit maximization or cost minimization assumption. However the main disadvantage of the Malmquist index is the necessity to calculate distance functions. Certainly, there are several techniques, like the parametric stochastic frontier analysis and non-parametric DEA, which could be used to measure the distance functions productivity indices. The DEA-like linear programming method is adequate to solve distance functions.

DEA-based total factor productivity measurement

Distance functions

Distance functions allow one to describe a multi-input, multi-output production technology without the need to specify a behavioural objective such as resource minimization and profit maximization. An input-oriented distance function characterizes the production technology by looking at a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of the output vector, given an input vector. Only an output distance function is defined in detail in this paper although input distance functions can be defined and used in a similar manner. Shephard (1970) first defined an output distance function under the production technology at period t as:

$$D_o^t(x^t, y^t) = \inf\left\{\theta : (x^t, y^t / \theta) \in S^t\right\} \tag{1}$$

The subscript 'o' represents an output-oriented distance function. x^t *and* y^t indicate respectively input and output vector in period t. Similarly, the input–output vector (x^t, y^t) of period t in the production technology S^{t+1} of period t+1 can be defined as:

$$D_o^{t+1}(x^t, y^t) = \inf\left\{\theta : (x^t, y^t / \theta) \in S^{t+1}\right\} \tag{2}$$

The input–output vector (x^{t+1}, y^{t+1}) of period t+1 in production technology S^t of period t can be defined as:

$$D_o^t(x^{t+1}, y^{t+1}) = \inf\left\{\theta : (x^{t+1}, y^{t+1} / \theta) \in S^t\right\} \tag{3}$$

where a production technology represents the set of all output vectors, y, which can be produced using the input vector, x. That is:

$$S^t = \left\{(x^t, y^t) : x^t \text{can produce } y^t \text{at time t}\right\} \tag{4}$$

To calculate the distance functions, this paper adopts a linear programming approach. Taking $D_o^t(x^t, y^t)\big| CRS$ and $D_o^t(x^t, y^t)\big| VRS$ as an example, they are defined for the ith observation as: the objective function $\left[D_o^t(x^t, y^t)\big| CRS\right]^{-1} = \max_{\theta,\lambda} \theta$ subjects to constraint conditions: $-\theta y_i^t + Y^t\lambda \geq 0$, $x_i^t - X^t\lambda \geq 0$ and $\lambda \geq 0$; and an extra constraint condition, convexity restriction $N1'\lambda = 1$, should be added when calculating $\left[D_o^t(x^t, y^t)\big| VRS\right]^{-1} = \max_{\theta,\lambda} \theta \cdot$

Lovell's decomposition technique and definitions of Malmquist indices

In this study, Lovell's decomposition technique of the Malmquist index is employed to evaluate Australian states' construction industry productivity changes from 1990 to 2007 at state and national levels. Lovell (2003) indicated that the scale efficiency change obtained from the conventional decomposition was not really associated with scale economy. Therefore, the technical change does not conform to the best practice production model, and cannot be interpreted in terms of economic meaning.

This research adopts the renovated decomposition in which concrete productivity analysis is suitable to economic practical situations, presenting the novel factorization under variable returns to scale (VRS). Malmquist total factor productivity change is decomposed into technological change consisting of neutral and bias technical changes, pure technical efficiency change and scale economy. To sum up, the Malmquist total factor productivity and its components are present in Figure 2.

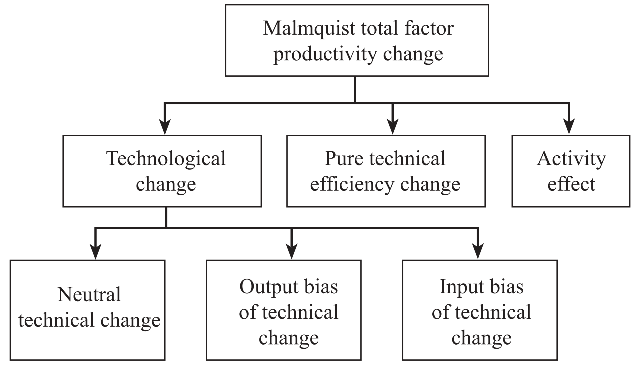

Figure 2 Lovell's Malmquist productivity decomposition

Malmquist productivity change (M) =

$$\left[\frac{D_o^t(x^{t+1}, y^{t+1}\big| CRS)}{D_o^t(x^t, y^t\big| CRS)} \times \frac{D_o^t(x^{t+1}, y^{t+1}\big| CRS)}{D_0^{t+1}(x^t, y^t\big| CRS)}\right]^{1/2} \tag{5}$$

The M index is to measure productivity changes between two adjacent periods. The productivity level between period t and period t+1 improves if the M index is greater than 1, remains unchanged if M is equal to 1 and declines if M is less than 1.

The technological change (TC) index is to quantify the contribution of technical change to productivity change based on the overall process of the new technology introduction. The TC indices with greater than 1, equal to 1 and less than 1 values indicate technical progress, technical stagnation and technical decline between periods t and t+1 respectively.

Technological change (TC) =

$$\left[\frac{D_o^t(x^{t+1}, y^{t+1}\big| VRS)}{D_o^{t+1}(x^{t+1}, y^{t+1}\big| VRS)} \times \frac{D_o^t(x^t, y^t\big| VRS)}{D_0^{t+1}(x^t, y^t\big| VRS)}\right]^{1/2} \tag{6}$$

The neutral technical change index (T) is to identify the value of technical change on the basis of a ray traversing (x^t, y^t), measuring technical change for unchanged outputs and inputs within period t under VRS in Equation 7:

$$\text{Neutral technical change (T)} = \frac{D_0^t(x^t, y^t\big| VRS)}{D_0^{t+1}(x^t, y^t\big| VRS)} \tag{7}$$

The output bias index (OB) is to compare two technical changes that are respectively from period t and period t+1 in output combinations in Equation 8. In this paper, there is no output bias impact on technical changes by adopting one output variable. Therefore, the index OB is a constant value, 1.

$$\text{Output bias index (OB)} = \left[\frac{D_o^t(x^{t+1}, y^{t+1} \mid VRS)}{D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)} \times \frac{D_o^{t+1}(x^{t+1}, y^t \mid VRS)}{D_o^t(x^{t+1}, y^t \mid VRS)}\right]^{1/2} \tag{8}$$

Input bias index (IB) is to compare two technical changes that are respectively from period t and period t+1 in the bundle of inputs in Equation 9. The IB index may be greater than, equal to or less than 1 depending on whether the deployment of production factors is an improvement.

$$\text{Iutput bias index (IB)} = \left[\frac{D_o^{t+1}(x^t, y^t \mid VRS)}{D_o^t(x^t, y^t \mid VRS)} \times \frac{D_o^t(x^{t+1}, y^t \mid VRS)}{D_o^{t+1}(x^{t+1}, y^t \mid VRS)}\right]^{1/2} \tag{9}$$

The pure technical efficiency change (PTEC) index, as given in Equation 10, is to evaluate the contribution of technical efficiency change to productivity change. It reflects the change in the ratio of the actual output to maximum potential output under VRS. The PTEC indices with greater than 1, equal to 1 and less than 1 indicate an improvement in technical efficiency, an unchanged technical level and a decline between periods t and t+1 respectively.

$$\text{Pure technical efficiency change (PTEC)} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1} \mid VRS)}{D_0^t(x^t, y^t \mid VRS)} \tag{10}$$

The activity effect index (AE) is to measure scale economy changes and is presented in Equation 11. It reflects the development of production scopes and scales. The AE index greater than 1 indicates an improvement in scale economy, equal to 1 an unchanged scale economy level and less than 1 a decline between periods t and t+1.

$$\text{Activity effect (AE)} = \left\{\left[\frac{D_0^t(x^{t+1}, y^{t+1} \mid CRS) / D_o^t(x^{t+1}, y^{t+1} \mid VRS)}{D_0^t(x^t, y^t \mid CRS) / D_o^t(x^t, y^t \mid VRS)}\right] \times \left[\frac{D_0^{t+1}(x^{t+1}, y^{t+1} \mid CRS) / D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)}{D_0^{t+1}(x^t, y^t \mid CRS) / D_o^{t+1}(x^t, y^t \mid VRS)}\right]\right\} \tag{11}$$

According to the Lovell's decomposition presented in Equations 6 to 11, the Malmquist productivity can be showed as follows:

$$M = TC \times PTEC \times AE = T \times OB \times IB \times PTEC \times AE \tag{12}$$

where the factors influencing the technological change are calculated respectively.

Diagrammatical illustrations and geometric significances of the efficiency change, the technological change and the scale effect under VRS are described in Figure 3 where a simple single-input and single-output production frontier is presented. It can be concluded that the production frontier may shift over time. Moreover, two different frontiers obtained in the period t and the period t+1 are labelled in Figure 3. It can be observed that it is producing at point A (x^t, y^t) in the period t and will produce at B (x^{t+1}, y^{t+1}) in the period t+1. Pure technical efficiency of the period t can be expressed as the ratio of the actual output a to the maximum potential output c in Frontier t. Similarly, pure technical efficiency of the period t+1 is represented as b/f. Therefore pure technical efficiency change can be expressed as $(b \times c)/(f \times a)$. The neutral technical change measures the movement condition of the frontier in the period t+1 with respect to the period t while the input quantity in the period t is kept, namely e/c, whereas the technological change calculates the geometric mean of such two movement conditions from keeping both the input quantity in the period t and the input quantity in the period t+1. The Equation can be expressed as $[(f \times e)/(d \times c)]^{1/2}$. The input or output bias of technical change will be 1 in the case of the single-input or single-output system.

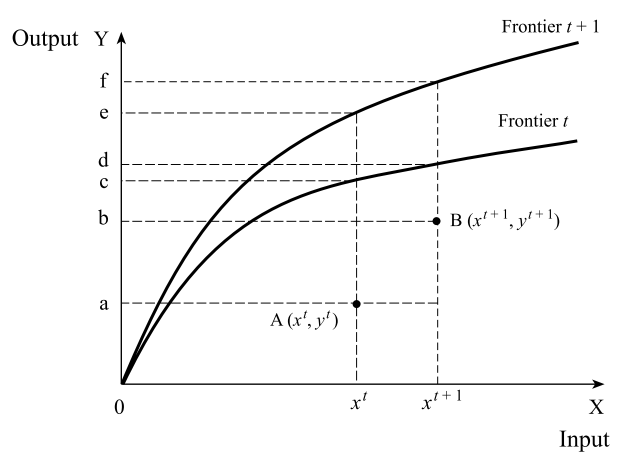

Figure 3 A conceptual model of the Malmquist index and productivity changes over time

Investigation of factors influencing construction productivity

Construction technological factors including many aspects are depicted as a group (Herbsman and Ellis, 1990). In particular, productivity may improve with the proper use of plant and tools. For instance, digging with an excavator can produce more than manual digging. The improvement in construction transportation enhances the capacity to supply materials. Therefore, quality also generally improves when suitable machines are used. In addition, technology progress could be achieved by developing construction methods, construction theories and process flows so that the capability for capital utilization could benefit from it. Advanced equipment and techniques of building construction are beneficial to enhance production efficiency. Obviously, the application of new technology increases the capacity of the construction industry to produce. The construction section can either produce more at the same price or the produce same output at a lower price (Gruneberg, 1997). Yet Allmon *et al.* (2000) supposed that advanced construction could be difficult to achieve in the construction industry because of the lack of a unified standard of utilizing advanced technological and site decentralization.

Pure technical efficiency aims to measure the organizational capacity required for managers by taking advantage of inputted resources to obtain effective output under reasonable operational strategies and to verify whether poor decisions, faulty management and waste of resources exist. This deals with microeconomics, outlining the various ways of efficiently allocating resources to achieve goals. Managers in the construction industry should formulate optimal scheduling and policy by taking into account demand and supply for infrastructure, housing, business buildings, and structure enforcement and repair engineering (Myers, 2003). With increased project size and complexity, these operational strategies will become more important. Management inadequacies can result in a regress in construction productivity. Technical efficiency could be affected by methods of training workers, the system of labour compensation and the strategies for utilizing land, labour, materials and capital.

Scale economics deeply affects productivity change. In the construction industry, the features of production determine the specificity of labour-intensive scale economics that can restrict improvement in production (Ofori, 1990). More specifically, the quantity fluctuation of labour in construction firms is an important factor (Zhi *et al.*, 2003). The output cost could be reduced and the construction industry value added could be enhanced when enlarging production scale in the whole industry. Nonetheless, this paper argues that there are other internal and external factors restricting the scale of economic development in the construction industry. The capacity of the unit and business capital should be emphasized as internal factors. Residents' housing needs, the requirement for reconstruction of roads, and convenient transportation are external factors affecting the performance of construction productivity.

Overall, these factors influencing construction productivity are not isolated (Dai *et al.*, 2009). One factor may affect the development of others. Specifically, the introduction of new construction technologies and tools may depend on management decisions and policy making. Construction scales and production scope are dominated by the policy approval. Efficient construction technologies may be beneficial to exploit construction scales for construction firms and organizations.

Data for assessing productivity in Australia's construction industry

This paper takes advantage of Australia's construction industry data from the Australian Bureau of Statistics to evaluate the industry's productivity. Australian states are selected for observations. They are Capital Territory (ACT), New South Wales (NSW), Victoria (Vic.), Queensland (Qld), South Australia (SA), Western Australia (WA), Tasmania (Tas.) and Northern Territory (NT). In the study, productivity measurements are based on two-input resources comprising construction work done and persons employed in the construction industry and a single-output variable being construction industry gross value added. The period of analysis is designated from 1990 to 2007, owing to data availability.

Construction work done as a capital input is an aggregation of building work done and engineering construction work done. It represents input assets in Australian construction industry, containing fees of material deliveries, labour cost and speculative contracts. The number of employees is indispensable in any approach to Malmquist indices. Murillo-Melchor (1999) analysed Spanish airports by number of employees serving as an input variable. Gillen and Lall (2001) made use of the same variable to evaluate the performance of US airports. Therefore, it is a representative input variable concerned with labour. The gross value added to the construction industry indicates the end results of construction production activities in the form of money during the reference period. It was selected as an output variable in that value added is an import output indicator. Also, it measures gross production by the construction industry. Likewise, three similar variables adopted by Xue *et al.* (2008) are used to measure the performance of China's construction industry.

The capital input data were derived from *Construction Work Done* (ABS, 2008b). The number of employees in the construction industry was obtained from *Labour Force* (ABS, 2008c). The gross value added to this industry was from *Australian National Accounts: State Accounts* (ABS, 2007). The final annual statistic was obtained by summing quarterly data. In addition, labour constitutes a major component of the total expenditure on inputs in many enterprises and industries. Annual amounts of total employees as a non-monetary input in the construction industry were calculated by averaging quarterly numbers. The annual gross value added is available in the data source.

To calculate the Malmquist index using two-input and one-output variables, 10 output-oriented distance functions must be defined by the Lovell decomposition technique, $D_0^t(x_t, y_t \mid CRS)$, $D_0^t(x_{t+1}, y_{t+1} \mid CRS)$, $D_0^{t+1}(x_t, y_t \mid CRS)$, $D_0^{t+1}(x_{t+1}, y_{t+1} \mid CRS)$, $D_0^t(x_t, y_t \mid VRS)$, $D_0^t(x_{t+1}, y_{t+1} \mid VRS)$, $D_0^{t+1}(x_t, y_t \mid VRS)$, $D_0^{t+1}(x_{t+1}, y_{t+1} \mid VRS)$, $D_0^t(x_{t+1}, y_t \mid VRS)$ and $D_0^{t+1}(x_{t+1}, y_t \mid VRS)$. These distance functions are then used to determine the economic factors of productivity as formulized in Equations 6 to 10 and finally to work out the total factor productivity. Furthermore, Australian states' productivity indices are displayed according to time and region. Based on temporal and spatial comparisons, construction productivity indices are analysed to reveal their changes in the industry over time and across the country.

Malmquist productivity changes

Malmquist total factor productivity

The results of neutral technical changes calculated by utilizing Equation 7 are detailed in Table 1A. The index T points out the characteristic of the technological changes as a factor obtained by decomposing technological changes. Among eight states' construction industries, no obvious continuous growth is observed during the study period (see Appendix 1). Results indicate that construction industries do not keep a balance of labour and capital in economic growth, especially the construction industry in Northern Territory during 1990–1998. Yet not long after that, the construction industry in Northern Territory experienced an obvious neutral technical change in 1998–2000. In addition, Tasmania's construction industry experienced the fastest growth in neutral technical progress in 2003–2004.

Taking advantage of Equation 9, Table 1B shows the input bias of technical changes of eight states from 1990 to 2007. According to the results from Australian Capital Territory and New South Wales, the construction industry in these two states displayed a rationalization of the deployment of production factors in the study period. Viewing the overall condition, this numerical value can reflect that the reasonable deployments of production factors contributed primarily to construction industries' technological progress in eight

Table 1A Neutral technical index changes (T)

Years	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990–91	0.96525	1.01807	1.03846	1.00200	0.99888	1.00515	1.02378	0.97466
1991–92	0.84531	0.96620	0.93721	0.93458	0.94383	0.94340	0.87763	0.74239
1992–93	1.15741	0.99010	0.99701	0.98328	0.98283	1.03995	0.98193	0.88968
1993–94	0.99096	1.04058	0.98039	1.05222	1.00000	1.04094	0.96111	0.86957
1994–95	0.99798	0.95420	0.97656	0.97714	1.04932	0.98141	1.10133	0.91575
1995–96	1.03627	1.02041	1.00604	1.02114	1.01729	1.01866	0.96852	0.93371
1996–97	0.91324	1.01937	0.91912	1.00103	0.88028	1.02689	1.11699	0.97466
1997–98	1.01626	1.00402	0.97182	1.01218	1.02775	0.99085	0.96320	0.85179
1998–99	0.96993	1.03882	1.04329	1.04512	1.01729	1.05238	1.12740	1.33690
1999–2000	0.74460	1.02743	1.03739	1.07296	1.07875	1.02334	1.24224	1.15207
2000–01	0.87184	0.91932	0.91128	0.90580	0.91912	0.93785	0.87638	0.87260
2001–02	1.01420	0.96618	1.01129	1.01010	0.98989	0.99624	0.98210	0.94697
2002–03	0.96805	1.04712	1.05353	1.03520	1.04592	1.04391	0.93476	0.93545
2003–04	0.98232	0.99602	1.00000	0.99602	1.03460	0.99671	1.35501	1.00200
2004–05	0.89366	1.03842	1.00635	1.00606	1.01124	1.00220	0.96596	1.03413
2005–06	0.61614	1.01937	1.02097	1.02148	1.01678	1.02854	0.66601	0.96432
2006–07	0.98814	0.96339	0.98092	1.01267	1.01782	1.08013	1.01729	1.00200
Means	0.93950	1.00171	0.99362	1.00523	1.00186	1.01227	1.00951	0.96463

Table 1B Input bias index changes (IB)

Years	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990–91	1.00062	0.99925	0.94041	1.00091	1.03238	1.00074	0.99745	1.01483
1991–92	1.01456	1.00424	1.00366	1.02274	1.00030	0.99310	1.02798	1.14995
1992–93	1.02217	1.00604	1.01961	1.00789	1.00093	0.98757	0.98495	1.31154
1993–94	1.00240	1.01804	1.03042	0.99708	1.00148	0.99776	0.99631	1.04800
1994–95	1.04596	1.01818	1.02551	1.00057	1.06177	1.00879	0.99742	1.09949
1995–96	1.04628	1.00179	1.01931	1.00021	1.00450	1.00551	1.00582	1.06683
1996–97	1.10102	1.01116	1.06049	1.01861	1.05663	1.00096	1.00302	1.05537
1997–98	1.06442	1.00804	1.01557	0.99995	1.00189	1.02848	0.99731	1.05716
1998–99	1.31773	1.00024	0.99922	0.99917	1.00304	0.99875	0.99815	0.95373
1999–2000	1.23352	1.03942	1.02561	1.00499	1.00604	1.03401	1.00112	1.07752
2000–01	1.05382	1.03285	1.01494	1.01608	0.99935	1.00293	1.00008	1.06961
2001–02	1.05215	1.03194	1.01176	1.03206	1.00081	1.04006	1.02498	1.15271
2002–03	1.07997	1.00697	0.99988	1.00789	0.99958	0.99948	0.94221	1.03818
2003–04	1.09465	1.00782	0.99886	1.00036	0.98718	1.00051	0.89959	0.99629
2004–05	1.03851	1.00663	1.00020	1.00396	1.00589	1.00080	1.00333	1.02356
2005–06	1.33986	1.05322	0.99978	0.99994	1.00063	0.99895	1.00543	1.01480
2006–07	1.24203	1.00515	1.00172	1.00120	0.99871	1.01207	0.98248	1.11230
Means	1.10292	1.01476	1.00982	1.00668	1.00948	1.00650	0.99221	1.07305

Australian states during 1990–2007 when combined with the analysis of neutral technical changes.

Table 1C lists the result of technological changes in eight Australian states' construction industry by Equation 6. Respectively in 1994–1999, 1995–2000, 1995–2000, 1995–2000 and 2002–2007 ACT, NSW, Qld, SA and WA took on their active phases of technological progress, having grown for five consecutive years. Moreover, the average growth rate in construction technologies is 9.9% for ACT during active periods, 3.4% for NSW and 3.5% for Qld. Therefore in general, there were distinct improvements in construction technologies for eastern states during the late 1990s. The year 1998 was the most crucial one for the whole construction industry on the basis of the all-round technological progress across Australia.

Pure technical efficiency changes are calculated by Equation 10. Results are showed in Table 1D. The

Table 1C Technological index changes (TC)

Years	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990–91	0.96585	1.01730	0.97658	1.00291	1.03123	1.00589	1.02117	0.98911
1991–92	0.85762	0.97030	0.94064	0.95583	0.94411	0.93688	0.90219	0.85371
1992–93	1.18307	0.99608	1.01656	0.99104	0.98375	1.02703	0.96715	1.16685
1993–94	0.99334	1.05936	1.01022	1.04915	1.00148	1.03861	0.95756	0.91130
1994–95	1.04385	0.97154	1.00148	0.97770	1.11413	0.99003	1.09849	1.00686
1995–96	1.08423	1.02224	1.02547	1.02135	1.02187	1.02427	0.97416	0.99611
1996–97	1.00550	1.03075	0.97472	1.01965	0.93014	1.02788	1.12036	1.02862
1997–98	1.08172	1.01209	0.98695	1.01214	1.02970	1.01907	0.96061	0.90048
1998–99	1.27811	1.03908	1.04248	1.04425	1.02038	1.05106	1.12531	1.27504
1999–2000	0.91848	1.06793	1.06396	1.07831	1.08526	1.05814	1.24363	1.24138
2000–01	0.91876	0.94953	0.92490	0.92037	0.91852	0.94060	0.87646	0.93334
2001–02	1.06709	0.99704	1.02317	1.04249	0.99069	1.03615	1.00663	1.09158
2002–03	1.04547	1.05442	1.05341	1.04337	1.04548	1.04338	0.88073	0.97117
2003–04	1.07530	1.00380	0.99886	0.99638	1.02134	0.99723	1.21895	0.99829
2004–05	0.92807	1.04531	1.00655	1.01005	1.01719	1.00300	0.96917	1.05849
2005–06	0.82554	1.07362	1.02075	1.02142	1.01742	1.02746	0.66962	0.97859
2006–07	1.22730	0.96836	0.98261	1.01389	1.01650	1.09317	0.99947	1.11453
Means	1.02937	1.01640	1.00290	1.01178	1.01113	1.01882	0.99951	1.03032

Table 1D Pure technical efficiency index changes (PTEC)

Years	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990–91	1.00000	1.01461	1.08932	1.00000	0.96292	1.02459	0.91120	1.00000
1991–92	1.00000	1.02881	1.00000	1.00000	1.06884	0.91100	0.97751	1.00000
1992–93	0.98700	1.00000	1.00000	0.94700	1.01092	0.92097	1.06135	1.00000
1993–94	1.00304	1.00000	1.00000	0.90285	1.07991	0.94398	1.19364	1.00000
1994–95	1.01010	1.00000	1.00000	1.12982	1.00000	1.03409	0.96852	1.00000
1995–96	1.00000	1.00000	1.00000	1.00932	1.00000	1.02564	1.00250	1.00000
1996–97	1.00000	1.00000	1.00000	1.02256	1.00000	0.90238	1.10973	1.00000
1997–98	1.00000	0.99000	0.96400	0.99900	1.00000	1.13984	1.12360	1.00000
1998–99	1.00000	0.98384	1.00726	1.00402	1.00000	0.96412	1.00000	1.00000
1999–2000	1.00000	1.00616	0.97322	1.00000	1.00000	1.01441	0.87200	1.00000
2000–01	1.00000	1.02041	0.94815	1.00000	0.97900	0.93964	1.00688	1.00000
2001–02	1.00000	1.00000	0.96652	1.00000	0.93054	1.04786	0.84852	1.00000
2002–03	1.00000	1.00000	1.06697	1.00000	1.01756	1.09375	1.34228	1.00000
2003–04	1.00000	1.00000	1.02922	0.99600	0.97087	1.00110	0.68100	1.00000
2004–05	1.00000	1.00000	0.97266	0.85944	1.01000	0.98902	0.98972	1.00000
2005–06	1.00000	1.00000	0.94486	1.02687	1.00550	1.09212	1.48368	1.00000
2006–07	1.00000	1.00000	1.08238	1.07736	1.03282	1.01626	1.00000	1.00000
Means	1.00001	1.00258	1.00262	0.99848	1.00405	1.00357	1.03365	1.00000

construction industry for NT neither progressed nor regressed in pure technical efficiency, the numerical value being 1 during the study period. In addition, the stable phases of technical efficiency in the construction sectors for ACT, NSW, Vic., Qld and SA are respectively 1995–2007, 2001–2007, 1991–1997, 1999–2003 and 1994–2000. The growth rate had surged to around 48% for Tas. in 2005, the fastest pace in the eight states. This indicates that Tasmania's construction industry experienced a huge improvement in operational strategies in 2005–2006. However, prior to this, the technical efficiency for Tas. also experienced a huge regress with a 31.9% decrease in 2003–2004.

Table 1E displays the activity effect indices of the construction industry by Equation 11. Overall, the numerical values are generally low. Tasmania's scale economy in the construction industry shows a

Table 1E Activity effect index changes (AE)

Years	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990–91	1.00141	0.97535	1.04232	1.00141	1.08261	0.99824	0.99206	1.00590
1991–92	0.98248	0.99383	1.00408	0.97259	0.98809	1.01372	0.98183	1.00000
1992–93	0.97410	1.01466	1.01224	1.00616	1.00011	0.97683	0.97912	1.00000
1993–94	1.00181	0.94667	0.96846	1.01864	1.00415	1.02279	1.00391	0.98099
1994–95	1.07164	1.03730	1.01820	1.01388	1.04023	1.01916	0.99944	0.98544
1995–96	0.98989	1.00800	1.00916	1.00054	0.99707	0.94448	1.01214	1.04193
1996–97	0.99550	0.97863	0.96851	0.97422	0.93978	0.99922	0.93695	0.96105
1997–98	0.99944	0.98115	0.98720	0.99702	0.99849	0.92287	0.99052	0.97626
1998–99	0.84776	1.00205	0.98755	1.00700	0.99264	1.11038	0.99814	0.98626
1999–2000	1.01168	1.00754	1.00411	1.00000	1.00344	0.99601	0.99878	1.01902
2000–01	1.03548	1.02203	1.01049	1.01731	1.00265	1.00031	0.99745	0.98840
2001–02	0.99886	0.96617	0.96893	0.92248	0.97975	0.90657	0.95739	0.99960
2002–03	0.99108	0.99206	0.98369	1.02993	0.99071	0.93002	0.96053	0.99575
2003–04	0.98893	1.00274	0.97263	0.97867	0.97872	0.99380	1.06902	1.00304
2004–05	0.98486	0.99356	1.01035	1.04358	1.02610	0.98367	0.97584	1.00074
2005–06	1.12838	1.03868	1.09234	0.94281	0.99441	0.91726	0.99608	1.00000
2006–07	0.85957	0.99852	0.98629	0.98585	0.99656	0.99276	1.01587	0.91456
Means	0.99193	0.99759	1.00156	0.99483	1.00091	0.98400	0.99206	0.99170

Table 2 Malmquist index changes (M)

Years	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990–91	0.96721	1.00672	1.10883	1.00433	1.07502	1.02882	0.92311	0.99495
1991–92	0.84259	0.99209	0.94448	0.92964	0.99709	0.86521	0.86588	0.85371
1992–93	1.13745	1.01068	1.02901	0.94430	0.99460	0.92395	1.00505	1.16685
1993–94	0.99817	1.00286	0.97835	0.96487	1.08600	1.00277	1.14745	0.89398
1994–95	1.12993	1.00778	1.01970	1.11997	1.15895	1.04340	1.06332	0.99220
1995–96	1.07326	1.03042	1.03486	1.03142	1.01889	0.99220	0.98845	1.03788
1996–97	1.00097	1.00872	0.94402	1.01578	0.87412	0.92681	1.16491	0.98856
1997–98	1.08112	0.98308	0.93924	1.00811	1.02814	1.07199	1.06911	0.87910
1998–99	1.08354	1.02438	1.03697	1.05579	1.01287	1.12520	1.12322	1.25752
1999–2000	0.92921	1.08262	1.03973	1.07831	1.08899	1.06910	1.08312	1.26499
2000–01	0.95136	0.99025	0.88614	0.93630	0.90162	0.88410	0.88023	0.92251
2001–02	1.06588	0.96331	0.95819	0.96167	0.90321	0.98429	0.81775	1.09114
2002–03	1.03614	1.04604	1.10563	1.07460	1.05396	1.06134	1.13553	0.96704
2003–04	1.06339	1.00656	0.99992	0.97122	0.97049	0.99214	0.88740	1.00132
2004–05	0.91402	1.03858	0.98917	0.90591	1.05418	0.97580	0.93603	1.05927
2005–06	0.93153	1.11515	1.05353	0.98888	1.01730	1.02927	0.98961	0.97859
2006–07	1.05496	0.96692	1.04898	1.07687	1.04625	1.10290	1.01533	1.01930
Means	1.01534	1.01624	1.00687	1.00400	1.01657	1.00466	1.00562	1.02170

downward trend from 1996 through 2003, in which the annual decline was 2.3%. This reveals that activity effects were not the main source of enhancing the development of total factor productivity. In contrast, ACT obtained the highest annual rate of 12.8% in 2005 compared with other results of activity effects.

By Equation 5, Table 2 indicates that ACT and NSW show their active phases of total factor productivity in 1994–1999 and 1992–1997 respectively based on consecutive growth. In addition, Queensland's construction industry productivity, the annual growth rate of which had surged to around 5.2%, increased for six consecutive years in 1994–2000. For the whole Australian construction industry, the performance is outstanding in 1998–1999, especially the productivity in NT which increased by a percentage of 25. Meanwhile, all eight states displayed improvements in total factor productivity, acquiring an average rate of 8.5% growth. Yet the construction industry for Australia has been through several downturns. Productivity indices for the eight states dropped entirely in 1991–1992 and 2000–2001.

Productivity analysis for regions

Table 3 presents Malmquist indices summary of states' means in 1990–2007. In terms of TC, all observed values are greater than 1 except for Tasmania. The technical change for states' mean level being greater than 1 indicates that construction technologies and equipment improvements are principal factors promoting the growth in construction industry productivity. Furthermore, the technical fluctuations can be attributed to three factors, namely technical change for invariable inputs and outputs, input bias and output

Table 3 Means of Malmquist indices of Australia's eight states

Australian states	T	OB	IB	TC	PTEC	AE	M
ACT	0.93950	1.00000	1.10292	1.02937	1.00001	0.99193	1.01534
NSW	1.00171	1.00000	1.01476	1.01640	1.00258	0.99759	1.01624
Vic.	0.99362	1.00000	1.00982	1.00290	1.00262	1.00156	1.00687
Qld	1.00523	1.00000	1.00668	1.01178	0.99848	0.99483	1.0040
SA	1.00186	1.00000	1.00948	1.01113	1.00405	1.00091	1.01657
WA	1.01227	1.00000	1.00650	1.01882	1.00357	0.98400	1.00466
Tas.	1.00951	1.00000	0.99221	0.99951	1.03365	0.99206	1.00562
NT	0.96463	1.00000	1.07305	1.03032	1.00000	0.99170	1.02170
Means	0.99104	1.00000	1.02693	1.01503	1.00562	0.99432	1.01137

bias. As shown in the OB and IB columns, the IB index is a primary reason for the growth in construction technologies of most states during the analysed period. Yet the OB index is 1 on account of the number of selected output variable.

On the basis of the results in respect of PTEC, it can be concluded that the pure technical efficiency change for Queensland being less than 1 shows that construction industry operating strategies for inputs and outputs have not been remarkably enhanced during the study period in Queensland. The pure technical efficiency changes for Northern Territory and Australian Capital Territory remain the same. Nevertheless, the improvement in operating strategies for inputs and outputs is crucial to promote the construction industry productivity in Tasmania's construction industry. Other states (NSW, Vic., SA and WA) also absorbed better operating strategies from interstate and international communications to reduce the input wastes.

According to statistical information concerning AE, all observations' indices approximate to 1. Among those DMUs, the AE for states' mean value is 0.99432. This reveals that the scale economy in the construction sector dropped annually by 0.568 percentage points. The range of fluctuation for AE is small when compared with 1.00156 for Victoria and 0.984 for Western Australia. This indicates that not only did national activity effect not increase but it was decreasing during the analysed period. In addition, it is difficult to improve activity effects because of the labour-intensive practice and non-standard production methods in this industry. It could be concluded that the inputted scale and produced activity effect did not contribute to the growth in productivity in the construction industry during the study period.

Adopting Lovell's method of Malmquist decomposition is beneficial to analyse the changes of construction industry productivities. Malmquist productivity indices for states and mean levels are slightly greater than 1. The total factor productivity for the construction industry's mean value rose annually by 1.137% during the study period. This indicated that the improvement in construction technologies mainly contributed to the increase in industry productivities, and the improvement in input bias mainly contributed to the increase in the technical indices. Yet the growth in construction productivities is not distinct. This is similar to the result presented by Pink (2008). To sum up, in conditions of improved equipment and technological advancement, inputted construction scales and scopes of production activity are critical factors hampering a rapid growth in total factor productivity.

Malmquist indices for the construction industry in each state were categorized by region. Descriptive statistics for technical change, pure technical efficiency change, activity effect change and construction industry productivity change are shown in Table 4. The highest construction technology growth in the Australian mid region derived the highest cumulative increase in the productivity index when comparing three regions, notwithstanding that activity effect was on the decline. In the Australian eastern region, the total factor productivity growth, the average rate of which reached only around 1%, ranked second in these three regions. Yet the proportion taken up by pure technical efficiency growth is the greatest among the factors contributing to construction industry productivity in the three regions. The construction productivity in the western region is lowest, and its activity effect declined most rapidly. In other words, in terms of patterns of productivity growth, the three regions were experiencing different circumstances, namely construction productivity growth relying on the improvement in construction technologies (mid region), construction productivity growth relating strongly to progress of management (eastern region), slow productivity growth effected by low inputted scale (western region). Overall, technical efficiency changes contributed to the increase in construction productivities for the three regions; every Malmquist index change was steady owing to small discreteness.

Table 4 Descriptive statistics of Malmquist indices by regions

Region	Descriptive statistic	TC	PTEC	AE	M
Eastern region	Mean	1.01199	1.00747	0.99559	1.00961
	Standard deviation	0.08570	0.08769	0.03754	0.07196
Mid region	Mean	1.02072	1.00203	0.99631	1.01914
	Standard deviation	0.08735	0.02432	0.02764	0.09582
Western region	Mean	1.01882	1.00357	0.98400	1.00466
	Standard deviation	0.03773	0.06584	0.04810	0.07149

Notes: Eastern region = ACT, NSW, Vic., Qld, Tas. Mid region = NT, SA. Western region = WA.

Productivity changes over time

The annual means of the Malmquist indices are presented in Figure 4. The results show that the input bias index fluctuated slightly between 1 and 1.1 during the study period. This indicates that deployment of production factors is reasonable notwithstanding that the fastest growth speed of the input-biased technical progress is not greater than 6%. The output bias index was not presented because the value is 1. T is a main factor contributing to technical change. Therefore, the indices T and TC, have the same change tendency. More specifically, the neutral technical change in Australian construction had descended into three deep slumps in 1991–1992, 2000–2001 and 2005–2006, dropping by around 10 percentage points. It could be observed that the regress in Australia's construction technology, over the same periods, was derived mainly from the poor performance of neutral technology.

In addition, the productivity change of the construction industry depended primarily on technological improvement, and the AE index and PTEC index had been almost constant at around 1 during the first 12 years. This may be the reason why the construction productivity change kept pace with technical change. In addition, high growth rates of the pure technical efficiency change were recorded in 2002–2003 and 2005–2006. Consequently, Australian and states' construction productivity tends to depend on technological improvement on the whole. In addition, the construction productivity, the growth rate of which reached three peaks, experienced three active periods in 1994–1995, 1998–2000 and 2002–2003. Although an average annual growth trend can be found for Australia's construction industry (as shown in Table 3), construction productivity does not show a stable increase during the study period. In particular, in 2000–2001, the temporary decrease in the productivity level may be relevant to the introduction of the Goods and Services Tax (Pink, 2008). The high variability seems to reveal that technological innovation should be steadily and continuously introduced in this field.

Conclusions

Productivity changes of Australia's construction industry were measured at the state level by using newly developed Malmquist indices. Lovell's decomposition technique was used to measure the construction productivity so as to better analyse the impact made by technical changes on productivity growth and explain the factors causing the improvement in construction technologies. The conclusions can be stated as follows.

According to the analysed Malmquist indices for the eight Australian states, the productivity levels of the construction industry were very slow growing. The growth was without stability and continuity. Improving mechanical equipment and construction technologies might play an important role in promoting construction

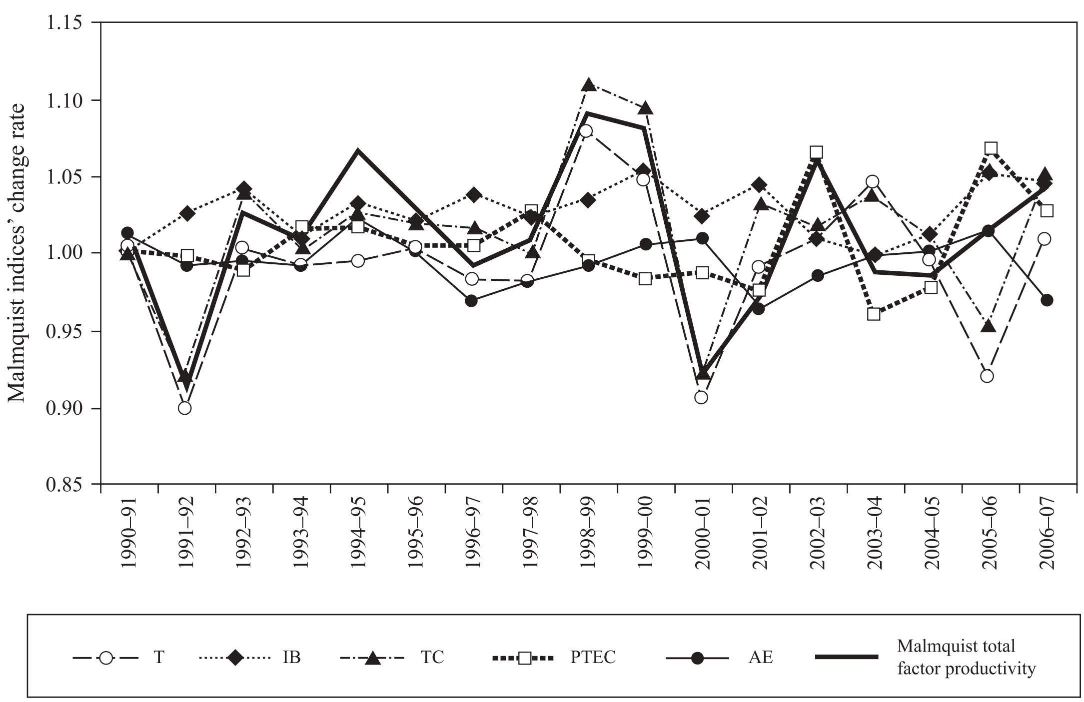

Figure 4 Annual means of Malmquist indices

productivity during the study period. The study further found the reasons leading to the increase in construction technical levels and optimizing production deployment were crucial factors.

The analysis results indicated that inputted construction scales and scopes of production activity were two critical factors that may hamper the rapid growth of construction productivity. Likewise, in terms of evaluating the trends to Malmquist indices, the analysis could also support this argument. Tasmania as an island state was restricted in technical exchanges.

Although the growth speeds of construction productivity show no obvious differences in Australia's states, the growth factors were diversified. This research revealed that technical progress, rather than pure technical efficiency improvement, was a core engine of construction productivity increase in the mid region of Australia. Yet the increase in pure technical efficiency played a crucial role in the productivity growth of the eastern region.

Factors influencing construction productivity performance were analysed based on temporal and spatial comparisons. Proposals and recommendations are expected to be beneficial for policy making and strategic decisions to improve productivity performance and competitiveness in the Australian construction industry. In particular, construction scales and production scopes that could be emphasized by future policies may stimulate further construction productivity growth.

References

ABS (2007) *Australian National Accounts: State Accounts,* Australian Bureau of Statistics, Canberra.

ABS (2008a) *Australian Economic Indicators,* Australian Bureau of Statistics, Canberra.

ABS (2008b) *Construction Work Done,* Australian Bureau of Statistics, Canberra.

ABS (2008c) *Labour Force,* Australian Bureau of Statistics, Canberra.

Allmon, E., Hass, C.T., Borcherding, J.D. and Goodrum, P.M. (2000) US construction labour productivity trends, 1970–1998. *Journal of Construction Engineering and Management,* **126**(2), 97–104.

Banker, R.D., Charnes, A. and Cooper, W.W. (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science,* **30**(9), 1078–92.

Caves, D.W., Christensen, L.R. and Diewert, W.E. (1982) The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica,* **50**(6), 1393–414.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) Measuring the efficiency of decision making units. *European Journal of Operational Research,* **2**(6), 429–44.

Crawford, P. and Vogl, B. (2006) Measuring productivity in the construction industry. *Building Research & Information,* **34**(3), 208–19.

Dai, J., Goodrum, P.M., Maloney, W.F. and Srinivasan, C. (2009) Latent structures of the factors affecting construction labor productivity. *Journal of Construction Engineering and Management,* **135**(5), 397–406.

Färe, R., Grosskopf, S., Norris, M. and Zhang, Z. (1994) Productivity growth, technical progress and efficiency change in industrialized countries. *American Economic Review,* **84**(1), 66–83.

Farrell, M.J. (1957) The measurement of productive efficiency. *Journal of the Royal Statistical Society,* **120**(3), 253–90.

Gillen, D. and Lall, A. (2001) Non-parametric measures of efficiency of US airports. *International Journal of Transport Economics,* **28**(3), 283–306.

Grifell-Tatjé, E. and Lovell, C.A.K. (1996) Deregulation and productivity decline: the case of Spanish saving banks. *European Economic Review,* **40**(6), 1281–303.

Gruneberg, S.L. (1997) *Construction Economics: An Introduction,* Macmillan, London.

Herbsman, Z. and Ellis, R. (1990) Research of factors influencing construction productivity. *Construction Management and Economics,* **8**(1), 49–61.

Lovell, C.A.K. (2003) The decomposition of Malmquist productivity indexes. *Journal of Productivity Analysis,* **20**, 437–58.

Murillo-Melchor, C. (1999) An analysis of technical efficiency and productivity changes in Spanish airports using the Malmquist index. *International Journal of Transport Economics,* **26**(2), 271–92.

Myers, D. (2003) *Construction Economics: A New Approach,* Spon Press, London.

Ofori, G. (1990) *The Construction Industry: Aspects of its Economics and Management,* Singapore University Press, Singapore.

Pink, B. (2008) *Experimental Estimates of Industry Multifactor Productivity,* Australia Bureau of Statistics, Canberra.

Shephard, R.W. (1970) *Theory of Cost and Production Functions,* Princeton University Press, Princeton, NJ.

Tan, W. (2000) Total factor productivity in Singapore construction. *Engineering, Construction and Architectural Management,* 7(2), 154–8.

Xue, X., Shen, Q., Wang, Y. and Lu, J. (2008) Measuring the productivity of the construction industry in China by using DEA-based Malmquist productivity indices. *Journal of Construction Engineering and Management,* **134**(1), 64–71.

Zhi, M., Hua, G.B., Wang, S.Q. and Ofori, G. (2003) Total factor productivity growth accounting in the construction industry of Singapore. *Construction Management and Economics,* **21**(7), 707–18.

Appendix 1

Neutral technical change