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CONSTRUCTION CAPITAL PRODUCTIVITY MEASUREMENT USING A DATA ENVELOPMENT ANALYSIS

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Abstract
During the past few decades, the construction industry has experienced a series of changes including the innovation of construction technologies and the enhancement of management strategies. These improvements should have had a considerable effect on industrial efficiency and productivity performance, but research is needed to address whether the capital productivity levels of the construction industry have in fact shown such a huge improvement. This paper aims to develop an analysis procedure to measure capital productivity changes and to reasonably quantify factors affecting productivity levels in the construction industry. Based on the data envelopment analysis method, this research has developed a novel model measuring capital productivity and has applied it to the Australian construction industry. The numerical results indicate that the average annual capital productivity levels of the construction industry are slowly growing in all the Australian states and territories except for Queensland and Western Australia. In addition, construction technologies are shown to have a close relationship with the changes in capital productivity according to the temporal-spatial comparisons of productivity indices. The research findings are expected to be beneficial for making policy and strategic decisions to improve the capital productivity performance.

Keywords
Construction industry, Capital productivity, Data analysis envelopment, Australia

INTRODUCTION

Productivity as a core index in economics aims to measure technical progress, economic efficiency, real cost control and production technology. The Royal Commission into the Building and Construction Industry (RCBCI) argued that there are three common productivities in the construction industry, namely multifactor productivity, labour productivity and capital productivity (RCBCI 2002). Among them, capital productivity aims to measure the ratio of industry output to capital input and evaluate the added benefits of increased flexibility (Gray 2006). It can provide an overall capital utilisation level of the construction industry.

Previous research laid out a path to show the development of capital productivity in the construction industry using formalised measurements. Capital productivity as a primary single-factor index can express a construction company's financial management though its use has been no more extensive than labour productivity (Lowe 1987). With regard to industrial management, the capital productivity index can strongly identify the output from the unit capital related to the construction industry's investment in factory buildings, equipments and machines (RCBCI 2002). This shows that factors outside technology also heavily influence capital utilisation levels in partial factor productivity in the construction industry (Goodrum and Haas 2002). In addition, the industrial capital productivity associated with industry gross value added may be suitable to measure the degree of output growth from cost consumption (BFC 2006). In other words, capital productivity can be measured and used to detect the return on invested capital. Pink (2007) evaluated the capital productivity for Australian industries and argued that the Goods and Services Tax introduced by the Australian government in 2000 may have reduced the construction industry's output and affected capital productivity performance. Yet factors affecting capital productivity performance cannot be presented from productivity and quantified simply by using the measurement. This measurement, therefore, may be insufficient for the exact analysis required to make a reasonable decision regarding capital productivity improvement.

This paper proposes a new approach for the measurement of capital productivity in the construction industry and examines how capital productivity levels have changed in the Australian construction sector during the study period (1990-2008). In addition, the paper quantifies the impact and contribution rates of technical efficiency, construction technologies and other components decomposed from these capital productivity changes based on the data envelopment analysis (DEA) method using the best production practice theory.

DATA ENVELOPMENT ANALYSIS BASED CAPITAL PRODUCTIVITY MEASUREMENT METHODOLOGY

The development of data envelopment analysis

Data envelopment analysis is a nonparametric method in operational research and economics, which is based on the economic notion of Pareto optimality. DEA aims to determine the efficiency of a decision-making unit (DMU) by the projection of input and output variables in geometric figures. Charnes *et al.* (1978) first introduced the nonparametric method according to the ideas of Farrell (1957), calculating relative values about efficiency by means of linear programming using constant returns to scale (CRS, changing inputs cause a proportional change in output). This method was later named the CCR model using the initials of the three authors of Charnes *et al.* (1978). The CCR model neither demands supposed production functions nor needs evaluated parameters, yet the CCR model has its own limitations and faults. Specifically, it is unable to judge whether scale or technical inefficiency results in final inefficiency. Therefore, the original CCR model is only applicable to technologies characterised by constant returns to scale. The BCC model presented by Banker *et al.* (1984), which was also abbreviated from the authors' names, is applicable to technologies of variable returns to scale (VRS, changing inputs do not cause a proportional change in output). This model could better explain the result of efficiency analysis by distinguishing between technical and scale inefficiencies by estimating pure technical efficiency on a given scale of operations. The BCC model could also evaluate observations of the scale effects in the analysis.

DEA models can be classified into two types according to the proportional movement towards an efficient frontier, namely input oriented and output oriented models. The former is used to work out the input quantities that can be proportionally reduced without a change in the output level. The latter is used to evaluate the output quantities that can be proportionally expanded without a change in the input level. Shephard (1970) first defined an output distance function in period *t* as:

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

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

$$S^t = \{(x^t, y^t) : x^t \text{ can produce } \ y^t \ \text{ at ime } \ \text{t}\,\} \tag{2}$$

The subscript "o" represents an output-oriented distance function in Eq. (1). An output distance function considers a maximal proportional expansion of the output vector, given an input vector. The output-oriented distance function concerned with the input-output vector (x^t, y^t) of period *t* in production technology S^{t+1}(named the production frontier) of period *t+1* can be expressed as

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

The output-oriented distance function concerned with the input-output vector (x^{t+1}, y^{t+1}) of period *t+1* in the production technology S^t of period *t* can be defined as

$$D_o^t(x^{t+1}, y^{t+1}) = \inf\{\theta : (x^{t+1}, y^{t+1} / \theta) \in S^t\} \tag{4}$$

To calculate the component distance functions, this paper adopts a linear programming approach. Taking $D_o^t(x^t, y^t \mid CRS)$ and $D_o^t(x^t, y^t \mid VRS)$ for example, they are defined as follows for the *i*th observation: the target function $\max\limits_{\theta,\lambda} \theta = [D_o^t(x^t, y^t \mid CRS)]^{-1}$ subjects to: $-\theta y_i^t + Y^t\lambda \ge 0$, $x_i^t - X^t\lambda \ge 0$ and $\lambda \ge 0$. The convexity constraint $N1'\lambda = 1$ should be added when calculating $\max\limits_{\theta,\lambda} \theta = [D_o^t(x^t, y^t \mid VRS)]^{-1}$ for ensuring that an inefficient DMU is only benchmarked against DMUs of a similar size. Therefore, $\max\limits_{\theta,\lambda} \theta = [D_o^t(x^t, y^t \mid VRS)]^{-1}$ should subject to $-\theta y_i^t + Y^t\lambda \ge 0$, $x_i^t - X^t\lambda \ge 0$, $\lambda \ge 0$ and $N1'\lambda = 1$.

Capital productivity measurement procedure

Lovell (2003) introduced a novel decomposition technique of Malmquist productivity indices, which are multilateral indices that can be used to compare the productivity technology of two or more economies. This new decomposition avoided technological factors that could not be interpreted well, in terms of economic meaning, using the conventional method. This paper constructs a model to measure capital productivity change (KPC). The capital productivity change model with a VRS distance function can examine three factors affecting the growth of capital productivity. The factors decomposed from KPC conform to Lovell's best production practice theory. Two industry input factors, labour and capital, produce an industry output under VRS. Capital productivity can be expressed as $y = Y/K$, and the labour-capital ratio x is L/K. The maximal potential capital productivity $\overline{y^t}(x^t)$, when giving an input x^t and an output y^t in production technology S^t of period t, could be defined as $\overline{y^t}(x^t) = y^t / D_o^t(x^t, y^t \mid VRS)$ where $D_o^t(x^t, y^t \mid VRS)$ represents an output-oriented distance function. Likewise, the maximal potential capital productivity $\overline{y^{t+1}}(x^{t+1})$ in production technology S^{t+1} of period $t+1$ can be defined as $\overline{y^{t+1}}(x^{t+1}) = y^{t+1} / D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)$. Furthermore, capital productivity which changes in periods t and $t+1$ by applying output-oriented distances and potential outputs could be expressed as:

$$KPC = \frac{y^{t+1}}{y^t} = \frac{D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)}{D_o^t(x^t, y^t \mid VRS)} \times \frac{\overline{y^{t+1}}(x^{t+1})}{\overline{y^t}(x^{t+1})} \times \frac{\overline{y^t}(x^{t+1})}{\overline{y^t}(x^t)} \tag{5}$$

in which $\overline{y^t}(x^{t+1}) = y^{t+1} / D_o^t(x^{t+1}, y^{t+1} \mid VRS)$. The first term on the right hand side of Eq. (5) is a pure technical efficiency index in capital productivity changes according to Lovell's decomposition technique. The second term corresponds to technological change. The last term on the right-hand side of Eq. (5) is a labour accumulation index, which means the variable quantity of capital productivity in period t if observation had access to the labour-capital ratio of period $t+1$ but still faced a technological frontier of period t. Similarly, Eq. (6) can be obtained according to different benchmarking.

$$KPC = \frac{D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)}{D_o^t(x^t, y^t \mid VRS)} \times \frac{\overline{y^{t+1}}(x^t)}{\overline{y^t}(x^t)} \times \frac{\overline{y^{t+1}}(x^{t+1})}{\overline{y^{t+1}}(x^t)} \tag{6}$$

in which $\overline{y^{t+1}}(x^t) = y^t / D_o^{t+1}(x^t, y^t \mid VRS)$. Eq. (6) can also be broken into three terms, the second of which represents the vertical shift between two adjacent periods under the period t labour-capital ratio. The last term aims to measure capital productivity change in period $t+1$ when the labour-capital ratio moves along the technical frontiers of different periods. By avoiding the randomness of selecting decomposed routes, taking advantage of the geometric mean of Eq. (5) and Eq. (6) could deduce Eq. (7) in which pure technical efficiency change (PTEC), technological (TC) and labour accumulation (LACCUM) make up the capital productivity change index.

$$\begin{aligned} KPC &= \frac{D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)}{D_o^t(x^t, y^t \mid VRS)} \times \left[\frac{\overline{y^{t+1}}(x^t)}{\overline{y^t}(x^t)} \times \frac{\overline{y^{t+1}}(x^{t+1})}{\overline{y^t}(x^{t+1})} \right]^{1/2} \times \left[\frac{\overline{y^{t+1}}(x^{t+1})}{\overline{y^{t+1}}(x^t)} \times \frac{\overline{y^t}(x^{t+1})}{\overline{y^t}(x^t)} \right]^{1/2} \\ &= \frac{D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)}{D_o^t(x^t, y^t \mid VRS)} \times \left[\frac{D_o^t(x^t, y^t \mid VRS)}{D_o^{t+1}(x^t, y^t \mid VRS)} \times \frac{D_o^t(x^{t+1}, y^{t+1} \mid VRS)}{D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)} \right]^{1/2} \end{aligned}$$

$$\times \left[\frac{D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)}{D_o^t(x^{t+1}, y^{t+1} \mid VRS)} \times \frac{D_o^{t+1}(x^t, y^t \mid VRS)}{D_o^{t+1}(x^{t+1}, y^{t+1} \mid VRS)} \times \left(\frac{y^{t+1}}{y^t} \right)^2 \right]^{1/2}$$
$$= PTEC \times TC \times LACCUM \quad (7)$$

Influencing factors of capital productivity

Pure technical efficiency is the effectiveness and organizational capacity for taking advantage of inputted resources to obtain effective output under reasonable operational strategies. It considers both managerial and scale effect on the performance of DMUs. Management inadequacies could result in a regression in construction productivity. However, in the construction industry, high pure technical efficiency means that managers are able to make optimal scheduling and policy by taking into account demand and supply for infrastructure, housing, business buildings, and structure enforcement and repair engineering (Myers 2003).

Construction technological factors are an essential part of the development of capital productivity. They include many aspects which are depicted as a group (Herbsman and Ellis 1990). Technological progress can reflect the ability to improve capital utilisation based on technical support. Clearly, productivity improves with the proper use of plant and tools. The improvement in construction conveyance enhances transport capacity to supply materials. It means the technical support can promote capital utilization.

Labour accumulation is an important factor in capital productivity which indicates the change in the per capital unit amount of the inputted labour owned, which drives the processes of capital productivity growth. The improvement in the labour accumulation can express industrial progress toward an increase in the capital utilisation rate.

CAPITAL PRODUCTIVITY IN AUSTRALIA'S CONSTRUCTION INDUSTRY

Data preparation

This paper takes advantage of Australian construction industry data from the Australian Bureau of Statistics (ABS) to evaluate productivity changes. Capital productivity measurement is based on a single-input resource that is the ratio of the number of persons employed to construction work done within the construction industry. A single-output variable is the ratio of construction industry gross value added to construction work done. The period analysed is from 1990 to 2008 owing to data availability. Construction work done is an aggregation of building work done and engineering construction work done. It represents all input assets of the Australian construction industry, containing fees of material deliveries, labour costs and speculative contracts. The number of employees as a representative factor concerned with labour is indispensable to any approach measuring productivities. The gross value added to the construction industry indicates the final results of the construction production activities in the form of money during the reference period. It represents the contribution of this industry to the overall production of goods and services in an economy.

The capital input data was derived from *Construction Work Done* (ABS 2009a). The number of employees in the construction industry was obtained from *Labour Force* (ABS 2009b). The gross value added to this industry was from *Australian National Accounts: State Accounts* (ABS 2008). The final annual statistics on construction work done were obtained by summing quarterly data. In addition, labour constitutes a major component of the total expenditure on inputs in many enterprises and industries. Annual totals of 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.

Figure 1 presents the changing trends of annual means of raw data. Numerical values on data are dealt with so that the first year (1990) is seen as a benchmark for later years. Overall, these data show increasing trends, especially from 2001 onward. Australia's construction industry faced a slump from 1990 to 1992. Decreases in industry gross value added, construction work done, and employed persons resulted in a reduction on the industrial scale. In 2001, capital investments and output levels in Australian construction were affected by the Goods and Services Tax introduced in 2000, leading to the second recession (Pink 2008).

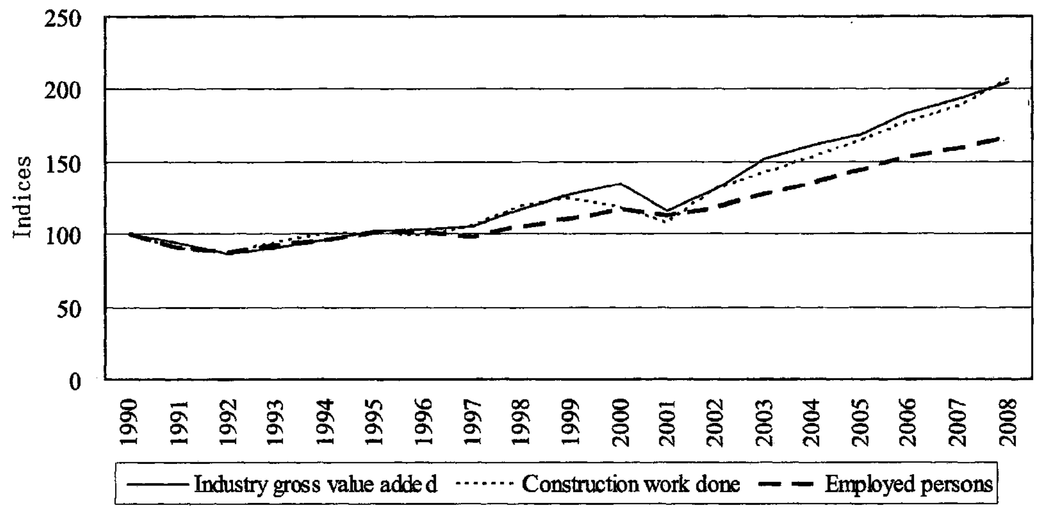

Figure 1: Changes of the Australian construction industry

Capital productivity changes

Capital productivity change values for the Australian construction industry are calculated in terms of Eq. (7), shown in Table 1. KPC integrates the pure technical efficiency change (PTEC), construction technological growth (TC) and labour accumulation factor (LACCUM) to express the industrial capital utilisation level in Australia. In the ACT, the capital productivity level saw a remarkable development due to continuous growth within the period 1994-98, reaching an average annual rate of 9.022% in those years. This reveals that the ACT capital utilisation had access to an active phase that propelled the development of capital productivity. This continuous increase was similarly experienced in NSW and Tas respectively in 1992-96 and 2002-06, and 1996-2000, with annual 1.905%, 5.618% and 11.041% growth. In addition, Australia's capital productivity improved in 1994-95 and 1999-2000 owing to the simultaneous increase in the all the observed states and territories, with mean growth rates of 9.268% and 14.1% respectively.

Table 1: Capital productivity changes in Australia's construction industry

Year	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990-91	0.97316	1.00672	1.20248	1.00357	1.07465	1.02806	0.92192	1.00423
1991-92	0.93202	0.97374	0.94033	0.87907	1.01532	0.90663	0.90796	0.98206
1992-93	1.07834	1.02888	0.99573	0.96259	0.99076	0.89065	1.04381	0.89168
1993-94	0.99874	1.00217	0.97801	0.96478	1.08587	1.00264	1.14709	0.91959
1994-95	1.21006	1.01402	1.02621	1.12105	1.18417	1.04741	1.06316	1.07534
1995-96	1.03106	1.03111	1.04737	1.03035	1.01723	0.97853	0.98709	0.93125
1996-97	1.08653	0.98262	0.91465	0.97097	0.86169	0.92937	1.16641	1.08434
1997-98	1.03324	0.97260	0.92453	1.00675	1.02770	0.98142	1.06958	0.82521
1998-99	0.99525	1.02520	1.03728	1.05519	1.01313	1.12608	1.12307	1.25684
1999-00	1.13184	1.14617	1.07944	1.08480	1.09160	1.14437	1.08259	1.36721
2000-01	0.89163	1.01020	0.90328	0.95295	0.90577	0.89295	0.88215	0.88118
2001-02	1.00892	0.96530	0.94923	0.91580	0.90606	0.93303	0.82056	0.32409
2002-03	0.99478	1.04549	1.09085	1.07493	1.05377	1.04077	1.13913	1.51170
2003-04	1.13406	1.00751	0.99958	0.97183	0.97151	0.98856	0.88953	1.02280
2004-05	0.93754	1.03891	0.99092	0.90808	1.05460	0.90259	0.94072	0.89795
2005-06	0.76518	1.13282	1.06943	0.96502	1.02452	0.88453	0.98955	1.08471
2006-07	1.11333	0.94515	1.02381	1.05141	1.03093	0.97625	1.00290	1.29024
2007-08	1.03689	0.99641	0.99229	0.95412	0.91720	0.96733	1.01623	0.79845
Mean	1.01959	1.01806	1.00919	0.99296	1.01258	0.97895	1.01075	1.00827

Pure technical efficiency change in capital productivity

According to Eq. (7), three sources affecting capital productivity are displayed, and the results of pure technical efficiency growths are listed in Table 2. The pure technical efficiency index in capital productivity is used to measure management methods and operations strategies related to capital utilisation rates in the Australia construction industry. The change in this index can express the progression or regression in industrial management factors concerned with the capability for capital utilisation and the impact of increases or decreases in the index on capital productivity changes.

Table 2: Pure technical efficiency changes in capital productivity

Year	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990-91	1.00000	1.00248	1.19872	0.99874	1.07060	1.02375	0.91806	1.00000
1991-92	1.00000	1.09282	0.95722	0.99622	1.03357	0.99145	0.95613	1.00000
1992-93	1.00000	0.98528	1.05140	0.91403	1.04640	0.87562	1.06646	1.00000
1993-94	1.00000	1.00345	0.97875	0.96542	1.08647	1.00281	1.14837	1.00000
1994-95	1.00000	0.83849	0.84799	0.92693	0.97857	0.86676	0.87855	1.00000
1995-96	1.00000	1.00000	1.01665	0.99845	0.98644	0.94822	0.95735	1.00000
1996-97	1.00000	1.07923	0.89169	1.10372	0.79387	1.04266	1.07373	1.00000
1997-98	1.00000	0.78861	0.84463	0.78962	0.99467	1.18003	1.03433	1.00000
1998-99	1.00000	1.02889	1.04181	1.06039	1.01740	0.74757	1.12863	0.70000
1999-00	1.00000	1.01404	0.95345	1.67504	0.96447	1.01113	0.95711	1.20857
2000-01	1.00000	1.13231	1.01347	0.61100	1.01637	1.00183	0.98848	1.18203
2001-02	1.00000	0.95652	0.94020	0.90835	0.89799	0.93956	0.81347	1.00000
2002-03	1.00000	1.05114	1.09717	1.08108	1.05830	1.04288	1.14490	1.00000
2003-04	1.00000	0.88919	0.88084	0.85667	0.85734	1.03364	0.78442	1.00000
2004-05	1.00000	1.10790	1.05850	0.96887	1.12521	1.08499	1.00355	1.00000
2005-06	1.00000	1.37174	1.31261	1.21687	1.25915	1.01833	1.22615	1.00000
2006-07	1.00000	0.91600	0.97895	0.97855	0.98372	1.21277	0.95101	1.00000
2007-08	1.00000	0.96070	0.95699	0.91906	0.88534	1.18893	0.97879	1.00000
Mean	1.00000	1.01216	1.00117	0.99828	1.00311	1.01183	1.00053	1.00503

The pure technical efficiency remained the same for the Australian Capital Territory construction industry. This revealed that there was no effect on ACT capital productivity in the last 19 years. The pure technical efficiency index for the NT is similar to one for the ACT, holding steady through the observed years, except for in 1998-2001. In addition, pure technical efficiency indices' construction rates for all the states and territories are, respectively, 0, 67.316%, 12.705%, 24.446%, 24,689%, -56.218%, 4.903% and 60.865% by the ratio of PTEC-1 to KPC-1. Among them, NSW was the most affected by pure technical efficiency change in capital productivity levels. It should be noted that the results of the contribution rates for Qld and WA are entirely different though the mean levels of capital productivity levels for both of the states are declining. The final mean contribution rate for the former is negative. This reveals that the decrease in the mean pure technical efficiency resulted in the reduction in the KPC. Yet the contribution rate interferes with the regression of KPC for the latter.

Technological change in capital productivity

Technological factors affecting capital productivity change are calculated by Eq. (7) that decomposes KPC into three sources. The results regarding the technological growth for districts are shown in Table 3. Evaluating technological factors affecting the capital productivity aims to measure the contribution to KPC, with the system of capital productivity as an output and the labour-capital ratio (labour intensity) as an input variable. The index is biased toward the capital utilisation by the introduction of advanced construction machinery, equipment and skills in the eight observed states.

Table 3: Technological changes in capital productivity

Year	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990-91	0.96953	1.00435	1.00407	1.00441	1.00373	1.00434	1.00436	0.97692
1991-92	0.86639	0.89695	0.98213	0.90209	0.98189	0.85574	0.92971	0.88247
1992-93	1.13586	1.03505	0.95439	1.04527	0.94702	1.10034	0.96233	1.10782
1993-94	0.98484	0.99885	0.99893	0.99859	0.99894	0.99930	0.99861	0.87676
1994-95	1.02620	1.14151	1.21076	1.20995	1.21026	1.20656	1.20983	0.92384
1995-96	1.16699	1.03125	1.03028	1.03143	1.03145	1.09819	1.03129	1.18500
1996-97	0.86853	0.95794	1.05537	0.96186	1.08633	0.88858	1.08632	0.89782
1997-98	1.29166	1.27074	1.13743	1.28249	1.03328	1.17414	1.03361	1.17387
1998-99	1.42926	0.99526	0.99510	0.99484	0.99537	1.22473	0.99480	1.33703
1999-00	0.71120	0.83644	0.84739	0.64377	1.13249	0.80742	1.13182	0.81275
2000-01	1.20531	0.89147	0.89129	1.17964	0.89150	0.89104	0.89202	1.10593
2001-02	1.15717	1.00906	1.00860	1.13491	1.00923	1.15663	1.00869	1.21907
2002-03	1.04239	0.99447	0.99495	0.98560	0.99565	1.05096	0.99475	0.92735
2003-04	1.04673	1.13348	1.13425	1.13423	1.13312	0.96567	1.13441	0.98949
2004-05	0.90948	0.93778	0.93723	0.91877	0.93761	0.91408	0.93752	1.08698
2005-06	0.93781	0.81792	0.80762	0.81925	0.81101	1.05926	0.80659	0.98793
2006-07	1.01397	1.03183	1.04828	1.07602	1.04503	0.93752	1.05311	0.96750
2007-08	1.00097	1.03687	1.03709	1.03762	1.03641	0.81949	1.03744	0.79732
Mean	1.04246	1.00118	1.00418	1.02004	1.01557	1.00856	1.01374	1.01421

In the ACT, the technology level reached a remarkable level in capital productivity due to continuous growth within the period 2000-04, reaching an average annual growth rate of 11.29% in those years. This reveals that the improvement in construction technologies and the introduction of equipment related to capital utilisation propelled the development of capital productivity. Vic., SA and Tas. experienced this kind of the continuous increase from 1994-98, with annual average 10.846%, 9.033% and 9.027% growth respectively. Therefore, the construction industry in the Australian southeast area had access to an active phase of construction technologies in these states. In addition, Australia's states and territories experienced a decrease in the overall level of construction technology in 1991-92 and 1993-94. It could be concluded that Australia's technological level remained depressed in these two periods. In particular, the construction technological factor decreased by 8.783% for states' mean level in 1991-92. On the other hand, the technological change in the capital productivity for all the states and territories enhanced simultaneously in 1995-96, 1997-98 and 2001-02. In particular, all the eastern states had a rapid growth in 1997-98, namely 29.166% for the ACT, 27.074% for NSW and 28.249% for Qld. This caused the high average annual growth rate, 17.465%. The development of Australia's average annual growth, therefore, did not show stable growth at the construction technology level.

Labour accumulation in capital productivity change

Labour accumulation effects, the results of which are shown in Table 4, are calculated according to Eq. (7). Specifically, the average annual growth rates in labour accumulation for all the states and territories are respectively 0.413%, 1.919%, 1.49%, 0.603%, 0.023%, -1.899%, 0.231% and 2.515%. Among the states, the highest impact on KPC, 304.114% for the NT, indicates that the Northern Territory's labour accumulation was the mainspring of the local construction labour productivity growth. On the other hand, Western Australia's labour accumulation has fallen annually by 1.899% over the last 19 years. This is the main reason why Western Australia's mean capital productivity is reducing. In SA, the level of labour accumulation remained relatively stable considering the data from the last 19 years. The greatest growth in LACCUM is just 0.326% in 2005-06.

Table 4: Labour accumulation changes in capital productivity

Year	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT
1990-91	1.00375	0.99988	0.99907	1.00042	1.00004	0.99987	0.99985	1.02795
1991-92	1.07575	0.99340	1.00023	0.97818	1.00047	1.06860	1.02141	1.11286
1992-93	0.94936	1.00890	0.99231	1.00751	0.99979	0.92442	1.01708	0.80489
1993-94	1.01412	0.99988	1.00033	1.00075	1.00051	1.00053	1.00027	1.04885
1994-95	1.17917	1.05942	0.99951	0.99956	0.99987	1.00154	1.00024	1.16399
1995-96	0.88352	0.99987	0.99993	1.00050	0.99977	0.93970	0.99978	0.78586
1996-97	1.25100	0.95045	0.97194	0.91461	0.99917	1.00311	0.99999	1.20775
1997-98	0.79993	0.97055	0.96234	0.99414	0.99992	0.70834	1.00045	0.70298
1998-99	0.69634	1.00115	1.00056	1.00026	1.00043	1.22991	1.00028	1.34289
1999-00	1.59144	1.35132	1.33603	1.00599	0.99940	1.40171	0.99936	1.39190
2000-01	0.73975	1.00077	0.99999	1.32215	0.99964	1.00030	1.00047	0.67407
2001-02	0.87188	1.00012	1.00099	0.88836	0.99976	0.85858	1.00002	0.26585
2002-03	0.95433	1.00016	0.99929	1.00884	1.00007	0.94959	1.00021	1.63013
2003-04	1.08342	0.99963	1.00049	1.00018	1.00003	0.99038	0.99964	1.03367
2004-05	1.03084	0.99994	0.99885	1.02011	0.99961	0.91008	0.99987	0.82610
2005-06	0.81592	1.00967	1.00881	0.96800	1.00326	0.82001	1.00056	1.09796
2006-07	1.09799	0.99999	0.99766	0.99855	1.00283	0.85863	1.00138	1.33358
2007-08	1.03589	1.00029	0.99981	1.00051	0.99959	0.99282	1.00078	1.00142
Mean	1.00413	1.01919	1.01490	1.00603	1.00023	0.98101	1.00231	1.02515

DISCUSSION

The paper has shown the results of capital productivity and the influencing factors, based on the new capital productivity model employed in the research. In addition the temporal-spatial analysis of capital productivity indices will be presented to directly show indices' numerical analysis across the country and the successive changes over time. This indicates that the analysis procedure is beneficial with regard to how these factors influence capital productivity in the construction industry.

The analysis for capital productivity indices by region

Table 5 lists DMUs' mean capital productivity changes and factors decomposed from those in 1990-2008. According to the pure technical efficiency index related to KPC, six districts excludes the ACT and Qld. show little progress in operational capacity regarding capital utilisation. This is because the values of pure technical efficiency are slightly larger than 1 that could indicate that management methods for utilising capital input have not been remarkably promoted for these six districts in the observed years. The phenomenon in Qld. is more worthy of note due to a 0.172% decrease in the pure technical efficiency index. If Queensland seeks to enhance its industrial capital productivity level, it must first establish more reasonable operational strategies and manage ideas to promote the utilisation rate of input resources to reduce costs. The index for the Australian Capital Territory's construction industry remained the same in the last 19 years. The capital productivity level did not benefit nor was it impaired by the industrial development strategies and operational methods.

Table 5: Capital productivity indices of DMUs' means

Indices	ACT	NSW	Vic.	Qld	SA	WA	Tas.	NT	Mean
PTEC	1.00000	1.01216	1.00117	0.99828	1.00311	1.01183	1.00053	1.00503	1.00401
TC	1.04246	1.00118	1.00418	1.02004	1.01557	1.00856	1.01374	1.01421	1.01499
LACCUM	1.00413	1.01919	1.01490	1.00603	1.00023	0.98101	1.00231	1.02515	1.00662
KPC	1.01959	1.01806	1.00919	0.99296	1.01258	0.97895	1.01075	1.00827	1.00629

According to statistical information concerned with construction technological levels, eight districts' indices were greater than 1. The technological growth for states where the mean level was larger than 1 indicates that improved construction equipment and advanced technologies were principal factors contributing to the improvement in industrial productivity levels. A 4.246% increase for the ACT also makes up for the shortage in the technical efficiency that has no positive effect on KPC

On the basis of the results shown for labour accumulation, this research could draw the conclusion that LACCUM is the other main driving force in the mean growth of capital productivity for most districts. However, Western Australia's construction industry has relied primarily on pure technical efficiency factors to promote capital production capacity over the last 19 years.

Applying the non-parametric DEA method to evaluate capital productivity is useful to analyse the fundamental causes for KPC. The mean capital productivity level for the Australian construction industry increased annually by 0.629% during the study period. However, Qld and WA decreased respectively by 0.704% and 2.105% operated with large capital inputs and the industrial output could not enhance the capacity to utilise the capital input. This resulted in the waste of capital investment in the Australian construction industry, which impacted on the overall level of the national capital utilisation rate. As for other states, the major impetus for promoting capital productivity was different. For instance, the growth in the ACT, SA and Tas. in KPC was stemmed from technological factors, whereas NSW, Vic. and the NT stemmed from LACCUM. It can be assumed that geographical locations do not play a pivotal role in the process affecting KPC. Overall, this paper draws the conclusion that both construction technologies and labour accumulation support the increase in the capital productivity. In other words, when equipment is updated and labour accumulation improves, the efficiency of utilising capital will then be enhanced.

The analysis of capital productivity indices over time

Australia's average annual growth rates of capital productivity levels and factors affecting them are shown in Figure 2. According to the results of the pure technical efficiency factor concerned with KPC, this index fluctuates between 0.9 and 1.2 during the observed periods. Capital productivity PTEC experienced three peak periods that were respectively 1999-2000, 2002-03 and 2005-06. The last peak period revealed that a significant increase in the technical efficiency of capital utilisation made up for the deficiency in the technological factor and labour accumulation to remain capital productivity stable in 2005-06. This indicates that the technical efficiency index in capital productivity should not be neglected though the average annual growth presented in Table 5 is not great.

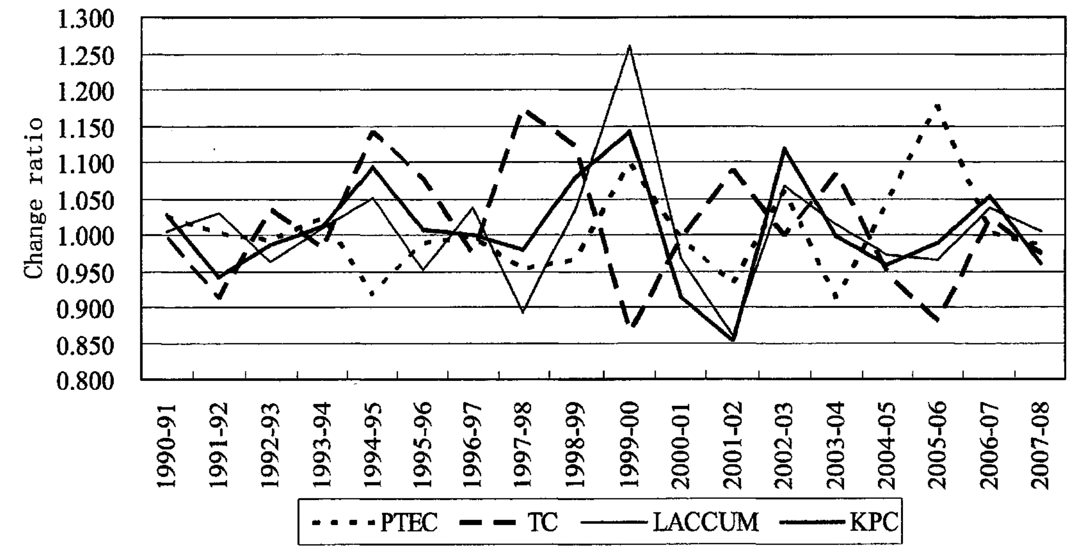

Figure 2: Annual means of capital productivity indices

The range of change according to the construction technology index is very large, between 0.85 and 1.2. The construction technology index experienced three major troughs in 1991-92, 1999-2000 and 2005-06. This growth trend is very different from the change in capital productivity. It indicates that the construction technology did not play a decisive role in the development of capital productivity even though its average annual growth is the largest of the factors decomposed from KPC.

In addition, the growth trend of labour accumulation is more like the capital productivity change than TC and PTEC. In other words, the increase or decrease in the capital utilisation level is often accompanied by the same change of LACCUM. Yet the slight fluctuations of LACCUM early stage of the last 19 year period indicates that labour accumulation only played a secondary or supplementary role in the development of capital productivity, based on the fact that KPC is the result of joint action from the PTEC, TC and LACCUM.

In Australia, capital productivity experienced a trough in the construction industry in 1991-92. The decline in capital utilisation was accompanied to a great extent by a huge regression in the construction technological index. The second trough in capital productivity in 2000-02 was accompanied by a huge regression in both LACCUM and PTEC. It can be concluded that the change in capital productivity in the early stage stems primarily from the impact of the construction technological level, and that the later stage growth was primarily affected by labour accumulation of the capital utilisation. However, the change in capital productivity and the affecting factors slowed down in the last year. This is worth further investigation.

CONCLUSION

This paper has studied the measurement of capital productivity changes in the Australian construction industry at a national, region and state level. This study has employed the data envelopment analysis method to construct the capital productivity model and to decompose capital productivity changes. The construction technologies and pure technical efficiency that are decomposed in this paper conform to Lovell's decomposition technique renovated for Malmquist productivity indices. The study has focused on analysing the changes in construction technologies and pure technical efficiency factors and what they bring to capital productivity levels under VRS. The conclusions can be stated as follows:

Based on the research of the analysed capital productivity indices for states territories and their mean values, the study considers that construction technological levels have not been sufficiently promoted to increase industrial capital utilisation rates in NSW, Vic., SA, WA, Tas. and the NT. The study also suggests that if the Queensland construction industry seeks to enhance its industrial capital productivity level, it must first establish more reasonable working theories and management ideas to promote the utilisation rate of input resources, thereby reducing cost. As for the development of the Australian capital productivity, change in the early stage of the capability stems primarily from the impact of the construction technological level, and the later stage growth is primarily affected by the labour accumulation level of capital utilisation. However, the change of capital productivity and the factors affecting it have slowed down in the last year. This is worth further observation and investigation, taking advantage of newer data.

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