Measuring efficiency, effectiveness and overall performance in the Chinese construction industry

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Abstract

Purpose – The purpose of this paper is to develop a simultaneous measurement of overall performance and its two dimensions of efficiency and effectiveness in the case of Chinese construction industry.

Design/methodology/approach – A relational two-stage data envelopment analysis (DEA) method, which builds a relationship between component stages and can effectively identify inefficient stages, is developed and applied in order to measure overall performance, efficiency and effectiveness.

Findings – The construction industry of the Eastern region in China demonstrated the best results for overall performance, efficiency and effectiveness. The gaps between regions were primarily reflected in differences of pure technical efficiency. Performance indicators in the whole construction industry improved steadily and but could be improved more effectively. The coefficients of variation became smaller and more well-balanced across the whole industry.

Practical implications – Improving overall performance should focus on promoting construction efficiency at the project level and increasing management effectiveness at the company level. Sustainable development policies, which may include large investment and preferential policies, can narrow performance differences among the regions' construction industries, and ultimately promote overall performance for the whole industry.

Originality/value – The relational two-stage DEA model is further developed in a variable returns-to-scale condition. The developed approach is generic and can provide a pathway for simultaneously measuring performance, efficiency and effectiveness and to recognise competitive advantages for promoting sustainable development.

Keywords China, Effectiveness, Construction industry, Efficiency, Overall performance, Relational two-stage data envelopment analysis

Paper type Technical paper

Introduction

Failure of performance measurement in the construction industry has been criticised in much literature, including a review by Yang *et al.* (2010). As performance measurement is crucial for management activities, various studies of performance measurement can be found from academics and practitioners in the construction domain (Tsolas, 2011). Lin and Shen (2007) reviewed papers related to performance measurement in the construction industry, and classified them into those with overall performance measurement and those with partial performance measurement. Partial performance studies demonstrate one aspect of performance (Lin and Shen, 2007; Deng and Smyth, 2013), such as safety performance, profitability, or schedule performance, and therefore are incapable of illustrating a complete view of performance. Overall performance is a combination of technical/functional performance and process/expressive performance, and can comprehensively describe what construction "is" and how it "works" (Liu and Fellows, 1999). Accordingly, overall performance can be regarded as a single indicator to measure performance in construction management research (Deng and Smyth, 2013). The evaluation of overall performance, which can prevent wrong decisions that improve

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one metric at the expense of decreasing overall firm efficiency, is particularly important (El-Mashaleh *et al.*, 2007).

In general, an overall performance measurement is defined as a process quantifying the efficiency and effectiveness of an action (Neely *et al.*, 1995). Past studies (e.g. Rämö, 2002; Tsolas, 2011) have defined efficiency as "doing things right" and effectiveness as "doing the right things". Efficiency and effectiveness measurements are critical in determining a firm's overall success in the highly competitive construction industry (El-Mashaleh *et al.*, 2007). Tsolas (2011) measured efficiency and effectiveness as two dimensions of the performance of construction firms. In non-storable commodity research, Chiou *et al.* (2010) analysed overall performance via a joint measurement of efficiency and effectiveness using integrated data envelopment analysis (DEA) approaches. However, in the construction domain, very little literature that simultaneously measures overall performance, efficiency and effectiveness can be identified.

The DEA application to performance measurement has been successfully described in many construction studies (Horta *et al.*, 2010). DEA is a non-parametric method used to investigate the relative efficiency of a decision-making unit (DMU) by projecting production variables in geometric figures. Compared to parametric and semi-parametric methods, which both assume a specific production function in estimation, the non-parametric method does not consider how to choose a specific production function and is not concerned with how to impose distributional assumptions on the efficiency term (Hampf, 2013). DEA was first introduced on the basis of the economic theory of Pareto optimality by Charnes *et al.* (1978). In the construction domain, earlier researchers employed the DEA approach to measuring the technical efficiency of an organisation (Ruddock, 1994) and to attempting to measure the performance of engineering (Busby, 1995). After these applications, the DEA approach gradually became the principal technique for measuring efficiency related to situations of multiple inputs and multiple outputs in construction.

The remainder of this paper includes three procedures. First, the primary gaps between the current two-stage DEA research in construction and the relational two-stage DEA approach are indicated. Second, the relational two-stage DEA model, although it can be used in other sectors, is provided in modelling overall performance for the construction industry. Third, the Chinese construction industry, which has become the largest construction market in the world (Comu *et al.*, 2013), is selected as an example to apply the new approach so as to evaluate its overall performance.

A two-stage DEA approach in construction

The DEA approach, which is also called the standard or one-stage DEA approach, is one of the most frequently used techniques for overall performance measurement in construction (Yang *et al.*, 2010). The DEA method has been significantly utilised to measure and benchmark overall performance for construction firms (El-Mashaleh *et al.*, 2007), to benchmark safety performance for construction contractors (El-Mashaleh *et al.*, 2010), to compare energy productivity and total factor productivity performance in the construction industry (Hu and Liu, 2016a), to assess the performance of construction companies by integrating several key performance indicators (Horta *et al.*, 2010) and to measure overall performance for the construction industry (Horta *et al.*, 2012). This is mainly because the DEA technique provides significant managerial information concerning rankings and targets in performance evaluation (Horta *et al.*, 2010), and DEA results have higher correlations with traditional performance indicators than do common econometric models (Cummins and Zi, 1998). However, these performance measurements, which are merely based on the results of one-stage efficiency scores, could be more precisely measured.

There are three powerful reasons for the popularity of DEA (El-Mashaleh *et al.*, 2010). First, DEA as a linear programming-based technique can solve complicated problems with multiple inputs and multiple outputs (Kuo *et al.*, 2008). Second, DEA avoids the assumption of prior conditions in constructing models, such as the weights and prices of inputs and outputs. Finally, DEA need not have the same measurement units for all variables and so is very useful for choosing data. As a deterministic method, DEA compares every individual production unit so as to identify the best practices. Moreover, the various scaling adjustments made for graphical purposes do not affect the relationships among input–output variables in the DEA technique (El-Mashaleh *et al.*, 2007). However, DEA has been criticised in that it treats a whole production system as a "black box" and ignores the internal structure of the system (Du *et al.*, 2011). In order to open this black box, the developed technique of a two-stage DEA model has been employed to investigate the construction production system and its internal structure.

The two-stage DEA approach is a type of DEA which measures the performance of a production system with a two-stage structure. In the construction domain, Tsolas (2011, 2013) first analysed the two-stage structure so as to investigate the performance of construction firms. Tsolas (2011) decomposed the construction production system into two stages, profitability efficiency and effectiveness, and utilised the standard two-stage DEA approach to measure these. This approach neglects the functions of the intermediate product of total revenue in the measurement process. In the first stage, the intermediate product should be produced so as to improve profitability efficiency; however, the intermediate product should be reserved in the second stage in order to improve effectiveness. These requirements are contradictory. A significant point is that the intermediate product should be equal between the first and second stages in the measurement process. To overcome this shortcoming, Tsolas (2013) applied a separate two-stage DEA model (so named in Chiou *et al.* (2010)), where an input-oriented model was used in the first stage to measure profitability efficiency and an output-oriented model was used in the second stage to measure the performance of the stock market, respectively. Chiou *et al.* (2010) indicated that the measurement of the separate two-stage DEA model should be further developed because the two stages are not interrelated. In addition, these two papers did not measure overall performance for the whole system. In spite of this, two-stage DEA research provides a rational pathway to simultaneously measuring overall performance and its two dimensions in construction.

The original linear programme of the relational two-stage DEA model was proposed by Kao and Hwang (2008) under a constant returns-to-scale (CRS) condition. The model measures the efficiency of the whole system and its components at the same time by taking into account the interrelationship of the components within the system (Kao, 2009). The model not only suitably describes the relationship between the whole system and the component sub-stages, but also more adequately measures efficiency scores (Kao, 2009). Therefore, the calculating scores of the model can help decision makers to more capably identify inefficient components and production benchmarks. The relational two-stage DEA model based on CRS and a global benchmark technology has been applied to assess profitability performance in the Australian construction industry (Hu and Liu, 2016b). The present study develops an envelopment form for the relational two-stage DEA model under a variable returns-to-scale (VRS) condition. Under the VRS condition, an efficiency score in a whole system is not equal to the product of scores from two separate stages as in a relational two-stage DEA model (Chen *et al.*, 2009). CRS assumes the proportional change in outputs is equal to the proportional change in inputs. However, the proportional change in outputs is not the same as the change in inputs under VRS. Therefore, conventionally, DEA models under CRS measure technical efficiency and under VRS measure pure technical efficiency (Tsolas, 2013). As construction scale plays an important role in construction development, the VRS model can provide an opportunity to investigate pure technical efficiency and scale efficiency. This approach is first applied to construction and provides a significant pathway to evaluate performance, efficiency and effectiveness simultaneously.

Relational two-stage DEA development for the construction industry

Variable identifications of a relational two-stage DEA model

According to the cash-flow cycle of the construction business (Schaufelberger, 2011), and the model of the profitability efficiency and effectiveness of construction firms (Tsolas, 2011), a two-stage structure is identified that aims to measure the overall performance of the construction industry. The first stage illustrates construction efficiency in relation to using resources to generate outcomes. "Doing things right" is producing as many outcomes as possible with specific resource consumption, no matter what kinds of outcomes are produced. The second stage demonstrates effectiveness in relation to achieving the final objectives under the initial outcomes, which mainly occurs at the construction company level. "Doing the right things" focuses on obtaining the revenue goals that the company expects from the outcomes. The whole process specifically describes the framework of overall performance in the construction industry. A specification of the two-stage structure and the indicators of inputs, intermediate product and output is proposed in Figure 1.

Identifying reasonable variables is a fundamental aspect of applying DEA (Hu and Liu, 2015). The construction industry consumes resources from other industry sectors, primarily including land, materials and energy. However, these resources are not the inputs from the construction industry itself, and cannot be inputs in this measurement. The construction industry itself criticised capital input (total assets) and labour input (staff and workers) in the construction process. Following Wang *et al.* (2013), who measured productivity for the Chinese construction industry, this study also uses "total power machinery and equipment owned" as an input indicator. Growth in the plant and machinery of contractors indicates technological improvement (Li *et al.*, 2013). On the other hand, the gross value added, indicating the newly created value of the construction industry, is a better choice to be the output indicator compared with the total output value, which includes the inputs from other industries. Therefore, the input variables of capital, labour, and equipment (total power machinery and equipment owned), and the output variable of gross value added have been selected to measure construction efficiency in the first stage.

The value of gross value added is equal to the sum of the depreciation of capital assets distilled in the reference year, labour payable, welfare payable, insurance and tax on work in overhead expenses, tax and surtax on construction balance and profit of construction balance (Xue *et al.*, 2008). On the other hand, profit, which is one of the most important conditions for survival, is an important objective of construction firms. Profit maximisation is the basis for the theory model of a perfect competition market. In the Dupont framework, profit margin is used as an effectiveness metric. Furthermore, Tsolas (2011) employed total revenue as the input variable and net income before taxes as the final output variable to measure effectiveness for construction firms. As a result, gross value added as the input variable and profit as the output variable have been chosen to measure effectiveness in the second stage. In summary, the structure of measuring construction efficiency, effectiveness and overall performance is identified from the input–output supply side.

Modelling efficiency, effectiveness and overall performance of construction

Consider decision-making unit DMU_j $(j=1, 2, \ldots, J)$ observed in t $(t=1, 2, \ldots, T)$ time period. In the first stage, the inputs of capital (K), labour (L) and equipment (Q) of each DMU

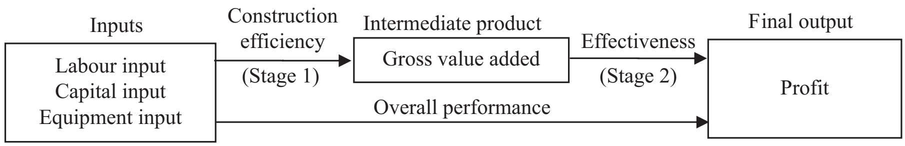

Figure 1. The two-stage structure and variables

produce quantities of gross value added (V). The production technology set F_1 in the first stage is F_1^t $(K^t, L^t, Q^t) = \{(V^t), K^t, L^t, Q^t$ produce V^t at time $t\}$. In the second stage, the intermediate product of gross value added produces quantities of profits (P). The production technology set F_2 in the second stage is F_2^t $(V^t) = \{(P^t), V^t$ produces P^t at time $t\}$. The inputs, intermediate product and output are all non-negative. The production technology sets are constructed by contemporaneous technology for three important reasons. First, the contemporaneous production technology determines a production frontier from all DMUs that occur in the same time, and identified benchmark technology(s) can be feasibly transferred in practise. Second, the case of the Chinese construction industry with 31 DMUs (discussed in the next section) satisfies the important requirement of DEA that the number of DMUs should be more than two times the sum of the numbers of inputs and outputs (Sun, 2011). Finally, the contemporaneous production technology ensures the consistency of statistical data at every calculation period, and avoids the weakness of statistical changes during all research periods. As well as contemporaneous technology, many production technology set definitions have been proposed in DEA, such as intertemporal technology, sequential technology, window technology and global technology.

The relational two-stage DEA models under the VRS condition are provided in Table I. Models (a), (b) and (c) measure efficiencies for the whole system, the first stage, and the second stage of the ith DMU with (K_i, L_i, Q_i; V_i; P_i), respectively. The constraint (see Equation (1)) demonstrates the requirement of capital input to be maintained at a constant level, where the variable of capital input is weakly disposable (Färe *et al.*, 1989). In China, if the capital input (fixed assets) of construction companies does not satisfy legal requirements, companies have no authorisation to participate in the construction market (Wang, 2010). Therefore, variables that are not strongly disposable should be treated with strict equality constraints, which are popularly applied in researching carbon reduction. The constraints (see Equations (2) and (3)) demonstrate the inputs of labour and technology with strong disposability and no more than current input values. The constraint (see Equation (4)) bonds the first and second stages, in which the output from the first stage should equal the input of the second stage. In the constraint (see Equation (5)), μ_j and γ_j, which are non-negative multipliers, are utilised in constructing production technology sets for the two stages, respectively. μ_j and γ_j are also considered to be the weights assigned to DMU_j in the first and second stages, separately.

In Table I, the constraints (see Equations (1)–(5)) are shared by Models (a), (b) and (c). Moreover, the three models each have independent constraints. The constraints (see Equations a6, b6 and c6) are for the output indicators, so as to separately measure the maximum values of e_1, e_2 and e_3 that are all greater than or equal to 1. Greater values of e_1, e_2 and e_3 illustrate worse efficiencies and longer distances between the DMU and the frontier of the

Table I. The relational two-stage DEA models under variable returns-to-scale

Model (a) Max e_1	Model (b) Max e_2	Model (c) Max e_3
	$\sum_{j=1}^{J} K_j^t \mu_j^t = K_i$ (1)	
	$\sum_{j=1}^{J} L_j^t \mu_j^t \leqslant L_i$ (2)	
	$\sum_{j=1}^{J} G_j^t \mu_j^t \leqslant G_i$ (3)	
	$\sum_{j=1}^{J} V_j^t \mu_j^t = \sum_{j=1}^{J} V_j^t \gamma_j^t$ (4)	
	$\mu_j^t \geqslant 0, \gamma_j^t \geqslant 0$ (5)	
$\sum_{j=1}^{J} P_j^t \gamma_j^t \geqslant e_1 P_i$ (a6)	$\sum_{j=1}^{J} V_j^t \mu_j^t \geqslant e_2 V_i$ (b6)	$\sum_{j=1}^{J} P_j^t \gamma_j^t \geqslant e_3 P_i$ (c6)
$\sum_{j=1}^{J} \mu_j^t = 1$ (a7)	$\sum_{j=1}^{J} P_j^t \gamma_j^t \geqslant P_i$ (b7)	$\sum_{j=1}^{J} V_j^t \mu_j^t \leqslant V_i$ (c7)
$\sum_{j=1}^{J} \gamma_j^t = 1$ (a8)	$\sum_{j=1}^{J} \mu_j^t = 1$ (b8)	$\sum_{j=1}^{J} \gamma_j^t = 1$ (c8)

production technology set; in other words, the DMU is producing more final outputs in current conditions. The constraint (see Equation (b7)) illustrates a precondition without influencing the final output in the first stage; and the next constraint (see Equation (c7)) requires that the input of the intermediate product must not be more than the current value in the second stage. The constraints (see Equations (a7), (a8), (b8) and (c8)) are VRS conditions. Furthermore, when deleting these constraints (see Equations (a7), (a8), (b8) and (c8)), efficiencies in the whole system, the first stage, and the second stage can be obtained through the relational two-stage DEA models under a CRS condition, considered e_4, e_5 and e_{36}, respectively.

As measured from an output-oriented function of DEA, overall performance, construction efficiency and construction effectiveness are the reciprocals of e_4, e_5 and e_6, respectively. The overall pure technical efficiency (OPTE), pure technical efficiency of the first stage (PTE-1), and pure technical efficiency of the second stage (PTE-2) are the respective reciprocals of e_1, e_2 and e_3. Moreover, the overall scale efficiency (OSE), scale efficiency in the first stage (SE-1) and scale efficiency in the second stage (SE-2) are the proportions between overall performance and OPTE, between construction efficiency and PTE-1, and between effectiveness and PTE-2, respectively. The relationships among overall efficiency, pure technical efficiency and scale efficiency have been investigated in much literature; this is called an efficiency decomposition approach (e.g. Tsolas, 2013).

Three critical enhancements of the relational two-stage DEA model can be observed. First, the relational model can measure overall efficiency for the whole system, e.g. Model (a). Second, when measuring stages' efficiencies, the relational model includes all constraints from both stages, embodied in the constraints (see Equations (1)–(5)). Finally, the intermediate product is considered in the measurement process. A constraint (see Equation (4)) explores the relationship between the first stage and the second stage following the practical function of intermediate products. In practice, the input to production cannot exceed existing maximum values and is completely consumed in order to achieve the maximum output. Therefore, the intermediate product is totally transformed from the first stage to the second stage, which is also in compliance with modern accounting standards. In addition, if there were one intermediate product in a production system, efficiency in each stage that is measured via the relational two-stage DEA model would be equal to the result that is measured by the standard two-stage DEA method (Cook *et al.*, 2010). However, if two or more intermediate products existed, the equation would not be correct (e.g. Kao and Hwang, 2008).

Measurement and discussions for construction industries in China

Variables and data used for empirical analysis

The methodology that is described in the previous section is now applied to the construction industries of the Chinese provinces and municipalities in Mainland China. China, which has a wealth of land, is usually divided into four regions: eastern, middleland, northeast and western regions. The economic development plans from the central government, such as the western region development programme and the revitalisation of the old industrial base in Northeast China, are always designed according to the different development situations in each region. Xue *et al.* (2008) measured the productivity of the four regions in the Chinese construction industry. The provinces and municipalities of the four regions are described in Figure A1. The abbreviations used in the present study are given in Table AI.

The construction industry from each province or municipality is a DMU in our research. The results of the four regions take the form of weighted mean values resulting from the scores of each DMU in the region. The weighting factor is the total output value divided by the sum of the total output value of each region. Because the total output value represents comprehensive ability and relative importance for an industry or area, many studies (e.g. Voigt *et al.*, 2014) have used it as a weighted factor. Besides, if the profit of a DMU were negative, the scores for the whole system and for the second stage would be regarded as zero for this DMU. There are some useful methods for dealing with negative data in DEA; the interested reader can refer to Pastor and Ruiz (2007). This particular approach has been chosen in our study because few DMUs have negative values and it is impracticable in a practical construction process to replace data.

Raw data of inputs, intermediate product and output are directly drawn from the *China Statistical Yearbooks*, which are published annually by the National Bureau of Statistics of China (NBSC, 2014), and are available online (www.stats.gov.cn/english/Statisticaldata/AnnualData). The data were collected in April 2016. The summary statistics for all factors are described in Table II. The data of labour input are "Number of staff and workers in the construction enterprises by registration status and region". The data of capital input are "Assets of construction enterprises by region". The technology input of "Total power of machinery and equipment owned" is selected from "Number and power of machinery and equipment owned by construction enterprises". The data of the intermediate product are "Value added of construction by region". The data of final output are "Total profits of construction enterprises by registration status and region". According to Table II, large gaps among the DMUs are observed in relation to all variables, especially the variables of gross value added and total profit (without considering negative values).

Measurement of China's provincial construction industries

There are 31 DMUs due to 31 provinces and 18 research time periods in the case of the Chinese construction industry. All mathematical operations have been implemented in Microsoft Excel worksheets. The three models under the conditions of CRS and VRS were individually solved using MS Excel Solver, which is an add-in to the Excel programme. First, according to the models of Table I under the VRS condition, the annual results of OPTE, PTE-1 and PTE-2 are obtained for each DMU. Second, utilising the models under the CRS condition, overall performance (OP), construction efficiency (CE) and effectiveness (Ef) are obtained. Third, the OSE, SE-1 and SE-2 are calculated based on these indicators using the efficiency decomposition approach. Finally, the annual figures for overall performance, construction efficiency, effectiveness, OPTE, PTE-1, PTE-2, OSE, SE-1 and SE-2 in four regions in China are calculated from each DMU in this region on a weighted average basis.

Here, an example of the China's provincial construction industry is given. The scores for all indicators in Beijing's construction industry are provided in Table III. PTE-1 in Beijing holds steady at 1.00 during all time periods, which implies that Beijing is always situated in each frontier of each construction production set under VRS in the first stage. Therefore, Beijing is a benchmark in terms of construction technology for the Chinese construction industry. However, Beijing demonstrates lower overall performance in several periods because of little profit. The other indicators for Beijing are also sometimes equal to 1.00. In contrast, the results for the regions and the whole industry cannot equal 1.00 because of the weighted average values of the indicators. Detailed discussions of all other provincial construction industries are omitted due to limited space and the research aims. Annual results for the regions and the whole construction industry are compared and discussed in depth.

Table II. Descriptive statistics of the Chinese construction industry

Variable	Unit	Mean	SD	Min.	Max.
Total assets	CNY million	151,983	221,126	456	1,628,124
Number of staff and workers	Thousand persons	940	1,077	10	7,872
Total power machinery and equipment owned	KW thousand	4,875	5,481	60	53,901
Gross value added	CNY million	36,080	61,596	139	590,754
Total profits	CNY million	6,167	10,981	2	98,044
Total output value	CNY million	177,017	289,678	358	2,459,293

Year	OP	OPTE	OSE	CE	PTE-1	SE-1	Ef	PTE-2	SE-2
1995	0.71	0.71	1.00	1.00	1.00	1.00	0.71	0.71	1.00
1996	0.69	0.78	0.89	0.89	1.00	0.89	0.78	0.78	1.00
1997	0.46	0.75	0.61	0.91	0.98	0.93	0.50	0.77	0.66
1998	0.63	0.78	0.81	0.98	1.00	0.98	0.65	0.78	0.83
1999	0.61	0.77	0.79	1.00	1.00	1.00	0.61	0.77	0.79
2000	0.52	0.76	0.68	0.95	1.00	0.95	0.55	0.76	0.71
2001	0.32	0.69	0.46	1.00	1.00	1.00	0.32	0.69	0.46
2002	0.55	0.94	0.59	0.90	1.00	0.90	0.61	0.94	0.65
2003	0.54	0.81	0.67	1.00	1.00	1.00	0.54	0.81	0.67
2004	0.54	0.81	0.67	1.00	1.00	1.00	0.54	0.81	0.67
2005	0.74	0.97	0.77	1.00	1.00	1.00	0.74	0.97	0.77
2006	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	0.66	1.00	0.66	1.00	1.00	1.00	0.66	1.00	0.66
2008	0.48	0.55	0.87	1.00	1.00	1.00	0.48	0.55	0.87
2009	0.74	1.00	0.74	1.00	1.00	1.00	0.74	1.00	0.74
2010	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table III. An example of results of all indicators for Beijing

A significant fact to note is that calculated figures between different years cannot be directly compared with each other in the contemporaneous technology of DEA. For instance, the overall performance of Beijing was 0.71 and 0.69 in 1995 and 1996, respectively, which does not show that the actual performance in 1996 was worse than in 1995. Here, the scores for Beijing merely indicate that the efficiency distance between Beijing and the frontier of the production technology set increased from 1995 to 1996. In other words, the relative performance of Beijing declined from 1995 to 1996, compared with other provincial construction industries.

Measurement of construction industries for four regions

Overall performance, OPTE and OSE for the construction industry in China are computed via Model 1 under CRS and VRS conditions and the efficiency decomposition approach, and displayed in Table IV. The construction industry in the eastern region attained better overall performance than any other region in all research periods. In 1997–2004, the western region demonstrated the second-best performance, which could have resulted from the stated strategy of the western region development programme (Xue *et al.*, 2008). From 2005 to 2014, the Northeast region developed the second-best performance, which could be due to the stated strategy of revitalizing the old industrial base of Northeast China. The national economic context strongly affects construction company performance (Horta *et al.*, 2012). The construction industry can benefit from heavy investment, tax preference and policy support of the stated development strategy in China. In 1997 and 1998, the profits of most provinces in the Northeast region were negative, which led to the lowest performance for this region. The middleland region did not attain a rapid increase in overall performance, but showed a stable and excellent score for average value. OPTE demonstrates similar trends to overall performance in the four regions, where the eastern region was the leading region and the other three regions illustrated approximate achievements. However, the eastern region lagged behind the other regions in the OSE factor, although there were no large gaps among them.

Table V illustrates the construction efficiency and its decomposition components calculated via Model 2 under CRS and VRS conditions and the efficiency decomposition method.

Table IV.
Overall performances and decompositions

Year	OP E	OP NE	OP M	OP W	OPTE E	OPTE NE	OPTE M	OPTE W	OSE E	OSE NE	OSE M	OSE W
1995	0.60	0.05	0.27	0.11	0.63	0.20	0.19	0.22	0.95	0.90	0.77	0.70
1996	0.71	0.14	0.37	0.17	0.86	0.14	0.37	0.28	0.85	0.83	0.89	0.61
1997	0.41	0.01	0.12	0.16	0.77	0.01	0.16	0.23	0.54	0.16	0.57	0.57
1998	0.56	0.02	0.14	0.22	0.78	0.03	0.15	0.25	0.72	0.20	0.73	0.64
1999	0.50	0.12	0.18	0.26	0.73	0.14	0.19	0.30	0.69	0.84	0.81	0.87
2000	0.42	0.18	0.16	0.22	0.73	0.25	0.20	0.29	0.59	0.74	0.71	0.73
2001	0.30	0.19	0.15	0.15	0.75	0.41	0.31	0.31	0.40	0.47	0.48	0.46
2002	0.41	0.19	0.20	0.20	0.77	0.31	0.32	0.32	0.53	0.63	0.64	0.61
2003	0.40	0.18	0.19	0.22	0.80	0.27	0.29	0.35	0.51	0.65	0.65	0.62
2004	0.45	0.21	0.21	0.27	0.76	0.30	0.29	0.38	0.60	0.71	0.73	0.71
2005	0.45	0.31	0.25	0.23	0.83	0.45	0.34	0.33	0.55	0.72	0.73	0.71
2006	0.48	0.28	0.25	0.24	0.82	0.35	0.30	0.27	0.60	0.86	0.86	0.88
2007	0.36	0.25	0.23	0.21	0.82	0.43	0.41	0.33	0.45	0.61	0.56	0.62
2008	0.53	0.51	0.43	0.38	0.78	0.61	0.56	0.46	0.69	0.83	0.77	0.83
2009	0.35	0.28	0.22	0.22	0.78	0.48	0.43	0.37	0.45	0.60	0.53	0.62
2010	0.49	0.38	0.33	0.34	0.80	0.54	0.50	0.40	0.63	0.75	0.71	0.85
2011	0.58	0.62	0.48	0.46	0.85	0.76	0.61	0.54	0.70	0.83	0.82	0.87
2012	0.55	0.48	0.45	0.42	0.81	0.64	0.61	0.50	0.70	0.79	0.77	0.86
2013	0.41	0.40	0.38	0.34	0.77	0.59	0.58	0.43	0.56	0.71	0.69	0.82
2014	0.44	0.39	0.39	0.35	0.76	0.50	0.55	0.40	0.61	0.78	0.75	0.87
Mean	0.47	0.26	0.27	0.26	0.78	0.37	0.37	0.35	0.62	0.68	0.71	0.72

Table V.
Construction efficiencies and decompositions

Year	CE E	CE NE	CE M	CE W	PTE-1 E	PTE-1 NE	PTE-1 M	PTE-1 W	SE-1 E	SE-1 NE	SE-1 M	SE-1 W
1995	0.93	0.85	0.90	0.75	0.98	0.95	0.92	0.77	0.95	0.90	0.97	0.82
1996	0.91	0.82	0.90	0.73	0.97	0.82	0.91	0.74	0.94	1.00	0.99	0.83
1997	0.90	0.80	0.82	0.89	0.96	0.80	0.83	0.90	0.93	1.00	0.99	0.99
1998	0.89	0.76	0.81	0.89	0.96	0.79	0.82	0.91	0.93	0.95	0.98	0.98
1999	0.89	0.79	0.79	0.86	0.95	0.80	0.79	0.89	0.94	0.99	0.99	0.97
2000	0.86	0.80	0.77	0.84	0.94	0.81	0.78	0.85	0.92	0.99	0.99	0.99
2001	0.87	0.80	0.74	0.77	0.94	0.81	0.75	0.78	0.93	0.99	0.99	0.99
2002	0.81	0.73	0.65	0.70	0.91	0.73	0.65	0.71	0.90	1.00	0.99	0.99
2003	0.84	0.71	0.64	0.67	0.92	0.71	0.65	0.68	0.92	1.00	0.98	0.98
2004	0.86	0.77	0.75	0.69	0.92	0.79	0.77	0.71	0.94	0.97	0.97	0.97
2005	0.86	0.82	0.70	0.64	0.92	0.82	0.71	0.65	0.93	1.00	0.99	0.98
2006	0.85	0.83	0.72	0.66	0.91	0.84	0.74	0.68	0.92	0.99	0.98	0.98
2007	0.85	0.85	0.71	0.69	0.91	0.86	0.73	0.71	0.93	1.00	0.98	0.98
2008	0.89	0.95	0.76	0.75	0.95	0.97	0.79	0.77	0.93	0.98	0.96	0.97
2009	0.84	0.92	0.68	0.70	0.94	0.99	0.75	0.76	0.90	0.93	0.91	0.93
2010	0.79	0.85	0.65	0.73	0.93	1.00	0.76	0.77	0.85	0.85	0.86	0.94
2011	0.83	0.83	0.72	0.73	0.93	0.93	0.80	0.77	0.88	0.90	0.90	0.95
2012	0.81	0.76	0.66	0.69	0.93	0.85	0.75	0.73	0.86	0.90	0.89	0.95
2013	0.84	0.78	0.76	0.75	0.96	0.87	0.83	0.81	0.88	0.91	0.92	0.92
2014	0.90	0.70	0.76	0.76	0.96	0.80	0.85	0.79	0.93	0.88	0.89	0.96
Mean	0.86	0.81	0.74	0.74	0.94	0.85	0.78	0.77	0.92	0.96	0.96	0.95

The results from Table V show better scores and fewer gaps than the results from Table IV. This illustrates that construction efficiency in the Chinese construction industry attained balanced and effective results in the research periods. The eastern region was the leading region in terms of construction efficiency and PTE-1 in the periods 1995–2007 and 2012–2014, whereas the northeast region achieved the highest scores in 2008–2011. The northeast region was also the second-most productive region from the average values for construction efficiency and PTE-1. Advanced construction technologies can promote the improvement of construction efficiency. A suitable example is the Liaoning province in the northeast region, which assisted large construction enterprises to build research and development (R&D) Centres and subsidised construction enterprises to replace construction equipment. The middleland and western regions demonstrated lower achievements because of worsening in PTE-1. In addition, the figures for scale efficiency in all regions are approximate. Heavy real estate investments resulted in a dramatic expansion of construction demands in China (Li *et al.* 2013); this can lead to increases in construction projects and scale merit.

Effectiveness and its decompositions for the Chinese construction industry have been obtained using Model 3 under CRS and VRS conditions and the efficiency decomposition method, as shown in Table VI. The eastern region displays top scores among all regions for effectiveness in the research periods. That is mostly due to an outstanding enhancement of PTE-2, which embodies advanced enterprise management technologies in the eastern region. However, regarding SE-2, the eastern region was slightly less efficient than the other regions. Therefore, the eastern region needs to concern itself with issues of enterprise scale, such as overstaffing, bureaucratic organisation and inefficient operation. The western, middleland and northeast regions demonstrate similar results in three indicators: effectiveness, PTE-2 and SE-2. The three regions display gradual increases in terms of PTE-2 and effectiveness. However, there are still marked gaps between these regions and the eastern region, as evidenced in the results for PTE-2 and effectiveness. Therefore, the construction industries in these three regions need to determine ways to enhance their enterprise management abilities, for instance, by introducing knowledgeable administrators, communicating with advanced businesses and adopting modern enterprise management systems.

	Ef				PTE-2				SE-2			
Year	E	NE	M	W	E	NE	M	W	E	NE	M	W
1995	0.64	0.21	0.19	0.13	0.64	0.21	0.19	0.13	1.00	1.00	0.80	0.72
1996	0.78	0.17	0.39	0.19	0.84	0.17	0.39	0.19	0.93	0.84	0.90	0.62
1997	0.45	0.01	0.14	0.17	0.79	0.01	0.19	0.24	0.58	0.16	0.57	0.58
1998	0.62	0.03	0.17	0.24	0.80	0.03	0.18	0.26	0.78	0.21	0.74	0.65
1999	0.55	0.15	0.22	0.29	0.75	0.17	0.23	0.32	0.74	0.90	0.84	0.89
2000	0.48	0.23	0.20	0.26	0.75	0.29	0.24	0.33	0.65	0.79	0.74	0.75
2001	0.34	0.24	0.20	0.19	0.79	0.49	0.39	0.38	0.43	0.48	0.51	0.48
2002	0.49	0.27	0.31	0.29	0.83	0.40	0.46	0.44	0.59	0.67	0.69	0.63
2003	0.47	0.24	0.28	0.32	0.84	0.36	0.42	0.47	0.57	0.68	0.68	0.68
2004	0.52	0.27	0.29	0.38	0.81	0.36	0.37	0.50	0.65	0.76	0.77	0.76
2005	0.52	0.33	0.35	0.37	0.88	0.48	0.46	0.47	0.60	0.73	0.77	0.78
2006	0.55	0.32	0.35	0.35	0.86	0.38	0.35	0.36	0.68	0.86	0.99	0.96
2007	0.42	0.27	0.32	0.30	0.86	0.47	0.51	0.45	0.50	0.61	0.63	0.66
2008	0.60	0.54	0.56	0.51	0.81	0.63	0.67	0.58	0.75	0.85	0.84	0.88
2009	0.41	0.30	0.32	0.31	0.81	0.48	0.49	0.44	0.52	0.65	0.66	0.71
2010	0.62	0.46	0.52	0.46	0.84	0.54	0.58	0.49	0.75	0.87	0.90	0.94
2011	0.71	0.74	0.67	0.63	0.89	0.81	0.71	0.66	0.80	0.91	0.95	0.95
2012	0.68	0.63	0.69	0.61	0.85	0.73	0.75	0.65	0.81	0.89	0.93	0.95
2013	0.49	0.51	0.50	0.45	0.80	0.67	0.69	0.53	0.62	0.78	0.75	0.88
2014	0.50	0.55	0.52	0.46	0.78	0.62	0.64	0.51	0.65	0.88	0.83	0.91
Mean	0.54	0.32	0.36	0.35	0.81	0.42	0.45	0.42	0.68	0.73	0.77	0.77

Table VI. Effectiveness factors and decompositions

Measurement of the entire construction industry in China

Figure 2 indicates the average values of all measurement indicators for the whole Chinese construction industry during 1995–2014. Each value is the weighted mean value of all DMUs, where the weighting factor is the total output value of a DMU divided by the sum of the total output value of the whole industry. The results for SE-1 are the highest scores. The OSE and SE-2 also show better results than other indicators in their respective groups. Since the implementation of "open-door" policies in China, total investment in fixed assets has increased rapidly across the whole country. For instance, the total investment in fixed assets rose more than 26 times in the research periods, from 2002bn Chinese Yuan (CNY) in 1995 to 37,469bn CNY in 2014 (NBSC, 2014), without considering the time-value of capital. The dramatic expansion of the total investment in fixed assets enhanced construction demand. Furthermore, according to strict construction regulations in China, projects of different types and sizes must be built by construction companies with appropriate certification levels that mainly correspond to the size of the company. As a result, the construction market can be divided in an orderly way in China, which tends to benefit scale efficiencies for the whole industry.

According to Figure 2, construction efficiency indicators for the first stage demonstrate higher scores and smaller fluctuations in the research periods when compared to the other indicators. Consequently, the criticised underperformance of the Chinese construction industry is mainly related to the low effectiveness of the second stage, which is converse to that of the Australian construction industry (Hu and Liu, 2016b). Li *et al.* (2013) described how Chinese contractors need to enhance their financial ability and managerial capability in contrast with Hong Kong's contractors. Furthermore, the indicators for overall performance, effectiveness, OPTE and PTE-2 all increase gradually in the research periods. Since China joined the World Trade Organisation in 2001, the construction industry has adopted many reform measures. State-owned enterprise reform is one of the most important of these measures. Previous studies (Lu *et al.*, 2008) indicated that most state-owned construction companies which had been founded on the planned-economy system were overstaffed and not competent in marketing, and companies needed to structure an efficient organisation and develop a modern enterprise system. In 2005, the Chinese Government published policies for accelerating construction reform and development in order to promote ownership reformation, innovation ability, industrial structure, international competition and the construction market. These reforms may lead to commercial and competitive growth, and promote the enhancement of effectiveness and overall performance for the whole industry.

Table VII indicates correlation coefficients among all indicators for the whole construction industry, where the table primarily describes two groups of significant correlation coefficients

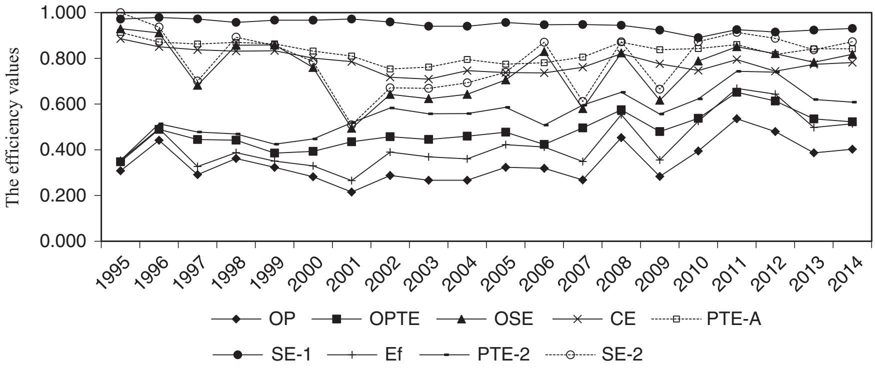

Figure 2.
Developments of all indicators in the whole Chinese construction industry

among them. The first group is that the indicators for overall performance, construction efficiency and effectiveness are all strongly correlated with their respective pure technical efficiency and not correlated with their scale efficiency. Many studies have addressed the importance of technologies as organisational competitive resources, e.g. Hampson and Tatum (1997). However, the more that advanced technologies are purchased or imported in the Chinese construction industry, the less they are utilised and operated fully and capably (Li *et al.*, 2013). As a result, overall performance and pure technical efficiency are barely satisfactory in the construction industry. Moreover, the size and history of construction companies are not foundations for achieving competitive advantage in the Chinese construction industry (Lu *et al.*, 2008). Li *et al.* (2013) also linked this idea that the scale of construction firms is not a determinant for contractors' efficiency, although the Chinese construction market has expanded rapidly. Consequently, construction companies can operate and improve pure technical abilities so as to enhance their overall performances. The second group with strong correlations is the indicators between the whole system and the second stage. The correlation coefficients for overall performance and effectiveness, OPTE and PTE-2, the OSE and SE-2 are 0.93, 0.96 and 0.94, respectively. Previous scholars have shown that taking advantage of firm resources adequately is important for performance development (Barney, 1991). Saving human resource costs and management expenses by taking advantage of firm resources clearly improves company profitability, and then benefits overall performance in the allocation of gross value added. The above two groups with significant correlations can also be obtained from Figure 2.

Furthermore, the variations of all indicators are measured in order to clearly illustrate regional imbalances and differences for the Chinese construction industry. Figure 3

	OP	OPTE	OSE	CE	PTE-1	SE-1	Ef	PTE-2	SE-2
OP	1.00	0.85	0.19	0.49	0.56	–0.11	0.93	0.79	0.25
OPTE		1.00	–0.30	0.38	0.60	–0.38	0.83	0.96	–0.17
OSE			1.00	0.19	–0.02	0.40	0.12	–0.35	0.94
CE				1.00	0.87	0.33	0.19	0.16	0.07
PTE-1					1.00	–0.18	0.36	0.37	0.03
SE-1						1.00	–0.31	–0.38	0.06
Ef							1.00	0.85	0.26
PTE-2								1.00	–0.22
SE-2									1.00

Table VII. Correlation coefficients among all indicators

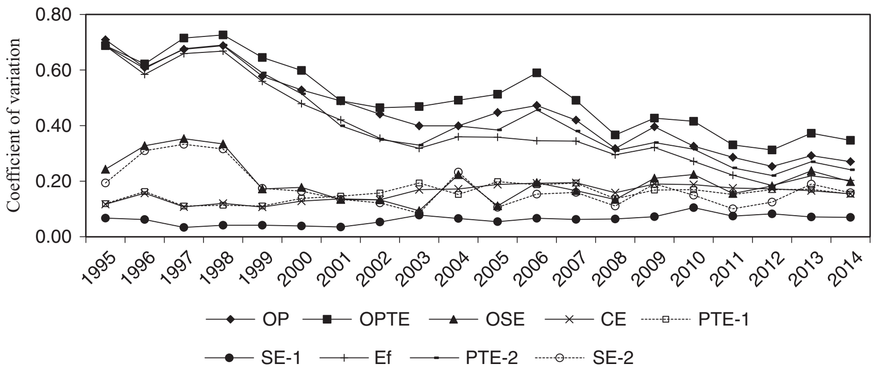

Figure 3. The coefficients of variation of all indicators in the Chinese construction industry

demonstrates the coefficients of variation (CV) for the whole construction industry during 1995–2014. The CV is expressed as the standard deviation of an indicator divided by its mean (Wang *et al.*, 2013). It is mainly employed to measure differences and imbalances in regional development. Larger CV scores of an indicator illustrate more differences among regions in relation to this indicator. According to Figure 3, all indicators for the first stage show slight improving variations. Variations in scale efficiency indicators are not obvious after 1999. The CVs for overall performance, effectiveness, OPTE and PTE-2 demonstrate marked reductions during the research periods, which implies that the differences of the four indicators decreased obviously among all DMUs. Furthermore, the CVs of all indicators approach each other with respect to their trends in the research periods. As a result, the implementation of regional development strategies and deep reforms in the Chinese construction industry can reduce imbalances among provincial construction industries.

All in all, three primary implications can be summarised from this investigation of the Chinese construction industry, which could benefit performance enhancement for other regions and countries. First of all, improving overall performance in the construction industry should not only focus on promoting construction efficiency at the project level, but should also pay more attention to increasing management ability at the company level. From the standpoint of developing profitability in the allocation of gross value added, enhancing enterprise management abilities mainly includes saving labour costs by developing human resource management capability, reducing the depreciation of capital assets by developing construction plant and equipment management capability, and decreasing management costs by developing resource allocation capability. Furthermore, promoting techniques is a significant pathway to enhancing overall performance, including construction technologies and management techniques, and this could be achieved through technological communication among different regions. The Counterpart Support policy and East–West Interaction policy have been implemented for many years in China, and so the coastal eastern regions provide personnel exchanges, and technological and capital supports to the western regions (Lu and Deng, 2013). Therefore, it can be seen that the imbalances among provincial construction industries have been clearly reduced in China. Finally, overall performance of the construction industry is highly influenced by macro development policies. Sustainable development policies, which may include large investment and preferential policies, can narrow performance differences among the regions' construction industries, and ultimately promote overall performance for the whole industry. For instance, the Chinese central government has launched the Great West Development Strategy, the Northeast revival strategy and "the rise of central China" programme, coming with sustained large investment (Chen and Zheng, 2008), which can develop the overall performance of the construction industry because of the growth of construction scale efficiency.

Conclusion

This study has modelled overall performance and its two dimensions of efficiency and effectiveness, and measured them simultaneously with a relational two-stage DEA approach. A sample of the Chinese construction industries was evaluated. Among the four regions of China, the construction industry of the eastern region demonstrated the best results for overall performance, construction efficiency and effectiveness, whereas the other three regions gained approximate figures for these indicators. The gaps between them were primarily reflected in differences of pure technical efficiency. The Chinese construction industry could promote open markets and enterprise communications among regions in order to narrow technical differences. For the whole construction industry, scale efficiency illustrated the greatest achievements of all indicators, and this was caused by a dramatic increase in the total investment in fixed assets, especially in the real estate industry. Overall performance, construction efficiency and effectiveness were all strongly correlated with pure technical efficiency and not correlated with scale efficiency. The overall performance indicators were better correlated with the effectiveness indicators, which demonstrate the significance of enterprise management for construction industry performance. Furthermore, the inefficiency of the Chinese construction industry was mainly embodied in the indicator of effectiveness. Furthermore, the coefficients of variation became smaller and more well-balanced across the whole industry. Consequently, the whole Chinese construction industry showed healthy development in the activity periods, especially in construction efficiency.

The study primarily contributes to the body of knowledge of construction research in two aspects. First, the method in this study promotes the progress of current DEA research in construction. The relational two-stage DEA method can produce adequate results when measuring efficiencies, because the relationship is considered between the first and second stages. Second, this study provides a pathway for simultaneously measuring performance, efficiency and effectiveness in construction. The relational two-stage DEA model not only provides overall scores for the whole system, but also yields scores in individual stages. The VRS form of the relational two-stage DEA model is proposed so as to investigate pure technical efficiency and scale efficiency. Furthermore, contemporaneous technology and variable with weak disposability have been applied in order to properly use the DEA approach. However, because of the factor of contemporaneous technology, a limitation of this study is that the calculated figures between different years cannot be directly compared with each other. Although DEA has been widely applied to solve construction issues, the relational two-stage DEA model can easily be replicated to investigate the performance of construction projects, organisations or industries. A two-stage DEA, which is a type of network DEA, could be applied to quantify overall performance, to identify internal inefficiency components and to recognise competitive advantages for a complex production system. However, investigating production structures and identifying support data may demand future research in the construction domain. Further work could also apply new methods to microcosmic analyses to attain more detailed results for enhancing overall performance in construction processes.

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(The Appendix follows overleaf.)

Appendix 1

Figure A1.
The provinces and municipalities of four regions in Mainland China

Appendix 2

Abbreviation	Full name descriptions
CE	Construction efficiency
CRS	Constant returns-to-scale
CV	Coefficients of variation
DEA	Data envelopment analysis
DMU	Decision-making unit
E	Eastern region in Mainland China
Ef	Effectiveness
M	Middleland region in Mainland China
NE	Northeast region in Mainland China
OP	Overall performance
OPTE	Overall pure technical efficiency
OSE	Overall scale efficiency
PTE-1	Pure technical efficiency of the first stage
PTE-2	Pure technical efficiency of the second stage
SE-1	Scale efficiency of the first stage
SE-2	Scale efficiency of the second stage
VRS	Variable returns-to-scale
W	Western region in Mainland China

Table AI. Abbreviations

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