A Target-oriented Data Envelopment Analysis for Regional Construction Efficiency Improvement in Mainland China

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Abstract

Construction industry is a significant contributor to China's national economy during the past decades. But as one of the pillar sectors, the development of construction industry is still labor intensive with low productive efficiency. Stagnant performance of construction productivity has been recognized as a main barrier to rapid and sustainable development of construction industry. Productivity remains to be a critical issue perplexing academia and industry for a long period of time, due to the heterogeneous metrics for measurement and improvement. Therefore, it is crucial for policy-makers to estimate the productivity change and have insightful information on regional input and output for further strategic planning and policy fine-tuning. Data envelopment analysis (DEA) is an objective benchmarking methodology for multiple inputs and outputs, which has been employed repeatedly for productivity measurement in construction industry. However, owing to the model restriction, traditional DEA model cannot provide detailed insights into efficient use of different inputs to produce desirable output in the state of full efficiency. With this respect, effective strategies might not be formulated and implemented for further productivity improvement. In context of unbalanced regional development in China, this paper aims to apply an updated DEA model, with integration of Distance friction minimization (DFM) method and target-oriented (TO) approach, to explore regional differences of China's construction industry. The results indicate that the unbalanced performance of regional construction productive efficiency is caused by unreasonable allocation and utilization of critical resources. To improve regional construction efficiency, recommendations are made for policy makings and strategic decisions based on the stepwise projection results of TO-DFM model with target efficiency scores (TES).

Keywords: Construction productivity, Benchmarking analysis, Distance friction minimization (DFM), Target-oriented (TO), Target efficiency score (TES).

1. Introduction

Construction industry is a significant contributor to China's national economy over the past years. As one of the pillar sectors, construction industry acts as a core engine of economic growth, also stabilizes the economy due to its multiple effects for other sectors during economic downturn. The expansion of China's construction industry was driven by intensive and extensive investment, and thus subject to significant variations by development policy and national plan. The massive investment in construction does not always boost economic growth effectively, on the contrary, the exhaustion or shortages of related resources may lead to a short-term contraction of construction development. In addition, inadequate investment for the construction industry can hardly have the desired economic stimulus, given that labor-intensive feature of construction development. The critical issue is whether the resources are used efficiently to maximize construction output. The poor performance of construction productivity has been recognized as a main barrier to the rapid and sustainable development, and further economic growth. There was a radical shift in China's regional development policy, and the emphasis was changed from equity to efficiency. The preferential allocation of resources allowed the coastal regions to 'get rich first', and to some extent resulted in regional disparity. As such, China's construction industry in coastal region has become more developed than inland regions, i.e. western and midland regions. The long-standing and increasing differences not only affect the overall productivity of China's construction industry, but also impede effective resources allocation and utilization in terms of regional development. This is further complicated by large economic volume and migrating population in China. Given that inherent divergences of regional construction performance, it is crucial for policy makers to estimate productivity changes and have insightful information on regional input of resources and construction output for further strategic planning and policy fine-tuning. Nevertheless, there has been very limited research on regional comparison and benchmarking analysis of construction productivity, and the causes of inefficiency and the sources of productivity growth are not clearly identified.

In the past decade, construction industry has played an important role in revitalizing the economy against the sustained pressure of global economic downturn. In response to that, the central government initiated a Four Trillion RMB Fiscal Stimulus Package since late 2008, primarily in terms of large-scale infrastructure construction and construction sector in the domestic market. The high-speed economic growth was partly attributed to enormous expansion in construction industry and stable contributions of related sectors. Huge construction demand for infrastructure and housing lifted the construction industry to a new strategic height, but did not effectively improve the overall productivity of China's construction industry. With the emergence of labor shortage across the entire industry, the problem of construction productivity begins to draw more concerns over recent years, corresponding changes in policies involving appropriate investment in relevant resources are required for productive growth in a new period of development. The formulation of development policies for construction industry varies by time and region with different focal areas. Inland region focus more on the quantitative growth through the establishment of leading construction enterprise with steady amount of construction works in traditional projects. Whereas coastal region encourages competitive contractors exploit external market with their competitive technologies, pursuing for a qualitative growth with large profit margins. Thus, the formulation of appropriate policies for construction development with clear targets is a key to boosting regional development and productivity growth. Productivity is a technical concept which can be simply interpreted as a ratio of output to input, and it does offer further information into industry competitiveness and economic development. The concept of total factor production (TFP) is thereby proposed that takes into account all factors of production, including labor, materials, equipment and others, to measure the level of productivity across the industry in a number of empirical studies.

Xue et al. (2008) applied Data Envelopment Analysis (DEA) to measure the productivity changes of China's construction industry, and found gaps that existed in productivity development level across various regions, exhibiting a ladder-like distribution among different economic areas (Wang et al., 2013). Chancellor and Lu (2016) employed Fare-Primont DEA method to investigate construction productivity across China from 1995 to 2012, and found Eastern China is the most productive region and Northern China is the least. Besides, Li and Liu (2010) used Malmquist productivity index (MPI) (Malmquist,

1953) with a novel decomposition technique to estimate the Australian construction industry TFP during the period of 1990 to 2007, revealing that productivity changes of construction industry vary over time and across the country. A variety of other research work that use MPI to evaluate productivity changes have been also explored among construction enterprises. Wang and Chau (1997) evaluated efficiency performance of construction subsectors in Hong Kong by using DEA model during the period of 1981 to 1994. Hung Chiang et al. (2012) and Li et al. (2013) adopted DEA-MPI to compare the productive efficiency of selected construction contractors between Mainland China and Hong Kong. Similarly, Park et al. (2015) conducted a cross-country analysis of construction productivity between China, Japan and Korea at firm level by using the DEA-MPI method. Horta et al. (2012) extended regional comparison into Europe, Asia and North America based on three main construction activities, i.e. buildings, heavy civil, and special trade. In addition, DEA-based methods have been extensively applied to benchmark other aspects, such as the safety performance of construction contractors (El-Mashaleh et al., 2010), as well as the productivity of construction subcontractors (El-Mashaleh et al., 2001).

DEA is an objective benchmarking methodology for multiple inputs and multiple outputs, which has been employed repeatedly for productivity measurement in the construction industry. It has gained popularity in numerous studies about benchmarking assessment and efficiency evaluation across various fields. However, owing to the model restriction, the traditional DEA model cannot provide detailed insights into efficient uses of different inputs to produce desirable output in the state of full efficiency. Therefore, the strategies might not be optimized for further productivity improvement, based on features of industry development and economic situation. In the context of unbalanced regional development in Mainland China, this paper aims to apply an updated DEA model, with an integration of distance friction minimization (DFM) and target-oriented (TO) approaches, to develop an efficiency measurement for construction industry and explore regional differences of China's construction industry. Besides, TO-DFM model (a combination of DFM and TO approaches) can not only help to have a better understanding of the efficient use of different inputs of resources to obtain the desirable output, but also provide a pathway towards the achievement of target efficiency scores (TES) for stepwise efficiency improvement, finally enhancing the regional performance.

The reminder of this paper is organized as follows. Section 2 introduces the research methods, and compares the models of DEA, DFM and TO-DFM. Then critical indicators used in estimating construction efficiency are presented in section 3. Further, the conventional DEA model is applied to evaluate the performance of productive efficiency in construction industry, and efficiency projection results from DEA and DFM models are compared by province and region. Three provinces are chosen as the representatives from each region for further discussion. Final, recommendations are made for policy makings and strategic decisions based on the stepwise projection results of TO-DFM model.

2. Research Methodology

2.1 Data envelopment analysis (DEA)

DEA is a popular and comprehensive evaluation tool in comparative assessment and benchmarking of the overall performance of complex organizations or research objectives (called Decision Making Units, or DMUs). The measure of 'decision making efficiency' is used in evaluating certain programs, which refers to a collection of DMUs with common inputs and outputs (Charnes et al., 1978) based on the work by Farrell (1957). It has the capability of measuring the relative efficiency of DMUs by establishing a piecewise linear production frontier, projecting the performance of each DMU onto the frontier. The DMUs on the production frontier are efficient in the state of full efficiency, whereas others off the production frontier are inefficient with an efficiency score below 1.0. In principle, there are an infinite number of routes to reach efficient frontier, hence there are many theoretic solutions for an efficient DMU to improve its efficiency. In the standard DEA method, efficiency improvement could be achieved by a uniform reduction in all inputs or increase in all outputs. That might not be the best choice to attain the objectives of input minimization and output maximization. To optimize that scheme of efficiency improvement, a wealth of literature on the integration of DEA model and multiple objective linear programming (MOLP) (Golany, 1988) has emerged. Distance friction minimization

(DFM) model developed by (Suzuki et al., 2010), proves to be one of effective approaches to overcome the inherent challenge and address the critical issue of efficiency improvement.

2.2 Distance friction minimization (DFM) approach

DFM is a non-oriented approach to evaluate efficiency performance without subjective preference on DMUs, and prior information is not necessarily required to make non-radial projection to attain the efficiency frontier by the shortest route (Suzuki et al., 2010). The direction of efficient projection depends on the characteristics of input and output data itself, with a different weight obtained from DEA model for each DMU. Built on the traditional DEA model, DFM approach can simultaneously address input reduction and output augmentation options by using a stepwise Euclidean distance method in the weighted spaces. The aim of distance function is to find an optimal solution that minimizes the sum of input reduction or output augmentation distance, which is incorporated in the improvement friction. The simultaneous treatment of input choices and output choices is an important feature of DFM approach compared with the traditional DEA model. By means of the DFM approach, a novel assessment framework for multi-dimensional performance on efficiency improvement problems can be established for decision making and strategic planning. Suzuki et al. (2010) used the case of European airports to conduct a comparative analysis between DEA model and DFM approach. DFM approach outperformed the conventional DEA model by providing better routes for efficiency improvement. Further, the extended forms of DFM approach were applied to a variety of industries or fields for efficiency measurement and improvement, such as, tourism sector (Suzukia et al., 2007), government finance (Nijkamp and Suzuki, 2009), energy consumption (Suzuki and Nijkamp, 2016), and sustainable city performance (Kourtit et al., 2017).

2.3 Target-oriented (TO) approach

Target-oriented (TO) model is developed within the framework of DFM approach, based on DEA method. The key differences lie in the setting of target efficiency score (TES) for inefficient DMU (Suzuki et al., 2015). Since it is a difficult task for less inefficient DMU to attain the full efficiency in the short run, the TO-DFM model is used to search for an appropriate solution for the stepwise efficiency improvement. TES is set by policy maker, in line with the strategic planning and development situation. The projections of efficiency improvement can be categorized into three types, according to the value of TES. An illustration of TO-DFM model showing the differences of improvement projection with DEA and normal DFM models is depicted in Figure 1.

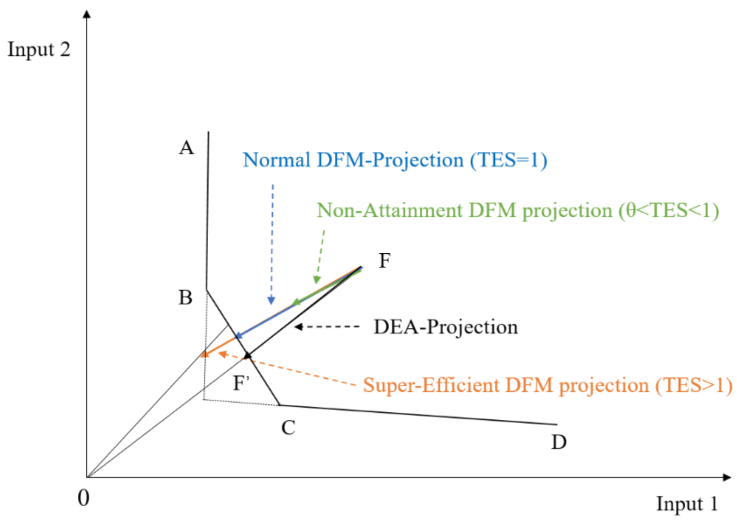

Figure 1 Degree of improvement of DEA, DFM and TO-DFM projections

If the value of TES =1, it equals to normal DFM projection and reaches the efficient frontier; If the value of TES >1, efficient DMUs are identified for super-efficient DFM projection; If the value of $\theta <$ TES <1, it denotes that inefficient DMUs are below the efficiency frontier, named non-attainment DFM projection. This is quite common in real practice, particularly for the less inefficient DMU. In this case, it is more feasible to enhance efficiency step by step. The improvement of efficiency score depends on the TES_0 parameter set by the decision maker. With this regard, a Magnification Parameter (MP_0) serves to adjust input reduction and output increase in the formula of TES_0 in Eq.(1).

$$TES_o = \frac{\theta^* + MP_0(1+\theta^*) \times \dfrac{1}{\left(1+\theta^*\right)}}{1 - MP_0(1-\theta^*) \times \dfrac{1}{\left(1+\theta^*\right)}} \qquad (1)$$

Then, the TES_0 parameter can be calculated by defining the value of MP_0, further TO-DFM model is solved to obtain the optimized distances for input and output data using the formulas within the framework of DFM in Eq. (2-6) (Suzuki et al., 2010).

$$\min Fr^x = \sqrt{\sum_m \left(v_m^* x_{mo} - v_m^* d_{mo}^x\right)^2} \qquad (2)$$

$$\min Fr^y = \sqrt{\sum_s \left(u_s^* y_{so} - u_s^* d_{so}^y\right)^2} \qquad (3)$$

$$s.t. TES_0 = \frac{\sum_s u_s^* \left(y_{so} + d_{so}^y\right)}{\sum_m v_m^* \left(x_{mo} - d_{mo}^x\right)} \qquad (4)$$

$$\sum_m v_m^* \left(x_{mo} - d_{mo}^x\right) = 1 - MP_o\left(1-\theta^*\right) \times \frac{1}{\left(1+\theta^*\right)} \qquad (5)$$

$$\sum_s u_s^* \left(y_{so} + d_{so}^y\right) = \theta^* + MP_o\left(1-\theta^*\right) \times \frac{\theta^*}{\left(1+\theta^*\right)} \qquad (6)$$

$$x_{mo} - d_{mo}^x \geq 0 \qquad (7)$$

$$d_{mo}^x \geq 0 \qquad (8)$$

$$d_{so}^y \geq 0 \qquad (9)$$

3. Data Selection and Source

This study considers the provinces as the basic units (DMUs). There are 31 provincial administrative units in Mainland China, including 4 municipalities, 5 autonomous regions and 22 ordinary provinces. Figure 2 shows the geographical location of these provinces in Mainland China, according to the national administration and economic areas.

Figure 2 Administrative layouts of China across various regions

According to the theory of Solow economic growth (Solow, 1956), there are three basic elements, namely labor, capital and technology inputs in production function, for determining the output at the industry level. Three indicators are accordingly selected as the typical proxies for these elements. The number of employed persons in the construction industry (CE) refers to the total number of persons employed in construction activities, it can well reflect the scale of labor input for the whole industry. The average salary of construction worker (CLW) is an indicator capturing the income level of construction worker. It is a typical proxy to reflect the supply and demand in construction labor market, which also directly or indirectly affects labor cost, labor productivity and other capital inputs in the construction industry. Technical equipment ratio (TER) refers to the value of fixed asset in machinery and equipment owned per capita. This indicator is a technical proxy to measure the application of plants and equipment in the construction industry, also the trend of eliminating manual works and labor savings for increased productivity. Finally, the value added of construction industry (CVA) characterizes the final output of construction production and operation activities.

Based on the review and summary on benchmarking the productive efficiency of the construction industry, the measurement of construction productive efficiency for this study are derived from three input variables: CE, CLW, TER; one output variable is CVA. All these input and output data can be obtained from the China Statistics Yearbook, annually published by the National Bureau of Statistics of China (Statistics, 2017). To ensure the validity of both input and output variables, no multicollinearity problem is found as the coefficients of correlation between dependent variable and independent variables fall within the range between -0.4 and 0.4. From Table 1, significant regional differences of China's construction industry among the provinces are discernible in terms of all the variables. Overall, construction industry in eastern region performs better than that in both midland region and western region in terms of scale effect and technical effect. It is noteworthy that nearly all input data and output data in western region lag far behind that of average level.

Table 1 Descriptive statistics of the China's construction industry at regional level (2016)

Region		All		Eastern		Midland		Western	
Variable	Unit	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CLW	RMB per year	52239	11296	56300	15603	48837	3525	49542	5363
CE	Number of persons	1638078	1844375	2288986	2475849	1910842	674179	796546	845874
TER	RMB per person	13458	6941	14972	9199	12731	4228	12182	4412
CVA	100 million RMB	1602.55	925.31	1867.83	1148.52	1795.28	465.17	1218.81	657.72

4. Results and Discussion

4.1 Comparison of regional efficiency improvement projection results

The regional efficiency evaluation results for China's construction industry across three regions in 2016 is shown in Table 2. Overall, the average efficiency score of China's construction industry is 0.66. But there is a variation with regards to its performance across three regions, their efficiency scores are 0.669, 0.648, and 0.657, from Eastern China to Western China. Notably, eastern region leads the construction development due to the strong performance of coastal areas including the efficient provinces of Jiangsu, Zhejiang, and Shandong. The efficiency score in midland region is lower, but regional construction development is similar among provinces. In contrast, although construction productive efficiency of western region keeps an upward trend over the recent years, construction development is mainly investment-driven for a quantitative growth. The main barriers to the improvement of productive efficiency in the construction industry are totally different among different regions. In terms of that, it is thereby essential to investigate the root causes leading to poor performance of construction efficiency, particularly for those inefficient DMUs in different regions, then make corresponding adjustments for further efficiency improvement through effective resource adjustments.

Table 2 Regional analysis of construction productive efficiency based on DEA model

Eastern	Score	Rank	Midland	Score	Rank	Western	Score	Rank

Beijing	0.366	28	Shanxi	0.408	25	Mongolia	0.747	12
Tianjin	0.265	30				Guangxi	0.927	6
Hebei	0.783	10	Anhui	0.711	16	Chongqing	0.873	8
Liaoning	0.780	11				Sichuan	0.918	7
Jilin	0.476	24	Jiangxi	0.731	14	Guizhou	0.551	20
Heilongjiang	0.512	21				Yunnan	0.791	9
Shanghai	0.379	27	Henan	0.705	17	Tibet	0.734	13
Jiangsu	1.000	1				Shaanxi	1.000	1
Zhejiang	1.000	1	Hubei	0.672	18	Gansu	0.394	26
Fujian	0.928	5				Qinghai	0.185	31
Shandong	1.000	1	Hunan	0.654	19	Ningxia	0.266	29
Guangdong	0.730	15				Xinjiang	0.501	22
Hainan	0.476	23						
Average	0.669	1	Average	0.647	3	Average	0.657	2
ALL				0.660				

The projection results of DEA and DFM models for all inefficient DMUs are presented in the Appendix A. Compared with the traditional DEA model, DFM projection does not incorporate a uniform ratio because it attempts to seek for the shortest distance to the efficient frontier, attaining the objectives of efficient resource allocation and utilization. The scores of inefficient provinces can be effectively improved via reasonable adjustments of basic inputs in accordance with construction development, based on the comparison of DEA and DFM projection results. For instance, the efficiency score for Beijing is 0.3659 according to the DEA model results, indicating that all inputs can be reduced by at least 63.4%, whilst outputs remain unchanged. In contrast, the results of the DFM model show that Beijing is inefficient because of relatively high wages, and slightly excessive investment in construction technical plant and equipment. Clearly, these change ratios in the DFM model are much smaller than those in the DEA model. In addition, the construction value added can thereby be increased by 46.4% based on that optimized combination of inputs, with the full efficiency. In conclusion, the DFM model can provide more efficient and economic solutions than the standard DEA projection for the improvement of construction efficiency.

To compare with the optimal system of full efficiency, a slack ratio, which is the value of input or output divided by the actual value, can either reflect the reduced percentage of inputs or the potential of increased outputs (Hu and Liu, 2017). Furthermore, it could provide better strategies for efficiency improvement of construction industry via the effective resource adjustments. Figure 3 summarizes the average slack ratios for increase in value added of construction industry and reductions in all inputs across the three regions in China. The potential increase in CVA is the largest with 24.1% in western region, followed by 22.1% in midland region and 21.7% in eastern region. This indicates that western region has a significant room for further growth in the coming period, albeit regional construction development lags behind that in midland and eastern regions. On the other hand, more than 15% of CLW and TER input shrinkage with more than 20% of CVA increase potentials reveal a high level of pressure in efficiency improvement for construction industry in China. The average slack ratios for all inputs provide insights into whether inputs are effectively utilized to produce the desirable output in the state of full efficiency. The absolute value of CLW is the largest slack ratio of all for three regions, followed by the slack ratios for TER and CE. This implies that China's construction development is facing pressure of rising labor cost, labor savings by investing construction technical equipment is important for sustaining the construction development.

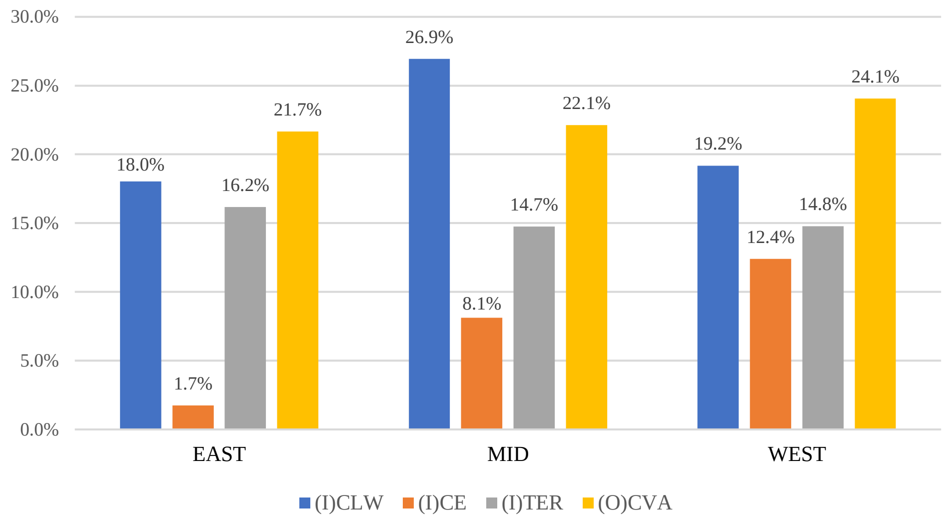

Figure 3 Average slack ratios of potential changes in China's construction industry at regional level

China's construction industry is still labor intensive with heavy reliance on cheap manpower, evidenced by the lowest slack ratio of CE across three regions. With the decreasing labor supplies in construction, raising labor wages to meet the requirements of increasing construction demands exerts more pressure on the management of construction cost and ultimately restricts the growth of construction efficiency. Providing high salaries, which is proved to be a short-term measure to attract additional workers for the construction works, works more effectively in developing midland region with comparative advantages in labor cost and market demand. Secondly, employing more construction equipment technology is significant for the long-term solution to improving construction productivity (Goodrum and Gangwar, 2004). This strategy turns out to be more applicable for the developed eastern region with effective use of construction technical equipment. But in western region, contractors are more inclined to recruiting more cheap workers rather than employing efficient yet expensive construction plants and equipment. Moreover, the strategies improving construction efficiency vary by region and time, but it is a difficult task for those less inefficient provinces to become efficient with a short period of time, especially underdeveloped or developing areas. Under this circumstance, setting a stage-wise target can not only overcome the restriction of critical resources, but also achieve the improvement of construction efficiency in a sustainable approach.

4.2 Stepwise efficiency improvement by TO-DFM model

The provinces with inefficient DMUs, i.e. an efficiency score of less than 1, need further productivity improvement by optimal adjustments of inputs via the TO-DFM model, attaining full efficiency in certain periods of time. TO-DFM model is able to present a more realistic plan for the stepwise improvement of construction productive efficiency. In this regard, three less inefficient provinces are selected from each region in China, i.e. Tianjin from developed eastern region, Jiangxi from developing midland region, and Guangxi from underdeveloped western region. The three selected provinces can epitomize construction development in different areas of different economic performance in China. As a case study, TO-DFM model is applied for the stepwise projection of efficiency improvement for the three selected provinces over next four years from 2017 to 2020.

Based on the results of TO-DFM shown in Table 3, the efficiency score of Tianjin can be gradually improved with a stepwise reduction of CLW, from 17.3% in 2017, 34.5% in 2018, 51.8% in 2019, to 69.1% in 2020. Accordingly, the efficiency score could achieve a steady growth from initial 0.3551, 0.4820, 0.6743, and finally 1.000. Tianjin represents the developed economic area in eastern region with a high population density and limited land for new construction. Given the evolution of industry focus, the contribution of construction industry tends to decrease with a less important role to play in regional economic development. On the other hand, reduced construction works refrain the rapid growth of construction efficiency in a shrinking market. The slow progress of reducing manpower use through the application of construction technology is also a contributing factor to lower construction efficiency, particularly during the transition process of industry upgrade and transformation.

Table 3 Stepwise projection results of TO-DFM model for Tianjin (2017-2020)

2016			2017	2018	2019	2020
DMU	DEA	DFM	TO-DFM	TO-DFM	TO-DFM	TO-DFM
TJ	0.2650	1.0000	0.3551	0.4820	0.6743	1.0000
(I)CLW	-73.50%	-69.1%	-17.3%	-34.5%	-51.8%	-69.1%
(I)CE	-73.50%	0.0%	0.0%	0.0%	0.0%	0.0%
(I)TER	-88.70%	0.0%	0.0%	0.0%	0.0%	0.0%
(O)CVA	0.00%	58.1%	14.5%	29.1%	43.6%	58.1%

As shown in Table 4, the efficiency score of Jiangxi is 0.7305 at the intermediate level of midland region in 2016. The results indicate that input reductions in CE of 6.4% and TER of 1.2% are initially required to attain the TES of 0.7897 in 2017, further reductions in ratios of input increase with an annual efficiency improvement of 0.07 over next few years. Jiangxi represents the developing region in Central China, where the regional gap of construction efficiency is relatively small. Regional construction industry is overall labor intensive rather than with medium level of reliance on construction equipment. Over-reliance on cheap labor is observed, which impedes the improvement of labor skills and labor productivity. In the past many years, cheap labor resources have constituted the foremost driving force for the rapid growth of construction industry. Currently, construction development is in the transition process from labor intensive to technology and equipment driven in the developing region. The dramatic increase of labor wages indicates that construction development can no longer rely on low labor costs. Increasing the production efficiency through advanced construction technology and extensive use of equipment is critical to the competition and sustainable development of regional construction industry.

Table 4 Stepwise projection results of TO-DFM model for Jiangxi (2017-2020)

2016			2017	2018	2019	2020
DMU	DEA	DFM	TO-DFM	TO-DFM	TO-DFM	TO-DFM
JIX	0.7305	1.0000	0.7897	0.8539	0.9237	1.0000
(I)CLW	-51.33%	-42.6%	0.0%	0.0%	0.0%	-42.6%
(I)CE	-26.95%	-17.8%	-6.4%	-10.2%	-14.0%	-17.8%
(I)TER	-26.95%	-13.2%	-1.2%	-5.2%	-9.2%	-13.2%
(O)CVA	0.00%	15.6%	3.9%	7.8%	11.7%	15.6%

According to the TO-DFM results in Table 5, the efficiency score of Guangxi is 0.9271 in 2016, and a stepwise reduction of CE from initial 1.7% to final 6.7% is suggested to become fully efficient in 2020. Owing to the slow economic development in the western areas, regional construction industry is characterized with low efficiency due to the limited construction activities. Besides, population density in western region is quite low and working environment is generally poor, unskilled workers are abundant yet skilled workers are in short supply. It is difficult to attract skilled construction workers from other places even with incentive measures. Although introducing construction equipment technology for labor savings is a viable strategy to reduce labor demand, this requires professional technical support for routine management, control, operation and maintenance, also skilled construction workers for efficient control and management. Therefore, it is recommended to recruit more workers with higher salaries ensuring construction progress, precautious yet steady investment in construction equipment for efficiency improvement based on the needs of construction projects.

Table 5 Stepwise projection results of TO-DFM model for Guangxi (2017-2020)

2016			2017	2018	2019	2020
DMU	DEA	DFM	TO-DFM	TO-DFM	TO-DFM	TO-DFM
GX	0.9271	1.0000	0.9448	0.9628	0.9812	1.0000
(I)CLW	-56.9%	-0.3%	0.0%	0.0%	0.0%	-0.3%
(I)CE	-7.3%	-6.7%	-1.7%	-3.3%	-5.0%	-6.7%
(I)TER	-7.3%	0.0%	0.0%	0.0%	0.0%	0.0%
(O)CVA	0.0%	3.8%	0.9%	1.9%	2.8%	3.8%

5. Conclusion and Implications

To explore the regional differences of construction development and improve the overall performance of construction efficiency, an advanced approach known as DFM, an updated DEA model, is used to measure and analyze the productive efficiency of China's construction industry across the three different geographical regions with different levels of economic development. The results indicate eastern region leads construction development due to the strong performance of coastal areas, regional construction industry is mainly investment-driven for a quantitative growth with lower productive efficiency in midland and western regions. The unbalanced performance of regional construction efficiency is caused by unreasonable resource distribution and utilization. The DFM model can provide more efficient and economic solutions than the standard DEA model, for the improvement of construction productive efficiency with overall consideration of regional development and economic growth. Three inefficient provinces that can epitomize construction development across different areas of economic development are selected from each of different regions, i.e. Tianjin from developed eastern region, Jiangxi from developing midland region, and Guangxi from underdeveloped western region. Considering that it is a difficult task for those low-efficiency provinces to become efficient with a short period of time, TO-DFM model is thereby employed for the stepwise projection of efficiency improvement over the next four years from 2017 to 2020. It can assist with decision making and strategic planning for further improvement of construction efficiency with stage-wise target settings.

For developed region, shirking labor supplies largely restrain the progressive growth of construction efficiency. Raising labor wages to attract construction workers is only a short-term measure. Taking advantage by strong economic development, advancing the process of construction mechanization or modular construction with government incentives can not only address the critical issue, but also promote the steady improvement of construction efficiency during the economic transition. In midland region, construction development is labor intensive with heavy reliance on cheap labor resources, which hinders the improvement of labor quality and construction productivity. Rising labor cost may diminish its comparative advantage in a competitive market, but promote the marketization process of labor wage with clear classification of labor trades and labor skills, enabling the industry to seek new catalyst for a productive growth. In comparison, rich labor resources reduce labor costs for construction industry in western region, providing opportunities for further development with large potential. Since negative industry image and poor working environment reduce the attractiveness for people to join the industry, competitive wages should be provided to retain and recruit construction workers, meanwhile balance the labor supply and demand. As the skill level of construction workers affects the level of construction productivity, therefore training skilled workers is also very important. Besides, more investment in technical plants and equipment is required to improving construction efficiency based on the needs of projects.

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Appendix

Table A Projection results of DEA and DFM models for all inefficient DMUs (2016)

DMU	TOS	DEA	DFM	DMU	TOS	DEA	DFM	DMU	TOS	DEA	DFM
Beijing	IS	0.3659	1	Hainan	NS	0.4762	1	Chongqing	IS	0.8725	1
(I)CLW	89464	-73.00%	-65.70%	(I)CLW	45557	-76.00%	0.00%	(I)CLW	51537	-54.00%	-29.40%
(I)CE	581441	-63.40%	0.00%	(I)CE	74219	-52.40%	0.00%	(I)CE	2090773	-12.70%	0.00%
(I)TER	17494	-63.40%	-54.90%	(I)TER	6170	-52.40%	-37.80%	(I)TER	5801	-12.70%	-8.50%
(O)CVA	1025.5	0.00%	46.40%	(O)CVA	424.5	0.00%	35.50%	(O)CVA	1715.12	0.00%	6.80%
Tianjin	NS	0.265	1	Shanxi	NS	0.4075	1	Sichuan	NS	0.9183	1
(I)CLW	67943	-73.50%	-69.10%	(I)CLW	46632	-59.20%	-54.00%	(I)CLW	48088	-29.00%	0.00%
(I)CE	736372	-73.50%	0.00%	(I)CE	754344	-59.20%	0.00%	(I)CE	2828652	-8.20%	0.00%
(I)TER	41928	-88.70%	0.00%	(I)TER	19473	-74.70%	0.00%	(I)TER	7972	-8.20%	-5.30%
(O)CVA	786.89	0.00%	58.10%	(O)CVA	895.63	0.00%	42.10%	(O)CVA	2472.96	0.00%	4.30%
Hebei	NS	0.7832	1	Anhui	IS	0.7107	1	Guizhou	IS	0.5512	1
(I)CLW	42662	-21.70%	-18.70%	(I)CLW	51399	-47.20%	-38.00%	(I)CLW	53487	-63.50%	-7.10%
(I)CE	1308848	-21.70%	0.00%	(I)CE	1679962	-28.90%	-17.40%	(I)CE	675305	-44.90%	0.00%
(I)TER	13196	-37.10%	0.00%	(I)TER	9104	-28.90%	-16.50%	(I)TER	9089	-44.90%	-40.70%
(O)CVA	1885.27	0.00%	12.20%	(O)CVA	1763.53	0.00%	16.90%	(O)CVA	955.44	0.00%	28.90%
Liaoning	NS	0.7802	1	Jiangxi	IS	0.7305	1	Yunnan	NS	0.7911	1
(I)CLW	43585	-22.00%	-18.60%	(I)CLW	50108	-51.30%	-42.60%	(I)CLW	41945	-20.90%	-17.30%
(I)CE	1261368	-22.00%	0.00%	(I)CE	1525715	-27.00%	-17.80%	(I)CE	1156319	-20.90%	0.00%
(I)TER	10941	-22.40%	0.00%	(I)TER	7913	-27.00%	-13.20%	(I)TER	11454	-27.40%	0.00%
(O)CVA	1880.85	0.00%	12.30%	(O)CVA	1610.91	0.00%	15.60%	(O)CVA	1806.22	0.00%	11.70%
Jilin	NS	0.476	1	Henan	NS	0.7053	1	Tibet	IS	0.734	1
(I)CLW	44968	-52.40%	-43.30%	(I)CLW	44753	-29.50%	0.00%	(I)CLW	59075	-84.80%	-82.50%
(I)CE	570236	-52.40%	0.00%	(I)CE	2609049	-32.30%	0.00%	(I)CE	28397	-26.60%	-15.30%
(I)TER	22815	-75.40%	0.00%	(I)TER	12640	-32.30%	-35.50%	(I)TER	17526	-86.20%	-84.10%
(O)CVA	960.87	0.00%	35.50%	(O)CVA	2292.04	0.00%	17.70%	(O)CVA	342.73	0.00%	15.30%
Heilongjiang	IS	0.5121	1	Hubei	NS	0.6722	1	Gansu	NS	0.3944	1
(I)CLW	39922	-48.80%	-37.50%	(I)CLW	54636	-44.70%	0.00%	(I)CLW	43683	-60.60%	-53.20%
(I)CE	373570	-48.80%	0.00%	(I)CE	2696423	-32.80%	0.00%	(I)CE	565755	-60.60%	0.00%
(I)TER	20243	-73.30%	-64.00%	(I)TER	10175	-32.80%	-23.30%	(I)TER	12753	-64.70%	0.00%
(O)CVA	874.23	0.00%	32.30%	(O)CVA	2192.97	0.00%	19.60%	(O)CVA	776.35	0.00%	43.40%
Shanghai	NS	0.379	1	Hunan	NS	0.6543	1	Qinghai	NS	0.1853	1
(I)CLW	88034	-80.60%	0.00%	(I)CLW	45492	-34.60%	-27.10%	(I)CLW	50431	-81.90%	0.00%
(I)CE	1040183	-62.10%	-17.40%	(I)CE	2199556	-34.60%	-13.50%	(I)CE	114412	-81.50%	-68.70%
(I)TER	11429	-62.10%	-58.80%	(I)TER	17079	-59.00%	0.00%	(I)TER	19548	-87.40%	0.00%
(O)CVA	879.81	0.00%	45.00%	(O)CVA	2016.59	0.00%	20.90%	(O)CVA	348.67	0.00%	68.70%
Fujian	NS	0.9281	1	Mongolia	NS	0.7472	1	Ningxia	IS	0.2658	1
(I)CLW	53557	-37.40%	0.00%	(I)CLW	42968	-25.30%	-16.20%	(I)CLW	46832	-75.80%	-24.10%
(I)CE	3252705	-7.19%	0.00%	(I)CE	297038	-25.30%	0.00%	(I)CE	99345	-73.40%	-58.00%
(I)TER	7361	-7.19%	-4.90%	(I)TER	17377	-50.80%	0.00%	(I)TER	12577	-75.70%	0.00%
(O)CVA	2421.34	0.00%	3.70%	(O)CVA	1322.5	0.00%	14.50%	(O)CVA	434.2	0.00%	58.00%
Guangdong	NS	0.7298	1	Guangxi	IS	0.9271	1	Xinjiang	NS	0.5008	1
(I)CLW	55263	-27.00%	-26.90%	(I)CLW	47079	-56.90%	-0.30%	(I)CLW	58576	-57.00%	0.00%
(I)CE	2285741	-27.00%	0.00%	(I)CE	1200224	-7.30%	-6.70%	(I)CE	384143	-49.90%	0.00%
(I)TER	14811	-34.60%	0.00%	(I)TER	5031	-7.30%	0.00%	(I)TER	13364	-49.90%	-38.50%
(O)CVA	2551.82	0.00%	15.60%	(O)CVA	1458.41	0.00%	3.80%	(O)CVA	1049.93	0.00%	33.30%

Note: Type of slack (TOS), Non-slack projection type (NS), Input-slack projection type (IS).