

# Research on the Production Efficiency of Construction Industry in China's Provinces along the Belt and Road

Xiaofeng Yi

School of Management, Shanghai University, Shanghai 200444, China

**Abstract:** The proposal of the Belt and Road Initiative (BRI) has had a profound impact on the development of the construction industry. Based on the panel data from 2014 to 2020 in 18 China's provinces along the Belt and Road, we combined the data envelopment analysis (DEA) with the Malmquist productivity index (MPI) model to analyze the static production efficiency of the construction industry in these provinces in 2020 and the changes in production efficiency from 2014 to 2020. The results show that the production efficiency of the construction industry in China's provinces along the Belt and Road in 2020 is relatively high, and nearly half of the provinces are effective for DEA. The production efficiency of the construction industry in the provinces along the Belt and Road declined from 2014 to 2020. During the period, the technical level of most provinces improved, while the technical efficiency declined. Finally, some suggestions were put forward based on the results.

**Keywords:** The Belt and Road, Construction Industry, Production Efficiency, DEA Model, Malmquist Productivity Index.

## 1. Introduction

As one of the important pillar industries of the national economy, the construction industry plays an important role in social and economic development, urban and rural construction, and the improvement of people's livelihood [1]. However, with the continuous expansion of the construction industry's scale, a series of problems such as low efficiency of resource allocation, low degree of industrialization, low profit margins, and safety hazards impede the sustainable development of the construction industry [2]. The resources invested in the construction industry may not be effectively utilized. Continuous attention to the production efficiency of the construction industry is of great significance for the sustainable development of the construction industry.

When Chinese President Xi Jinping visited Central Asia and Southeast Asia in 2013, he proposed the strategic concept of building the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road" respectively, namely the major strategic concept of the Belt and Road. The Belt and Road Initiative (BRI) not only promotes national strategic development but also drives the development of all walks of life. It also brings new opportunities to the development of the construction industry, and it has epoch-making strategic significance for China's provinces along the Belt and Road.

At present, many studies on the development of related industries in the countries and regions along the Belt and Road have been carried out, and have put forward valuable policy suggestions for the sustainable development of China and the global economy. Some scholars have carried out relevant research on agriculture [3, 4], manufacturing [5], and other industries in countries along the Belt and Road. In addition, many scholars have studied the development of related industries in China's provinces along the Belt and Road [6-9]. However, few studies focus on the development of the construction industry in China's provinces along the Belt and Road from an input-output perspective. Therefore, it is necessary to explore the temporal and spatial differences in the production efficiency of the construction industry of China's provinces along the Belt and Road and put forward practical suggestions based on the results, contributing to the

sustainable development of the related provinces. The sustainable development of the construction industry in these provinces along the Belt and Road can drive the development of entire China's construction industry and improve the technical level of China's overall construction industry.

## 2. Method

The methods of efficiency measurement mainly include stochastic frontier analysis (SFA) and data envelopment analysis (DEA). As a parametric analysis method, SFA uses a functional form to establish the relationship between inputs and outputs, and applies econometric methods to estimate unknown parameters to identify boundaries [10]. However, SFA cannot deal with multiple outputs, it needs to combine multiple outputs into a comprehensive output. Compared with SFA, DEA is a non-parametric analysis method, which can evaluate the efficiency with multiple inputs and multiple outputs. And it does not need to set a specific functional form ahead. There are two basic DEA models. One is the CCR model, which assumes constant returns to scale (CRS) [11]. The other one is the BCC model, which is under the assumption of variable returns to scale (VRS) [12]. Doubling all inputs bring about doubling all outputs in the CCR model, while doubling all inputs may cause more or less doubling of outputs in the BCC model [13].

Assume that the Nth decision-making unit (DMU) has  $m$  inputs and  $s$  outputs. The CCR model can be defined as Eq. (1):

$$\begin{aligned} \max \theta &= \sum_{r=1}^s u_r y_{rk} \\ \text{s.t.} &\begin{cases} \sum_{r=1}^s u_r y_{rj} - \sum_{i=1}^m v_i x_{ij} \leq 0 \\ \sum_{i=1}^m v_i x_{ik} = 1 \\ u_r \geq 0, v_i \geq 0, r = 1, 2, \dots, s; i = 1, 2, \dots, m; j = 1, 2, \dots, n \end{cases} \end{aligned} \quad (1)$$

where  $y_{rk}$  represents the  $r_{th}$  output of the  $k_{th}$  DMU,  $x_{ik}$  represents the  $i_{th}$  input of the  $k_{th}$  DMU,  $u_r$  represents the  $r_{th}$  weighted output of the  $k_{th}$  DMU, and  $v_i$  represents the  $i_{th}$  weighted input of the  $k_{th}$  DMU.

Similarly, the BCC model can be defined as Eq. (2):

$$\begin{aligned} \max \theta &= \sum_{r=1}^s u_r y_{rk} - \mu_0 \\ \text{s.t.} \quad &\begin{cases} \sum_{r=1}^s u_r y_{rj} - \sum_{i=1}^m v_i x_{ij} - \mu_0 \leq 0 \\ \sum_{i=1}^m v_i x_{ik} = 1 \\ u_r \geq 0, v_i \geq 0, \mu_0 \text{ free,} \\ r = 1, 2, \dots, s; i = 1, 2, \dots, m; j = 1, 2, \dots, n \end{cases} \end{aligned} \quad (2)$$

However, the CCR model and the BCC model can only measure the efficiency of a DMU at a certain moment from a static perspective by using cross-sectional data, and cannot measure the efficiency across different periods from a dynamic perspective. Therefore, the Malmquist productivity index model based on the traditional DEA model was put forward to evaluate the changes in efficiency [14]. The Malmquist productivity index chooses the distance function of different periods to denote the efficiency of different periods. In addition, it can be decomposed into several meaningful indexes, so as to analyze more information and explore the reasons for the changes in efficiency.

The distance function  $D^t(x^t, y^t)$  is defined as the smallest  $x^t$  that can produce  $y^t$ . If  $D^t(x^t, y^t)=1$ , production is on the frontier of technology at period t, which means production is technically efficient. When taking the technology of period t as a reference, the MPI between period t and period t+1 can be shown as Eq. (3):

$$MPI^t = \frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \quad (3)$$

When taking the technology of period t+1 as a reference, the MPI can be defined as Eq. (4):

$$MPI^{t+1} = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \quad (4)$$

The productivity index is usually defined by the geometric mean value of two MPIs in Eq. (3) and Eq. (4), which can be illustrated as:

$$MPI = \left[ \frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \quad (5)$$

$MPI > 1$  means that the productivity has increased from period t to t+1.  $MPI = 1$  means that the productivity has not changed.  $MPI < 1$  means that the productivity has declined.

The MPI is decomposed into two components, technical efficiency change (EC) and technical change (TC), which can further explore the reasons for the changes in efficiency. Eq. (6) represents EC, while Eq. (7) denotes TC. Therefore, Eq. (5) can be further expressed as Eq. (8).

$$EC = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \quad (6)$$

$$TC = \left[ \frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \quad (7)$$

$$MPI = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \left[ \frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \quad (8)$$

EC measures the catch-up effect from period t to period t+1, reflecting changes in management level.  $EC > 1$  means that the technical efficiency has improved.  $EC < 1$  means that the technical efficiency has declined. TC measures the change in the production frontier from period t to period t+1, indicating changes in the technological level.  $TC > 1$  represents the production technology has improved during this period, while  $TC < 1$  indicates the production technology level has declined.

Eqs. (3)-(8) are based on the assumption of CRS, but under the assumption of VRS, EC can be further decomposed into pure technical efficiency change (PEC) and scale efficiency change (SEC). It can be shown as Eq. (9):

$$MPI = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \left[ \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \times \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \right] \left[ \frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \quad (9)$$

$= PEC \times SEC \times TC$

PEC denotes to the changes caused by the improvement of the level of operations and management. When PEC is greater than 1, the pure technical efficiency increases. When PEC is less than 1, the pure technical efficiency declines. SEC reflects the contribution of scale efficiency to productivity improvement. When SEC is greater than 1, the production scale is close to the optimal production scale. When SEC is less than 1, the production scale deviates from the ideal state.

### 3. Empirical Analysis

#### 3.1. Indicator Selection and Data Source

To evaluate the production efficiency of the construction industry, the selection of indicators is very important. The construction industry is still a labor-intensive industry, which requires a large amount of capital and labor. In addition, the construction industry also needs investment in technical equipment. Therefore, we selected the total assets, the number of employees, and the technical equipment rate of construction enterprises in the provinces along the Belt and Road as inputs. In terms of outputs, we chose the total output value of the construction industry and the total profit of construction enterprises as outputs, which reflect the scale, operation efficiency, and economic value of construction production activities.

The data in this study were from the China Construction Industry Statistical Yearbook, and we collected the panel data of inputs and outputs of the construction industry in China's provinces along the Belt and Road from 2014 to 2020.

### 3.2. Static Analysis of Production Efficiency

Combining the CCR model with the BCC model, we calculated the production efficiency of the construction industry in China's provinces along the Belt and Road in 2020

and compared the development of the construction industry in each province from the perspective of comprehensive efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE). The Deap2.1 software was used for calculation. And the results are shown in Table 1.

**Table 1.** Production Efficiency of the Construction Industry in Provinces along the Belt and Road in 2020

Province	TE	PTE	SE	RTS
Fujian	1.000	1.000	1.000	-
Gansu	0.634	0.637	0.996	irs
Guangdong	1.000	1.000	1.000	-
Guangxi	1.000	1.000	1.000	-
Hainan	1.000	1.000	1.000	-
Heilongjiang	0.661	0.681	0.971	irs
Jilin	0.947	0.953	0.994	drs
Liaoning	0.770	0.774	0.995	irs
Inner Mongolia	0.688	0.713	0.965	irs
Ningxia	0.845	0.952	0.888	irs
Qinghai	0.839	1.000	0.839	irs
Shaanxi	0.946	0.964	0.981	drs
Shanghai	1.000	1.000	1.000	-
Xinjiang	0.881	1.000	0.881	irs
Yunnan	0.952	0.967	0.984	irs
Zhejiang	1.000	1.000	1.000	-
Chongqing	1.000	1.000	1.000	-
Tibet	1.000	1.000	1.000	-
mean	0.898	0.925	0.972	

It can be seen from Table 1 that in 2020, the mean values of production efficiency, pure technical efficiency and scale efficiency of the construction industry in the 18 provinces along the Belt and Road are 0.898, 0.925, and 0.972, respectively. It shows that the overall development level of the construction industry in each province is relatively high. Nearly half of the provinces are effective for DEA, but the production efficiency value of some provinces is lower than 0.7, indicating significant differences among provinces. The specific analysis is as follows:

(1) There are eight provinces with effective DEA. In Fujian, Guangdong, Guangxi, Hainan, Shanghai, Zhejiang, Chongqing, and Tibet, the production efficiency and the decomposition indexes of the construction industry are all in the production frontier, and the return to scale remains unchanged. So the production management level, output transformation mechanism, input-output scale, and resource allocation level of the construction industry in these provinces performed well in 2020, they were the reference objects of other provinces.

(2) There are two provinces with weakly effective DEA, including Qinghai and Xinjiang. The pure technical efficiency of the construction industry in the two provinces is 1, while the scale efficiency is less than 1, resulting in the overall noneffective production efficiency. It means that the management level and output transformation mechanism of the two provinces reached the optimal level, but the inappropriate input resources, output scale, and unreasonable resource allocation may be their shortcomings in their construction activities. However, Qinghai and Xinjiang are

both in the condition of increasing returns to scale, indicating that they can improve scale efficiency by increasing construction employees and equipment investment of construction enterprises, expanding investment, optimizing resource allocation, and other measures in future development.

(3) There are eight provinces with invalid DEA. In Gansu, Heilongjiang, Jilin, Liaoning, Inner Mongolia, Ningxia, Shaanxi, and Yunnan, the production efficiency and the decomposition index are all less than 1, and the pure technical efficiency is generally lower than the scale efficiency. Among them, Gansu, Heilongjiang, Liaoning, Inner Mongolia, Ningxia, and Yunnan are in the condition of increasing returns to scale, while Jilin and Shaanxi are in the condition of decreasing returns to scale. The scale efficiency and the pure technical efficiency of the eight provinces performed poorly, they can improve by strengthening the management level of the construction industry, increasing the number of construction workers, increasing the equipment investment of construction enterprises, and optimizing resource allocation.

### 3.3. Dynamic Analysis of Changes in Production Efficiency

In order to further analyze the dynamic changes in the production efficiency of the construction industry in the provinces along the Belt and Road, the Malmquist productivity index model was used to measure the dynamic changes in the production efficiency from 2014 to 2020. The results are shown in Table 2 and Table 3.

**Table 2.** MPI and Corresponding Decomposition of Construction Industry in Provinces along the Belt and Road in 2014-2020

Year	EC	TC	PEC	SEC	MPI
2014-2015	0.997	0.908	0.974	1.023	0.905
2015-2016	1.007	1.040	1.012	0.995	1.048
2016-2017	0.968	1.042	0.962	1.007	1.008
2017-2018	0.998	1.015	1.000	0.998	1.013
2018-2019	1.001	1.008	1.008	0.993	1.009
2019-2020	0.995	1.000	1.008	0.987	0.995
mean	0.994	1.001	0.994	1.000	0.995

According to Table 2, we know that the annual average MPI of the construction industry in the provinces along the Belt and Road is 0.994, indicating that the production efficiency of the construction industry in the provinces decreased by 0.6% annually from 2014 to 2020. According to the specific decomposition results, it can be found that the mean of EC is 0.994, and the mean of TC is 1.001, indicating

that the decrease in technical efficiency led to a decrease in production efficiency. From the perspective of each year, there are fluctuations in EC and TC. According to the decomposition results of EC, the mean of SEC is 1, while the mean of PEC is less than 1, indicating that the reduction of pure technical efficiency resulted in the decrease of technical efficiency.

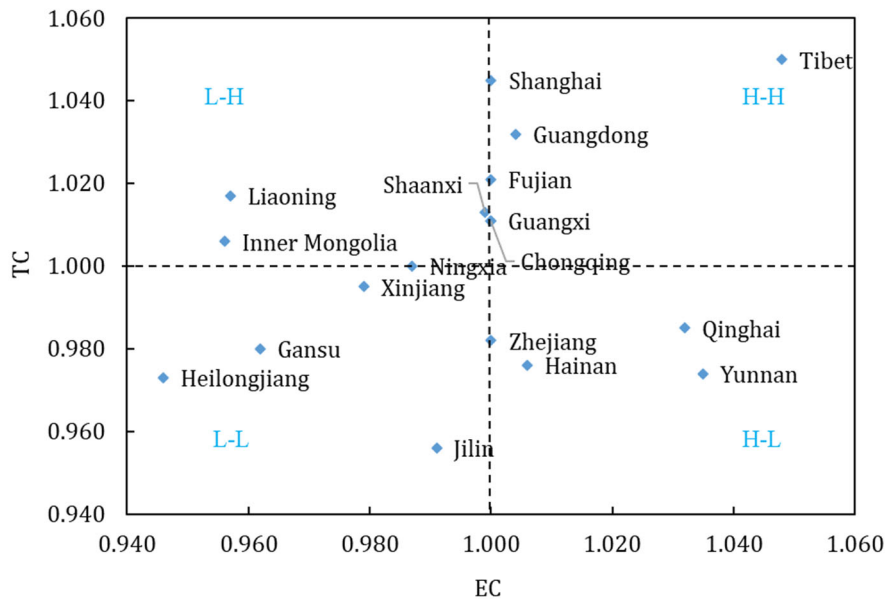
**Table 3.** MPI and Corresponding Decomposition of Each Province of Construction Industry along the Belt and Road in 2014-2020

Province	EC	TC	PEC	SEC	MPI
Fujian	1.000	1.021	1.000	1.000	1.021
Gansu	0.962	0.980	0.962	1.000	0.942
Guangdong	1.004	1.032	1.000	1.004	1.036
Guangxi	1.000	1.011	1.000	1.000	1.011
Hainan	1.006	0.976	1.000	1.006	0.983
Heilongjiang	0.946	0.973	0.951	0.995	0.920
Jilin	0.991	0.956	0.992	0.999	0.947
Liaoning	0.957	1.017	0.958	0.999	0.974
Inner Mongolia	0.956	1.006	0.960	0.995	0.961
Ningxia	0.987	1.000	0.992	0.995	0.987
Qinghai	1.032	0.985	1.051	0.982	1.016
Shaanxi	0.999	1.013	0.998	1.001	1.011
Shanghai	1.000	1.045	1.000	1.000	1.045
Xinjiang	0.979	0.995	1.000	0.979	0.974
Yunnan	1.035	0.974	1.030	1.005	1.008
Zhejiang	1.000	0.982	1.000	1.000	0.982
Chongqing	1.000	1.011	1.000	1.000	1.011
Tibet	1.048	1.050	1.000	1.048	1.101
mean	0.994	1.001	0.994	1.000	0.995

It can be seen from Table 3 that there are nine provinces whose MPIs are greater than 1, including Fujian, Guangdong, Guangxi, Qinghai, Shaanxi, Shanghai, Yunnan, Chongqing, and Tibet. The production efficiency of the construction industry in these provinces improved during the study period. Among them, the values of EC and TC of Guangdong and Tibet are all greater than 1, indicating the management level and technical level of their construction industry improved from 2014 to 2020. The improvement of production efficiency in the construction industry of Qinghai and Yunnan stemmed from the improvement of technical efficiency, indicating that the production management level, output transformation mechanism, input-output scale, and resource allocation of their construction industry performed well. The increase in production efficiency of the construction industry in Fujian, Guangxi, Shaanxi, Shanghai, and Chongqing stemmed from technological progress, indicating that the technological level of their construction industry improved during the study period.

Taking 1 as the boundary, a two-dimensional matrix

diagram is constructed with EC and TC as the horizontal and vertical coordinates. The results are shown in Figure 1. The 18 provinces are divided into 4 types based on EC and TC. The construction industry in L-L type provinces should focus on the improvement of production management level and technical level at the same time. The construction industry in L-H type provinces should focus on improving the production management level. The construction industry in H-L type provinces should focus on its technical level and attach importance to technological innovation. The construction industry in H-H type provinces should continue to maintain the trend of improving technical efficiency and technological progress, so as to steadily promote the continuous improvement of the total factor productivity of the construction industry. Various types of provinces should take corresponding measures to improve the productivity of the construction industry according to their own conditions, so as to promote the sustainable development of the construction industry in the provinces along the Belt and Road.



**Figure 1.** Two-dimensional matrix diagram of EC - TC of the construction industry in the provinces along the Belt and Road in 2014-2020

## 4. Conclusion

This study used the DEA model to measure the production efficiency of the construction industry in the provinces along the Belt and Road in 2020 from a static perspective, and used the Malmquist productivity index model to study the dynamic changes in the production efficiency in 2014-2020 from a dynamic perspective, and analyzed the reasons for the changes. The research conclusions are as follows:

(1) In 2020, the overall production efficiency of the construction industry in the provinces along the Belt and Road is relatively high, and nearly half of the provinces are effective. Specifically, there are eight provinces with valid DEA, two provinces with weak DEA, and eight provinces with invalid DEA.

(2) The construction industry of the provinces along the Belt and Road showed a downward trend from 2014 to 2020. From the perspective of individual provinces, there are nine provinces with an upward trend in the production efficiency of the construction industry. Compared with technical efficiency, the technological progress of most provinces was better, which means the technical level improved more than the management level did.

Therefore, in order to promote the sustainable development of the construction industry in China's provinces along the Belt and Road, the construction industry in each province needs to pay attention to the simultaneous improvement of technical efficiency and technological progress. For the construction industry of the provinces with a lower technological progress index, it is necessary to strengthen the investment in technological innovation and strive to improve the technical level of the construction industry and the quality of employees. For the construction industry of the provinces with lower technical efficiency index, it is necessary to strengthen the improvement of the management level. Construction enterprises in all provinces should seize the opportunity brought by BRI to speed up the promotion of BIM technology, the PPP model, and prefabricated buildings. At the same time increase the allocation rate of machinery, reduce excessive dependence on labor, and effectively promote the construction industry's transformation from

extensive to intensive.

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