Green Total Factor Productivity of China's Construction Industry: Based on the SBM-GML Model

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Abstract
The construction industry plays an important role in China's national economy, and belongs to the industry with high pollution and high energy consumption. It is necessary to calculate the green total factor productivity of construction industry (GTCI). Based on the panel data of 30 provinces in Chinese mainland in 2007-2019, the paper calculates the GTCI and its decomposition indicators by using the SBM-GML model, and examines the dynamic evolution characteristics from two aspects of the whole country and the regions. The results show that: (1) From 2007 to 2019, the GTCI has increased by 4.73%, and in space, it is the highest in the western region. (2) From 2007 to 2019, the growth of GTCI depends both on efficiency and technology. And the contribution of technological progress is greater than efficiency improvement. (3) The whole GTCI under the common frontier is lower than that under the regional frontier, but it is still the highest in the western region.

Keywords*-China; Construction industry; Green total factor productivity; SBM-GML model*

1. INTRODUCTION

China is the largest construction market in the world. According to the statistics in "China Statistical Yearbook", the gross output value of the construction industry in 2019 is 19356.7 billion yuan, accounting for 26.3% of the national GDP. While contributing to China's GDP, the construction industry also has a certain impact on the green quality of China's economic growth [1]. CO_2 emissions increased at an average annual rate of 4.55%. Therefore, this paper measures the GTCI, which is conducive to the sustainable development of the construction industry, while responding to the national call of "Energy Conservation and Emission Reduction".

The existing literature on green total factor productivity focuses on the field of industry and agriculture, and the research on construction industry mostly focuses on total factor productivity. Jonsson (1996) used DEA model to analyze the efficiency of 104 construction projects in Sweden from 1989 to 1992, and put the added value index into the output index, and the cost of staff and equipment into the input index. Through multiple regression analysis, the paper finally puts forward that the degree of efficiency differentiation among enterprises in the construction industry is more obvious [2]. Xue et al. (2002) used DEA method to calculate the efficiency of several selected construction contracting companies, and added some management indicators to make the calculation results more comprehensive and accurate [3]. Li and Liu (2010) took the Australian construction industry as the research object, calculated its efficiency, and explored the influencing factors of efficiency change and the dynamic factors of the whole construction industry reform [4]. Jarkas and Bitar (2012) used DDF method to analyze the scale efficiency and technical efficiency, and found the measures to improve the efficiency [5]. Hu et al. (2017) excluded a productivity measurement method considering construction growth and carbon emission reduction, and used it to measure the development of construction industry in Australia [6]. Jorgenson and Stiroh (2000) believe that economic growth is not the same in different sectors and industries, so it is biased to use aggregate data to describe the overall picture of economic growth. It must be measured from the perspective of different industries, so it is necessary to study the green total factor productivity of construction industry [7].

The innovation of this paper is as follows. Firstly, there is little research on GTCI, and the main body of this

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paper has great innovation. Secondly, this paper uses SBM-GML model to divide 30 provinces into three regions under the common frontier and regional frontier respectively. Thirdly, the sample data selected is from 2007 to 2019, which has a large time span and is the latest available year data. It has strong reference value.

2. METHODOLOGY AND SOURCES OF DATA

2.1.Methodology

Cooper et al. (2004) establish DEA-SBM model considering the environmental factor [8], it can be defined as equation (1):

$$\min \rho = \frac{1-\frac{1}{M}\sum_{m=1}^{M}\frac{s_m^x}{x_{m0}}}{1+\frac{1}{N+I}\left(\sum_{n=1}^{N}\frac{s_n^y}{y_{n0}}+\sum_{i=1}^{I}\frac{s_i^b}{b_{i0}}\right)}$$

$$s.t.\begin{cases}\sum_{k=1}^{K}\theta x_{km}+s_m^x=x_{m0}, m=1,\cdots,M;\ \sum_{k=1}^{K}\theta y_{kn}-s_n^y=y_{n0}, n=1,\cdots,N;\\ \sum_{k=1}^{K}\theta b_{ki}+s_i^b=b_{i0}, i=1,\cdots,I;\ \theta\ge 0; s_m^x\ge 0; s_n^y\ge 0; s_i^b\ge 0\end{cases} \tag{1}$$

The traditional DEA method analyzes total factor productivity from a static point of view. Malmquist index analyze it from a dynamic point of view, but it has some defects in dealing with unexpected output. Therefore, Chung et al. (1997) proposed Malmquist-Luenberger (ML) productivity index, which still produce the problems of relaxation variables [9]. Therefore, this paper chooses Global-Malmquist-Luenberger (GML) productivity index to reasonably evaluate GTCI. The GML index formula is as equation (2):

$$GML_{t-1}^{t}=\sqrt{\frac{1-P_{t-1}\left(x^t,y^t,b^t;y^t,-b^t\right)}{1-P_{t-1}\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}\times\frac{1-P_t\left(x^t,y^t,b^t;y^t,-b^t\right)}{1-P_t\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}}$$

$$=\sqrt{\frac{1-P_{t-1}\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}{1-P_t\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}\times\frac{1-P_{t-1}\left(x^t,y^t,b^t;y^t,-b^t\right)}{1-P_t\left(x^t,y^t,b^t;y^t,-b^t\right)}}$$

$$\times\frac{1-P_t\left(x^t,y^t,b^t;y^t,-b^t\right)}{1-P_{t-1}\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}=TC_{t-1}^{t}\times EC_{t-1}^{t} \tag{2}$$

GML is abbreviated as MI. Under common frontier and group frontier, the GTCI is as follows:

$$mMI_{t-1}^{t}=\sqrt{\frac{1-P_{t-1}^{m}\left(x^t,y^t,b^t;y^t,-b^t\right)}{1-P_{t-1}^{m}\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}\times\frac{1-P_t^{m}\left(x^t,y^t,b^t;y^t,-b^t\right)}{1-P_t^{m}\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}} \tag{3}$$

$$gMI_{t-1}^{t}=\sqrt{\frac{1-P_{t-1}^{g}\left(x^t,y^t,b^t;y^t,-b^t\right)}{1-P_{t-1}^{g}\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}\times\frac{1-P_t^{g}\left(x^t,y^t,b^t;y^t,-b^t\right)}{1-P_t^{g}\left(x^{t-1},y^{t-1},b^{t-1};y^{t-1},-b^{t-1}\right)}} \tag{4}$$

2.2.Sources of data

Based on the existing study, this paper selects six indicators and the details are as follows:

(1) Labor input: The number of employees in the construction industry.

(2) Asset input: Net value of fixed assets.

(3) Equipment input: Expressed by technical equipment rate. The calculation formula is as follows.

$$TER=\frac{NVMQ}{NP} \tag{5}$$

Where the TER represents the technical equipment rate; NVMQ is the net value of mechanical equipment at the end of the period; and NP is the number of people at the end of the report period.

(4) Energy input: Expressed by total energy consumption. The calculation formula is as follows.

$$TEC=\sum_{j=1}^{k}EEC_j\times CCC_j \tag{6}$$

Where the TEC represents the total energy consumption; EEC is the energy consumption of each energy; and CCC is the coal conversion coefficient of each energy.

(5) Expected output: Total output value of construction industry.

(6) Unexpected output: CO2 emission. The calculation formula is as follows.

$$CO_2\ emission=\sum_{j=1}^{k}EEC_j\times ALC_j\times CEC_j\times COR_j\times\frac{44}{12} \tag{7}$$

Where ALC represents the average low calorific value; CEC is the carbon emission coefficient; and COR is carbon oxidation rate.

The research sample is 30 provinces in Chinese mainland from 2007 to 2019 (taking into account the availability of data, Tibet, Hong Kong, Macao and Taiwan are not included). The data are from "China Statistical Yearbook" and "China Energy Statistical Yearbook". The 30 provinces are divided into three regions: the eastern region (Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan); the central region (Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan); the western region (Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, Chongqing).

3. EMPIRICAL ANALYSIS

3.1.Dynamic timely analysis of GTCI

As can be seen from Table 1 and Table 2, no matter under the common frontier or the group frontier, the GTCI of the whole country and all regions in 2007-2019 is higher than 1 in most years, showing a positive growth, and only the values in 2015 and 2018 are less than 1. This shows that GTCI has been growing in the past decade. China's construction industry is changing from extensive growth mode to intensive growth mode under the constraint of low-carbon target.

There are two reasons for the low GTCI in 2015: Firstly, the country's economic development is in the process of deep adjustment, the original development mode driven by real estate and construction industry is fading, the overall increment of construction industry is insufficient, the sales volume is sluggish, and the capital chain is incomplete; Secondly, the industry practitioners failed to transform as soon as possible according to the general trend, such as opening up the rural construction market. In 2017, high-speed rail quality problems, Beijing Daxing "11.18" fire accident, Guangzhou "3.25" high-altitude platform collapse accident and other quality problems occurred frequently. All of these reasons have directly led to the lowest GTCI in 2018.

TABLE 1. GTCI AND ITS DECOMPOSITION INDEX UNDER THE COMMON FRONTIER.

	Nationwide			Eastern Area			Central Area			Western Area		
	MI	EC	TC	MI	EC	TC	MI	EC	TC	MI	EC	TC
2008	1.062	1.006	1.056	1.039	0.993	1.047	1.067	1.011	1.055	1.084	1.015	1.068
2009	1.089	1.010	1.078	1.077	1.009	1.068	1.100	1.008	1.090	1.091	1.012	1.077
2010	1.117	1.018	1.101	1.098	1.019	1.090	1.093	0.997	1.096	1.159	1.036	1.117
2011	1.082	0.992	1.091	1.076	1.005	1.071	1.073	0.981	1.094	1.097	0.989	1.111
2012	1.032	1.021	1.011	1.027	1.005	1.021	1.038	1.032	1.005	1.034	1.028	1.005
2013	1.049	1.000	1.053	1.052	0.975	1.088	1.048	1.010	1.038	1.048	1.019	1.029
2014	1.035	1.008	1.030	1.052	0.993	1.060	1.015	0.994	1.021	1.035	1.037	1.007
2015	0.965	0.977	0.995	0.988	1.015	0.986	0.944	0.957	0.987	0.960	0.953	1.014
2016	1.044	1.006	1.038	1.031	1.000	1.032	1.078	1.027	1.049	1.028	0.994	1.035
2017	1.068	0.937	1.141	1.160	0.994	1.154	1.012	0.912	1.122	1.019	0.896	1.145
2018	0.941	1.184	0.806	0.896	1.049	0.852	0.959	1.199	0.816	0.974	1.318	0.748
2019	1.082	1.027	1.056	1.047	1.044	1.007	1.101	1.024	1.077	1.104	1.011	1.093

TABLE 2. GTCI AND ITS DECOMPOSITION INDEX UNDER THE GROUP FRONTIER.

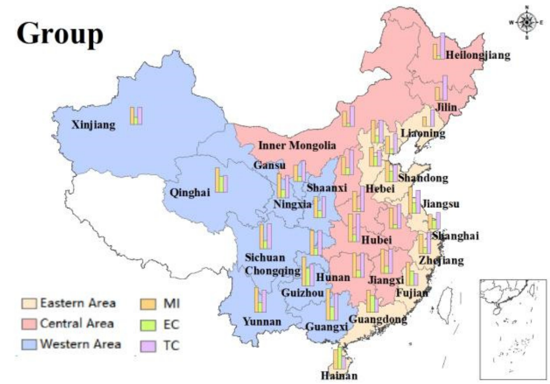
	Nationwide			Eastern Area			Central Area			Western Area		
	MI	EC	TC	MI	EC	TC	MI	EC	TC	MI	EC	TC
2008	1.069	0.991	1.079	1.039	0.993	1.047	1.069	0.993	1.076	1.101	0.987	1.116
2009	1.086	1.018	1.067	1.077	1.009	1.068	1.078	1.024	1.057	1.101	1.024	1.076
2010	1.095	1.007	1.093	1.099	1.019	1.092	1.088	1.013	1.074	1.098	0.989	1.112
2011	1.092	0.992	1.103	1.076	1.005	1.071	1.099	0.966	1.143	1.102	1.002	1.103
2012	1.033	1.024	1.014	1.026	1.005	1.021	1.036	1.003	1.038	1.038	1.064	0.985
2013	1.062	1.008	1.060	1.052	0.975	1.089	1.061	1.021	1.043	1.075	1.034	1.044
2014	1.064	0.987	1.078	1.052	0.993	1.059	1.028	0.989	1.040	1.108	0.980	1.132
2015	0.974	0.984	1.005	0.989	1.015	0.988	0.973	0.961	1.040	0.958	0.969	0.993
2016	1.034	1.005	1.041	1.030	1.000	1.031	1.056	0.994	1.092	1.018	1.022	1.006
2017	1.080	1.002	1.081	1.161	0.994	1.155	1.032	1.000	1.053	1.036	1.011	1.024
2018	0.957	1.012	0.951	0.900	1.050	0.854	0.978	0.937	1.055	1.001	1.039	0.964
2019	1.070	1.031	1.045	1.047	1.081	0.977	1.059	0.996	1.064	1.104	1.009	1.103

3.2.Regional spatial analysis of GTCI

As can be seen from figure 1, the development of GTCI is the best in the western region. It shows that in the past decade, the western region has paid more attention to environmental problems and green development of construction industry, while the central and eastern regions still have the phenomenon of high energy consumption and high carbon dioxide emissions in exchange for economic growth. Under the common frontier, the values of GTCI in eastern, central and western regions are 1.0451, 1.0439 and 1.0526 respectively. And under the regional frontier, they are 1.0457, 1.0465 and 1.0616 respectively. It shows that China's construction industry has paid attention to the control of carbon dioxide emissions and environmental pollution in recent years, and ecological protection has achieved initial results. From the decomposition index, the values of TC in all provinces are greater than 1, showing a positive growth. The values of EC in Liaoning, Shanghai, Tianjin and Zhejiang in the eastern region, Heilongjiang, Jilin and Inner Mongolia in the central region, and Xinjiang in the western region are all less than 1. Therefore, these regions should improve the utilization efficiency of building materials, avoid the waste of resources, and improve the GTCI.

Under the common frontier, the average annual growth rate is 4.73%, in which EC contributes 1.54% and TC contributes 3.82%. Under the regional frontier, the average annual growth rate is 5.12%, in which EC contributes 0.52% and TC contributes 5.13%. This shows that the technological progress of the construction industry has played a leading role in promoting the growth of GTCI. Technological innovation can improve the input-output ratio of construction production to reach the optimal value, thus reducing energy consumption and environmental pollution, so that the total output value of the construction industry can get a greater level of growth. However, there is still a lot of room for the technical efficiency of the construction industry to improve. The growth trend of GTCI is characterized by volatility.

(a)



(b)

Figure 1. GTCI and its decomposition index in three regions.

4. CONCLUSION

Based on SBM-GML model, this paper estimates the GTCI from 2007 to 2019, and draws the following conclusions: (1) Under the common frontier, the GTCI in the eastern, central and western regions of China from 2007 to 2019 are 1.0451, 1.0539 and 1.0526 respectively. Under the regional frontier, they are 1.0457, 1.0465 and 1.0616 respectively. Whether in the common frontier or group frontier, the GTCI in the western region is the highest. (2) Under the common frontier, the values of EC and TC are 1.0154 and 1.0382, respectively, while under the regional frontier, the values of EC and TC are 1.0052 and 1.0513, respectively. The contribution of technological progress is greater than that of efficiency improvement. (3) Under the common frontier, the GTCI increased by 4.73% as a whole, while under the regional frontier, the GTCI increased by 5.12% as a whole. The result of common frontier is lower than that of regional frontier.

According to the above empirical results, there is still considerable room for the development of China's construction industry in the future. Therefore, in order to promote the progress of the construction industry, we must pay attention to improving R&D capital investment, and strengthening technological innovation. The construction industry in the eastern and central regions needs to change the production mode of high energy consumption and high emission, promote the use of low-carbon building materials, and finally make the construction industry in China develop towards the green direction.

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