Research on the Temporal and Spatial Evolution and Driving Factors of Green Total Factor Productivity in the Construction Industry
——Empirical analysis based on the Yangtze River Economic Belt from 2008 to 2017

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Abstract—Promoting the green development of the construction industry is an important measure for China to implement a sustainable strategy. This study is based on the SBM model that considers undesired output, measures the green total factor productivity of the construction industry in 11 provincial administrative regions of the Yangtze River Economic Belt from 2008 to 2017, and further establishes a geographic detector model to explore the driving factors of evolution. The study found that: consider the green total factor productivity of undesired output is always lower than the total factor productivity of which unexpected output is not considered. Among them, the green total factor productivity of the construction industry in Shanghai, Zhejiang and Jiangsu is always 1; the level of economic development is always the driving force during the study period. The key factors in the change of green total factor productivity in the construction industry are not independent of each other. Finally, according to the research results, relevant suggestions for improvement are put forward.

1. INTRODUCTION
As one of China's pillar industries, the construction industry has made significant contributions to the national economy and social development while also consuming large amounts of energy and producing pollution. According to statistics, China's construction industry consumes 40% of the country's resources and emits 36% of carbon dioxide [1]. The Yangtze River Economic Belt is an economic belt with a concentrated population, densely populated cities, the highest level of economic development, and the strongest comprehensive competitiveness. As of 2019, its output value in the construction industry accounts for 57.54% of the total output value of China's construction industry, so it plays a vital role in the process of achieving the carbon emission reduction goal of the construction industry. In November 2018, the Opinions of the Central Committee of the Communist Party of China and the State Council on the Establishment of a More Effective New Mechanism for Coordinated Regional Development clearly stipulated that the Yangtze River Economic Belt should be given full play to its geographical advantages across the three major sectors of East, Middle and West, and promote the coordinated development of the upper, middle and lower reaches of the Yangtze River and the high-quality development of the areas along the Yangtze River led by ecological priority and green development. Therefore, measuring and analyzing the spatial and temporal changes in total factor productivity of the construction industry under
the environmental constraints and further exploring its improvement path will not only help to achieve the high-quality coordinated development goals of the Yangtze River Economic Belt, but also contribute to the implementation of the national sustainable development strategy which plays a driving role.

The research methods related to the production efficiency of the construction industry mainly include three types: labor productivity method, multi-factor productivity method and total factor productivity method. Among them, the labor productivity method and multi-factor productivity method ignore the role of building materials in productivity improvement. Therefore, in the study of the production efficiency of the construction industry, the application range of total factor productivity (TFP, Total Factor Productivity) is more extensive. Many scholars used the total factor productivity method to study the production efficiency of the construction industry very early: Ling Yu et al. [2] based on the CCR model, analyzed the total factor relative productivity of construction enterprises of different economic types in China; Li Baiji [3] et al. using the DEA method, studied the relative production efficiency of the construction industry in various provinces in China, and carried out a comparative analysis. However, in recent years, as environmental problems have become more prominent, China’s construction industry urgently needs to accelerate green transformation. While the economy continues to contribute to GDP, it needs to consider the cost of the environment and incorporate indicators that reflect resources and environmental factors into total factor productivity and include the theoretical framework to improve the Green Total Factor Productivity (GTFP) of the construction industry. At present, there are few literatures on green total factor productivity in the construction industry considering environmental constraints at home and abroad, and existing studies mostly analyze the influencing factors of total factor productivity of the construction industry from the four basic aspects of economic development level, industrial development level, energy consumption structure, and technological innovation level [4-6]. The research methods are also different. Wang Shanshan [7] et al. used the Tobit model to study the influencing factors of total factor efficiency; there are also scholars who build econometric models [8], and use two-stage analysis to analyze the random effect regression [9].

In general, although many achievements have been made in academia, there are still improvements: First, the current research on the total factor productivity of the construction industry is mainly focused on the nationwide scope, and there are few more detailed investigations of the specific characteristics of the region. Second, most domestic research on total factor productivity of the construction industry is based on traditional total factor productivity calculations. In the context of the sustainable development of the international social environment, research on total factor productivity rarely incorporates environmental factors; third, at present, there is a lack of research on the mechanism of green total factor productivity in the construction industry. How to focus on the driving factors of its changes and improve the green total factor productivity in the construction industry is a question worth discussing. Based on this, this paper takes 11 provincial-level administrative regions of the Yangtze River Economic Belt (hereinafter collectively referred to as provinces) as the research objects, uses the SBM model to measure the green total factor productivity of the construction industry that contains undesired output, and analyzes its spatial and temporal evolution characteristics to further establish a geographic detector model to study the driving factors in order to provide a targeted reference for the development strategy and environmental policy of the construction industry in the Yangtze River Economic Belt.

2. PROBLEM ANALYSIS
In order to overcome the shortcomings of the common DEA model in the same radial and single angle, to further comprehensively consider the relationship between input, output, and pollution, and to effectively solve the slack problem, Tone [10] proposed an SBM that considers undesirable output model. \( y \) is recorded, \( s \) the expected output matrix, \( q_1 \) is the number of expected output indicators; \( \alpha \) is the unexplained output, \( \mathrm{tput} \) matrix, \( q_2 \) is the number of undesired output indicators. The SBM model of establishing green total factor productivity with variable returns to scale is shown in equation (1):

\[
\text{SBM} = \frac{g_0 + g_1 \text{tput} + g_2 \text{tput}^2 + ... + g_{q_2} \text{tput}^{q_2}}{s - \alpha}
\]
\[
\min \rho^* = \frac{1 - \left(\frac{1}{m}\right) \sum_{i=1}^{m} \frac{s_i^r}{s_i^{10}}}{1 + \left(\frac{1}{q_1 + q_2}\right) \left(\sum_{r=1}^{q_1} s_r^b y_{r0} + \sum_{r=q_1+1}^{q_2} s_r^b y_{r0}\right)}
\]

(1)

Among them, \(s_r^k\) is the expected output shortage of the decision-making unit to be evaluated, and \(s_r^b\) is the undesired output exceeding standard quantity of the decision-making unit to be evaluated. The range of values \(\rho^*\) is \([0, 1]\). At that time, all of them were 0, and the decision-making unit was valid. When \(\rho^*\) doesn’t equal to 1, \(s^r\), \(s^k\), \(s^b\) not all take 0, not all of decision-making unit were 0. If the decision-making unit was invalid, the input and output needed to be improved.

3. Model Establishment

3.1. Geographic detector model

Geographical detector (Geographical Detector) as a novel statistical method, its main function is to detect and use spatial differentiation and reveal the driving factors behind it. This method has a clear physical meaning and no fixed linear assumption. The basic idea is: assuming that the study is divided into several sub-regions, if the sum of the variances of the sub-regions is smaller than the total variance of the regions, there is spatial differentiation; if the spatial distribution of the two variables tends to be consistent, there is a statistical correlation between the two [11].

The research objects of this paper can be abstracted into 11 point data in 11 provinces of the Yangtze River Economic Belt. Firstly, the 6 numerical driving factor variables are discretized, and the 6 index values are divided into 5 categories from low to high: low (20%), medium low (20%), general (20%), medium high (20%), high (20%) horizontal area, the category of each driving factor index value is determined by this ratio, and then Y and the discretized X distribution are superimposed, so that the dependent variable value(X, Y) of each discrete point are extracted. The geographic detector model is as follows.

3.1.1. Factor explanation.

It mainly detects the degree of explanatory power or spatial differentiation of a certain factor (i.e., driving factor) to the green total factor productivity of the construction industry. The calculation formula is (2):

\[
q_{D,H} = 1 - \frac{1}{n\sigma^2} \sum_{h=1}^{L} n_h \sigma_h^2,
\]

(2)

In the formula(2), \(q_{D,H}\) indicates the explanatory power of the driving factor \(D\) to the green total factor productivity \(H\) of the construction industry, and \(n\) and \(\sigma^2\) is the sample size and variance respectively. \(h = 1, \cdots, L\) is the stratification of variables \(H\) or factors \(D\), and \(n_h\) and \(\sigma_h^2\) is the sample size and variance respectively. \(q_{D,H}\) is the range of values, is \([0, 1]\). The larger the value, the more obvious the spatial differentiation. If the stratification is generated by factors \(X\), the larger the value \(q\), the stronger the explanation for the green total factor productivity of the construction industry. When \(q = 1\), the explanatory factor \(X\) could completely explain the green total factor productivity of the construction industry; when \(q = 0\), the explanatory factor \(X\) had nothing to do with the green total factor productivity of the construction industry.

3.1.2. Interactive detection.

It is used to identify whether the combined effects of factors X1 and X2 will increase or decrease the explanatory power of green total factor productivity in the construction industry, and determine whether there is an interaction between the two factors, as shown in Figure 1.
In addition, the geographic detector can also check the strength, direction, linearity and nonlinearity of the interaction, as shown in Table 1.

**Table 1** Types of interaction between two independent variables and dependent variables

| Criterion                                                                 | Interaction                           |
|---------------------------------------------------------------------------|---------------------------------------|
| Non-linear attenuation                                                    |                                       |
| Single, factor non-linear attenuation                                      |                                       |
| Two-factor enhancement                                                    |                                       |
| $q(X_1 \cap X_2) > q(X_1) + q(X_2)$                                      | Nonlinear enhancement                 |
| $q(X_1 \cap X_2) = q(X_1) + q(X_2)$                                      | Independent                           |

3.2. **Index selection and data processing**

This article selects the construction industry related data of 11 provinces in the Yangtze River Economic Belt from 2008 to 2017. All data are from "China Statistical Yearbook", "China Energy Yearbook", "China Statistical Summary" and "China Science and Technology Statistical Yearbook". In order to exclude the influence of inflation and other factors, the original data was converted into constant price data based on 2008. In addition, for missing and outliers, mathematical methods are used to fill.

3.2.1. **Input-output indicators of SBM model**

With reference to Wang Xueqing et al. [4], Jiang Qianying et al. [12], Feng Bo et al. [13] scholars' selection of total factor productivity evaluation indicators and the characteristics of the construction industry itself, this article defines the input and output variables of the construction industry as follows:

- Input indicators of construction industry. This paper selects "employees in the construction industry" to reflect labor input; "total assets of construction enterprises" reflects capital investment; "technical equipment rate of construction industry" reflects mechanical equipment investment; the "total amount" reflects energy input, which is converted into "10,000 tons of standard coal" and then summed up, and the total energy consumption obtained is used as energy input.
• Expected output. Choose "total output value of construction industry" as an indicator to measure the expected output of the construction industry.
• Unexpected output. The “carbon emissions from construction industry” selected for the main energy consumption accounting of the construction industry reflects undesired output, namely coal, oil, natural gas and electricity. This paper draws on the calculation method of Ding Juan et al. [14], converts the four kinds of energy consumption (physical statistics) into standard coal according to a certain conversion standard, and then multiplies it by the emission coefficient to add up, which is the carbon emissions of the construction industry.

3.2.2. Drivers of green total factor productivity in the construction industry
Referring to Gao Sihui et al. [15] and Xiang Yong et al. [16] scholars' selection of driving factors of total factor productivity in the construction industry, this paper selects economic development level, industrial development level, marketization degree, energy consumption structure, technology level, and technological innovation capability as Driving factors, and establish the definition system consisting of the characteristic variables corresponding to the six driving factors is shown in Table 2.

| Driving factor                      | Characteristic variable                      | Variable definition                                                                 |
|------------------------------------|----------------------------------------------|-------------------------------------------------------------------------------------|
| Economic development level         | GDP per capita in the region                  | GDP per capita (100 million yuan)                                                   |
| Industry development level         | Construction industry development level       | Regional gross output value of construction industry / GDP of the region (%)          |
| Degree of marketization            | Degree of marketization of construction industry | 1-total output value of state-owned enterprises in the construction industry / total output value of the construction industry (%) |
| Energy consumption structure       | Energy consumption structure of construction | consumption industry Energy consumption of construction industry / Total energy consumption of construction industry (%) |
| Technical level                    | Technical level of construction industry     | Total power of self-owned construction machinery and equipment at the end of the year (ten thousand kilowatts) |
| Technology innovation capability   | Technology innovation degree                 | R & D internal expenditure / GDP (%)                                                |

3.3. Research results and analysis

3.3.1. Analysis of the spatiotemporal evolution of green total factor productivity of the construction industry in the Yangtze River Economic Belt
Using MaxDEA software to estimate the green total factor productivity (GTFP, considering undesired output) and total factor productivity (TFP, excluding undesired output) of the construction industry in the Yangtze River Economic Belt, the results are shown in Figure 2.
6

Figure 2. Time evolution of GTFP and TFP in the construction industry of the Yangtze River Economic Belt

From the perspective of time series, the average GTFP and TFP of the construction industry in the Yangtze River Economic Belt from 2008 to 2017 are generally "M" shaped. Both have shown a clear upward trend since 2008 and reached the highest point in 2012, with a mid-low point in 2013, and a slight rebound in the following year, and then slowly declined in 2015, which may be due to the Chinese stock market in 2015 after the crisis, the growth rate of domestic investment dropped significantly, which also had a negative impact on the construction industry [17]. Since then, with the implementation of the "Outline of the Yangtze River Economic Belt Development Plan" in 2016, the environmentally friendly construction industry has received attention and the use of low-carbon and environmentally friendly construction materials has increased. Therefore, GTFP has shown a more obvious upward trend than TFP. Although GTFP and TFP in the construction industry of the Yangtze River Economic Belt in Figure 2 maintain the same trend, when considering the effect of undesired output, GTFP is significantly lower than TFP, indicating that environmental pollution has caused a large degree of loss of production efficiency.

Based on the SBM model considering undesired output, based on the GTFP of 11 provinces in the Yangtze River Economic Belt from 2008 to 2017, the cross-sectional data of 2008, 2011, 2014 and 2017 were selected, and ArcGIS 10.8 software was used to GTFP in the construction industry realizes spatial visualization, and plots the evolutionary distribution of the spatial and temporal pattern as shown in Figure 3.

Figure 3. Spatial distribution of green total factor productivity of the construction industry in the Yangtze River Economic Belt

It can be seen from Figure 3 that the GTFP construction industry in the Yangtze River Economic Zone has significant spatial differences. Throughout the study period, the construction industry GTFP in the upstream areas of Shanghai, Jiangsu, and Zhejiang has been at the highest level and remained stable. The
construction industry GTFP of each of the three is 1 each year, which is a completely effective area. The research conclusions are consistent. This aspect is closely related to the relatively high-efficiency production methods of the construction industry brought about by the higher economic development level and production level of the three provinces. On the other hand, thanks to the leading technology level and advanced carbon emission reduction technology, the undesired output of the construction industry has been reduced, and GTFP has maintained a high level. At the same time, the construction industry's GTFP in Hubei and Jiangxi fluctuated to 1 during the study period, which may be due to the large scale of the construction industry and good economic foundation of the two, which is conducive to promoting the improvement of scientific and technological levels and the construction industry's shift to low-emission development. GTFP in Hunan is "inverted U-shaped", which may be due to the adjustment of its early industrial scale and production factors to promote the development of the construction industry. GTFP can be improved; later due to the rapid heavy construction industry and the reduction of environmental policy implementation, the degree of environmental pollution is increasing seriously, so GTFP declined [18]. In addition, Chongqing, Sichuan, Guizhou, Yunnan and Anhui's GTFP has always been at a low level (below the national average); among them, in Chongqing and Sichuan, although the construction industry is large in scale and the economic development level is high, but excessive energy consumption has caused severe carbon emissions and then excessive economic losses caused by environmental pollution, GTFP has always been at a low level; while Guizhou, Yunnan and Anhui have poor economic foundations, the construction industry has developed relatively backward, and GTFP in the construction industry has not been significantly improved.

3.3.2. Analysis of driving factors for differences in green total factor productivity of the construction industry in the Yangtze River Economic Belt

Based on the previous analysis and the actual situation, this study further established a geographic detector model to detect the 2008-2017 Yangtze River Economic Belt from six aspects: economic development level, industrial development level, marketization degree, energy consumption structure, technology level, and technological innovation capability, which are the driving factors and mechanism of green total factor productivity in construction industry. The value of q measured by geographic detectors is the degree of each factor’s driving interpretation of the green total factor productivity of the construction in industry. The larger the value of q, the greater the driving control of the factor for the construction industry’s green total factor productivity. The detection results are shown in Table 3.

| Detection index                  | q2008 | q2011 | q2014 | q2017 |
|----------------------------------|-------|-------|-------|-------|
| The level of economic development| 0.742*** | 0.667*** | 0.737*** | 0.817*** |
| Industry development level       | 0.732*** | 0.208*** | 0.247*** | 0.220*** |
| Degree of marketization          | 0.601* | 0.375* | 0.357** | 0.425** |
| Energy consumption structure     | 0.601*** | 0.471*** | 0.654*** | 0.220*** |
| Technique level                  | 0.688*** | 0.524*** | 0.484*** | 0.474*** |
Technological innovation capability 0. 407*** 0. 771*** 0. 571*** 0. 737***

Note: ***, **, and * indicate significant at 1%, 5%, and 10% confidence levels respectively

Overall, the economic development level of the Yangtze River Economic Belt during the study period was a key factor in promoting green total factor productivity in the construction industry (the four-year contribution factors were 0. 742, 0. 667, 0. 737, and 0. 817, respectively). The level of economic development is the material basis of all activities. Raising the level of economic development is conducive to the supply of all production factors needed for the development of the construction industry and promotes the increase of the green total factor productivity of the construction industry. This also explains that The GTFP of Shanghai, Jiangsu, Zhejiang's construction industry is higher than that of economically underdeveloped areas.

In 2008, the industry development level (0. 732) was the main factor affecting the green total factor productivity of the construction industry. The more advantageous the construction industry is in terms of talents, technology, capital, and markets, the relatively higher green total factor productivity of the construction industry; in 2011 and 2017, technological innovation capabilities (contribution coefficients were 0. 771 and 0. 737, respectively) became the main driving factors that affect the green total factor productivity of the construction industry. Increased investment in scientific research is more likely to bring about technological innovation and progress and realize the use of low-carbon technologies and promotion, which is conducive to the improvement of green total factor productivity; in 2014, the energy consumption structure (0. 654) significantly promoted the green total factor productivity of the construction industry, possibly because it was passed by experts in 2014 and was called "the strictest environmental protection in history." The new environmental protection law of the "Law" has increased the focus on carbon emissions in various regions and increased the proportion of clean energy consumption, which has had a profound impact on the green total factor productivity of the construction industry during this period.

For the construction industry of the Yangtze River Economic Belt in different stages of development in 2008, 2011, 2014 and 2017, the driving factors of green total factor productivity in the construction industry are not independent of each other, but satisfy the double factor enhancement or nonlinear enhancement.

In 2008 and 2017, the interaction effect of the evolution of green total factor productivity in the construction industry of the Yangtze River Economic Belt ranked first in the synergy combination of the level of economic development and industrial development (interactive explanatory power was 99.9%, 100%). As the economic level improves, the construction market tends to be standardized, and the construction industry is more likely to achieve economies of scale, driving the rational allocation of various production factors, indicating that the level of economic development is closely related to the level of industrial development, and promotes the construction of green factors. Increased productivity; the factor interaction ranked No. 1 in 2011 is technological innovation capability and technical level (0. 931). Technological innovation in the construction industry includes green and environmentally friendly building materials, low-carbon construction technology, etc. The improvement of technological innovation capability is the improvement of technological level which provide support to help achieve low-carbon production and improve the mechanization level of the construction industry, thereby improving the green total factor productivity of the construction industry; the factor interaction ranked first in 2014 was the coordinated combination of economic development level and energy consumption structure (1. 000). It should control energy consumption while developing the economy, especially the current fossil energy Consumption still accounts for the major part, should increase the proportion of clean energy consumption, reduce carbon emissions from the construction industry, in order to improve the green building industry total factor productivity. The interaction force of driving factors should not be underestimated during the spatial and temporal evolution of green total factor productivity in the
construction industry. In the planning process, the interaction of driving factors should be emphasized, and factor matching should be carried out flexibly and reasonably to achieve the improvement of green total factor productivity in the construction industry.

4. MODEL EVALUATION

4.1. Advantages of the model
Based on a comprehensive analysis of the problems to be solved, according to the actual agreement, our model has the following advantages:

- The geographical detector model can check the spatial differentiation of single variables
- By checking the consistency of the spatial distribution of the two variables, the geographic exploration model can detect the possible causal relationship between the two variables.

4.2. Disadvantages of the model
At the same time, our model also has some disadvantages:

- The factors considered in the model are not comprehensive enough, resulting in a certain gap between the results and the actual situation;
- The anti-interference ability of the model is not strong;
- The model cannot avoid uncertainty.

4.3. Model improvement
For the problems in the model, for our model, we consider more factors to improve it. The multi-factor consideration method is indispensable, so we need to explore the influencing factors according to the multi-factor and multi-level.

5. CONCLUSIONS

5.1. Research conclusion
This paper uses the panel data of the Yangtze River Economic Belt from 2008 to 2017, combined with the SBM model that considers undesirable output, to estimate the green total factor productivity of the construction industry in the provinces of the Yangtze River Economic Belt, and analyzes the temporal growth and spatial distribution characteristics of factor productivity of the Yangtze River Economic Belt in the past ten years. Based on the geographic detector model, it explored the characteristics of the driving factors of the spatial and temporal changes of green total factor productivity in the construction industry. The following conclusions can be drawn from this:

First, the GTFP considering undesired output is always lower than the TFP not considering undesired output, indicating that the integration of carbon emissions into the productivity analysis framework is of great significance to the sustainable development of the construction industry. From a time point of view, the average GTFP and TFP of the construction industry in the Yangtze River Economic Belt from 2008 to 2017 are generally "M" shaped. From a spatial perspective, the construction industry's GTFP in Shanghai, Zhejiang, and Jiangsu has always remained at 1, GTFP in Hubei and Jiangxi fluctuated up to 1 during the study period, GTFP in Hunan showed an "inverted U" shape, while Chongqing, Sichuan, and Guizhou The GTFP in Yunnan, Anhui and Anhui have always been lower than the national average and have not shown a significant improvement.

Second, for the driving factors of GTFP in the construction industry of the Yangtze River Economic Belt, except for the marketization degree of 5% or 10% confidence level, the economic development level, industrial development level, energy consumption structure, technology level, and technological innovation capabilities are all in the 1% confidence level, and the level of economic development has always been a key factor in promoting green total factor productivity in the construction industry during the study period. Moreover, the driving explanatory factors are not independent of each other, and have
the interactive effect of double factor enhancement or nonlinear enhancement in the process of driving
the spatial and temporal evolution of green total factor productivity in the construction industry in the
Yangtze River Economic Belt.

5.2. Policy recommendations

Based on the above research conclusions, according to the development trend and geographical
differences of the construction industry in the Yangtze River Economic Belt, combined with the current
sustainable development strategic goals, reasonable policy guidelines should be implemented to increase
the green total factor productivity of the construction industry in the Yangtze River Economic Belt. This
article makes the following recommendations:

First, increase the proportion of clean energy consumption and optimize the energy consumption
structure of the construction industry. The energy consumption structure and carbon emissions are
inextricably linked. The high dependence on petrochemical energy will lead to the continuous
development of the construction industry at the cost of high energy consumption and high emissions,
inhibiting the sustainable green development of the construction industry. The promotion and use of clean
energy, such as electric energy, in the construction industry should be strengthened.

Second, increase investment in scientiﬁc and technological research and development in the
construction industry to improve the level of technology. The government and related enterprises should
intensiﬁy the research and development of construction industry science and technology, promote the
construction industry equipment update and mechanization level improvement, and promote the
construction industry production technology and carbon emission technology improvement. Especially
in areas with backward science and technology, it is necessary to strengthen contact and communication
with advanced areas of science and technology to drive the improvement of the overall green factor
productivity of the construction industry in the Yangtze River Economic Belt.

Third, increase the degree of marketization and optimize the market competition mechanism. Adjust
the market structure of the construction industry to ensure the rational flow of capital and labor factors in
market competition. Relevant government departments should reduce the proportion of nationalization
of the construction industry, encourage non-public ownership economies, realize free competition
among enterprises, and provide a good market environment for the improvement of green total factor
productivity in the construction industry.

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