Factors influencing carbon emissions of China's construction industry: A dynamic analysis based on PVAR model

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Abstract. Analyzing the effect of influencing factors on carbon emissions in the construction industry is significant for carbon emissions reduction. The effect of factors on carbon emissions are dynamic at various stages while the long-term dynamic impact has not been discussed in depth in most of the existing studies. Taking 30 provinces in China as examples, PVAR model is used to study the dynamic impact of influencing factors on carbon emissions. The influencing factors include building construction area, value of unit building area, indirect emissions intensity, carbon emissions per unit energy consumed, energy intensity and total factor productivity. The results indicate that building construction area, value of unit building area and total factor productivity have positive influence on carbon emissions. The long-term effect of building construction area is more significant. Moreover, carbon emissions per unit energy consumed and building construction area is the main factor of main outflow plate and main inflow plate respectively. This study provides recommendations for reducing emissions in the construction industry in provinces with different characteristics in China.

1. Introduction

The construction industry, as an important source of China's carbon emissions, is the key implementation target of energy saving and emission reduction. Therefore, exploring the influencing factors of carbon emissions in the construction industry is vital to reduce carbon emissions. At present, many researchers establish the index system affecting the carbon emission of the construction industry mostly from the supply or demand, which isn't conducive to analyzing and comparing the effect of different dimensional factors. LMDI model and multiple linear regression model always be used to analyze results, which often describe the effect of impact under the whole time series. However, factors such as technology have a rebound effect, with significant variability in the effect of different periods[1]. Therefore, exploring the long-term dynamic effects of other influencing factors is necessary to properly understand the effects of different stages and to propose effective mitigation measures. On the other hand, most of the present studies take one province or all provinces in China as the research object, lacking a specific classification of provinces, which isn't beneficial to propose specific and feasible measures for each province. Therefore, we first established the influencing factors index system from the perspective of supply and demand. And 30 provinces are classified according to the climate and the carbon emission networks. PVAR model is used to analyze the long-term dynamic effect on carbon emissions of construction industry. The paper will provide suggestions and direction for regional provinces to reduce carbon emissions in the construction industry.

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2. Methodology

2.1. Carbon emissions of China's building sector

With reference to existing studies, carbon emissions from the construction industry are divided into two parts: the direct carbon dioxide emissions refer to the carbon emissions from energy sources such as raw coal, gasoline, diesel, fuel oil, and electricity that are directly consumed throughout the building's life cycle, and the indirect carbon dioxide emissions refer to carbon emissions from construction materials such as glass, aluminum, steel, cement and wood consumed for construction. The carbon dioxide emissions, direct carbon dioxide emissions and indirect carbon dioxide emissions of the construction industry can be calculated by the equation (1), according to the IPCC carbon emission estimation methodology[2].

$$C=C_{dir}+C_{indir}=\Sigma_{i=1}E_i\times NCV_i\times D_i\times O_i\times \frac{44}{12}+P\times K+\Sigma_{j=1}M_j\times F_j\times(1-R_j) \quad (1)$$

where C, C_{dir} and C_{indir} represent the carbon dioxide emissions, direct carbon dioxide emissions and indirect carbon dioxide emissions respectively; i and j denote the types of fossil energy and construction materials respectively; E_i , P and M_j are consumptions of each fossil energy, electricity and construction materials in the building sector respectively; NCV_i is the low calorific value on average; D_i is the carbon content of each fossil energy; O_i is the oxidation carbon factor; K and F_j are coefficients of the carbon dioxide emissions of electricity and each type of construction materials respectively; R_j is the construction material recycling factor of every materials, as shown in Table 1.

Table 1. Coefficients and recycling factors of construction materials.

construction materials	glass	aluminum	cement	steel	wood
F_j	0.9655	2.6000	0.8150	1.7890	-842.8000
R_j	0.7	0.85	——	0.8	0.2

2.2. Influencing Factors

This study constructs an index system of influencing factors from the perspective of supply and demand. Table 2 presents a description of all selected influencing factors variables[3]. Referring to many previous studies, the Cobb-Douglas production function is used to calculate the total factor productivity in building construction sector as follows:

$$Y(t) = A(t)K(t)^{\alpha}L(t)^{\beta} \quad (2)$$

where *Y(t)* denotes the add value of the construction sector; *A(t)* represents the total factor productivity; *K(t)* is the fixed assets in the construction sector; *L(t)* is the average number of people directly engages in activities of the construction sector; α and β are the output elasticities of capital and labor inputs, respectively, where α=0.281 and β=0.719.

Table 2. Declaration of influencing factors variables.

Symbol	Variable	Definition
y	Carbon emissions of China's building sector	The total output of carbon dioxide from China's construction industry in one year.
x1	Building construction area	The sum of building construction area at the end of the year.
x2	Value of unit building area	The ratio of completed value to completed area of buildings.
x3	Indirect emissions intensity	The ratio of indirect embodied carbon dioxide emissions to economic total output value of the building construction sector.
x4	Carbon emissions per unit energy consumed	The ratio of direct embodied carbon dioxide emissions to direct energy consumed in the building construction sector.
x5	Energy intensity	The ratio of direct energy consumed to the added value of the building construction sector.
x6	Total factor productivity in building construction sector	Obtained by the Cobb-Douglas production function.

2.3. The impact on carbon emissions

The PVAR model was first proposed by Holtz-Eakin in 1990s. Combining the different advantages of traditional time series models and panel models, this equation is mostly used for macro dynamic problems. The PVAR model is as follows:

$$Y_{it} = \alpha_0 \sum_{j=1}^{P} \alpha_j Y_{i,t-j} + \sum_{j=1}^{P} \beta_j X_{i,t-j} + \theta_i + \varphi_t + \varepsilon_{it} \quad (3)$$

where *i* and *t* represent region and time respectively; *j* is the lag period; θ_i is the individual fixed effect; φ_t is the time fixed effect; ε_{it} is the random perturbation term; α_j and β_j are the model parameters to be estimated.

The study used STATA 17 for PVAR model and impulse response function analysis, mainly including descriptive analysis, stationary test, lag order selection, granger causality Wald test and impulse response analysis[4]. The optimal lag orders of the PVAR model are selected using AIC, BIC and HQIC. The impulse response function can be used to further analyze the impact relationship between variables, giving the effect of a positive shock to one endogenous variable on the current and future values of other endogenous variables.

3. DATA

In this study, a sample of 30 provinces and cities in China is used based on data from 2005 to 2020. The study classifies the provinces in two different ways as shown in Table 3 and Table 4. According to the carbon emission networks, samples are divided into four plates: main inflow plate, main inflow plate, bidirectional spillover plate and agent plate[5]. Referring to climate zones in the construction industry, samples can also be divided into four areas: severe cold regions, cold regions, hot summer and cold winter regions and hot summer and warm winter regions[6].

As for the equation (1), consumptions of each fossil energy, electricity and the low calorific value are derived from the China Energy Statistical Yearbook and consumptions of each construction materials are derived from the China Statistical Yearbook on Construction. The carbon content of each fossil energy and oxidation carbon factor are obtained from the Guidelines for the Preparation of Provincial Greenhouse Gas Inventories. The coefficients of the carbon dioxide emissions of electricity are from 2019 Annual Emission Reduction Project China Regional Grid Baseline Emission Factor.

As for influencing factors, the building construction area, completed value, economic total output value of the building construction sector and fixed assets in the construction sector are derived from the China Statistical Yearbook on Construction. The added value of the building construction sector is obtained from the China Statistical Yearbook.

Table 3. Segmentation of carbon emission networks.

Plates	Provinces
Main Inflow plate	Jiangsu, Guangdong, Fujian, Shanghai, Zhejiang
Main Outflow plate	Hubei, Hunan, Anhui, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Jiangxi, Xinjiang
Bidirectional Spillover plate	Beijing, Tianjin, Inner Mongolia, Shandong
Agent plate	Jilin, Hebei, Shanxi, Liaoning, Ningxia, Heilongjiang, Henan

Table 4. Division of climate zones in the construction industry.

Regions	Provinces
Severe cold regions	Inner Mongolia, Xinjiang, Qinghai, Liaoning, Jilin, Heilongjiang
Cold regions	Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan, Shaanxi, Gansu, Ningxia
Hot summer and cold winter regions	Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan
Hot summer and warm winter regions	Fujian, Guangdong, Guangxi, Hainan, Guizhou, Yunnan

4. RESULTS

4.1. Carbon emissions in building sector

From 2005 to 2020, the national construction industry carbon emissions are generally on an upward trend. Among them, Zhejiang Province and Jiangsu Province, as the provinces with the most rapid economic development in China, have been at a high level of carbon emissions from the construction industry. While Hainan Province, Ningxia Province and Qinghai Province are more backward in development, so carbon emissions from the construction industry have been at a low level.

4.2. Analysis results of 30 provinces

4.2.1 Unit root test

Before estimating the PVAR model, unit root tests of the variables are required to avoid pseudoregression due to the nonstationary of the variable data. In this paper, unit root tests are performed on the variable data based on HT test, IPS test and ADF-Fisher test. The results are shown in Table 5. When the logarithm of all variables is tested as a unit root, part of the original hypothesis cannot be rejected, which means there are unstable variables. When the unit root test is performed again after first-order differencing of all variables, all variables reject the original hypothesis at 1% significance level. Therefore, the series can be considered smooth for subsequent model estimation.

Table 5. Results of the unit root test for the panel data

Variables	HT tests	IPS tests	ADF-Fisher tests
	P-value	P-value	P-value
lny	0.0000***	0.0000***	0.0178**
lnx1	0.9998	0.3122	0.9903
lnx2	0.0000***	0.0000***	0.2348
lnx3	0.0000***	0.0000***	0.0286**
lnx4	0.0642	0.0001***	0.0924*
lnx5	0.1521	0.0001***	0.4071
lnx6	0.3117	0.0018***	0.0000***
dlny	0.0000***	0.0000***	0.0000***
dlnx1	0.0000***	0.0000***	0.0000***
dlnx2	0.0000***	0.0000***	0.0000***
dlnx3	0.0000***	0.0000***	0.0000***
dlnx4	0.0000***	0.0000***	0.0000***
dlnx5	0.0000***	0.0000***	0.0000***
dlnx6	0.0000***	0.0000***	0.0000***

Note: *p<0.1, **p<0.05, ***p<0.01

4.2.2 Selection of the optimal lag order

In this paper, the optimal lag order of the model is determined by calculating the AIC, BIC and HQIC with lags of 1~3 periods. The minimum value of each criterion is usually considered to be the optimal lag order chosen for that criterion. The results are shown in Table 6, when the lag order is one, the minimum values of AIC, BIC and HQIC exist. So lag one is chosen as the optimal lag order for the PVAR model in this study.

Table 6. The optimal lag orders of the PVAR model

lag	AIC	BIC	HQIC
1	-6.84073*	-4.2068*	-5.79663*
2	-6.65518	-3.3304	-5.33319
3	-6.69318	-2.58325	-5.05379

4.2.3 Granger causality test

This paper further exam the Granger causality between the variables by the Wald statistic. As shown in Table 7, influencing factors including building construction area, value of unit building area, indirect emissions intensity, carbon emissions per unit energy consumed, energy intensity and total factor productivity are significant Granger causes of carbon emissions in building sector and they pass the 5% significance level test.

Table 7. Results of panel VAR-Granger causality Wald test

Null hypothesis	Chi^2	*P*-value
Building construction area does no Granger-cause carbon emissions	88.834	0.000***
Value of unit building area does no Granger-cause carbon emissions	55.197	0.000***
Indirect emissions intensity does no Granger-cause carbon emissions	140.491	0.000***
Carbon emissions per unit energy consumed does no Granger-cause carbon emissions	36.289	0.000***
Energy intensity does no Granger-cause carbon emissions	25.497	0.000***
Total factor productivity does no Granger-cause carbon emissions	5.802	0.016**

Note: *p<0.1, **p<0.05, ***p<0.01

4.2.4 Impulse response analysis

After 200 Monte-Carlo simulations, the impulse response function analysis of carbon emissions with 10 periods is obtained.

For a positive shock from building construction area (x1), the carbon emission (y) responds positively. The magnitude of its response shows a trend of first increasing and then decreasing. This indicates that in the short term, the increase in building construction area greatly promotes carbon emissions of the construction industry. But in the long term, this promotion effect gradually converges. From the 1990s to the present, the rapid development of China's infrastructure industry has largely led to the change of population structure and the increase of residents' consumption level and the building area has also increased[3]. The construction activities and residential use in the infrastructure construction process will generate carbon dioxide, thus increasing the carbon emissions.

When value of unit building area (x2) is subjected to a positive shock, the carbon emission (y) always responds positively. In the long term, the increase of unit building area value leads to the increase of carbon emission in the construction industry. With the improvement of people's living standard, people have higher requirements for the appearance, quality and performance of building products. The construction technology of buildings is becoming more and more refined, the shape is becoming more and more exotic and the function is becoming more and more perfect, leading to increasing energy and materials consumed, which further leads to the increase of carbon emissions[3].

For a positive standard shock from indirect emissions intensity (x3), the carbon emission (y) is a negative effect. However, the higher the indirect carbon emission, the more construction materials are consumed and the more carbon dioxide is produced under a certain economic GDP of the construction industry. From the collected data, the indirect carbon emission intensity of 30 provinces in China from 2005 to 2020 shows a decreasing trend, while the carbon emission of the construction industry shows the contrary trend. This indicates that indirect emissions intensity contributes to carbon dioxide emissions, which means the indirect carbon emission intensity is not the main factor affecting the carbon emissions of the construction industry.

When carbon emissions per unit energy consumed (x4) is subjected to a positive shock, the carbon emission (y) responds positively. An increase in carbon emissions per unit of energy consumed will lead to an increase in direct carbon emissions when energy consumption is constant.

When energy intensity (x5) is subjected to a positive shock, the carbon emission (y) responds negatively in the current period and then responds positively. However, the higher the energy intensity, the more energy consumption and the more carbon dioxide produced for a certain industry GDP. From the collected data, the energy intensity of 30 provinces in the country shows a decreasing trend from 2005 to 2020, while the carbon emissions from the construction industry shows an increasing trend. This indicates that energy intensity contributes to carbon emissions. So energy intensity is not the main factor affecting carbon emissions from the construction industry.

When total factor productivity (x6) is subjected to a positive shock, the carbon emission (y) responds positively. Increasing production efficiency will lead to an increase in total construction output, which will also raise carbon emissions.

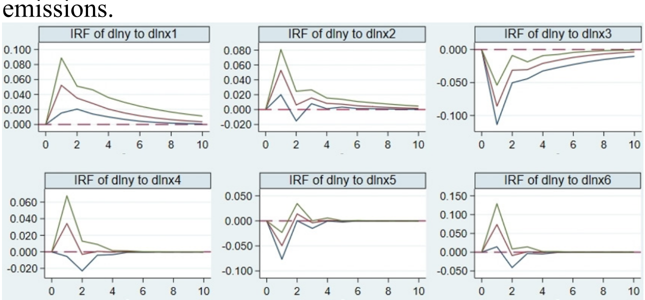

Figure 1. Impulse response analysis in the domestic construction industry.

4.3. Analysis results of provincial groups

In the cold regions, the magnitude of changes in the x1 and x3 indicators exceeds the national average, indicating that building construction area and indirect emission intensity are the main factors. Thus, they should focus on controlling local building construction area growth, timely regulation of carbon emission intensity of upstream and downstream enterprises related to the construction industry and optimization of energy intensity in the future.

For the provinces in the main inflow plate**,** building construction area and unit building area are the main factors affecting carbon emissions.

The impulse response effect of the main outflow plate is the same as that of the whole country. The x1, x3, x6 have a slightly reduced degree of influence. The x2 and x4 have about the same degree of influence as that of the whole country. Specially, x1 has a more obvious long-term effect. It is necessary to promote urban cluster development and control the excessive growth of new construction land. x2 and x4 have more significant short-term effects. Future emission reduction approach can focus on the optimization of construction equipment and the optimization of the energy sector reform. It is also inevitable to optimize the architectural design and construction program to reduce the energy consumed.

The degree of impact of x3 in agent plate is smaller than that of the national provinces. And compared with the main outflow plate, the positive and negative impact of x3 has been fluctuating and changing, with more significant short-term effects and less obvious long-term effects. Therefore, for this part, it is supposed to control the carbon emission intensity of related industries as the main measure to reduce carbon emissions in the construction industry.

5. Conclusion

Based on the data of 30 provinces in China from 2005 to 2020, this study explores the dynamic effects of influencing factors on carbon emissions in different kind of regions of according to the climate and the carbon emission networks by PVAR model.

According to the results, this study puts forward the following suggestions. First, in terms of 30 provinces, building construction area, value of unit building area and total factor productivity have an obvious positive impact all the time, especially the long-term effect of building construction area is remarkable. So fundamentally controlling the demand for building construction area is the important measure to reduce carbon emissions of China's construction industry. Second, it is necessary to balance the relationship between people's demand for new buildings and energy consumption per unit of building construction area. It not only pursues the ultimate experience of shape and function, but also take into account green and low-carbon goals. Third, as the supply side of raw materials, the main outflow plate needs to promote urban cluster development in the long term, scientifically determine the scale of construction, and control the excessive growth of new construction land. In addition, the control of carbon emission intensity of related industries in agent plate should be taken as the main measure to reduce carbon emission in the construction industry.

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