FDI, economic growth and carbon emissions of the Chinese steel industry: New evidence from a 3SLS model

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Highlights:

- ✧ The paper explores the relationship between China's economic growth, carbon emissions in the Chinese steel industry and FDI inflows.
- ✧ It uses the STIPRAT model and the 3SLS model, spanning the period 2000 to 2015.
- ✧ It combines the economic growth function, carbon emission production function, and the FDI function of Chinese steel industry.
- ✧ The results show a complete two-way causal relationship of three variables in the whole country and the western region.
- ✧ There is no bidirectional causal relationship between carbon emissions and FDI in the eastern region.

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Abstract

Determine the main factors affecting carbon emissions of Chinese steel industry is indispensable commitments to achieve the sustainable development of China. Hereby, based on the Stochastic Impacts by Regression on Population, Affluence and Technology (STIPRAT) model, this paper combines the economic growth function, carbon emission production function, and the FDI function of Chinese steel industry, and uses the three-stage least square equation model (3SLS) to analyze the relationship between China's economic growth, carbon emissions in the steel industry and FDI (Foreign Direct Investment) inflows. The results document a complete two-way causal relationship of three variables in the whole country and the western region, while the relationship in the eastern region and the central region is not complete. Moreover, no bidirectional causal relationship between carbon emissions and FDI in the eastern region, while only bidirectional causality between carbon emissions and FDI in the central region. These findings are of great significance for Chinese steel industry to formulate effective emission reduction policies.

***Keywords*:** carbon emissions; Chinese steel industry; 3SLS; economic growth; FDI

1. Introduction

In recent years, the impact of carbon emissions on climate change has attracted global attention (Wen et al., 2020). China is currently the world's largest carbon dioxide emitter (Wang and Zhang, 2020). Reducing carbon emissions is China's main task in dealing with global climate change (Wen et al., 2020). In order to better deal with the severe domestic environmental problems and the great pressure of the international community, the Chinese government has made a series of ambitious emission reduction commitments (Zhang et al., 2020). In 2009, China committed to reduce carbon emissions per unit of GDP (i.e., carbon intensity) by 40%-45% compared with 2005 by 2020, and 60%-65% compared with 2005 by 2030 (NDRC, 2015; Lomborg, 2016). Reducing emissions in energy-intensive industries is essential to meet these commitments. A series of measures aimed at phasing out backward production capacity in energy-intensive industries have also proved the attention paid to energy-intensive industries.

Chinese steel industry is an indispensable part of the global circular economy and the core of a modern society's sustainable development, also is an important symbol of the national industrial level and comprehensive national strength (Dong et al., 2013). As one of the pillar industries of China's economic development, the Chinese steel industry directly affects the national economy's operation (Ma et al., 2014; Zhang et al., 2020). With the rapid urbanization and the increasing demand for various infrastructure construction activities, Chinese steel industry, which represents the world's largest steel consumption and production (Xu and Lin, 2016), has been concerned by the international community for a long time.

At present, China is one of the largest steel producers in the world (Han et al., 2019). Meanwhile, the Steel industry has become the largest industrial energy consumption industry and the largest source of greenhouse gas and air pollutant emissions in the world (Zhang et al., 2014). As for as China is concerned, the Steel industry is the third-largest greenhouse gas emission industry in China, accounting for 10% of China's total greenhouse gas emissions (Zeng et al., 2009). In 2017, it emitted

1.83 tons of carbon dioxide per ton of steel production, accounting for 7% to 9% of the direct global emissions using fossil fuels (WSA, 2019). Over the past few decades, its steel production has been proliferating (Fig. 1). From 2000 to 2017, China's crude steel production increased from 129 million tons to 832 million tons, accounting for the proportion of the world's steel production from 15.1% to 49.2%. The output of semi-finished products and finished products increased from 3.6% to 16.2%, while the output of imported semi-finished products and finished products accounted for the world's steel production from 7.0% to 3.1% (WSA, 2009, 2018). Therefore, the Chinese steel industry plays an essential role in greenhouse gas emission reduction (Tian et al., 2013). Specifically, because coal industry is the upstream enterprise and fuel supply industry of steel industry in China, the coal demand of steel industry will inevitably decline sharply during the process of "carbon neutral".

<Insert Figure 1>

Moreover, the importance of FDI (Foreign Direct Investment) in economic growth is gradually increasing, and its importance for the environment has attracted more and more attention (Bakhsh et al., 2017). Therefore, the role of FDI in economic growth and environmental pollution has aroused fierce debate. FDI is essential to China's economic growth process, and it can directly and substantially stimulate the country's economic boost (Lee, 2013). That's because, FDI is the main source of external financing (Bustos, 2007), which can shorten the distance between domestic savings and target investments (Ndikumana and Verick, 2008), provide direct financing channels, generate positive external effects, transfer advanced technology, and improve economic activities stimulated by high productivity (Lee, 2013).

While promoting economic growth, FDI cannot exempt environmental costs (Shahbaz et al., 2015). Especially as the largest developing country in the world, China's environmental regulation is relatively loose, that is to say, the so-called Pollution Haven Hypothesis (Hao and Liu, 2015). In this case, it is easy to encourage multinational companies to invest in China, to make full use of production cost reduction, leading to the phenomenon known as the industrial flight hypothesis (Asghari, 2013). However, FDI will also bring advanced and energy-efficient technologies, better management concepts and management systems, reduce emissions, and improve China's environmental quality. This phenomenon is called the pollution halo hypothesis. Generally, if multinational companies or foreign investors adopt advanced technologies in the production process, FDI is expected to reduce energy intensity and carbon emissions (Lee, 2013); otherwise, FDI will affect the environmental quality using energy-intensive technologies to increase carbon emissions.

Under above background, this paper uses Chinese provincial panel data, spanning the period 2000 to 2015, based on the STIRPAT model, and combines the economic growth function, the carbon emission production function and the FDI function of the Chinese steel industry, as well as the relationship between China's economic growth, steel industry carbon emissions and FDI by using the 3SLS model. Meanwhile, based on the status of Chinese steel industry and its contribution review, we consider the following hypotheses:

Hypotheses: There is a complete two-way correlation relationship of three variables (FDI, economic growth and carbon emissions) in China.

The contribution of this paper to the existing knowledge field is multifold. First, there is a lack of research on carbon emissions reduction in the steel industry, and the results are inconsistent (Xu et al., 2016; Wang et al., 2007). We empirically explore the interaction between FDI, economic growth and carbon emissions of the Chinese steel industry. Second, we use a provincial panel data set for research. Most of the existing studies on carbon emissions of Chinese steel industry have focused on national carbon emissions using time-series or cross-sectional data (Morfeldt et al., 2014). On this basis, the STIRPAT model is used to combine the economic growth function, carbon emission production function and FDI function of Chinese steel industry. Third, the paper uses a 3SLS model, instead of the 2SLS (two-stage least square method), cointegration and causality approaches. The 3SLS model can solve the potential correlation between regression and random error terms, and improve the reliability of the results (Mahmood et al., 2019). In particular, compared with other methods, the 3SLS model allows the correlation between unobserved interferences between different equations to be used in the analysis, and its estimation is more uniform and asymptotic normal. Under some conditions, the asymptotic estimation of the 3SLS model is more effective than the single-equation estimation. It is a combination of multivariate regression and two-stage regression, and it can solve some technical and economic problems (Zellner and Theil, 1962).

The remainder of the paper is organized as follows. Section 2 provides the related literature review, while Section 3 offers the theoretical framework and methodological issues. Section 4 presents the empirical results and discussions. Finally, conclusions and policy implications are offered in Section 5.

2. Literature review

The industrial sector is China's largest energy consumption industry and the main source of carbon emissions (Lin and Ouyang, 2014), while it is also considered the central area of low-carbon technology development in the country (Liu et al., 2013). Therefore, it is vital to understand and investigate the influencing factors of carbon emissions in China's major industries (Lin and Moubarak, 2014; Lin and Xie, 2014).

Many research studies on carbon emission across countries, regions and even industries, but the studies on carbon emissions in the steel industry have not been put into enough attention. Over the recent years, with the increasing of emissions and the pressure of emissions reduction in the steel industry, Chinese steel industry's carbon emissions have been studied in depth from different perspectives. First, many kinds of research focus on the prediction of Chinese steel industry demand in the future, mainly aiming at the future carbon emissions trend and the characteristics of the steel industry (Long et al., 2016); Liu and Gao, 2016; Wang et al., 2017). Some of these studies document that the increase in production is the main reason for carbon emissions changes (Kim and Worrell, 2002; Chen et al., 2014). For example, Chen et al. (2014) analyze the steel demand, energy consumption and carbon emission of Chinese steel industry in 2010-2050 by using the MARKAL-EFOM model and the system dynamics model. The results reflect that China's steel production will increase from 627 million tons in 2010 to 772 million tons in 2020 and gradually decrease to 527 million tons in 2050. Liu et al. (2014) analyze carbon tax and policy control's role in reducing emissions in the steel industry. The results illustrate that policy control is more effective than the carbon tax.

Secondly, a flood of literature focuses on the key factors affecting carbon emissions in Chinese steel industry through different methods. One method is exponential decomposition. The logarithmic mean divisor index (LMDI) method is widely used in the existing literature to study carbon emissions in the steel industry (Sun et al., 2011; Tian et al., 2013; Lin and Ouyang, 2014; Hasanbeigi et al., 2014; Ren et al., 2014; Wang et al., 2020). Tian et al. (2013) use a similar method to study the steel industry emissions. They stress that the total scale effect and the structural effect are the main driving forces for the growth of Chinese steel industry's carbon emissions. Ren et al. (2014) use the LMDI method based on the extended Kaya identity to explore the impact of the industrial structure, economic output, energy structure, energy intensity and emission factors of China's manufacturing industry on total carbon emissions 1996-2010. Using LMDI method, Wang et al. (2020) studied the factors influencing the emission of air pollutants from Chinese steel industry from the aspects of environmental regulation effect, pollutant generation intensity effect, energy structure effect, technological progress effect and scale effect. They found that environmental regulation plays a decisive role in reducing air pollution in Chinese steel industry. Another method is the econometric modelling approach (Zhang et al., 2012; Yu et al., 2015; Xu and Lin, 2016; Xu and Lin, 2017; Xu et al., 2017). In particular, Zhang et al. (2012) use regression analysis to verify the relationship among carbon emission reduction practices, the determinants and the performance reported by steel companies based on various companies' questionnaires in China. The results highlight that although some CO_2 emission reduction measures can produce a significant environmental performance, their impact on improving this economic performance is not obvious. Xu and Lin (2017), based on 30 provincial panel data from 2000 to 2013, and a nonparametric additive regression model, analyze the main driving forces of carbon emissions in Chinese steel industry and document that the nonlinear impact of economic growth on carbon emissions conforms to the Environmental Kuznets curve (EKC) hypothesis.

Also, the carbon emission reduction potential of the steel industry is another topic of general interest concerned in the previous literature (Wang et al., 2007; Zhang and Wang, 2008; Guo and Fu, 2010; Wen et al., 2014; Lin and Wang, 2014; Lin and Wang, 2015). For example, many scholars have studied the production process and technological improvement of the steel industry to calculate China's potential (Li and Zhu, 2014; Wang and Lin, 2017). Wang et al. (2007) evaluate Chinese steel industry's carbon emission reduction potential based on different carbon emission scenarios from 2000 to 2030, and find that adjusting the industry's structure and improving technology plays an essential role in reducing carbon emissions. Lin and Wang (2015) investigate the carbon emission performance of total factors and estimate Chinese steel industry's emission reduction potential in 2000-2011. In another paper, they also use cointegration and scenario analysis to analyze the energy-saving potential of Chinese steel industry (Lin and Wang, 2014).

Moreover, certain studies have focused on improving the energy efficiency of Chinese steel industry. Some researchers analyze the macroeconomic environment and hope to provide decision support for policy formation (Guo and Fu, 2010; Smyth et al., 2011; Choi et al., 2012; Price et al., 2012; Zhang et al., 2012; Wang et al., 2017). Lastly, many studies also adopt different methods and nuclear research logic to analyze carbon emission reduction measures in Chinese steel industry (Ma et al., 2002; Wei et al., 2013; Zhang et al., 2013; Ma et al., 2014; Zhang et al., 2014; Dai, 2015). For example, Ma et al. (2014), Zhang et al. (2014) and Dai (2015) all use the system optimization method to evaluate the operation efficiency, structure and scale of the steel industry; they all find that increased energy efficiency helps to reduce carbon emissions, while energy consumption in the steel industry continues to grow. Using the data envelopment analysis (DEA) model, Ma et al. (2002) argue that technological progress could reduce carbon emissions in the steel industry.

It can be seen from the above that it is important to study the carbon emission of Chinese steel industry. However, the above research either forecasts demand and emissions reduction potential or analyze factors and technologies. The literature on carbon emissions of Chinese steel industry does not cover economic growth and carbon emissions under a single combination framework; it lacks the analytical framework to investigate carbon emissions in the steel industry, while there is no specific study on the impact of FDI on carbon emissions in Chinese steel industry. Moreover, there is limited literature on the impact of regional differences on carbon emissions in Chinese steel industry. At the same time, most of the existing studies lack the appropriate theoretical background to guide the model's construction, which is prone to some technical and economic problems, such as endogenous problems. Our paper designs a comprehensive framework based on the STIRPAT model. The combination of the economic growth function, the carbon emission production function and the FDI function in Chinese steel industry, or study discusses the relationship between economic growth, carbon emissions in the steel industry and FDI from the national and regional perspectives. The main driving forces of carbon emissions in the steel industry are discussed on this basis. The results can guide policymakers to design better regional emission reduction policies for Chinese steel industry.

3. Theoretical framework and methodology

3.1 Theoretical framework

STIRPAT model was originally stated as IPAT (Impact by Population Affluence and Technology), which was proposed by Ehrlich and Holdren (1971) to quantifying the impact of human economic activities on the natural environment. Dietz and Rosa (1994) reformulated the IPAT model as a stochastic form known as the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model in order to test the hypothesis more strictly. The theory supporting this study is that of an extensible STIRPAT model. This model is usually used to investigate the influencing factors of environmental pollution (Xu et al., 2017), as follows:

$$I_t = aP_t^b A_t^c T_t^d \xi_t \tag{1}$$

where I represents the degree of environmental pollution and a is the intercept term. P refers to population size, A refers to national influence, and T refers to technological progress. b, c and d denote the elasticity of the environmental impact on P, A and T respectively. ξ_t is a random error term, and subscript t represents the time dimension of the modelling approach.

However, the standard STIRPAT model is a nonlinear multivariate equation, so it is very difficult to calculate the coefficients of a, b, c, d. and ξ_t. In specific applications, all variables in the Eq (1) are usually converted to logarithmic form for easy calculation.

$$\ln I_t = \ln a + b \ln P_t + c \ln A_t + d \ln T_t + \ln \xi_t \tag{2}$$

where the definition of variable in the Eq (2) is the same as that in the Eq (1). Previous studies have revealed that in addition to those variables that were originally established in the model, other potentially relevant variables can affect environmental quality. Therefore, other possible factors need to be included in the model to reduce misjudgment (Gani, 2021).

3.2 Model extension

To investigate the trio of China's per capita GDP, FDI, and carbon emissions in the steel industry, as well as the factors affecting carbon emissions in the steel industry, we extend the STIRPAT model accordance with the STIRPAT framework. Specifically, on the basis of the original model, industrialization, urbanization, energy intensity, energy structure and foreign trade dependence are included in the new expanded model.

3.2.1 The economic growth function

The development of the steel industry is significant to the growth path of the Chinese economy. To achieve green and sustainable economic growth of Chinese steel industry, the industry's investment capital, labor and energy must be combined and used in an environmentally friendly way. Therefore, it is urgent to study the relationship between the steel industry's economic growth and carbon emissions. In the previous literature, the relationship between economic growth and carbon emissions is summarized into three types: growth relationship, conservation relationship and feedback relationship. According to the growth relationship, carbon emissions in the Chinese steel industry can, directly and indirectly, affect economic growth. For FDI, the increase of FDI may lead to huge investments in the steel industry, which promotes the economic activities of the sector and the entire national economic growth process. The conservation relationship holds that carbon emissions and economic growth in the steel industry are a process of a mutual game. A growing economy has increased per capita real income, which further improves the level of total demand in Chinese steel industry, thus, increasing the level of economic activity that requires high levels of energy consumption, which in turn causes Chinese steel industry to emit more carbon dioxide. In contrast, with Chinese steel industry's continuous economic growth, it is possible to reduce carbon emissions by upgrading technology effectively. The feedback relationship emphasizes the two-way causal relationship between the steel industry's economic growth and carbon emissions. Therefore, to fully understand the impact of labor (*P*), carbon emissions (*I*), foreign direct investment (*FDI*) and other factors (*U*) on economic growth (*GDP*), the following economic growth function models are constructed:

$$GDP_t = I_t P_t FDI_t U_t \tag{3}$$

3.2.2 The production function of carbon emission in Chinese steel industry

The construction of the production function of carbon emission in the steel industry is generally consistent with the EKC hypothesis (Grossman and Krueger, 1995), and the Kaya equation (Lin and Zhang, 2016). The carbon emissions in the steel industry depend, to a certain extent on the level of economic activity, and the increase of GDP also needs to be realized by using more steel, while the production of steel itself directly leads to more carbon emissions. FDI may also have an impact on carbon emissions in the steel industry. Energy intensity is also crucial for carbon emissions in the steel industry, with the energy intensity determining the industry's future energy-saving potential (Lin and Wang, 2014). Therefore, we express carbon emissions (*I*) in the steel industry as a function of economic growth (*GDP*), foreign direct investment (*FDI*), labor (*P*), energy intensity (*EI*) and other factors (*X*) that affect carbon emissions in the steel industry. The production function of carbon emissions in Chinese steel industry is as follows:

$$I_t = GDP_t P_t FDI_t EI_t X_t \tag{4}$$

3.3.3 The FDI function

FDI has a great impact on environmental pollution and economic growth (Bakhsh et al., 2017). However, over recent years, the impact of FDI on the environment has become a controversial topic: Although FDI is regarded as the engine of economic growth in many developing countries, it may also lead to environmental degradation. Therefore, in order to investigate the impact of FDI on China's economic growth and carbon emissions in the steel industry like many studies (Zhang, 2011; Kivyiro and Arminen, 2014; Hao and Liu, 2015), the analysis uses economic growth (*GDP*), carbon emissions (*I*), and economic and social factors (*Y*) to investigate the causal relationship between them and FDI. The form of the FDI function yields:

$$FDI_t = GDP_t P_t I_t Y_t \tag{5}$$

Based on the above discussion, our study focuses on economic growth, the relationship between carbon emissions and FDI in the steel industry, as well as on the factors affecting carbon emissions in the steel industry, which can be described by a simultaneous equation model based on the combination of equations (3), (4) and (5), as shown below:

$$\begin{aligned} GDP_t &= I_t P_t FDI_t U_t \\ I_t &= GDP_t P_t FDI_t I_t X_t \\ FDI_t &= GDP_t P_t I_t Y_t \end{aligned} \tag{6}$$

3.3 Model specification

Determining the relationship between economic growth, carbon emissions in the steel industry and FDI, and the key drivers of carbon emissions are critical to developing effective environmental protection and emission reduction policies (Xu and Lin, 2017). Following the above analysis framework, in order to comprehensively investigate and study the relationship between China's economic growth, FDI and carbon emissions in the steel industry, and through the STIRPAT modelling approach, the analysis introduces industrialization, urbanization, energy structure, energy intensity and dependence on foreign trade as control variables based on China's specific national conditions, the EKC equation and the relevant literature on the influencing factors of Chinese steel industry (Xu and Lin, 2016). The main reason is that the industrialization process in industrialized countries almost starts from the steel manufacturing industry. As the largest developing country in the world, China is in the process of rapid industrialization. The steel industry is one of the driving forces of China's economy. The foundation of rapid industrialization and urbanization is the steel industry (Geng and Doberstein, 2008) because rapid industrialization and urbanization are the two main reasons for the huge demand for steel products (Tian et al., 2013).

Moreover, China is currently accelerating industrialization and urbanization, and the growing energy consumption and carbon emissions pose a real challenge (or threat?) to the economy (Adams and Shakmurove, 2008). At the same time, urbanization is a feature of the Chinese economic growth process (Li et al., 2015). Therefore, to achieve sustainable growth, industrialization and urbanization must be taken into account when formulating appropriate greenhouse gas emission reduction policies. Besides, steel production is an energy-intensive manufacturing process; both the energy intensity and energy structure of steel production directly affect overall energy consumption and carbon emissions. Since the reforms and opening up in 1978, China has changed from a domestic market-oriented model to an export-oriented economic growth model. Although this model has greatly promoted China's economic growth, especially after China acceded to the WTO in 2001, it has led to an increase in domestic resources and energy consumption hurting the domestic environment. However, at present, only a few kinds of literature consider the dependence of foreign trade in the carbon emissions factor model (Zhang and Zhang, 2018). Therefore, this paper puts industrialization, urbanization, energy intensity, energy structure and foreign trade dependence into the 3SLS modelling approach concerning Chinese steel industry. According to the panel data model, the simultaneous Equation (6) is redefined by using the terms of logarithmic linearity and per capita:

$$\begin{aligned}
\ln\left(GDP_{it}\right) &= a_0 + a_{1i}\ln\left(CO2_{it}\right) + a_{2i}\ln\left(FDI_{it}\right) + a_{3i}\ln\left(EI_{it}\right) + a_{4i}\ln\left(URB_{it}\right) + \delta_{it} \\
\ln\left(CO2_{it}\right) &= b_0 + b_{1i}\ln\left(GDP_{it}\right) + b_{2i}\ln\left(FDI_{it}\right) + b_{3i}\ln\left(EI_{it}\right) + b_{4i}\ln\left(ENS_{it}\right) + b_{5i}\ln\left(IND_{it}\right) + \varepsilon_{it} \\
\ln\left(FDI_{it}\right) &= c_0 + c_{1i}\ln\left(GDP_{it}\right) + c_{2i}\ln\left(CO2_{it}\right) + c_{3i}\ln\left(IND_{it}\right) + c_{4i}\ln\left(FTD_{it}\right) + \theta_{it}
\end{aligned} \tag{7}$$

The definitions of all explanatory variables and dependent variables in Equation (7) are shown in Table 1. *i* represents the province, *t* the year dimension, *a*, *b* and *c* are the regression parameters of the explanatory variables in the 3SLS model, δ_{it}, ε_{it} and θ_{it} are white noise interference terms.

<Insert Table 1>

The analysis uses the 3SLS model to solve the above simultaneous equation model (Eq (7)). The 3SLS model is more effective than the 2SLS model, because the 3SLS model allows correlation between unobserved interferences between different equations to be used in the analysis (Bakhsh et al., 2017). Therefore, to avoid this type of problematic issues (i.e., the endogeneity of the error term between the modified equations and the simultaneous correlation problem), the analysis uses the 3SLS model and makes a comparative analysis of its robust estimation at the provincial level.

3.4 Data

Compared with time series and cross-section data models, panel data can control individual heterogeneity, reduce the collinearity effect between variables, improve degrees of freedom, improve estimation efficiency, and allow more information data (Al-mulali, 2012). Therefore, the analysis employs a panel data model to study the relationship between economic growth, carbon emission and FDI. However, so far, detailed information on the past and present carbon emissions of the steel industry is quite limited (Tian et al., 2013). Therefore, this paper selects data from 30 provinces in China, spanning 2000 to 2015 (Tibet is not included in the sample due to the lack of data). All data are obtained from the China Statistical Yearbook, the China Energy Statistical Yearbook, and the province's Provincial Statistical Yearbook. Based on the consumption of various fossil fuels and their CO_2 emission factors reported by the Intergovernmental Panel on climate change (IPCC) in 2006, we calculate CO_2 emissions in the steel industry across 30 administrative regions. Exchange rate conversion data and total import and export data are sourced from the Wind database.

4. Empirical results and discussions

4.1 Summary statistics

Table A.1 provides certain summary statistics of the natural logarithm across different variables in each province. The statistical data describe the characteristics of the variables used in the 3SLS regression analysis.

4.1.2 Diagnostic tests

Generally speaking, the sequence of economic variables in reality is basically non-stationary. If we use a non-stationary sequence for regression analysis, it will lead to the appearance of pseudo regression. For this purpose, we need to test the robustness of economic variables. Besides, China is a vast country with significant economic development differences, energy intensity, urbanization and industrialization in different provinces. Therefore, to reliably determine each series's stationarity in the panel, four main panel unit root tests, LLC, IPS, Fisher ADF and Fisher PP (Levin et al., 2002; Im et al., 2003; Choi, 2001), are used in this paper. These panel unit root tests assume independent cross-section. Where ADF and PP have similar characteristics (including asymptotics), but PP is nonparametric, and heteroscedasticity and autocorrelation are considered. LLC allows uniform parameters, it tests the invalid hypothesis that each time series contains unit roots, which is the opposite of the fixed alternative hypothesis for each time series. In contrast, although IPS are similar to the Fisher type test (ADF and PP) in using single unit root test information, the Fisher type test seems to be advantageous because it can use different lag lengths in single ADF regression. Variables are used in model estimates based on the respective stability levels shown in Table A.2. The results show that all variables are stable, especially their first-order difference sequences. Therefore, all variables can be directly regression analysis. Apart from unit root tests, we tested the data with overidentification test and serial correlation test respectively. The results of the two tests are shown in Table A.3 and Table A.4 respectively. According to Table A.3 and Table A.4, our results are reliable. Specifically, we do not reject that null hypothesis at the 95% level of confidence.

4.2 Results and discussions

It is of great significance to determine the relationship between economic growth, carbon emission and FDI of steel industry, as well as the influencing factors of carbon emission of steel industry, so as to reduce carbon emission of steel industry and formulate effective industrial policies. Most of the existing studies are based on time series data, and there are obvious differences across regions in China. Therefore, we need to pay attention to the analysis at the regional level and the national level (Xu and Lin, 2016). Therefore, the analysis constructs a provincial panel data set studying the relationship between economic growth, FDI and carbon emissions in the steel industry, and the factors affecting carbon emissions. Meanwhile, it also makes a regional analysis of the trio the three factors and carbon emission factors in China. Based on the statistics of China's National Bureau of Statistics (Xu and Lin, 2016), this paper divides the 30 Chinese provinces (excluding Tibet) into Eastern, Central and Western regions (Table 2).

<Insert Table 2>

4.2.1 The influence of carbon emissions of the steel industry and FDI on economic growth

Table 3 reports the impact of FDI and carbon emissions in the steel industry on GDP per capita. The results show that on a national level, all variables are statistically significant at 1%. Both FDI and carbon emissions in the steel industry positively affect per capita GDP, implying that when other factors remain unchanged, a 1% increase in carbon emissions in the steel industry lead to an 0.18% increase in per capita GDP. This also shows that China has not yet reached the inflexion point of its EKC curve in terms of the steel industry. Moreover, an 1% increase in FDI generates a 0.70% increase in GDP per capita. That is to say, FDI has a strong positive impact on economic growth, indicating that FDI inflows are a main driving force for China's economic growth. For

GDP per capita, the influence of the urbanization rate and energy intensity is negative, while both are statistically significant. The elasticity of the urbanization rate is the largest (- 0.99), which indicates that when other factors remain unchanged, an 1% increase in the urbanization rate leads to a 0.99% decrease in per capita GDP. The main reason is that China's urbanization rate increased significantly from 2000 to 2015, with a growth rate of 97.66%. However, compared with the per capita GDP of the original urban population, the new urban resident population's per capita income is relatively low, leading to the decline of the overall per capita GDP. It is likely that with the further development of the economy and society, the growth rate of the urbanization rate will gradually decline, and the urbanization rate and per capita GDP will also change in the same direction. Also, with a certain amount of energy consumption, the increase in energy intensity implies lower per capita GDP. It may be that in recent years, China has strictly controlled carbon emissions in the steel industry. Meanwhile, China accelerated the adjustment of the industry's internal structure and improved the energy utilization technology, albeit to a certain extent, which has also affected real output.

As far as the region is concerned, all variables in the Eastern region are statistically significant, with FDI being significant at 1%, while carbon emissions, the urbanization rate and energy intensity in the steel industry are all significant at 5%. Carbon dioxide emissions, FDI and GDP per capita are all positively correlated, while the urbanization rate, energy intensity and GDP per capita are negatively correlated. Among the four factors, FDI elasticity is the largest, which indicates that when other factors remain unchanged, FDI contributes the most to economic growth in the Eastern region. In the case of the Central region, all variables are not significant. Moreover, for the Western region, all variables are statistically significant; both FDI and energy intensity are significant at 1%, while carbon emissions, the urbanization rate and energy intensity are significant at 5%. As in the East, carbon emissions, FDI and GDP per capita in the steel industry in the Western region change in the same direction, while the urbanization rate, energy intensity and GDP per capita change to the opposite direction. FDI contributes the most to economic growth in the case of the Eastern region. The results document that apart from the Western region, carbon emissions in the steel industry and FDI have a positive impact on per capita GDP in the cases of the national economy, the Eastern region and the Western region; the urbanization rate and energy intensity have a negative impact on per capita GDP in the cases of the national economy, the Eastern region and the Western region. Compared with carbon emissions in the steel industry, FDI has a more drastic impact on economic growth, because of its greater elasticity. FDI plays a greater role in the East's economic growth path than in the West, mainly because foreign-funded enterprises are located in coastal cities in the East. In contrast, carbon emissions in the steel industry play a greater role in economic growth in the West than in the East, indicating that economic growth in the West mainly depends on high-emission industries.

<Insert Table 3>

4.2.2 The influence of economic growth and FDI on carbon emissions of the steel industry

The impact of GDP per capita and FDI on carbon emission in the steel industry is presented in Table 4. The results exemplify that, except for the case of the Central region, per capita GDP of the national economy and the three regions has a significant positive impact on carbon emissions in the steel industry, among which the national and Western regions are significant at 1%, while in the Eastern region is significant at 5%. The elasticity of per capita GDP to carbon emissions in the steel industry is the highest in the entire Chinese economy (5.18), followed by that in the Eastern (4.46) and the

Western region (2.84). The impact of per capita GDP on carbon emissions in the steel industry is in line with 'prior' expectations, i.e. the expansion of demand causes production increases, resulting in higher carbon emissions. Because China is still in a rapid growth process, it is expected that its emission peak will not be reached until around 2030. In terms of Chinese steel industry, the existing findings do not support the traditional view of the EKC hypothesis. The level of environmental pollution first increases with income, then stabilizes, and finally declines.

For FDI, both the Central and Western regions are significant at 1%, while the national economy turns out to be significant at 10%, with that in the Eastern region not being significant. The impact of FDI on carbon emissions in the steel industry is negative in the case of the national economy and across all regions. This supports China's halo effect hypothesis, according to which FDI increases are conducive to reducing China's carbon emissions. The reason may be that China pays more attention to environmental issues over recent years, while the formulation and supervision of relevant environmental laws and regulations are stricter. Also, multinational companies may have more advanced technologies while spreading clean technology with less harm to the environment. Especially with the inflows of FDI, it may help promote the management of production technologies, professional technical skills and innovation, while such policies may also be indirectly or directly transferred to domestic companies. Therefore, an increase in FDI inflows reduces carbon emissions in the Chinese steel industry, while improving the country's environmental quality. The impact of FDI on carbon emissions in the Western region is also negative (-1.58), with increases in FDI inflows leading to reducing carbon emissions. It may be that the development of the Western region is relatively late, and the laws and regulations are relatively strict, especially under the current global temperature rises; multinational companies will tend to promote their green technologies to their counterparts in the Western region, leading to the reduction of carbon emissions. Furthermore, the Central region has carbon leakages and the pollution paradise hypothesis, because increases in FDI will lead to the rise of carbon emissions. Given that FDI is mainly used in carbon-intensive industries (Zhang, 2011), the only purpose of FDI is to maximize profits. Investments under this motivation will have a positive impact on economic growth and have a specific negative effect on the Central region associated with deteriorating environmental quality.

In terms of the other control variables, the urbanization rate in the national economy and the Eastern region is elastic, while the urbanization rate in the Central and the Western regions is significantly elastic (at 1%). However, with energy elasticity, the national economy, the Eastern region, the Central region and the Western region are elastic, while the energy structure is inelastic for the national economy, the Eastern and the Central regions and the Western region. Specifically, the urbanization rate has a negative impact on the Central region (-1.46), while it has a positive impact on the Western region (2.61); this may be because the growth rate of urbanization in the Western region is higher than that in the Central region (the average growth rate of urbanization in the region of the West is 103.34% in 2000-2015, while that in the Central region is 102.69%). The main reasons for this phenomenon are in the process of rapid urbanization, urban platoon the growth rate of large volume is faster than that of rural emissions, and the direct carbon emissions of urban and rural households continue to increase, resulting in the reduction of indirect carbon emissions of Rural Households (Li et al., 2015). Energy intensity has a positive effect, indicating that there are energy rebound effects in Chinese steel industry, including the direct rebound effect and the indirect rebound effect. Due to the rebound effect, the consumption of energy increases, leading to increases in carbon emissions. The rebound elasticity of the Western region is the largest (1.81). In contrast, for the national economy, the Eastern region and the Western region, per capita GDP has the largest carbon emissions in the steel industry, because under certain conditions, per capita GDP has the greatest elasticity. However, for the Central region, FDI has the greatest impact on carbon emissions in the steel industry, indicating serious carbon leakages, validating the pollution paradise hypothesis in the Central region.

<Insert Table 4>

4.2.3 The influence of economic growth and carbon emissions in the steel industry on FDI

The impact of GDP per capita and carbon emissions in the steel industry on FDI is shown in Table 5. GDP per capita and carbon emissions in the steel industry has a significant positive impact on FDI in the national economy and all three regions. In contrast, the impact of per capita GDP on FDI is higher than the influence of carbon emissions in the steel industry in the corresponding region on FDI (the coefficient is relatively large). It is worth noting that the research results show that per capita GDP increases by 1%, while FDI in the national economy and the Western region increased by about 2.06% and 1.73%, respectively, indicating that the FDI elasticity in these areas is higher than that of any other region. Especially compared with other regions, FDI has the highest contribution to economic growth in the Western region (1.73). Similarly, carbon emissions increased by 1%, and FDI in the national economy and the Western region increased by 0.41% and 0.67%, respectively, indicating that these FDI elasticities are higher than that in any other region. However, differently from per capita GDP, the elasticity of carbon emissions in the Western region is higher than that in the national economy, which may be due to the relatively backward energy-saving and emission reduction technologies adopted in the Western region. When carbon emissions rise, the dependence of the Western region on foreign investment is higher.

As far as other variables are concerned, industrialization has a significant negative impact on FDI at both national and regional levels. Apparently, with the rapid development of the economy and technology, the industrial structure's adjustment and the reduction of superior investment policies in recent years, it is getting more difficult for the steel industry as a low-end manufacturing industry to introduce foreign capital. In particular, the proportion of high-end technology in the steel industry is relatively small. With the rise of local enterprises in China, there is overcapacity in the steel industry. Moreover, the Chinese government attaches great importance to environmental issues, and the environmental costs and environmental requirements of Foreign Direct Investment Enterprises are significantly increased. Therefore, with the significant improvement of China's industrialization, the introduction of FDI is reduced considerably. Besides, the degree of dependence on foreign trade between the country and the Central region is flexible, while trade between the Eastern and Western regions is elastic. At the national level, the degree of dependence on foreign trade has little impact on FDI, but the degree of dependence on foreign trade has a significant positive impact on FDI for the Central region.

<Insert Table 5>

To sum up, the relationship between GDP per capita and carbon emissions in the steel industry and FDI are summarized in Table 6. The empirical results confirm a complete two-way correlation relationship of three variables in the whole country and the Western region, while the relationship in the Eastern region and the Central region is not complete (this research results verified the rationality of the hypotheses). There is no two-way relationship between carbon emissions and FDI in the Eastern region, while there is only a bilateral relationship between carbon emissions and FDI in the Central region. For a more precise presentation of the results, Figure 2 shows the direction of influence of the three variables.

<Insert Table 6>

<Insert Figure 2>

5. Conclusion and policy implications

This paper investigates the relationship between China's economic growth, carbon emissions in the steel industry and FDI, spanning the period 2000 to 2015. Based on the STIRPAT modelling approach, this paper combines the economic growth function, the carbon emission production function and the FDI function of Chinese steel industry, and discusses the main driving forces of carbon emissions in the steel industry. Given the regional division of the whole country, the national economy, the Eastern region, the Central region and the Western region are generated, compared and analyzed by using the simultaneous equation model. The empirical results documents a complete two-way relationship of three variables in the national economy and the Western region, while the relationship in the Eastern and the Central regions is not complete. There is no two-way relationship between carbon emissions and FDI in the Eastern region, while there is only a two-way relationship between carbon emissions and FDI in the Central region. Specifically, except for the Central region, carbon emissions and FDI in the steel industry in the economy and the three regions have a significant positive impact on per capita GDP. In contrast, per capita GDP across all cases significantly affects carbon emissions in the steel industry. FDI has a detrimental effect on carbon emissions in the steel industry in the national economy and the Western region but positively impacts the Central region. GDP per capita and carbon emissions in the steel industry significantly impact FDI across all cases. Finally, the impact of the urbanization rate, energy intensity and energy structure on carbon emissions is different across regions.

Based on the above findings, this paper gives policy recommendations to reduce carbon emissions of Chinese steel industry. More specifically:

(1) China needs to improve policy concerning foreign direct investment inflows further, provide relevant policy guidance, and implement appropriate policies. FDI plays a vital role in the Chinese economy, and its negative impact on the environment has attracted more attention from the Chinese government. Although FDI inflows promote rapid economic development, in the long run, environmental degradation will lead to the decline of economic activities, and eventually, to environmental degradation and the decline of economic quality. Therefore, it is imperative that China needs to pay more attention to attracting investments that can produce more technological effects and guide a large number of FDI. Besides, because large FDI inflows still exists in the field of high carbon emissions (Zhao and Yan, 2017), changes in the FDI inflow structure are very important, especially in the Central region; it is suggested that the central government should include as many high carbon industries as possible into the prohibited industries, while at the same time, make great efforts to ensure that relevant policies are fully implemented (Zhang and Zhang, 2018).

(2) China should speed up the optimization of its economic and industrial structure, vigorously promote tertiary industries' development. The results showed that the elasticity of GDP in the steel industry and the Eastern region was greater than that in the Western region, which is consistent with China's actual situation, that is, the industrial scale in the Eastern region is far larger than that in the Western region. It is suggested that the eastern region should transfer its energy-intensive industry and capital-intensive industry to the Western region. The eastern region should also optimize its industrial structure, actively develop high-tech industries and tertiary

industries, and reduce carbon emissions while maintaining rapid economic growth.

(3) Reducing energy intensity is not enough as a way to reduce carbon emissions. The government must consider and pay attention to the rebound effect and accurately measure energy intensity improvement measures' effectiveness. The reduction of energy intensity is expected to lead to an increase in energy demand, and the effect of energy-saving by improving efficiency will be lower than expected. The government should not aim at solely minimizing energy intensity. It should also minimize energy use. Therefore, while emphasizing energy intensity in the steel industry, policymakers should strengthen total carbon emissions by involving some form of energy tax and other incentive mechanisms.

(4) Regional urbanization planning should be different. For the Central region, local governments should speed up urbanization, attract talents through preferential policies, encourage technological innovation, and improve the technical level of strategic research. The Western region should effectively control real estate development and reduce steel consumption and corresponding carbon emissions. Meanwhile, by providing competitive wages and an attractive working environment, attracting top technicians and advanced energy-saving and emission reduction technologies, they can improve the urbanization rate and reduce carbon emissions simultaneously.

Due to the lack of data and the limited application of the model, this paper does not consider the impact of other factors (such as trade structure, technical advancement, fossil energy, etc.) on carbon emissions of Chinese steel industry. This may be a research direction in the future.

Appendix

<Insert Table A.1>

<Insert Table A.2>

<Insert Table A.3>

<Insert Table A.4>

Acknowledgements

We sincerely thank the anonymous reviewers and the Editor for many constructive suggestions, which significantly enhance our paper's exposition and scholarship. Meanwhile, thanks to Prof. Christopher F. Baum and Dr. Wanhai You for their advice and help in revising this paper.

Credit Author Statement

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Funding

This work was carried out with financial support from the National Natural Science Foundation of China (No. 71850012, 71790593), the National Social Science Fund of China (No. 19AZD014), the Major special Projects of the Department of

Science and Technology of Hunan province (No. 2018GK1020), and Hunan social science achievement review committee (No. XSP21YBC087).

Data availability

The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

Ethical approval This article does not contain any studies with human participants or animals performed by any authors.

Consent to participate Not applicable.

Consent to publish Not applicable.

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Tables

Table 1 Definition of explanatory variables and dependent variables in the 3SLS model of China's steel industry

Variable	Definition	Unit
CO_2	Carbon dioxide emission of the steel industry	Ten thousand tons
GDP	GDP per capita (the base year is 2000)	Yuan
FDI	Foreign direct investment	100 million
EI	Energy intensity of the steel industry	Tons of Standard coal/ton
URB	The urbanization rate	%
ENS	Energy structure of steel industry	%
IND	The industrialization rate	%
FTD	The Ratio of Dependence on Foreign Trade	%

Table 2 Division of 30 administrative regions in China

Region	Administrative division (Provincial, autonomous regional, and municipal)
Eastern Region	Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan
Central region	Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan
Western Region	Inner Mongolia, Sichuan, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi

Note: Due to the lack of data, the Tibet Autonomous Region is not included.

Table 3 Influence of FDI and carbon emissions of steel industry on per capita GDP (3SLS)

Dependent variable: GDP per capita

Variables	Constant	CO_2	FDI	URB	EI
The whole country	4.21***	0.18***	0.70***	-0.99***	-0.24***
Eastern Region	4.63***	0.23**	0.64***	-0.43**	-0.38**
Central region	-10.75	-2.13	3.40	-3.12	1.76
Western Region	4.72***	0.35**	0.57***	-0.94**	-0.63***

Note: *, * *, * * * represent 10%, 5% and 1% significant level respectively.

Table 4 Effect of GDP per capita and FDI on carbon emission of the steel industry (3SLS)

Dependent variable: carbon emission of the steel industry

Variables	Constant	GDP	FDI	URB	EI	ENS
The whole country	-22.59***	5.18***	-3.53*	4.93	1.37***	0.04
Eastern Region	-20.65***	4.46**	-2.88	1.90	1.69***	0.01
Central region	-5.28	-0.48	1.61***	-1.46**	0.83***	0.06
Western Region	-13.63**	2.84***	-1.58***	2.61***	1.81***	0.01

Note: *, * *, * * * represent 10%, 5% and 1% significant level respectively.

Table 5 The impact of GDP per capita and carbon emissions on FDI (3SLS)

Dependent variable: FDI

Variables	Constant	GDP	CO_2	IND	FTD
The whole country	-14.97***	2.06***	0.41***	-2.31***	-0.08**
Eastern Region	-3.72***	1.03***	0.13**	-0.57**	-0.04
Central region	-7.72***	1.53***	0.22***	-0.72***	0.43***
Western Region	-11.99***	1.73***	0.67***	-1.65**	-0.20

Note: *, * *, * * * represent 10%, 5% and 1% significant level respectively.

Table 6 Summary of the results of the relationship between GDP per capita, carbon emissions and FDI

	CO_2→GDP	FDI→GDP	GDP→CO_2	FDI→CO_2	GDP→FDI	CO_2→FDI	GDP↔CO_2	GDP↔FDI	CO_2↔FDI
The whole country	+	+	+	-	+	+	√	√	√
Eastern Region	+	+	+	×	+	+	√	√	×
Central region	×	×	×	+	+	+	×	×	√
Western Region	+	+	+	-	+	+	√	√	√

Note: + represents the existence of a positive relationship; **-** represents the existence of a negative relationship; ×represents no relationship; √ represents there is a bidirectional causal relationship between representatives.

Appendix

Table A.1 Data summary statistics for 3SLS regression analysis

Province	Statistics	CO_2	GDP	FDI	EI	URB	ENS	IND	FTD
Beijing	Minimum	0.04	8.07	5.18	-1.66	-0.25	3.10	-1.82	-0.12
	Maximum	4.39	9.56	6.70	0.39	-0.15	3.36	-1.36	0.53
	Mean	1.21	8.89	5.96	-0.94	-0.18	3.20	-1.57	0.26
	Stdev	1.48	0.48	0.36	0.65	0.03	0.07	0.15	0.17
Tianjin	Minimum	-0.69	7.44	4.95	-1.07	-0.33	3.64	-0.83	-0.82
	Maximum	0.88	9.44	7.18	-0.56	-0.19	3.89	-0.67	0.14
	Mean	0.29	8.46	6.18	-0.78	-0.26	3.74	-0.73	-0.23
	Stdev	0.60	0.67	0.68	0.12	0.05	0.07	0.05	0.29
Hebei	Minimum	0.01	8.53	4.35	-1.71	-1.34	3.83	-0.97	-2.45
	Maximum	1.42	10.02	6.13	-0.54	-0.67	4.07	-0.71	-1.79
	Mean	0.95	9.32	5.39	-1.28	-0.93	3.96	-0.83	-2.12
	Stdev	0.45	0.50	0.57	0.33	0.20	0.09	0.08	0.19
Shanxi	Minimum	-0.92	7.53	3.48	-2.87	-1.05	3.65	-1.46	-2.60
	Maximum	1.21	9.07	5.33	-0.44	-0.60	3.98	-0.65	-1.92
	Mean	0.78	8.39	4.54	-0.97	-0.81	3.80	-0.82	-2.38
	Stdev	0.54	0.52	0.61	0.58	0.14	0.10	0.21	0.22
Inner Mongolia	Minimum	-0.19	7.34	3.67	-0.54	-0.85	3.70	-1.71	-3.14
	Maximum	1.34	9.42	5.70	-0.08	-0.51	3.92	-0.70	-2.05
	Mean	0.77	8.47	4.91	-0.37	-0.67	3.82	-0.96	-2.60
	Stdev	0.54	0.72	0.73	0.17	0.12	0.08	0.27	0.42
Liaoning	Minimum	0.28	8.45	5.52	-1.43	-0.61	3.67	-1.36	-1.55
	Maximum	1.23	10.00	7.49	-0.80	-0.39	3.86	-0.74	-0.85
	Mean	0.77	9.28	6.51	-1.17	-0.50	3.76	-0.87	-1.14
	Stdev	0.32	0.54	0.72	0.19	0.07	0.06	0.15	0.22
Jilin	Minimum	-1.51	7.58	3.71	-1.07	-0.70	3.72	-1.37	-2.47
	Maximum	0.01	9.22	6.28	-0.44	-0.59	4.09	-0.67	-1.65
	Mean	-0.66	8.43	5.01	-0.89	-0.64	3.90	-0.93	-2.02
	Stdev	0.53	0.57	0.96	0.17	0.03	0.12	0.18	0.20
Heilongjiang	Minimum	-2.41	8.06	4.51	-1.47	-0.66	4.14	-1.30	-3.15
	Maximum	-0.86	9.52	5.85	-0.11	-0.53	4.39	-0.71	-1.60
	Mean	-1.39	8.83	5.11	-0.94	-0.60	4.25	-0.87	-2.29
	Stdev	0.53	0.50	0.44	0.36	0.04	0.08	0.15	0.55
Shanghai	Minimum	0.94	8.48	6.03	-1.10	-0.12	3.55	-1.26	-0.05
	Maximum	1.15	9.94	7.05	-0.93	-0.11	3.89	-0.82	1.97
	Mean	1.06	9.28	6.54	-1.02	-0.12	3.74	-0.97	0.41
	Stdev	0.07	0.48	0.31	0.05	0.00	0.12	0.13	0.46
Jiangsu	Minimum	-1.59	9.05	6.28	-1.12	-0.87	3.61	-1.19	-0.82
	Maximum	0.55	10.75	7.72	-0.92	-0.41	3.91	-0.67	0.04
	Mean	-0.24	9.95	7.22	-1.02	-0.62	3.77	-0.80	-0.37

	Stdev	0.70	0.56	0.43	0.06	0.15	0.10	0.13	0.29
Zhejiang	Minimum	-1.23	8.72	5.33	-1.14	-0.72	3.59	-2.39	-0.98
	Maximum	0.84	10.29	7.05	-0.84	-0.42	3.82	-0.72	-0.33
	Mean	-0.10	9.58	6.63	-0.99	-0.55	3.71	-0.94	-0.59
	Stdev	0.54	0.51	0.49	0.06	0.09	0.08	0.42	0.19
Anhui	Minimum	-1.58	7.97	3.33	-1.40	-1.27	3.80	-1.19	-2.38
	Maximum	0.11	9.61	6.74	-1.03	-0.68	4.08	-0.76	-1.80
	Mean	-0.66	8.79	5.16	-1.27	-0.95	3.95	-0.95	-2.04
	Stdev	0.59	0.55	1.16	0.10	0.19	0.09	0.15	0.19
Fujian	Minimum	-2.27	8.23	5.21	-0.98	-0.87	3.96	-1.55	-0.88
	Maximum	-0.08	9.90	6.17	0.04	-0.47	4.21	-0.83	-0.38
	Mean	-1.31	9.07	5.84	-0.55	-0.65	4.11	-0.92	-0.64
	Stdev	0.68	0.56	0.27	0.32	0.13	0.09	0.18	0.16
Jiangxi	Minimum	-1.54	7.60	2.93	-1.36	-1.28	3.71	-2.01	-2.86
	Maximum	0.57	9.27	6.38	0.34	-0.66	4.03	-0.76	-1.73
	Mean	-0.44	8.45	5.31	-0.76	-0.93	3.80	-1.01	-2.21
	Stdev	0.54	0.55	0.97	0.42	0.19	0.09	0.32	0.40
Shandong	Minimum	-0.78	9.03	5.75	-1.57	-0.96	3.72	-1.18	-1.41
	Maximum	0.52	10.71	6.92	0.87	-0.56	3.83	-0.65	-1.02
	Mean	-0.03	9.92	6.53	-1.02	-0.75	3.78	-0.78	-1.19
	Stdev	0.40	0.56	0.35	0.94	0.12	0.03	0.13	0.13
Henan	Minimum	-2.42	8.53	3.39	-2.38	-1.46	3.66	-1.51	-3.29
	Maximum	-1.20	10.14	6.91	-1.45	-0.76	4.02	-0.64	-0.23
	Mean	-1.60	9.36	5.31	-1.91	-1.07	3.85	-0.82	-2.60
	Stdev	0.43	0.54	1.25	0.30	0.22	0.12	0.23	0.72
Hubei	Minimum	-2.64	8.17	4.36	-3.77	-0.90	3.79	-1.27	-2.59
	Maximum	-1.41	9.82	6.32	-2.82	-0.56	4.03	-0.83	-2.07
	Mean	-1.97	8.99	5.42	-3.31	-0.76	3.93	-0.98	-2.32
	Stdev	0.46	0.55	0.58	0.34	0.12	0.08	0.13	0.17
Hunan	Minimum	-1.81	8.18	4.45	-1.19	-1.21	3.68	-1.91	-2.94
	Maximum	0.09	9.82	6.58	-0.69	-0.68	4.06	-0.87	-2.53
	Mean	-0.66	9.00	5.50	-0.97	-0.92	3.87	-1.09	-2.72
	Stdev	0.68	0.56	0.71	0.19	0.17	0.12	0.27	0.12
Guangdong	Minimum	-3.30	9.28	6.97	-3.00	-0.59	3.70	-1.14	-9.02
	Maximum	-1.37	10.90	7.43	-1.71	-0.38	4.09	-0.75	1.91
	Mean	-2.65	10.16	7.26	-2.61	-0.47	3.90	-0.85	-4.51
	Stdev	0.46	0.53	0.12	0.34	0.07	0.13	0.10	5.13
Guangxi	Minimum	-1.95	7.64	3.77	-1.43	-1.26	3.71	-1.86	-2.73
	Maximum	0.19	9.29	4.68	0.12	-0.75	4.12	-0.88	0.19
	Mean	-0.43	8.48	4.09	-0.63	-1.00	3.91	-1.13	-2.05
	Stdev	0.59	0.56	0.24	0.51	0.17	0.13	0.27	0.64
Hainan	Minimum	-7.03	6.27	3.86	-3.36	-0.87	3.47	-2.03	-1.60
	Maximum	-3.91	7.83	5.03	-0.91	-0.60	3.85	-1.50	0.41
	Mean	-4.97	7.06	4.37	-1.86	-0.74	3.67	-1.75	-1.12

	Stdev	0.87	0.52	0.36	0.76	0.09	0.13	0.16	0.48
Chongqing	Minimum	-2.20	7.49	3.35	-1.47	-1.10	3.63	-1.84	-2.60
	Maximum	-1.03	9.32	6.53	-0.30	-0.50	3.86	-0.91	-0.89
	Mean	-1.63	8.38	5.05	-0.86	-0.74	3.75	-1.09	-1.97
	Stdev	0.39	0.61	1.25	0.40	0.19	0.08	0.25	0.56
Sichuan	Minimum	-1.51	8.28	4.34	-1.21	-1.32	3.67	-1.78	-2.93
	Maximum	-0.10	9.96	6.57	-0.93	-0.74	3.86	-0.80	-1.86
	Mean	-0.62	9.13	5.39	-1.07	-1.02	3.78	-1.03	-2.28
	Stdev	0.47	0.57	0.93	0.09	0.19	0.07	0.25	0.33
Guizhou	Minimum	-0.97	6.94	2.05	-0.25	-1.43	3.81	-1.56	-3.21
	Maximum	0.09	8.62	5.10	0.42	-0.87	4.17	-1.03	-2.59
	Mean	-0.47	7.75	3.18	0.07	-1.20	3.99	-1.14	-2.86
	Stdev	0.34	0.55	1.00	0.21	0.19	0.12	0.12	0.18
Yunnan	Minimum	-1.49	7.61	1.68	-1.20	-1.45	3.66	-1.33	-2.60
	Maximum	0.11	9.12	5.23	-0.70	-0.85	3.87	-1.02	-1.95
	Mean	-0.40	8.34	3.60	-0.91	-1.13	3.73	-1.11	-2.23
	Stdev	0.52	0.50	1.25	0.15	0.19	0.06	0.09	0.22
Shaanxi	Minimum	-2.88	7.50	3.17	-2.39	-1.13	3.69	-1.48	-2.75
	Maximum	-0.93	9.27	5.66	-1.52	-0.62	4.00	-0.75	-2.27
	Mean	-1.77	8.40	4.45	-1.95	-0.88	3.85	-0.91	-2.47
	Stdev	0.71	0.60	0.80	0.32	0.17	0.10	0.19	0.13
Gansu	Minimum	-1.18	6.96	2.81	-0.92	-1.42	3.76	-1.46	-3.11
	Maximum	0.55	8.50	3.56	-0.41	-0.84	4.13	-0.93	-1.87
	Mean	-0.06	7.74	3.19	-0.60	-1.12	3.91	-1.10	-2.41
	Stdev	0.59	0.50	0.24	0.17	0.18	0.11	0.14	0.35
Qinghai	Minimum	-0.21	5.57	1.12	0.27	-1.05	2.90	-1.43	-3.31
	Maximum	1.23	7.27	3.16	0.83	-0.69	3.76	-0.72	-2.28
	Mean	0.60	6.45	2.34	0.56	-0.88	3.34	-0.97	-2.97
	Stdev	0.51	0.56	0.69	0.19	0.12	0.31	0.22	0.30
Ningxia	Minimum	-2.44	5.69	0.96	-0.97	-1.12	3.02	-1.39	-2.83
	Maximum	0.67	7.28	3.10	0.41	-0.59	4.24	-0.86	-1.85
	Mean	-0.61	6.50	2.29	-0.24	-0.82	3.69	-1.03	-2.29
	Stdev	1.07	0.53	0.56	0.37	0.16	0.45	0.13	0.31
Xinjiang	Minimum	-1.96	7.22	0.24	-1.95	-1.08	3.70	-1.34	-2.32
	Maximum	0.49	8.71	3.39	-1.28	-0.75	3.84	-0.87	-1.00
	Mean	-0.69	7.96	2.07	-1.53	-0.92	3.77	-1.06	-1.62
	Stdev	0.89	0.49	1.16	0.22	0.11	0.04	0.14	0.33
The whole country	Minimum	-7.03	5.57	0.24	-3.77	-1.46	2.90	-2.39	-9.02
	Maximum	1.48	10.90	7.72	0.87	-0.11	4.39	-0.64	1.97
	Mean	-0.63	8.63	5.01	-1.06	-0.76	3.81	-1.00	-1.85
	Stdev	1.36	1.03	1.56	0.81	0.30	0.23	0.28	1.42

Table A.2 The panel unit root test results

	Variable sequence	LLC		IPS		Fisher ADF		Fisher PP	
		intercept	intercept and trend	intercept	intercept and trend	intercept	intercept and trend	intercept	intercept and trend
Level value	CO_2	-7.92***	1.39	-1.61*	3.48	73.20	41.28	138.06***	49.40
	GDP	-17.14***	6.26	-6.28***	4.27	153.42***	30.63	54.59	24.17
	FDI	-4.28***	-13.92***	0.49	-4.52***	63.07	112.53***	61.49	84.67**
	EI	-1.58*	-3.27***	-0.39	-2.67***	68.36	88.15**	110.06***	163.24***
	URB	-6.11***	-4.26***	1.8344	0.82	57.26	53.16	203.19***	53.08
	ENS	1.70	-9.90***	6.91	-6.50***	11.72	133.27***	21.05	205.45***
	IND	2.85	6.53	-0.35	2.88	69.19	46.83	273.44***	216.30***
	FTD	-1.75**	-2.82***	-0.010	1.60	57.98	39.52	48.17	20.55
First-order difference	CO_2	-3.75***	-5.72***	-3.86***	-3.33***	113.36***	99.13***	203.078***	210.86***
	GDP	1.65	-5.40***	1.00	1.61	44.05	59.97	38.17	95.62***
	FDI	-14.57***	-9.97***	-9.40***	-6.02***	200.82***	150.67***	277.69***	276.57***
	EI	-7.87***	-6.39***	-9.57***	-5.62***	203.71***	136.45***	440.95***	345.51***
	URB	-4.84***	-4.52***	-2.83***	-1.43*	89.01***	78.22*	136.94***	172.96***
	ENS	-11.99***	-7.78***	-11.21***	-6.30***	231.97***	151.23***	440.62***	342.03***
	IND	-0.4	0.7800	-7.37***	-6.65***	168.06***	150.73***	489.54***	461.48***
	FTD	-7.08***	-9.15***	-5.69***	-4.64***	136.56***	130.96***	198.73***	244.02***

Note: *, * *, * * * represent 10%, 5% and 1% significant level respectively.

Table A.3 The overidentification test results

Interpretation	Value
Number of equations	3
Total number of exogenous variables in system	6
Number of estimated coefficients	13
Linear constraints / dependencies	3
Hansen-Sargan overidentification statistic	10.78
Under H0, distributed as Chi-sq(5), pval	0.06

Note: The pvalue exceeding 0.05 implies that we do not reject that null hypothesis at the 95% level of confidence (Any test of 'overid' has the null hypothesis that the instruments are suitably uncorrelated with the error terms.).

Table A.4 The serial correlation test results

	GDP	CO_2	FDI	EI	URB	ENS	IND	FTD
GDP	1	0	0	0	0	0	0	0
CO_2	-0.35	1	0	0	0	0	0	0
FDI	-0.99	0.35	1	0	0	0	0	0
EI	0.34	0.20	-0.34	1	0	0	0	0
URB	-0.65	0.09	0.65	-0.15	1	0	0	0
ENS	0.06	-0.03	-0.06	-0.13	-0.40	1	0	0
IND	-0.32	0.56	0.32	-0.05	0.16	0.16	1	0
FTD	-0.27	0.07	0.27	0.03	0.45	-0.26	-0.05	1

Figures

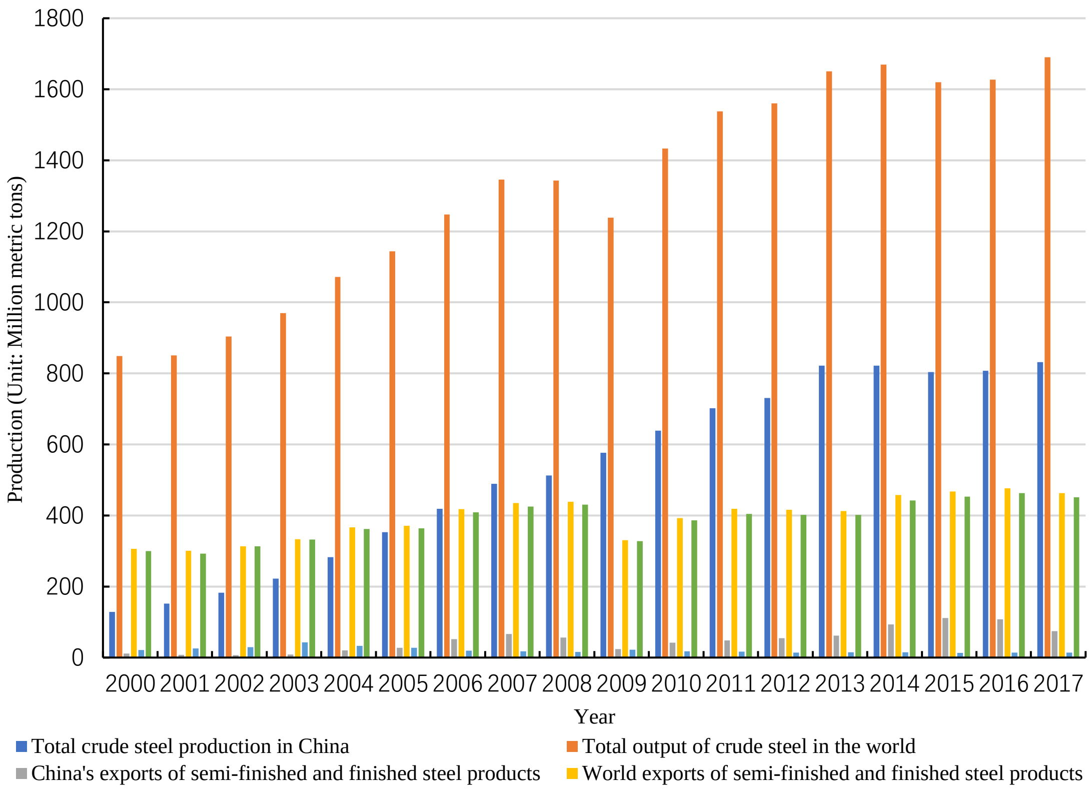

Fig. 1. 2000-2017 crude steel production and import and export volume in China and the world （Source: WSA, 2009, 2018）

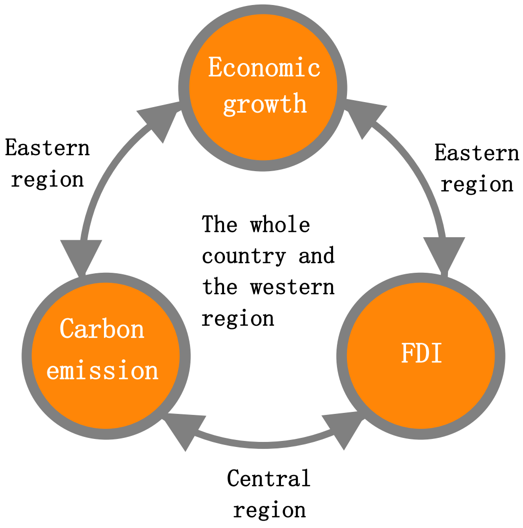

Fig. 2. The relationship between GDP per capita, carbon emissions and FDI