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Assessing CO_2 emissions in China's iron and steel industry: Evidence from quantile regression approach

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ABSTRACT

China is currently the largest carbon dioxide (CO_2) emitter in the world, and the iron and steel industry is the main contributor to the growth in CO_2 emissions. Most of the existing studies use the average estimation method to investigate the main drivers of CO_2 emissions in the iron and steel industry. However, the data distribution of economic variables is often not normal distribution, and the tail of the data hidden important information. In order to provide a realistic basis for emission reduction in this industry, this study uses the quantile regression model to explore the driving forces of CO_2 emissions under high, medium and low emission levels. The results show that the effect of economic growth on CO_2 emissions in the upper 90th quantile provinces is stronger than those in other quantile provinces due to the differences in fixed–asset investment and automobile production. However, the impact of energy efficiency in the upper 90th quantile provinces is lower than those in other quantile provinces. The influence of industrialization in the lower 10th quantile provinces is stronger than those in other quantile provinces. The influence intensity of energy structure has a similar story owing to the differences in coal consumption. Therefore, policymakers should focus on the heterogeneous effects of driving forces on CO_2 emissions in different quantiles during the process of carbon reductions.

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1. Introduction

Population growth and increasing human production activities emit large amounts of carbon dioxide (CO_2), leading to a gradual increase in global temperatures (Xu and Lin, 2017). The rising temperatures produce a series of undesirable consequences, such as rising sea levels, the damage of the ozone layer and the frequent occurrence of extreme weather events (De Silva et al., 2017). All these will have negative impact on the balance of the Earth's ecosystem, and even threaten human survival. China is currently the largest emitter of CO_2 (Xu and Lin, 2015), and CO_2 emissions reached 11.6 billion tons in 2015. Thus, China is facing increasing international pressure to reduce CO_2 emissions. It is well known that the industrial sector is the main source of energy consumption and CO_2 emissions, whether it is in China or in other countries of the world. Therefore, to explore the driving forces of CO_2 emissions of China's major industrial sector is of great significance.

As a pillar industry of the national economy, the iron and steel industry has enjoyed rapid growth along with economic development. According to the data in China Industry Economy Statistical Yearbook, pig iron production rose from 131.01 million tons in 2000 to 691.41 million tons in 2015. During the same period, crude steel and finished steel productions rose from 128.50 to 131.46 million tons to 803.83 and 1123.50 million tons respectively. The average annual growth rates of pig iron, crude steel and finished steel productions were 11.7%, 13.0% and 15.4% respectively, higher than that in real GDP in the same period. China is currently the largest iron and steel producer and consumer in the world (Xu and Lin, 2016a), accounting for nearly 50% of global steel output. In 2015, the iron and steel industry released 1.94 billion tons of CO_2, accounting for 16.7% of China's total CO_2 emissions. Consequently, in order to cope with increasingly severe environmental challenge in China, there is the need to pay attention to CO_2 emissions in the iron and steel industry. Identifying the key driving forces of the industry's CO_2 emissions is essential for formulating effective

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environmental protection and emission reduction policies.

This paper uses the quantile regression model to investigate the main driving forces of CO_2 emissions in the iron and steel industry. Compared to the traditional OLS estimation, quantile regression does not only improve the robustness of the model, but also reveal important information on the tail of the data distribution and obtain a fuller picture of the sample data, especially for non−normal distribution data (Zhu et al., 2016). Specifically, this article focuses primarily on two issues. Firstly, why does this article choose the quantile regression model to explore this industry's CO_2 emissions? Secondly, how do these driving forces affect CO_2 emissions under different quantiles?

The remaining parts of the paper are organized as follows. Section 2 briefly reviews the related literature and previous studies on CO_2 emissions in the iron and steel industry. Section 3 describes the applied method and sample data. Section 4 presents and discusses the empirical results. Section 5 offers conclusions, and policy suggestions are provided in Section 6.

2. Literature review

The existing literature has extensively studied CO_2 emissions in the iron and steel industry using different methods. The methods used in studying this industry's CO_2 emissions are basically divided into four categories. The first method is the index decomposition method. According to this method, the changes in the iron and steel industry's CO_2 emissions are often decomposed into fuel structure, emission factors, industrial structure, energy efficiency and economic activity. Using the Log mean Divisia Index (LMDI) method, Sheinbaum et al. (2010) explored the CO_2 emissions in Mexico's iron and steel industry between 1970 and 2006. The results showed that economic development led to an increase in CO_2 emissions, while economic restructuring, energy structure optimization and energy efficiency improvement were contribute to reducing CO_2 emissions. Tandon and Ahmed (2016) applied a structural decomposition method to investigate the role of production technology on energy consumption and CO_2 emissions in India's iron and steel industry. Their results indicated that production technology improvements could significantly reduce energy consumption and CO_2 emissions. The second method is the bottom−up method. Applying a bottom−up modelling, Karali et al. (2014) investigated the role of international carbon trade, product structure, and energy efficiency in mitigating the CO_2 emissions in the US steel industry. They reached the conclusion that importing steel products from China and India were helping to reduce CO_2 emissions in the US steel industry, and optimizing product mix and improving energy efficiency also had a favorable effect. Brunke and Blesl (2014) also used the bottom−up method to explore CO_2 emissions in the German steel industry, and found that the reduction effect of top gas recovery blast furnace technology was limited. Therefore, the iron and steel enterprises and related research institutions should increase the R&D of the new energy−saving and emission reduction technologies. The third method is the system optimization. Applying a nonlinear optimization method, Helle et al. (2011) got the opposite conclusion that top gas recycling technology was economically feasible, and could drastically reduce CO_2 emissions in the iron and steel industry. Similarly, De Oliveira Junior et al. (2016) examined the effect of the burner switching penalties and gas holders on energy saving in the steelmaking industry with a linear optimization method. The estimation results indicated that the application of these devices and technologies was conducive to energy conservation, thereby reducing CO_2 emissions. The fourth method is the econometric method. Using computable general equilibrium model, Schumacher and Sands (2007) analyzed the impact of electricity prices on the iron and steel industry. Their conclusions were that the rise in electricity prices would increase the cost of iron and steel production, and prompted the iron and steel enterprises to focus on the R&D of energy−saving technology. Moreno and da Silva (2016) investigated the impact of European financial subsidies, carbon trading, and stock returns on Spanish industrial sectors with a panel data model and found that carbon trading and stock returns were more conducive to monitoring emission reduction of the iron and steel industry.

China is now the largest producer of iron and steel products around the world, causing the iron and steel industry to consume lots of fossil energy and emit large amounts of CO_2. Thus, increasing scholars focus on the main driving forces of CO_2 emissions in China's iron and steel industry with different methods. Firstly, the decomposition method. Using the LMDI decomposition method, Liu et al. (2007) surveyed the changes in CO_2 emissions in China's 36 industrial sectors. They showed that industrial scale and energy intensity were the dominant factors of the growth in CO_2 emissions in the iron and steel industry, while the impacts of emission factors, fuel mix, and industrial structure were small. Wei et al. (2016) studied the impact of technological progress, economic structure, economical scale and sectoral relevance on CO_2 emissions in Beijing's steel industry with structural decomposition analysis. The empirical results indicated that economic scale was the main factor of the increase in CO_2 emissions; however, technological progress and economic structure optimization were conducive to reducing CO_2 emissions. Secondly, the bottom−up method. By employing a bottom−up model, Hasanbeigi et al. (2013) found that technological progress and energy structure optimization awere all potentials of energy−saving and emission reduction; hence, the government should adopt fiscal and tax policies to promote R&D of energy−saving technology and also ensure the development of new energy such as nuclear and biological. With a similar model, Chen et al. (2014) tried to predict the steel production and CO_2 emissions in China's iron and steel industry between 2010 and 2050, and found that iron and steel output would reach a peak point of 772 Mt in 2020. Thirdly, the system optimization method. Using a system optimization method, Chen et al. (2015) found that the recycling rate of residual energy and heat in China's steel industry was only 30%−50%, much lower than that in the developed countries such as Japan, the United States and Sweden. Lu et al. (2016) applied a production optimization model to measure the energy consumption and CO_2 emissions of different production modes in China's iron and steel industry. The results showed that the carbon reduction effect of ironmaking production optimization was much larger than that in the steel−rolling process optimization. Fourthly, the econometric method. By applying vector autoregression (VAR) model, Yu et al. (2015) explored the effects of economic growth, technological progress and investment activities on the CO_2 emissions in the iron and steel industry; they indicated that all these influencing factors had a positive effect on CO_2 emission. With panel data model, Xu and Lin (2016b) found that the effects of industrialization, energy efficiency, urbanization, and energy structure on CO_2 emissions in China's iron and steel industry had significant regional differences. Furthermore, Liang et al. (2016) applied spatial autocorrelation regression model to investigate the distribution of the iron and steel industry's CO_2 emissions in China's 31 provinces, the results indicated that CO_2 emissions had significant cluster and heterogeneous effects. Thus, they suggested that governments should take full account of the regional relevance of CO_2 emissions during the process of emission reduction.

Although many researchers have carried out fruitful studies on CO_2 emissions in the iron and steel industry, most researchers used the OLS method to analyze the impact of driving forces on CO_2 emissions. In fact, the impacts of the driving forces on CO_2 emissions under various quantiles are different. Compared with the

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