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Measurement of carbon emission impact factors and the choice of mitigation instruments: A review

Xiaoyin Xie

School of Economics and Management, Guangxi Normal University, Guilin, China
xiexiaoyin@stu.gxnu.edu.cn

Abstract: *Cutting-edge economics research is currently centered on and heated by concerns connected to reducing carbon emissions globally. China's carbon emission reduction policy plays a crucial role in addressing international climate change, controlling domestic environmental pollution, and achieving early peaking of carbon and carbon neutrality. This article reviews and compares research on the measurement of impact factors of carbon emissions and the selection of emission reduction tools. The first answers the question of what affects carbon emissions and the second answers the question of how to effectively achieve carbon emission reduction. By comparing the differences between various methods of decomposition of carbon emission impact factors and various abatement tools in terms of abatement effectiveness, abatement costs, and resistance to implementation, this article provides recommendations for the launch and operation of a national carbon emission market, which is of great significance. This article will provide a basis for timely adjustment of policy design in China and theoretical support for the government to select and develop carbon emission reduction instruments.*

Keywords: *Carbon neutrality, impact factors of carbon emissions, carbon trading, carbon tax*

1. Introduction

The excessive use of fossil fuels is the primary cause of global warming, which has drawn attention from all over the world. From the middle of the twentieth century, greenhouse gases (mostly carbon dioxide) emitted by human activity have been the primary cause of global warming, and they will inflict significant harm to the biological environment on which humans depend. Chinese academics have conducted considerable and in-depth studies on issues related to carbon emission reduction in recent years, as the subject of climate change has become a hot topic around the world. The question of whether and how China can meet its CO_2 reduction goals has been the subject of much discussion. These studies are based on the new concept of green development, grounded in Chinese reality, and aim to serve the great practice of Chinese economic and social development, focusing on the organic combination of theoretical rigour and policy inspiration.

Realistically, it is more urgent and difficult for China to achieve its carbon neutrality goal than for developed countries. To achieve the vision of carbon peaking and carbon neutrality, effective and scientific emission reduction policies are indispensable. China has actively taken various measures to reduce CO_2 emissions, such as gradually adjusting its energy and industrial structure, increasing investment in energy saving and emission reduction technologies, and using market instruments. In terms of efficiency of policy implementation and the effectiveness of emission reduction, existing studies tend to favor environmental policies based on market mechanisms and economic incentives rather than administrative command-based environmental regulation policies. The use of market mechanisms to decrease carbon emissions is more effective than traditional policies, and the selection of a reasonable market-based policy instrument is crucial to decreasing emissions.[1] Carbon trading is an effective tool to reduce greenhouse gas emissions through market mechanisms and has achieved great achievements in promoting the reduction of greenhouse gas emissions in China. However, carbon trading policies alone cannot effectively address all of China's carbon emissions, and there is an urgent need to seek other emission reduction policies or tools, such as a carbon tax.[2]

Currently, there are few systematic reviews of research on methods for measuring the impact factors of carbon emissions and the selection of carbon abatement tools. Most previous reviews have focused on summarizing the progress of a single method to measure the impact of carbon emissions or carbon reduction policies, rather than a comprehensive analysis. Furthermore, existing studies have not yet reached a unified conclusion on how to choose carbon emission reduction tools in China, and the

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questions of whether carbon emissions trading policies and carbon tax policies should be used in combination and how to balance the relationship between the two when using them need further investigation. To address these shortcomings, this article presents some suggestions for optimising emission reduction policies by reviewing recent studies on the decomposition of carbon emission impact factors and the selection of emission reduction tools, in order to provide theoretical references and decision-making bases for timely adjustment of mechanism design, strengthening the construction of carbon market, and realising the vision of carbon neutral carbon peaking as soon as possible.

This article selects relevant representative studies and presents three aspects from them: first, the decomposition of the factors influencing carbon emissions, which corresponds to the question of what affects carbon emissions; second, the choice of carbon reduction policy tools, which corresponds to the question of how governments can effectively achieve carbon reduction; and finally, the conclusion and research outlook.

2. Factors influencing carbon emissions

In the study of carbon emissions, it is necessary to measure the specific magnitude of the emission reduction effect of the different influencing factors. What are the specific factors that influence carbon emissions reductions? And what are the most important of these factors? Scholars have studied this in depth and in detail. The former includes structural decomposition analysis (SDA) and index decomposition analysis (IDA).

2.1. Structural decomposition analysis

The structural decomposition analysis (SDA) is a comparative static analysis method based on input-output models. Leontief and Ford[3] first used the structural decomposition method to study changes in air pollution emissions in the United States. Zhang[4] conducted a structural decomposition of the intensity of carbon dioxide emissions in China. The study found that China's carbon intensity fell by 66% between 1987 and 2007, with the fall in energy intensity contributing the most to the fall in carbon intensity, more than 90%, while the contribution of changes in energy mix was only about 1%. This means that technological advances in energy were the main reason for the decrease in China's intensity of carbon emissions.

2.2. Index decomposition analysis

The index decomposition analysis (IDA) has been widely used in the study of carbon emissions. Based on the Kaya constant equation and the logarithmic mean divisa index (LMDI) decomposition technique, it has undergone development in the direction from total carbon emissions to carbon emissions intensity.[5] However, the LMDI decomposition method has certain limitations. This means that only one absolute quantity factor can be considered. Therefore, Vaninsky[6] improved it and proposed a new exponential decomposition framework (index decomposition analysis, IDA). The exponential decomposition framework can quantify the influence of carbon emissions at a much finer level, and it has become the mainstream method for studying such issues. Wang et al.[5] based on the province dimension to decompose the intensity of carbon emissions in terms of energy intensity, energy structure and industrial structure. The findings are similar to those of Zhang.[4] The decrease in China's intensity of carbon emissions is mainly due to the decrease in energy intensity, which is consistent with China's excessive consumption of energy to promote economic development at that time. According to Tu[7], Kaya's constant equation does not distinguish between the production and non-production sectors. The author compared carbon dioxide emissions from thermal power generation companies with other industries to calculate carbon dioxide emissions of each industry more scientifically, and on this basis, the intensity of carbon emission is studied and similarly decomposed into other industries, proposing to promote the optimization of the industrial structure and energy structure, promote energy-saving technology development, and process innovation to follow a new industrialization path.

2.3. Econometric regression analysis

Econometric regression analysis was also used to examine factors influencing carbon emission reduction. Using panel data, Li and Qi[8] used static and dynamic panel models to investigate the relationship between trade openness and carbon dioxide emissions. The study found that trade openness led to an increase in carbon emissions and carbon intensity in Chinese provinces and regions, and that

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international trade had a negative impact on the Chinese environment. Shao et al.[9] examined the impact of the economic agglomeration and energy intensity on emission reduction using a dynamic spatial Durbin model using panel data at the provincial level in China from 1995-2016. The study found that the effect of economic agglomeration on carbon emission intensity showed an "inverted N" curve, while the effect of energy intensity on carbon emission intensity showed an "inverted U" curve. Guo et al.[10] examined the impact of digital economy on urban carbon emissions using panel data for Chinese cities from 2011 to 2019. The study found that the digital economy was able to reduce urban carbon emissions through technological innovation. On the other hand, Xu et al.[11] used the difference-in-difference (DID) method and the spatial Durbin model to study the spatial effects of the development of the digital economy on urban carbon emissions based on the analysis of the spatial evolution pattern of the digital economy and carbon emissions. The study found that the spatial spillover effect of digital economy development on carbon emissions peaks at 1100 km. This means that it varies in different economic circles. In addition to macro-data, an increasing number of researchers are using micro-data to study the impact of specific factors on carbon emissions. For example, Chen[12] combined a database of Chinese corporate pollution with a database of Chinese industrial firms and industry tariffs and found that lowering trade barriers led to a decrease in the intensity of coal. Furthermore, existing studies have focused on examining the effects of environmental regulation[13], low-carbon city pilot policies[14], smart city policies and innovative city policies[15] on reducing carbon emissions at the city level, exploring the effects of economic restructuring[16], low-carbon technological advances[17], industrial structure upgrading[18] and regional integration[19] on carbon emissions.

3. Policy tools to achieve carbon reduction

The vision of carbon peaking and carbon neutrality cannot be achieved without the development of effective and scientific policies to reduce emissions. Administrative policies may lead to significant emission reductions, but they may have a negative long-term impact on economic development. Therefore, existing studies tend to favor environmental policies based on market mechanisms and economic incentives, with emissions trading and carbon taxes being the main policy tools.

3.1. Carbon emission trading policy

Governments and academics have paid close attention to the effectiveness of carbon emissions trading policy as a strategy to decrease greenhouse gas emissions through market mechanisms, with most studies affirming the emission reduction effect of carbon trading mechanisms.[20] Since 2011, China has implemented carbon trading policies in eight industries (including the power, steel, petrochemical, building materials, chemical, article, aviation, and non-ferrous metal industries), using Beijing, Shanghai, Tianjin, Shenzhen, Chongqing, Guangdong, Hubei, and Fujian as the eight provinces and cities that will serve as the country's pilot regions. Regions and sectors are two crucial starting points for investigating the consequences of emission reduction.

On the regional front, on the regional level, there is a trade-off between overall efficiency and interregional equity when developing carbon emissions trading policies. On the one hand, the benefits of carbon emission trading policies on the reduction of carbon emissions vary according to the pilot regions. Prices for carbon emissions vary, and there are some variations in the scope and effectiveness of emission reduction due to the various levels of economic growth, industrial structures, methodologies and models used in each region.[21] To quickly identify their issues and offer solutions for the implementation and operation of the national carbon emission market, it is crucial to investigate the fundamental state of carbon emission trading policies in various pilot regions. According to research by Qiao and Duan[22], allocating carbon emission rights to developed regions would increase total corporate profits but widen regional disparities, whereas allocating carbon emission rights to developing regions would increase consumer welfare and total tax revenue, narrow regional disparities, and increase consumer welfare while lowering total corporate profits. Chen et al.[23] used a did model to analyse China's 2007-2016 panel data and found that the level of regional development was negatively related to the effect of carbon emission reduction. The most significant emission reduction effect was found in the western region, followed by the central and eastern regions. On the other hand, pilot regions had better emission reduction effects compared to non-pilot regions. Hu et al.[24] used a did method based on provincial industrial panel from 2005 to 2015 to analyze the benefits of reducing carbon emissions through carbon emission trading regulations. According to the findings, compared to the non-pilot areas, carbon emissions decreased in the pilot areas. It is crucial to improve the design of the carbon emissions trading policy and foster regional cooperation because the transfer of industries from the pilot areas to the non-pilot areas of the

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carbon emissions trading policy may also contribute to the increase in carbon emissions in the non-pilot areas. Depending on the circumstances of various provinces, such as their endowment of resources, industrial structure, and level of economic growth, specific emission reduction tasks must be developed.

At the sectoral level, the research framework on the effects of carbon trading mechanisms on emissions reductions in the energy, electricity, and industrial sectors is well established, with the construction and transport sectors receiving attention in recent years. As excessive CO_2 emissions from human activities are closely linked to the heavy use of carbon-based fuels, and sectors are intrinsically and extensively economically linked through the electricity system, research has therefore continued to focus on the impact of carbon trading mechanisms on curbing energy consumption and energy intensity and promoting energy restructuring.[25] According to a simulation analysis by Sun et al.[26], the introduction of a carbon price has a greater impact on total energy consumption in the energy sector than in the non-energy sector. The cost of carbon emissions contributed more than 80% of the change in unit energy use costs in all sectors.

The carbon emissions trading policy has made great achievements in promoting carbon emission reduction in China. However, carbon trading policies alone cannot effectively solve all the problems of China's carbon emissions, and there is an urgent need to seek other emission reduction policies or tools, such as carbon taxes. The carbon tax policy has been successfully applied in many countries as one of the effective tools to reduce carbon emissions. According to China's National Development and Reform Commission, after 2020, a carbon tax can be imposed on emission entities excluded from the carbon emissions trading market.[27] Although carbon trading policies are more effective than carbon tax policies in reducing emissions in the short term, they have a more significant potential to reduce emissions and lower abatement costs in the long term.[28] On the basis of China's increasing attention to carbon tax policies, the impact of carbon tax policies on carbon emission reduction in China must be assessed.

3.2. Carbon tax policy

The economic theory underlying environmental taxation is the Pigouvian tax. What environmental tax rate is appropriate and what the economic and environmental consequences are, are the focus of scholars studying environmental tax policy. Yang and Peng[29] studied the impact of the carbon tax on carbon leakage and international competitiveness from an international perspective. Their findings show that unilateral carbon tariffs not only reduce trade competitiveness, but also increase the carbon leakage rate and carbon emissions of countries, which is not conducive to climate change mitigation. Carbon tax collection should be coordinated internationally. Li[30] conducted a counterfactual analysis of carbon tax policies based on a multiregional input-output table in China in 2017, and found that carbon tax policies lead to fluctuations in China's manufacturing industry chain, and that under the framework of a carbon tax policy based on the value added of the industry chain, the existence of an optimal carbon tax rate makes the carbon tax policy have the least impact on China's manufacturing industry chain. Liu[31] argues that carbon tax has negative spatial spillover effects, there is a "pollution paradise" phenomenon, and that the carbon tax can reduce carbon emissions by improving energy efficiency and energy consumption structure. From a supply chain perspective, Zhang et al.[32] established a three-tier supply chain consisting of manufacturers, transporters and retailers, and argued that increasing the carbon tax rate would have different impacts on different types of supply chain with different carbon emissions, and that for clean supply chains, a higher tax rate would stimulate carbon emitting companies to increase their emissions reduction efforts, but for polluting supply chains, a higher tax rate would cause companies to increase their carbon emissions.

3.3. Comparison of the differences between carbon emissions trading policies and carbon tax implementation

3.3.1 Emission reduction effect

Carbon trading is a quantity-based tool in which the government sets the overall level of emissions while the market mechanism decides the price of carbon, mostly through the application of overall regulation. Through the distribution of carbon emission allowances, carbon trading programs can quantify emission reduction targets. Although the costs of emission reduction are highly unclear, the advantages of emission reduction are certain. This is because the price of carbon is highly uncertain. A carbon tax is a pricing-based policy where the government sets the price of carbon emissions, and the market determines the overall quantity of emissions. The costs of a carbon tax are somewhat predictable because of the tax rate, but the benefits of a carbon tax are very unknown. While carbon trading regimes

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can dramatically cut carbon emissions and GDP losses, a carbon tax would result in a lower GDP loss and less money spent on abatement. Based on a dynamic CGE model, Shi[33] built an energy-economic-environmental policy model for China, and designed different scenarios, including a single carbon tax, a single carbon emissions trading, and a combination of carbon tax and carbon trading, and simulated and analyzed the emission reduction effects, economic impacts, and abatement costs of different policies. The study finds that the carbon tax has the smallest GDP loss rate and low abatement costs; the carbon trading scenario has a higher abatement pressure on the mechanism-covered industries, which suffer from excessive shocks and higher abatement costs.

3.3.2 Implementation costs

While carbon tax costs are focussed on carbon pricing expenses, the costs of carbon trading plans are mostly associated with government governance costs. Although very adaptable in terms of emission reduction goals, market transparency, stage of economic development, and energy costs can all affect the cost of trading carbon allowances. A high level of uncertainty in the cost of abatement can result from the potential of price fluctuation. Even the EU ETS, which has a reasonably well-developed market economy, has seen pricing failures as a result of excessive allowance allocation and financial crises.[34] The implementation of a carbon trading strategy will use a lot of human, financial and other social resources as a market-based mechanism to reduce emissions. High implementation costs are associated with a carbon trading strategy, as it requires market monitoring, regulation, and the development of a relevant supporting infrastructure for the fair distribution of carbon credits. As opposed to a carbon trading program, a carbon tax would be more easily regulated and its implementation would be very transparent. The cost of abatement is predictable and the carbon tax rate is typically assessed based on the carbon content of fuel or other energy-related products. Enterprises can modify their manufacturing processes to select the best strategy to reduce emissions according to the tax rate.[35] However, carbon tax rates are difficult to determine, do not respond to market conditions in a timely manner, and lack flexibility. A high tax rate would increase the burden on businesses, with the end consumer or the actual 'taxpayer', potentially increasing the divide between rich and poor. Too low a tax will not motivate companies to reduce emissions, resulting in ineffective or inefficient regulation.[36]

3.3.3 Resistance to implementation

The long-term reduction in CO_2 emissions and the optimization of the economic structure depend heavily on the implementation of a carbon price policy. By imposing a carbon tax, the government may raise more money to invest in lowering carbon emissions. Businesses that have a high burden of emission reduction can receive varied percentages of tax income as subsidies from the government.[37] A carbon tax may result in higher costs for consumers to purchase products and services such as food, public transportation, energy, heat, water, and gas, as well as welfare losses. There may also be stronger opposition to its implementation, particularly among low- and middle-income households. As a result, proposals involving a carbon tax have a harder time being implemented. Yet, at the start of the carbon emissions trading policy's operation, the majority of allowances in the carbon market are distributed gratuitously, which does not raise the production costs of enterprises. Later in the process, enterprises convert to being more environmentally friendly through technology research and development, etc. The excess emission rights allowances can then be sold on the market. As a result, there is little opposition to the implementation of carbon trading laws, and enterprises are more likely to accept them.[38] The primary cause of the delay in the implementation of the carbon tax policy is that, compared to its benefits, the adverse effects of the carbon tax policy on China's current economic progress are intolerable.

3.4. International practice of coordinating and linking carbon emissions trading policies with carbon taxes

In terms of global carbon pricing practice, European countries, including the UK and Norway, American countries such as Canada and Mexico, Asian countries such as Japan and India, and Oceanian countries such as Australia have all adopted a hybrid policy of carbon markets and carbon taxes. In terms of coverage linkages, carbon markets and carbon taxes are highly complementary. In terms of carbon price linkage, the carbon market is connected to the carbon price of the carbon tax, which can effectively play a carbon pricing function.[36]

In conclusion, experts have concentrated on which policy is more appropriate for China's national conditions because there are disparities between carbon trading policies and carbon tax policies in terms of abatement costs. Some academics contend that a carbon tax policy is more appropriate given China's national circumstances[39], while others contend that a carbon trading policy is more appropriate given

China's current circumstances.[40] Still others contend that a combination of both policies is more appropriate given China's national circumstances and that such a policy may be a more practical means of reducing emissions.[41] Considering the initial pressure to implement, a carbon tax policy could be a complement to a carbon trading policy.

4. Conclusions

4.1. Conclusions

China's rapid economic growth in recent decades has been largely at the expense of excessive energy consumption, resulting in environmental problems such as excessive carbon dioxide emissions. Issues related to carbon emission reduction are currently the focus of attention and hot topics in frontier research in economics around the world. China's carbon emission reduction policy plays a crucial role in international climate change, domestic environmental pollution control, and the early achievement of carbon peaking and carbon neutrality.

This article reviews the methods for measuring the factors that influence carbon emissions and the latest developments in China's carbon emissions trading policy, carbon tax, and other carbon reduction policy tools. The former answers the question of what influences carbon emissions, the main methods being factor decomposition and econometric regression analysis; the latter answers the question of how to effectively achieve carbon emission reductions. Studies on carbon reduction policy instruments have found that choosing the right market-based policy instruments is the key to reducing emissions and that using market mechanisms to reduce carbon emissions is more effective than traditional policies. Carbon trading policies and carbon tax policies have great potential to reduce carbon emissions. The current carbon trading policy covers a limited number of sectors and, given the urgency of achieving peak carbon neutrality, a combination of the two policy instruments may be more appropriate for China's actual situation. In addition, it is important to compare carbon trading policies with carbon tax policies to provide recommendations for the launch and operation of a national carbon market. The research in this article can provide some theoretical and policy support for China to promote carbon emission reduction and carbon neutrality, and it can also provide experience for other countries with high carbon emissions but have not implemented carbon trading policies, as well as help promote the improvement of carbon emission reduction mechanisms in other countries with similar problems as China.

4.2. Research perspective

Based on the current state of research on carbon emission reduction in China, an outlook is presented on the future development of the carbon market.

Firstly, a national carbon market could expand its coverage. At present, the coverage of China's carbon market is limited. In terms of the sectors covered, the current carbon market covers few sectors and the Chinese carbon market only includes key sectors (electricity and heat production and supply). With the gradual improvement of the national carbon market, the types of greenhouse gases to be covered will become more comprehensive. In terms of coverage of enterprises, the carbon market covers large enterprises with high energy consumption, high emissions, and high pollution. In terms of coverage, the carbon market and carbon tax policy could include individuals when conditions are ripe, promoting "carbon reduction for all".

Secondly, carbon trading policies and carbon taxes can be used in conjunction with each other to provide incentives for emitters to reduce emissions and maximise the efficiency of emission reductions. Practice has shown that the combined use of these two policy instruments is more conducive to achieving emission reduction targets than their single use. At present, China's carbon emissions trading system is not perfect, and although China has not yet formally implemented a carbon tax policy, the introduction of a carbon tax has been included in policy discussions. When the carbon trading market fails, a carbon tax policy can be used as a supplementary means of reducing carbon emissions. Initially, a lower tax rate could be adopted to reduce resistance to the introduction of a carbon tax, and after a period of stable implementation, the tax rate could be gradually increased, with reference to the price set by the carbon market. Furthermore, the introduction of new carbon emission reduction policy tools, such as the carbon credit system and carbon finance, should be actively explored and the carbon finance market should be actively developed to speed up the development of carbon finance products.

Third, implement a differentiated carbon emission reduction policy. While playing the role of pilot

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areas as early demonstrators, each region should formulate differentiated carbon emission reduction policies according to its own stage and level of economic development, and appropriately tilt resources towards provinces with high emission reduction potential, so as to achieve high emission reduction at low cost. Establish and improve relevant supporting policies to achieve interconnectedness and coordinated development in reducing carbon emissions across sectors and regions.

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