



Effect mechanism of Chinese-style decentralization on regional carbon emissions and policy improvement: evidence from China's 12 urban agglomerations

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Abstract

Chinese-style decentralization has brought about the miracle of rapid economic growth for more than thirty years in China. However, with the implementation of the coordinated development strategy of economy and environment, it has set up obstacles to the decrease in regional carbon emissions. In this study, we clarified the effect of Chinese-style decentralization on regional carbon emissions. Then, we tested the effectiveness of emission reduction policies and their potential emission reduction spaces under the Chinese-style decentralization using the panel data of China's 12 urban agglomerations. The research results are: (1) Chinese-style decentralization affects regional carbon emissions mainly through factor market distortion, investment bias, and environment regulation. (2) Under the influence of Chinese-style decentralization, the effectiveness of emission reduction policies is not fully realized and shows significant spatial interaction. (3) 1% increase in political decentralization causes an 8.9% decrease in the effectiveness of executive order policy; 1% increase in fiscal revenue decentralization causes a 7.1% decrease in the effectiveness of carbon tax policy; 1% increase in financial decentralization causes a 10.6% decrease in the effectiveness of the cleaner production policy. (4) Collaborative governance of carbon emissions between regions is the direction of future emission reduction, and the redesign of emission reduction policies should be formulated based on the degree of regional synergy.

Keywords Decentralization system · Carbon emissions · Environment policy · Policy improvement · Impulse effect

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1 Introduction

Decentralization between the central and local governments (Chinese-style decentralization) is one of the main reasons for the miracle of rapid economic growth since the reform and opening up in China. However, under the Chinese-style decentralization, the performances of local governments are assessed based mainly on regional GDP, leading to the extensive economic growth (Song et al., 2020; Song et al., 2020). This in turn causes serious environmental pollution, especially the increase in carbon emissions (Zang & Liu, 2020). According to the *China Statistical Yearbook on Environment 2019*,¹ the total carbon emissions exceeded 11 billion tons in 2018. Compared with 2016, the carbon emissions and the carbon emission intensity increased by 2.7% and 0.49%, respectively. At the 2018 climate conference, China reiterated its goal that the peak of carbon emissions would be reached in around 2030 and the fossil energy would account for only 20% of the primary energy consumption. In China, the low-carbon transformation would be achieved in the process of industrialization and urbanization, which is different from the developed countries (Li & Xu, 2020). Moreover, as one of the largest carbon emitters (Li et al., 2019), China plays a very important role in the global challenge of emission reduction. Chinese president Xi Jinping clearly promised that the carbon emissions of per unit of GDP in China would decrease by 60–65% in 2030 compared with 2005 at the 2015 climate conference in Paris (Zhang et al., 2020a). According to the *China Statistical Yearbook on Environment 2020*,² the carbon emission intensity per unit of GDP in 2019 is \$970/ton, and the number was \$536/ton in 2005. However, there is still a 72% gap compared with the target promised in the Paris climate conference.

A fact is that China has made many attempts to reduce carbon emissions. In terms of energy saving, attempts include improving the technology of coal-fired power plants (high-efficiency pulverized coal boiler technology), shutting down enterprises with low production capacity, and upgrading the processes of metallurgical and cement industries. In terms of new energy, the growth rates of the installed capacity of the photovoltaic and wind power generations are ahead of the global level. It can be seen that China has made great efforts to reduce carbon emissions. With the transformation of the economic growth mode and the upgrading of industrial structure, urban agglomeration economy has become an important carrier of China's economic growth (Ouyang & Peng, 2018). The environmental Kuznets curve of China indicates that the carbon emissions are increasing in the urbanization. Therefore, reducing carbon emissions in the process of new urbanization is an important path for emission reduction in China. However, according to the *China energy statistical yearbook*,³ the energy consumption of per unit of GDP has increased by 13.2% from 2010 to 2019. The main reason for this is local government decision-making competition (Li & Xu, 2020), and the most essential reason behind this is Chinese-style decentralization. Therefore, it is of great significance for achieving the emission reduction goals to study the effect of Chinese-style decentralization on regional carbon emissions and put forward measures for improving the effectiveness of emission reduction policies.

There is no unified definition of Chinese-style decentralization at present. Fiscal decentralization is used to describe the Chinese-style decentralization in many studies,

¹ <https://www.yearbookchina.com/navibooklist-n3021040201-1.html>.

² <https://www.yearbookchina.com/navibooklist-n3020013264-1.html>.

³ <https://www.yearbookchina.com/navibooklist-n3020013309-1.html>.

defined as the decentralization of rights in tax between the central and local governments (Kuai et al., 2019). This definition ignores the decentralization of rights in personnel appointing and dismissing, which has a great impact on policy effectiveness (Taylor et al., 2019). This inaccurate definition of Chinese-style decentralization leads to that many studies have few practical contributions. Therefore, in order to comprehensively analyze the effect mechanism of Chinese-style decentralization on carbon emissions and improve the emission reduction policies, the Chinese-style decentralization is defined as the division of rights in political and economic affairs between the central and local governments in this study, including the political and economic decentralizations. Political decentralization is defined as the division of political rights between the central and local governments. Part of the rights in personnel appointing and dismissing and economic management are given to local governments by the central government. Economic decentralization is defined as the division of rights in economic resources allocation between the central and local governments, including the fiscal decentralization and financial decentralization. Under the fiscal decentralization, more autonomous rights in fiscal revenue and expenditure are given to local governments by the central government. Under the financial decentralization, market plays a decisive role in the allocation of financial resources, and local governments only have the regulation right. The fiscal and financial decentralizations interact with each other to regulate the macroeconomics. Sometimes they are in step with each other, and sometimes they have contradictions (Xiong & Shen, 2019).

At present, when analyzing the effect of decentralization on regional carbon emissions, on the one hand, only the fiscal decentralization is considered in most studies, and the political decentralization is neglected. Fiscal decentralization is only a part of the economic decentralization under the Chinese-style decentralization. Also, the financial decentralization is often overlooked. On the other hand, external environment is not considered in most studies, especially the urbanization, coordinated development, etc., which makes the research results impractical. To strengthen the regional emission reduction under the Chinese-style decentralization, it is important to clarify the connotation of decentralization, to analyze the effect mechanism of decentralization on regional carbon emissions in-depth, and to test the effectiveness of emission reduction policies and improve them. Only by this, can we put forward more practical and implementable solutions, rather than only giving theoretical analysis. Then, the effectiveness of regional emission reduction policies can be increased, and the regional emission reduction target can be achieved.

The research design of this study is as follows: first, starting from the decomposition of the influencing factors of carbon intensity, the effect mechanism of Chinese-style decentralization on regional carbon emissions is clarified. Second, the effectiveness of emission reduction policies and their potential emission reduction spaces under the Chinese-style decentralization are tested using the panel data of China's 12 urban agglomerations. Third, the emission reduction policies are redesigned and improved, and then, the practical and feasible emission reduction measures are proposed.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literatures and gives the originalities of this study. In Sect. 3, the effect mechanism of Chinese-style decentralization on regional carbon emissions is analyzed. In Sect. 4, the effectiveness of emission reduction policies and their potential emission reduction spaces under the Chinese-style decentralization are tested. In Sect. 5, we redesign the emission reduction policies to improve their effectiveness. Section 6 concludes this study.

2 Literature reviews

The governance of carbon emissions is essentially an issue of public goods, and the emission reduction policies and goals are closely related to the Chinese-style decentralization. China's decentralization is different from the decentralization of Europe and the USA, and it is ineffective to learn from their experiences. Recently, there are increasing studies analyzing the Chinese-style decentralization and carbon emissions, mainly focusing on the Chinese-style decentralization and environmental regulation, local government competition and regional carbon emissions, and the fiscal decentralization, and environmental policies.

Studies on the Chinese-style decentralization and environmental regulation mainly focus on the effectiveness of environmental regulation policies and their effecting factors under the Chinese-style decentralization. Zhang et al. (2017) believed that Chinese-style decentralization is the reason of the “green paradox” phenomenon of environmental policies. Pan et al. (2015) pointed out one reason for this. Under the Chinese-style decentralization, the weights of economy and environment in the performance evaluation system of local governments directly affect the decision-making of local governments. The existing performance evaluation system causes the “free riding” behavior of local governments in environment regulation (Cheng et al., 2020). In recent years, the Chinese government has gradually incorporated environmental governance into its assessment of local governments (Sun et al., 2020). Ahmed et al. (2020) and Khan et al. (2021) argued that Chinese-style decentralization affects carbon emissions through various channels such as institutions and human capital. Tian and Wang (2018) tried to explain the positive impacts of fiscal decentralization on CO₂ emissions from the perspective of land finance and urban infrastructure construction. Cheng et al. (2020) and Chen and Chang (2020) argued that this is due to ignoring that only under certain condition can Chinese-style decentralization affect carbon emissions, such as nonlinear, spatial relationship, and so on. Cheng et al. (2020) found that the direct impact of fiscal decentralization on CO₂ emissions is nonlinear, and the higher the per capita fiscal expenditure, the more fiscal decentralization can reduce CO₂ emissions (Cheng et al., 2020; Liu, Ding, et al., 2019; Liu, Luo, et al., 2019). Zhang and Chen (2018) found there is an inverted N-shaped relationship between local government competition and environmental regulation, and the essential reason for this is that the implementation of the environmental regulation policies is influenced greatly by the Chinese-style decentralization. Feng et al., and and's (2019) research shows that Chinese-style fiscal decentralization leads to the distorted fiscal expenditure and then, is accused of causing environmental degradation. Wu et al. (2020)' research shows that the improvement of environmental decentralization can lead to negative moderating effect of environmental regulation on China's green total factor energy efficiency. With the further expansion of environmental decentralization, the local government' autonomous choice of pollution control is improved. Yang, Tang, et al. (2021), Yang, Yan, et al. (2021), Yang, Yang, et al. (2021)) explored the moderating mechanism of Chinese-style fiscal decentralization on the relationship between environmental regulations and carbon emissions using longitudinal data of 30 provinces in China from 2002 to 2017. They found that this moderating effect is not significant for the entire country as a whole, and there are significant spatial regional differences in this moderating effect. Yang, Tang, et al. (2021), Yang, Yan, et al. (2021), Yang, Yang, et al. (2021)) compared the effects of centralized and decentralized governance on the efficiency of environmental regulation based on a two-level principal-agent model. Their results suggest that under decentralized

environmental governance, the local governments' incentives increase, which results in either "race to the top" or "race to the bottom" competition in environmental regulation. Xia et al. (2021) found that the promotion pressure of officials plays a positive role in moderating the impact of fiscal decentralization on carbon emissions, and at the same time weakens the suppression of carbon emissions by environmental decentralization. Du and Sun (2021)'s empirical research shows that biased technological progress determines the direction of the impact of Chinese-style fiscal decentralization on carbon emissions. Song, Bian, et al. (2020), Song, Chen, et al. (2020)) studied the cooperation in environmental governance between local governments under the Chinese-style decentralization and found that it mainly depends on the fiscal revenue and risk attitudes of local governments.

Studies on the effect mechanism of government competition on carbon emissions under the Chinese-style decentralization mainly analyze the mediator and moderator effects of tax, investment, technological progress, environmental policies, and some other key factors. Khan et al. (2018) believed that there is an inverted U-shaped trend between environmental regulation and low-carbon economy under the moderator effect of local government competition, and the threshold value is closely related with environmental regulation (Yang et al., 2018), industrial structure (Feng et al., 2019), and technological innovation (Chen et al., 2019). He and An (2019) analyzed the relationships between environmental regulation, factor productivity, and local government competition using the panel data of China's 30 provinces of 2001–2015. Their research shows that the economic competition between local governments and the promotion game between local officials intensify the vicious competition between regions. Local governments develop regional economies at the expense of environment deterioration. Renner et al. (2018) and Farajzadeh (2018) studied the effect of carbon taxation on carbon emissions at the household consumption level in Mexico and Iran, respectively. They found that carbon taxation could effectively reduce carbon emissions in the short term. In the long term, a low-carbon consumption habit is more effective. Ouyang et al. (2019) pointed out that fiscal decentralization has a threshold effect on the influence of FDI on technology spillovers, leading to that cities with different levels of fiscal decentralization have different technology spillovers. Shi and Shen's (2013) research shows that, as local governments have free riding tendency in environment governance, industrial agglomeration cannot have the expected increasing scale effect on energy efficiency, and there is a U-shaped relationship between energy efficiency and urban density.

Studies on fiscal decentralization and environment policies mainly focus on their relationship and the analysis of the effect mechanism. Some scholars study the nonlinear relationship between fiscal decentralization and carbon emissions from different aspects (Ji et al., 2021). Khan et al. (2021) found that there is an inversed U-shaped relationship between fiscal decentralization and emission reduction effectiveness based on the empirical analysis of Chins' 28 provinces of 1995–2012, but the threshold value is not given. Liu, Ding, et al. (2019), Liu, Luo, et al. (2019)) verified the nonlinear relationship between fiscal decentralization and carbon emissions. According to Du and Sun (2021), fiscal decentralization reduces carbon emissions in areas with higher environmental technology level but increases carbon emissions in areas with higher energy-biased technology progress in China. Luo and Wang's (2017) research shows that the increase in fiscal decentralization causes a decline in ecological efficiency. In the eastern regions with higher degree of fiscal decentralization, the space spillover effect is significant. Peng et al. (2019) pointed out that fiscal decentralization has a positive promotion effect on the implementation efficiency of environmental regulations in China, and there is a synergistic effect between them. Cheng

et al. (2020) studied the effect of fiscal decentralization on carbon emissions using China's provincial data of 1997–2015. They found that the direct effect is nonlinear and that the fiscal expenditure per capita has a significant moderator effect.

In summary, these studies have four characteristics. First, only the effect of fiscal decentralization on carbon emissions is analyzed in most studies. However, fiscal decentralization is a part of the economic decentralization. The effects of political and financial decentralizations are not studied. Second, the effect mechanism of fiscal decentralization on carbon emissions is mostly analyzed from the perspective of fiscal revenue (tax, land finance, etc.), while the effect from the perspective of fiscal expenditure (fiscal investment, regional development policies, etc.) is rarely included. Third, the relationship between decentralization and carbon emissions is analyzed empirically in most studies, mainly testing the shape and direction of their relationship. There is less theoretical analysis on the effect mechanism. Fourth, most researches only focus on the policy enlightenments at the macro-level, without testing the effectiveness of emission reduction policies or redesigning them. Practical and feasible measures are not proposed.

In this study, there are three originalities: first, about the effect mechanism of Chinese-style decentralization on regional carbon emissions, we do not test whether the influence is positive or negative. Through decomposing the Kaya formula of carbon emission intensity, the effect mechanism is studied from the aspects of political, fiscal, and financial decentralizations. Second, considering the influence of Chinese-style decentralization, the effectiveness of emission reduction policies and their potential emission reduction spaces are tested using the panel data of China's 12 urban agglomerations. Third, to avoid the negative effect of Chinese-style decentralization, we redesign and improve the emission reduction policies and put forward practical emission reduction measures to increase the effectiveness of regional emission reduction policies.

3 Analysis of the effect mechanism

When analyzing the effect of Chinese-style decentralization on regional emission reduction, either the theoretical mechanism or the empirical relationship is analyzed in most studies. Theoretical analysis can explain the internal effect mechanism, and the empirical test can reflect the actual situation. In this study, combining the advantages of the two aspects, starting from the influencing factors of carbon emissions, the theoretical analysis and empirical test are combined to conduct the analysis, which makes this research more cautious and effective.

3.1 Theoretical analysis of the effect mechanism

3.1.1 Methodology

Methods of efficiency analysis, empirical test, and production function analysis are usually used to explain the effect mechanism of decentralization on emission reduction. The empirical test method is relatively intuitive, but the prerequisite is to know the influence relationship between variables. The production function analysis method is relatively comprehensive, but it is difficult to obtain the data, and the calculation error is large. The efficiency analysis method is based on the carbon emission efficiency. IDA and PDA are two methods commonly used to decompose the influencing factors of efficiency. The definitions of the decomposition

components of IDA are intuitive, and it is essentially an economic accounting method. The decomposition of PDA bases on the production theory, which provides a better economic explanation for the changes caused by input variables. In this study, the direct input variables that affect carbon emissions are to be found, and the relationships between them and the decentralization are to be analyzed. Therefore, to measure the impacts of the driving factors more accurately, a two-stage decomposition model combining the IDA and PDA is built to decompose the carbon emission efficiency.

(1) The first stage of decomposition: IDA model

The Logarithmic Mean Divisia Index (LMDI) method is used to decompose the carbon emission intensity.

$$CI^i = \frac{CQ^i}{GDP^i} = \frac{CQ^i}{E^i} \times \frac{E^i}{GDP^i} = \frac{CQ^i}{GDP^i} \times \frac{\sum_k E_k^i}{\sum_k Y_k^i} = \frac{CQ^i}{GDP^i} \times \sum_k \left[\frac{E_k^i}{Y_k^i} \times \frac{Y_k^i}{\sum_k Y_k^i} \right] = CC^i \times \sum_k [EI_k^i \times y_k^i]$$

where CQ is the carbon emissions; CI is the carbon emission intensity; k is the three industries; i is the regions; CC^i is the influence of changes in energy structure on carbon emission intensity in region i ; EI_k^i is the influence of changes in energy intensity of industry k on carbon emission intensity in region i ; y_k^i is the ratio of the total production of industry k to the GDP of region i , representing the influence of changes in industry structure on carbon emission intensity.

The carbon intensity is decomposed using the LMDI method. The increase in carbon intensity is:

$$\begin{aligned} \Delta CI_{i,k} &= \Delta CI_{i,k}^{cc} + \Delta CI_{i,k}^{ei} + \Delta CI_{i,k}^y \\ &= \sum_k L(W_{k,\tau}^i, W_{k,t}^i) \ln(CC_{k,\tau}^i / CC_{k,t}^i) + \sum_k L(W_{k,\tau}^i, W_{k,t}^i) \ln(EI_{k,\tau}^i / EI_{k,t}^i) \\ &\quad + \sum_k L(W_{k,\tau}^i, W_{k,t}^i) \ln(y_{k,\tau}^i / y_{k,t}^i) \end{aligned}$$

where L is the weight function, Δ is the increment function.

$$L(x, y) = \begin{cases} (x - y) / (\ln x - \ln y), & x \neq y \\ x, & x = y \end{cases}$$

where $W_{k,\tau}^i = CC_{k,\tau}^i \times [EI_{k,\tau}^i \times y_{k,\tau}^i]$, $\Delta CI_{i,k}^{cc}$ is the changes in carbon emission intensity caused by changes in energy structure; $\Delta CI_{i,k}^y$ is the changes in carbon emission intensity caused by changes in economic structure; $\Delta CI_{i,k}^{ei}$ is the changes in carbon emission intensity caused by changes in energy efficiency.

Changes in energy intensity are also affected by technological progress, scale efficiency, and changes in input factors. In the IDA model, these influences are not stripped out completely. Therefore, in the next stage, we will further decompose the changes in energy intensity.

(2) The second stage of decomposition: PDA model.

The PDA model is built based on the Shephard production distance function. Considering the heterogeneity of production technology between different industries, the production distance function of industry k is set based on the following production technology set:

$$K_{k,t} = \{ (K_{k,t}, L_{k,t}, E_{k,t}; Y_{k,t}) : (K_{k,t}, L_{k,t}, E_{k,t}) \text{ has a production of } (Y_{k,t}) \}$$

where $K_{k,t}$ is the capital input, $L_{k,t}$ is the labor input, and $Y_{k,t}$ is the output. The production technology set T in the production distance function satisfies the standard hypothesis. The production distance function of industry k in region i at period t is defined as:

$$D_{k,t}^i(K_{k,t}, L_{k,t}, E_{k,t}, Y_{k,t}) = \inf \{ \theta : (K_{k,t}, L_{k,t}, E_{k,t}, Y_{k,t} / \theta) \in T_{k,t} \}$$

The production distance function in two different periods (t and τ) is:

$$D_{k,\tau}^i(K_{k,t}, L_{k,t}, E_{k,t}, Y_{k,t}) = \inf \{ \theta : (K_{k,t}, L_{k,t}, E_{k,t}, Y_{k,t} / \theta) \in T_{k,\tau} \}$$

Therefore, the decomposition of changes in energy intensity of industry k in period t and τ is:

$$\begin{aligned} \frac{EI_{k,\tau}^i}{EI_{k,t}^i} &= \left[\frac{E_{k,\tau}^i / (Y_{k,\tau}^i / D_{k,\tau}^i)}{E_{k,t}^i / (Y_{k,t}^i / D_{k,t}^i)} \times \frac{E_{k,\tau}^i / (Y_{k,\tau}^i / D_{k,\tau}^i)}{E_{k,\tau}^i / (Y_{k,t}^i / D_{k,t}^i)} \right]^{\frac{1}{2}} \times \left(\frac{D_{k,\tau}^i}{D_{k,t}^i} \right)^{-1} \times \left(\frac{D_{k,t}^i}{D_{k,\tau}^i} \times \frac{D_{k,t}^i}{D_{k,\tau}^i} \right)^{-\frac{1}{2}} \\ &\equiv PEC_k^i \times \frac{1}{EFF_k^i} \times \frac{1}{TEC_k^i} \end{aligned}$$

where $PEC_k^i = \sqrt{\frac{D_{k,\tau}^i \times E_{k,\tau}^i}{Y_{k,\tau}^i}}$.

Replacing the effect of energy intensity in the formula of carbon intensity decomposition with the decomposition result of energy intensity.

$$\Delta CI_{i,k}^{ei} = \Delta CI_{i,k}^{pe} + \Delta CI_{i,k}^{eff} + \Delta CI_{i,k}^{te}$$

where $\Delta CI_{i,k}^{pe} = \sum_k L(W_{ik}^\tau, W_{ik}^t) \ln PEC_{i,k}$, $\Delta CI_{i,k}^{eff} = \sum_k L(W_{ik}^\tau, W_{ik}^t) \ln \frac{1}{EFF_{i,k}}$, $\Delta CI_{i,k}^{te} = \sum_k L(W_{ik}^\tau, W_{ik}^t) \ln \frac{1}{TEC_{i,k}}$.

Combining the decomposing results of IDA and PDA, $\Delta CI_{i,k} = \Delta CI_{i,k}^{cc} + \Delta CI_{i,k}^{pe} + \Delta CI_{i,k}^{eff} + \Delta CI_{i,k}^{te} + \Delta CI_{i,k}^y$.

3.1.2 Analysis of the effect mechanism of investment bias

(1) $\Delta CI_{i,k}^{eff}$ represents the influence of changes in scale efficiency on carbon emission intensity under the Chinese-style decentralization. Regional financial factor is one of the key factors promoting regional economic development. According to the research of Wu (2017), as the hidden debt of local government increases, the financial pressure of local government becomes an important factor affecting the promotion of officials. Local officials tend to make up for the fiscal deficit by allocating the local financial resources purposefully, giving enterprises with high-tax and high-emission more credit funds. The increase in credit funds encourages these enterprises to expand their production scale, generating more carbon emissions. This is consistent with the research results of Zhou and Li (2020). What is more, with the increase in regional unemployment pressures, local governments make full use of the role of finance in promoting employment. When the regional unemployment pressure is great, more financial resources are purposefully allocated by the local governments to the labor-intensive industries, which have the characteristic of high emissions. This is consistent with the research of Liu, Ding, et al. (2019), Liu, Luo, et al. (2019)).

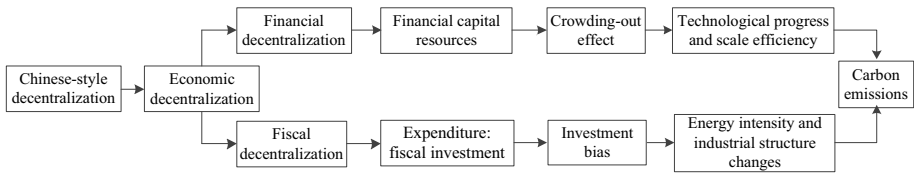


Fig. 1 The effect mechanism of investment bias

(2) $\Delta CI_{i,k}^{cc}$ represents the influence of energy structure on carbon emission intensity under the Chinese-style decentralization. The traditional theory of political decentralization believes that, to gain more votes from the people, local governments tend to invest in public services under the dual pressures of “voting by hand” and “voting by foot”. However, in China, the appointment and promotion of local officials are decided mainly by the higher-level governments, and people have no right in it. Therefore, it is difficult for local officials to make decisions based on the needs of people under the effect of political decentralization (Zhao et al., 2021). Moreover, because the performances of local governments are assessed bases on regional GDP, investment in emission reduction by local governments is insufficient, and the improvement of energy structure lacks endogenous motivation. According to the research of Yang, Tang, et al. (2021), Yang, Yan, et al. (2021), Yang, Yang, et al. (2021)), local officials tend to invest the resources brought by political decentralization in productive areas that can produce benefits in a relatively short period rather than in environment protection. The effect mechanism of investment bias is as shown in Fig. 1.

3.1.3 Analysis of the effect mechanism of factor market distortion

(1) $\Delta CI_{i,k}^{pe}$ represents the influence of changes in input factors on carbon emission intensity under the Chinese-style decentralization. Under the economic decentralization, to pursuit rapid economic growth, local governments actively decrease the prices of labor, resources, and capital and make more production factors flow into the labor- and resource-intensive industries, which are generally low-end manufacturing. This increases the production scale of low-end manufacturing (Li & Liu, 2020) and then, causes the increases of energy consumption and carbon emissions in the short-term (Chen et al., 2020). For industries with poor production competitiveness that should be eliminated in market competition, factor market distortion can make up for their production losses or even make profits, thereby avoiding being eliminated in competition. Increase in energy consumption by industries with poor production competitiveness accelerates the regional carbon emissions (Li & Deng, 2018). Moreover, factor market distortion also causes the “short-term behavior” of enterprises. Enterprises decrease or even have no investment in R&D, which leads to no increase in energy intensity and then causes the acceleration of carbon emission increase.

(2) $\Delta CI_{i,k}^{eff}$ represents the influence of changes in scale efficiency on carbon emission intensity under the Chinese-style decentralization. Regional financial factor is one of the key factors promoting regional economic development. Under the influence of promotion psychology and the limited term of work position, local officials are more willing to pursue short-term economic benefits, and some industries with high emissions are expanded and developed, resulting in the increase in regional carbon emissions. Moreover, after the deepening reform of China’s financial system, it is the local governments rather than the central government that manage the state-owned commercial banks

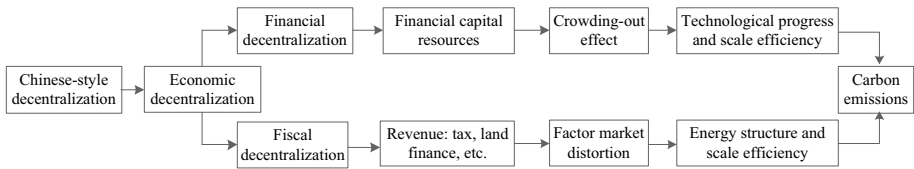


Fig. 2 The effect mechanism of factor market distortion

vertically. According to the research of Qu et al. (2021), local governments promote the short-term economic growth in their jurisdictions by controlling the flow of local financial resources. Scale expansion leads to an increase in carbon emissions.

(3) $\Delta CI_{i,k}^t$ represents the influence of pure technology progress on carbon emission intensity under the Chinese-style decentralization. With the development of economy, finance has become an important factor of economic growth. Driven by “profit-seeking,” financial resources begin to gather in regions with high levels of economic development and geographical advantages. According to the research of Chen et al. (2021), the financing channels of enterprises expand with the increased mobility of financial resources. Moreover, the agglomeration of financial resources also attracts a large number of talents, which fills the needs of talents in the rapid expansion of enterprises. This could promote the technological innovation, improve the production efficiency, and accelerate the transformation of enterprises from labor-intensive to technology-intensive. The increase in regional carbon emissions is suppressed effectively. This is consistent with the research results of Usman et al. (2021). The effect mechanism of factor market distortion is as shown in Fig. 2.

3.1.4 Analysis of the effect mechanism of environment regulation

$\Delta CI_{i,k}^y$ represents the influence of changes in economic structure on carbon emission intensity under the Chinese-style decentralization. The excessive and biased investment of local governments under the promotion incentive suppresses the upgrading of regional industry structure and the technological progress directly and indirectly, which in turn leads to an increase in regional carbon emissions. Because of the mutual squeeze between the fiscal expenditures in environmental governance and economic growth, local governments need to make choices between environmental governance and economic growth (Shen & Zhou, 2020). In order to promote the regional economic growth and increase their fiscal revenue, local governments tend to attract the investment with high economic benefits through fiscal subsidies, tax reductions, and some other preferential measures. These investments often have high energy consumptions and carbon emissions (Lu & Yang, 2019). This kind of biased investment leads to that the investment in environment governance is insufficient and the regional carbon emissions increase continuously. Moreover, due to the positive externalities of environment governance, there exists the phenomenon of “free riding.” Local governments are unwilling to pay the cost of environment governance, but they all want to enjoy the positive results of environment governance. The “free-riding” behavior of local governments leads to the insufficient expenditures in environment governance (Du et al., 2019). Thus, the efficiency of environment governance is low and the regional carbon emissions continue to increase. The effect mechanism of environment regulation is as shown in Fig. 3.

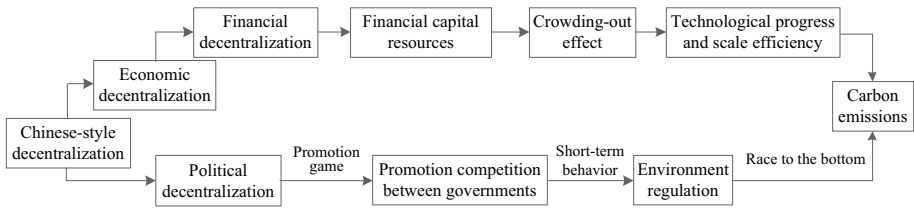


Fig. 3 The effect mechanism of environment regulation

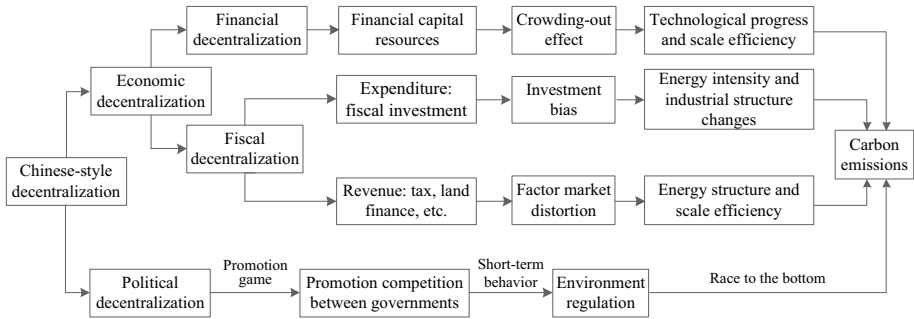


Fig. 4 The effect mechanism of Chinese-style decentralization on regional carbon emissions

In summary, the Chinese-style decentralization affects regional carbon emissions mainly through investment bias, factor market distortion, and environment regulation, and the effect mechanism is as shown in Fig. 4.

3.2 Empirical evidence

3.2.1 Materials and methods

(1) Model.

Based on the theoretical analysis above, Chinese-style decentralization affects regional carbon emissions mainly through three paths. To compare the effects of the three paths in different regions, the panel data model is chosen to do the empirical analysis.

$$CQ = b_{j0} + \sum_{j=1}^{13} \sum_{i=1995}^{2019} b_{ji}x_{ji} + m_t$$

$$m \sim IID(0, s^2); j : 1 - 3; t : 1 - 25;$$

$$x_1 - x_{13} : I, Fac, Regu, U, PD, FDI, FDE, FD, EI, ES, PS, PT, SE, TE$$

where *CQ* is the regional carbon emissions, *I* is the investment bias, *Fac* is the extent of factor market distortion, *Regu* is the environment regulation, *U* is the urbanization, *PD* is the political decentralization, *FDI* is the fiscal revenue decentralization, *FDE* is the fiscal expenditure decentralization, *FD* is the financial decentralization, *EI* is the energy intensity, *ES* is the energy structure, *PS* is the proportion of the second industry, *PT* is the

proportion of the tertiary industry, SE is the scale efficiency improvement, and TE is the pure efficiency improvement.

(2) Data.

Urban agglomerations have gradually become the carrier of the rapid economic development in China. According to the *China Urban Agglomeration Integration Report 2019*, there are 12 urban agglomerations (157 cities above the prefecture level), accounting for 19.57% and 82.03% of China's total land area and GDP, respectively. The 12 urban agglomerations have become the pillar areas of China's economic development and can represent the economic and environmental characteristics of China. In addition, the tax sharing system between the central and local governments in China matured in 1995. Therefore, the panel data of these 12 urban agglomerations of 1995–2019 are chosen to conduct the empirical analysis.

The data of CQ are calculated by the method used by the International Panel on Climate Change. The data of PD are calculated by the formula “the proportion of officials above the divisions or equivalents level promoted annually to the total officials/the proportion of economic growth” (Zhang et al., 2019). The data of officials promoted above the divisions or equivalents level come from the websites of provinces. The data of FDI are calculated by the formula $\frac{1}{2}[(\text{tax revenue} + \text{land finance})/\text{total finance of local government}]$ (Wu (2017)). FD is measured by $(\text{the total loans of financial institutions}/\text{the total loans of financial institutions of the province}) \times (\text{the number of employees of local financial institutions}/\text{the number of employees of all financial institutions})$ (Chen & Deng, 2017). I is described by the $I-DZ$ (the investment bias of local governments in terms of labor and resources), $I-IN$ (the investment bias of local governments in terms of infrastructure), and $I-CD$ (the investment bias of local governments in terms of industrial transfer), and the calculation formula is $I = \frac{1}{3}(I-DZ + I-IN + I-CD)$. Fac is described by the $Fac-IP$ (the distortion extent of production resource markets), $Fac-LF$ (the distortion extent of land market), $Fac-SE$ (the distortion extent of technology transfer), and $Fac-TE$ (the distortion extent of technology innovation), and the calculation formula is $Fac = \frac{1}{4}(Fac-IP + Fac-LF + Fac-SE + Fac-TE)$. $Regu$ is described by the $Regu-G$ (the administration orders in emission reduction goals), $Regu-C$ (the capital investment in carbon emission reduction), and $Regu-L$ (the environmental policy score), and the calculation formula is $Regu = \frac{1}{3}(Regu-G + Regu-C + Regu-L)$. The data of U are calculated by the formula $\frac{\text{Total population} - \text{Rural population}}{\text{Total population}}$. The logarithmic mean Divisia index (LMDI) approach (Ang, 2005) is used to calculate the EI and ES . The data of PS and PT stem from the *China statistical yearbook*. $Tech$ is measured by the total factor productivity (TFP) (Cai & Zhou, 2017), and the TFP is calculated by the Malmquist productivity index and is decomposed into the technological progress, the scale efficiency improvement, and the pure efficiency improvement. The calculation methods are described in detail in the supplementary information.

3.2.2 Panel data pre-analysis methods

This sub-section details the pre-analysis methods employed to assess panel data's basic statistical features to guide the final estimation process.

(1) Dimensionless processing of data.

The variables above have different dimensions and cannot be compared directly. Referring to Lin and Du (2013), we use the formula $X = \frac{[\max(x) - x]}{\max(x)} \times 100\%$ to do the process, where X is the value of x after dimensionless processing.

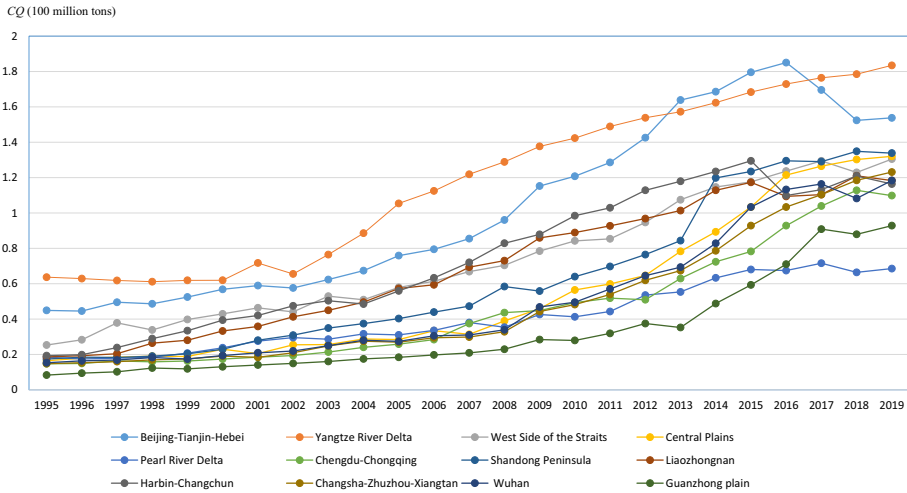


Fig. 5 The carbon emissions of the 12 urban agglomerations

(2) Testing panel unit root.

To avoid the spurious regression, learning from Shi and Li, the augmented Dickey–Fuller (ADF) method is used to do the unit root test. For the level series, the ADF values of all variables are greater than the critical values. For the first difference series, the ADF values of all variables are less than the critical values. Therefore, the data are stationary and the model can be estimated. The results are described in the supplementary information.

(3) The F test and the Hausman test.

We use the F test to determine whether the panel data model in this paper is a fixed-effects model or a mixed effects model. $F = \frac{(sse_e - sse_o) / (n-1)}{sse_o / (nt-n-1)} = \frac{(46.358 - 0.456) / (25-1)}{0.456 / (520-25-1)} = 2017.97 > F_{0.05}(106.99) = 12.83$ and it is a fixed-effects model. The free variable α is assumed as random variable in the F test, and it is also necessary to test whether the model is an individual fixed-effects model or an individual random-effects model. The Hausman test is used to do the test. $Hausman = 106.994 > \chi^2_{0.05}(1) = 3.8$, and it is an individual fixed-effects model.

3.2.3 Estimating the effect of Chinese-style decentralization on regional carbon emissions

The carbon emissions of the 12 urban agglomerations are as shown in Fig. 5. The effect of Chinese-style decentralization on regional carbon emissions is analyzed using the data of 12 urban agglomerations of 1995–2019, and the results are shown in Table 1.

As shown in Fig. 5 for most of these 12 urban agglomerations, their carbon emissions are still increasing. For the Beijing–Tianjin–Hebei, the Pearl River Delta, the Chengdu–Chongqing City Group, the Liaozhongnan City Groups, and the Harbin–Changchun megapolopolis, the carbon emissions are beginning to decrease. This is related with the urbanization, industrial structure, economic development strategies, and the regional synergy of these regions.

Table 1 Empirical analysis results of the influence path of Chinese-style decentralization on regional carbon emissions

Variables	Model-1		Model-2		Model-3		Model-4		Model-5		Model-6	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
<i>I</i>	-0.214***	-0.207***	-0.122***	-0.277**	0.224*	0.217**	0.218**					
<i>Fac</i>	-0.262**	-0.213*	-0.256*	-0.256*	0.175***	0.163**	0.165**					
<i>Regu</i>	-0.375**	-0.311**	-0.387*	-0.387*	0.112*	0.098*	0.099*					
<i>PD</i>	-0.173**	-0.124*	-0.098**	-0.131**	0.114**	0.176***	0.242***					
<i>FDI</i>	-0.156*	-0.135**	-0.184***	-0.224**	0.352**	0.275***	0.198***					
<i>FDE</i>	-0.313***	-0.235**	-0.295**	-0.254*	0.453**	0.324**	0.289**					
<i>FD</i>	-0.364**	-0.286***	-0.327**	-0.304***	0.231*	0.208**	-0.143***					
<i>PST</i>	-0.345**	-0.425**	-0.275***	-0.275***	0.365***	0.311**	0.315***					
<i>SE</i>	-0.215*	-0.342***	-0.296**	-0.296**	0.425**	0.375***	0.377**					
<i>TE</i>	-0.365***	-0.303*	-0.334***	-0.334***	0.241*	0.276*	0.279**					
<i>ES</i>	-0.278**	-0.286**	-0.402*	-0.402*	0.256*	0.274**	0.278*					
<i>EI</i>	-0.301*	-0.274*	-0.365**	-0.365**	0.278**	0.286*	0.287***					
<i>R²</i>	0.412	0.398	0.403	0.368	0.395	0.456	0.478					
<i>D-W</i>	2.005	1.964	1.986	2.045	1.881	2.175	1.996					
<i>F</i>	12.36	10.42	15.63	17.45	13.57	16.45	14.56					
						13.25	17.54					
Variables	Model-7		Model-8		Model-9		Model-10		Model-11		Model-12	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
<i>I</i>	0.215**	0.225**	0.233**	0.227**	0.235**	0.226**	0.234*	0.227**	0.235**	0.219**	0.203*	0.227**
<i>Fac</i>	0.163*	0.177**	0.177**	0.181***	0.113*	0.178**	0.355**	0.166**	0.166**	0.166**	0.402**	0.177*
<i>Regu</i>	0.094**	0.113*	0.113*	0.117**	0.253**	0.116*	0.349***	0.102*	0.102*	0.102*	0.269**	0.116*
<i>PD</i>	0.479**	0.324**	0.233**	0.217**	0.357**	0.119*	0.453**	0.128**	0.153*	0.128**	0.453***	0.166**
<i>FDI</i>	0.293**	0.174***	0.354***	0.253**	0.397**	0.314**	0.323**	0.176**	0.356**	0.176**	0.414***	0.269**
<i>FDE</i>	0.254**	0.141***	0.456**	0.417***	0.397**	0.415**	0.453**	0.247**	0.356**	0.247**	0.453***	0.414***
<i>FD</i>	-0.187***	-0.112**	0.204**	0.114*	0.338***	0.236*	0.136***	-0.206*	-0.225***	-0.206*	0.234**	0.139**

Table 1 (continued)

Variables	Model-7		Model-8		Model-9		Model-10		Model-11		Model-12	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
<i>PST</i>		0.312*		0.369**		0.371**		0.366*		0.312***		0.368**
<i>SE</i>		0.373**		0.427*		0.429*		0.427**		0.375**		0.428*
<i>TE</i>		0.275***		0.244***		0.245**		0.242**		0.287*		0.245***
<i>ES</i>		0.271*		0.262***		0.263*		0.259*		0.276***		0.258*
<i>EI</i>		0.283**		0.279*		0.282**		0.281**		0.289*		0.283*
<i>R²</i>	0.456	0.512	0.553	0.478	0.496	0.523	0.514	0.553	0.478	0.469	0.438	0.531
<i>D-W</i>	1.968	2.212	2.031	1.996	1.786	1.869	2.017	1.862	2.147	1.862	2.134	1.998
<i>F</i>	13.45	13.52	14.78	20.36	20.14	23.52	14.07	13.62	18.53	13.42	17.45	16.85

*, **, and *** denote a confidence level of 1%, 5%, and 10%, respectively. Models 1–12 represent the estimation results of 12 urban agglomerations. They are the Yangtze River Delta, the Beijing–Tianjin–Hebei, the Pearl River Delta, the Central Plains Urban Agglomeration, the Urban Agglomeration on the West Side of the Straits, the Chengde–Chongqing City Group, the Shandong Peninsula Urban Agglomeration, the Liaozhongnan City Groups, the Harbin–Changchun megalopolis, the Changsha–Zhou–Xiangtan City Group, the Wuhan Metropolitan Area, and the Guanzhong plain city group



Fig. 6 The radar chart of effect extent of decentralization on carbon emissions in regions with high synergy

Noted in Table 1, based on the influence mechanism of Chinese-style decentralization on regional carbon emissions, we classify the 12 urban agglomerations into three categories. The first category is regions with high synergy, including the Yangtze River Delta, the Beijing–Tianjin–Hebei, and the Pearl River Delta. The second category is regions with middle synergy, including the Urban Agglomeration on the West Side of the Straits, the Chengdu–Chongqing City Group, the Shandong Peninsula Urban Agglomeration, and the Wuhan Metropolitan Area. The third category is regions with low synergy, including the Central Plains Urban Agglomeration, the Liaozhongnan City Groups, the Harbin–Changchun megalopolis, the Changsha–Zhuzhou–Xiangtan City Group, and the Guanzhong plain city group.

For regions with high synergy, decentralization has a significant inhibitory effect on carbon emissions. According to Table 1, all the coefficients of *PD*, *FDI*, *FDE*, and *FD* of models 1–3 are negative (e.g., *PD*-Model-1-Before = -0.173, *FDI*-Model-1-Before = -0.156, *FDE*-Model-1-Before = -0.313, and *FD*-Model-1-Before = -0.364). Moreover, the effect of financial decentralization on carbon emissions is the greatest and the effect of political decentralization is the smallest. The reason for this is that, in regions with high synergy, the speed of urbanization and industrial upgrading is rapid. Although regional economic development is still the main bargaining chip of local governments in the promotion game, the development of market economy does not rely entirely on local governments, and the contribution of market-oriented economy is constantly increasing. Therefore, policy environment and financial resources are the main soft competitiveness of economic development in regions with high synergy and have the greatest effect on carbon emissions. The radar chart of effect extent of decentralization on carbon emissions in regions with high synergy is shown in Fig. 6.

For regions with middle synergy, political decentralization has a positive promotion effect on carbon emissions (*PD*-Model-5-Before = 0.191); fiscal decentralization has a positive promotion effect on carbon emissions (*FDI*-Model-6-Before = 0.198, *FDE*-Model-6-Before = 0.298); financial decentralization has a negative inhibitory effect on carbon emissions (*FD*-Model-7-Before = -0.187). The reason behind this is that, in regions with middle synergy, there exists interaction between local government decision-making competition and market forces. On the one hand, local governments are trying hard to upgrade the industry structure. On the other hand, in order to pursuit rapid economic growth, local governments have to tolerate some high-emission enterprises.

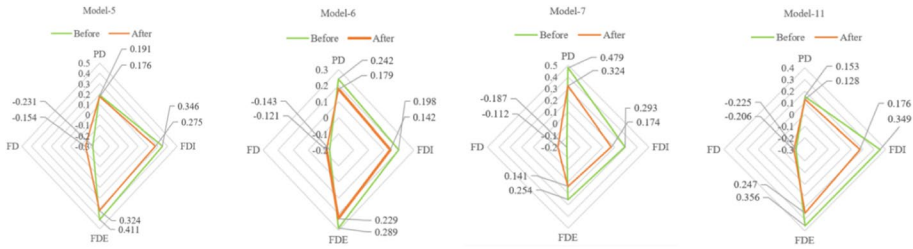


Fig. 7 The radar chart of effect extent of decentralization on carbon emissions in regions with middle synergy

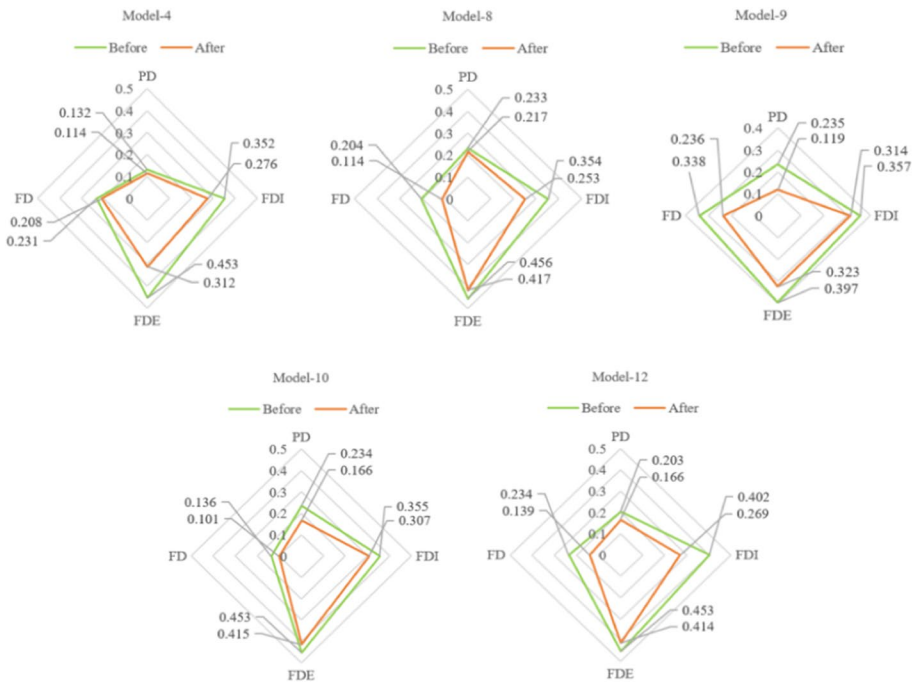


Fig. 8 The radar chart of effect extent of decentralization on carbon emissions in regions with low synergy

The radar chart of effect extent of decentralization on carbon emissions in regions with middle synergy is shown in Fig. 7.

For regions with low synergy, political decentralization has a significant positive promotion effect on carbon emissions. According to Table 1, all the coefficients of *PD*, *FDI*, *FDE*, and *FD* of models 4, 8, 9, and 12 are positive (e.g., *PD*-Model-4-Before=0.132, *FDI*-Model-4-Before=0.352, *FDE*-Model-4-Before=0.453, and *FD*-Model-4-Before=0.231). The effect of fiscal decentralization on carbon emissions is the greatest. The reason for this is that, in regions with low synergy, political benefits are the main goal of local governments. They take the development of regional economy as their main task and the means used for promoting economic growth is mainly fiscal expenditure. Therefore, fiscal expenditure decentralization has the greatest effect. The radar chart of effect extent of decentralization on carbon emissions in regions with low synergy is shown in Fig. 8.

According to the method of mediation effect test in the research of Fang and Wen (2018), variables I , Fac , $Regu$, PS , PT , SE , TE , ES , and EI are added in models-1–12-After. The coefficients of PD , FDI , FDE , and FD of models-1–12-After are smaller than models-1–12-Before. Taking the Yangtze River Delta urban agglomeration as an example, $Model-1-Before-PD = -0.173 < Model-1-After-PD = -0.124$, $Model-1-Before-FDI = -0.156 < Model-1-After-FDI = -0.135$, $Model-1-Before-FDE = -0.313 < Model-1-After-FDE = -0.235$, and $Model-1-Before-FD = -0.364 < Model-1-After-FD = -0.286$. It can be seen that, mainly through investment bias, factor market distortion, and environment policies, Chinese-style decentralization influences energy intensity, energy structure, technological progress, and industrial structure and then affects regional carbon emissions.

4 Policy effectiveness and the impulse effect

4.1 The effectiveness of emission reduction policies

According to the analysis in Sect. 3, Chinese-style decentralization affects regional carbon emissions mainly through environment regulation, factor markets, and fiscal investment, and the degree and main aspects of their effects are significantly heterogeneous. Therefore, the universality and practicality of emission reduction policies are restricted, leading to the decrease in the effectiveness of emission reduction policies. According to Zhang et al. (2020), carbon emission reduction policies used all over the world mainly include four categories, the executive order policies, carbon tax policies, cleaner production policies, and carbon emission trading policies. In China, only the executive order policies, carbon tax policies, and cleaner production policies are used, and the carbon emission trading policies are still in the pilot state. Using the method of testing the effectiveness of policies in von and Musshoff (2021), we test the effectiveness of emission reduction policies under the Chinese-style decentralization using the panel data of 12 urban agglomerations of 1995–2019.

The research model established in this study is:

$$\ln CQ_{st} = \alpha_0 + \alpha_1 X_{st} + \alpha_2 X_{st} Y_{st} + \alpha_3 Y_{st} + \varepsilon_{st}$$

$$X = PD, FDI, FDE, FD$$

$$Y = GP, CT, CP$$

where s is the region; t is the time; ε is the residual item; X is the Chinese-style decentralization, including PD , FDI , FDE , and FD ; Y is the emission reduction policy, including GP , CT , and CP ; GP is the executive order policy; CT is the carbon tax policy; CP is the cleaner production policy. The executive order policy is that the central government mandatorily requires local governments to reduce a certain amount of carbon emissions in a year. We use the carbon emissions stated in the annual report of local governments to describe it. The carbon tax policy is policies using carbon tax to limit carbon emissions of enterprises and is introduced by local governments for carbon emission reduction targets. We use the carbon emission tax levied by the provincial governments in a year to describe it. The cleaner production policy is described by the annual fiscal expenditure invested by provincial governments for the clean production of regional enterprises. The regression results are shown in Table 2.

As for the executive order policy, Chinese-style decentralization affects its effectiveness mainly through the political decentralization ($Model-GP-1-PD = -0.234$)

Table 2 Test of the effectiveness of emission reduction policies

Variable	Model-GP		Model-CT		Model-CP	
	Model-GP-1	Model-GP-2	Model-CT-1	Model-CT-2	Model-CP-1	Model-CP-2
<i>PD</i>	-0.234**	-0.205*	-0.152**	-0.134**	-0.112**	-0.106**
<i>FDI</i>	-0.189**	-0.175***	-0.285**	-0.236**	-0.145**	-0.117*
<i>FDE</i>	-0.256***	-0.214**	-0.152*	-0.127**	-0.263***	-0.234***
<i>FD</i>	-0.124*	-0.104***	-0.189***	-0.176*	-0.247*	-0.228**
<i>GP</i>	0.345**	0.232**				
<i>CT</i>			0.225**	0.186*		
<i>CP</i>					0.368*	0.357**
<i>PD&GP</i>		-0.089***				
<i>FDI&GP</i>		-0.032***				
<i>FDE&GP</i>		-0.075***				
<i>FD&GP</i>		-0.026***				
<i>PD&CT</i>				-0.039***		
<i>FDI&CT</i>				-0.071***		
<i>FDE&CT</i>				-0.035***		
<i>FD&CT</i>				-0.066***		
<i>PD&CP</i>						-0.084***
<i>FDI&CP</i>						-0.096***
<i>FDE&CP</i>						-0.112***
<i>FD&CP</i>						-0.106***
<i>R</i> ²	0.365	0.412	0.453	0.562	0.474	0.523
<i>D-W</i>	2.135	1.869	1.995	2.045	1.964	2.134
<i>F</i>	2.3e+03	2.1e+05	1.6e+04	1.7e+02	2.0e+03	1.8e+04

*, **, and *** denote a confidence level of 1%, 5%, and 10%, respectively

and the fiscal expenditure decentralization (Model-GP-1-*FDE* = -0.256). This is consistent with the research results of Sect. 3. The main reason for this is that, the executive order policy is formulated mainly based on the political decentralization between the central and local governments, and fiscal expenditures contribute to the implementation of the policy. According to the test method of the mediating effect, comparing the results of Model-GP-1 and Model-GP-2, after adding the cross-term of Chinese-style decentralization and emission reduction policies, the effect of Chinese-style decentralization decreases (Model-GP-1-*PD* = -0.234 > Model-GP-2-*PD* = -0.205, Model-GP-1-*FDI* = -0.189 > Model-GP-2-*FDI* = -0.175, Model-GP-1-*FDE* = -0.256 > Model-GP-2-*FDE* = -0.214, and Model-GP-1-*FD* = -0.124 > Model-GP-2-*FD* = -0.104), and the coefficients of the cross-terms are less than 1 (Model-GP-2-*PD&GP* = -0.089 < 1, Model-GP-2-*FDI&GP* = -0.032 < 1, Model-GP-2-*FDE&GP* = -0.075 < 1, and Model-GP-2-*FD&GP* = -0.026 < 1). This indicates that Chinese-style decentralization has a negative inhibitory effect on the effectiveness of the executive order policy. Moreover, the effect of political decentralization is the greatest (Model-GP-2-*PD&GP* = -0.089), that is, 1% increase in political decentralization causes 8.9% decrease in the effectiveness of executive order policy. This is consistent with the study of Zhao et al. (2021).

As for the carbon tax policy, Chinese-style decentralization affects its effectiveness mainly through the financial decentralization (Model-CT-1-FD = -0.189) and the fiscal revenue decentralization (Model-CT-1-FDI = -0.285). This is consistent with the research results of Sect. 3. The main reason for this is that, the carbon tax policy is implemented mainly through investment bias, and the financial decentralization and the fiscal revenue decentralization are important means that affect the investment bias. According to the test method of the mediating effect, comparing the results of Model-CT-1 and Model-CT-2, after adding the cross-term of Chinese-style decentralization and emission reduction policies, the effect of Chinese-style decentralization decreases (Model-CT-1-PD = -0.152 > Model-CT-2-PD = -0.134, Model-CT-1-FDI = -0.285 > Model-CT-2-FDI = -0.236, Model-CT-1-FDE = -0.152 > Model-CT-2-FDE = -0.127, and Model-CT-1-FD = -0.189 > Model-CT-2-FD = -0.176), and the coefficients of the cross-terms are less than 1 (Model-CT-2-PD&GP = -0.039 < 1, Model-CT-2-FDI&GP = -0.071 < 1, Model-CT-2-FDE&GP = -0.035 < 1, and Model-CT-2-FD&GP = -0.066 < 1). This indicates that Chinese-style decentralization has a negative inhibitory effect on the effectiveness of the carbon tax policy. Moreover, the effect of fiscal revenue decentralization is the greatest (Model-CT-2-FDI&GP = -0.071), that is, 1% increase in fiscal revenue decentralization causes 7.1% decrease in the effectiveness of carbon tax policy. This is consistent with the research of Cao et al. (2021).

As for the cleaner production policy, Chinese-style decentralization affects its effectiveness mainly through the financial decentralization (Model-CP-1-FD = -0.247) and the fiscal expenditure decentralization (Model-CP-1-FDI = -0.263). This is consistent with the research results of Sect. 3. The main reason for this is that, the cleaner production policy is implemented mainly through factor market, and the financial decentralization and the fiscal expenditure decentralization are important means that influence the factor market. According to the test method of the mediating effect, comparing the results of Model-CP-1 and Model-CP-2, after adding the cross-term of Chinese-style decentralization and emission reduction policies, the effect of Chinese-style decentralization decreases (Model-CP-1-PD = -0.112 > Model-CP-2-PD = -0.106, Model-CP-1-FDI = -0.145 > Model-CP-2-FDI = -0.117, Model-CP-1-FDE = -0.263 > Model-CP-2-FDE = -0.234, and Model-CP-1-FD = -0.247 > Model-CP-2-FD = -0.228), and the coefficients of the cross-terms are less than 1 (Model-CP-2-PD&GP = -0.084 < 1, Model-CP-2-FDI&GP = -0.096 < 1, Model-CP-2-FDE&GP = -0.112 < 1, and Model-CP-2-FD&GP = -0.106 < 1). This indicates that Chinese-style decentralization has a negative inhibitory effect on the effectiveness of the cleaner production policy. Moreover, the effect of fiscal expenditure decentralization is the greatest (Model-CP-2-FDE&GP = -0.112), that is, 1% increase in fiscal expenditure decentralization causes 11.2% decrease in the effectiveness of the cleaner production policy. This is consistent with the research of Pan et al. (2021).

4.2 The impulse effect of Chinese-style decentralization

According to the research results in Sect. 4.1, under the Chinese-style decentralization, the effects of emission reduction policies have not been fully realized. Therefore, there are still potential emission reduction spaces.

With full consideration of the influence of Chinese-style decentralization, a correct estimation of the potential spaces of emission reduction can help local governments to formulate appropriate emission reduction policies. There are mainly three methods that can

(1) $PD \rightarrow GP$, $PD \rightarrow CT$, and $PD \rightarrow CP$

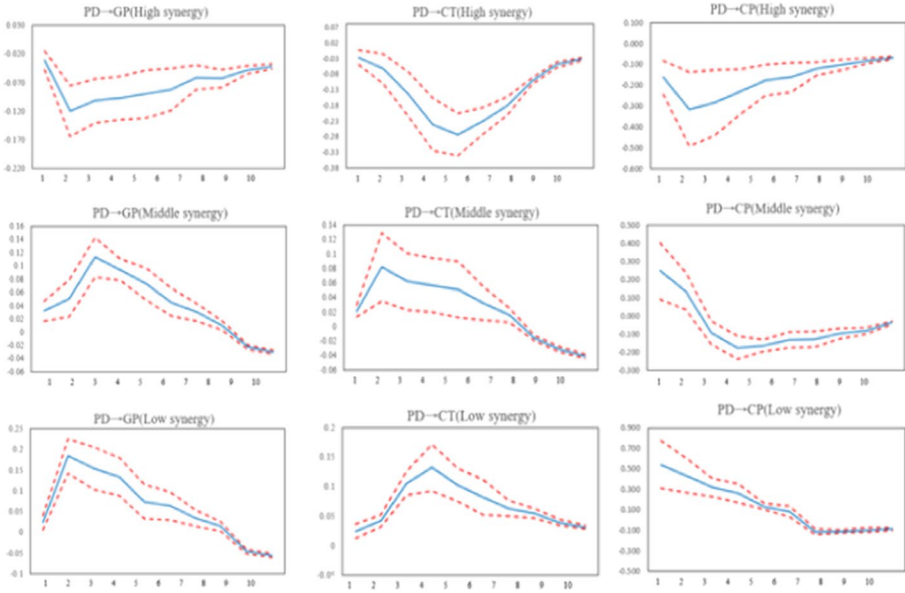


Fig. 9 The pulse effects of PD on GP , CT , and CP

be used for forecasting, the Life Cycle Assessment (LCA), the Gray Models (GM), and the Data Envelopment Analysis (DEA). LCA is mainly used for estimation of sub-stages. GM is an estimation method based on the changing trend of the data themselves, and the external influences are not considered. DEA is an estimation method based on the input and output and is usually used to calculate the emission reduction potentials of industries. These three methods are not suitable for this study. Learning from Lyu (2020), we use the impulse response function to estimate the effect of decentralization on emissions reduction policies. In order to calculate the potential of regional emission reduction under the influence of decentralization accurately, the impulse response function is used in this study. By giving a unit of impulse to decentralization, the influences of decentralization on regional emission reduction policies are estimated.

First, we analyze the effect of political decentralization on regional emission reduction. The impulse responses are different in regions with different degree of synergy, which shows that the degree of regional synergy plays a regulatory role. As shown in Fig. 9, the characteristics of the effect of political decentralization on regional emission reduction in regions with different degree of synergy are compared. (1) For urban agglomerations with high synergy, political decentralization has a negative inhibitory effect on regional carbon emissions, and the impulse peaks of GP , CT , and CP are -0.12 , -0.27 , and -0.31 , respectively. The cleaner production policy is most effective. (2) For urban agglomerations with middle synergy, the effect of political decentralization on regional carbon emissions is positive first and then become negative, and the impulse peaks of GP , CT , and CP are 0.11 , 0.08 , and -0.17 , respectively. The executive order policy is most effective. (3) For urban agglomerations with low synergy, the effect of political decentralization on regional carbon emissions is positive first and then become negative, and the impulse peaks of GP , CT , and CP are 0.18 , 0.13 , and -0.11 , respectively. The executive order policy is most

(2) $FDI \rightarrow GP$, $FDI \rightarrow CT$, and $FDI \rightarrow CP$

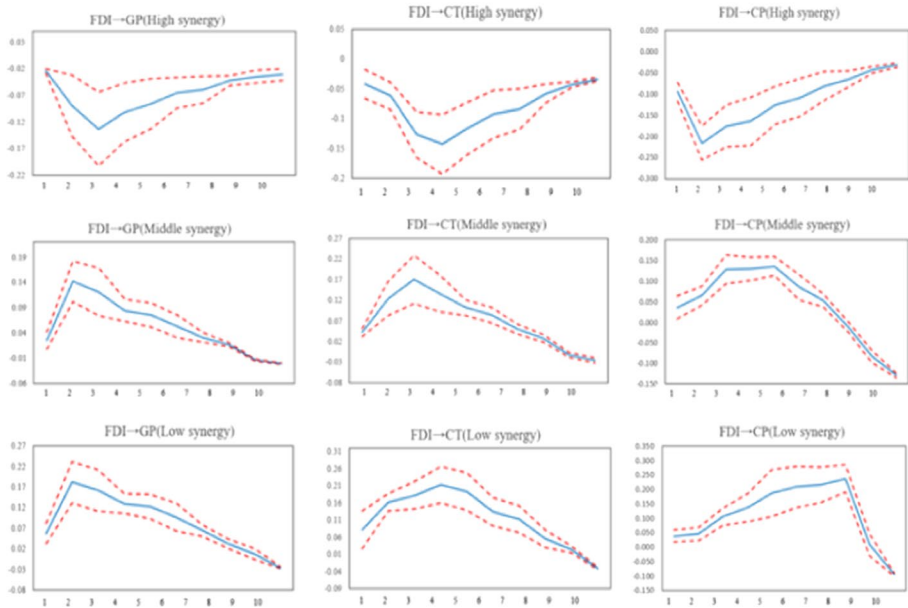


Fig. 10 The pulse effects of FDI on GP , CT , and CP

effective. The potential emission reduction space of urban agglomerations with low synergy is greater than that of urban agglomerations with middle synergy. These three results are consistent with the results in Sect. 4.1. The main reason is that the degree of regional synergy could enhance the effectiveness of the administrative orders, especially in the strategic direction of cleaner production.

Second, we analyze the effect of fiscal revenue decentralization on regional emission reduction. The impulse responses are different in regions with different degree of synergy, which shows that the degree of regional synergy plays a regulatory role. As shown in Fig. 10, the characteristics of the effect of fiscal revenue decentralization on regional emission reduction in regions with different degree of synergy are compared. (1) For urban agglomerations with high synergy, fiscal revenue decentralization has a negative inhibitory effect on regional carbon emissions, and the impulse peaks of GP , CT , and CP are -0.13 , -0.14 , and -0.21 , respectively. The cleaner production policy is most effective. (2) For urban agglomerations with middle synergy, the effect of fiscal revenue decentralization on regional carbon emissions is positive first and then become negative, and the impulse peaks of GP , CT , and CP are 0.14 , 0.17 , and 0.13 , respectively. The carbon tax policy is most effective. (3) For urban agglomerations with low synergy, the effect of fiscal revenue decentralization on regional carbon emissions is positive first and then become negative, and the impulse peaks of GP , CT , and CP are 0.18 , 0.21 , and 0.23 , respectively. The cleaner production policy is most effective. These three results are consistent with the results in Sect. 4.1. The main reason is that the degree of regional synergy could enhance the effect of fiscal revenue, especially in production, which is closely connected with fiscal revenue.

Third, we analyze the effect of fiscal expenditure decentralization on regional emission reduction. The impulse responses are different in regions with different degree of synergy,

(3) $FDE \rightarrow GP$, $FDE \rightarrow CT$, and $FDE \rightarrow CP$

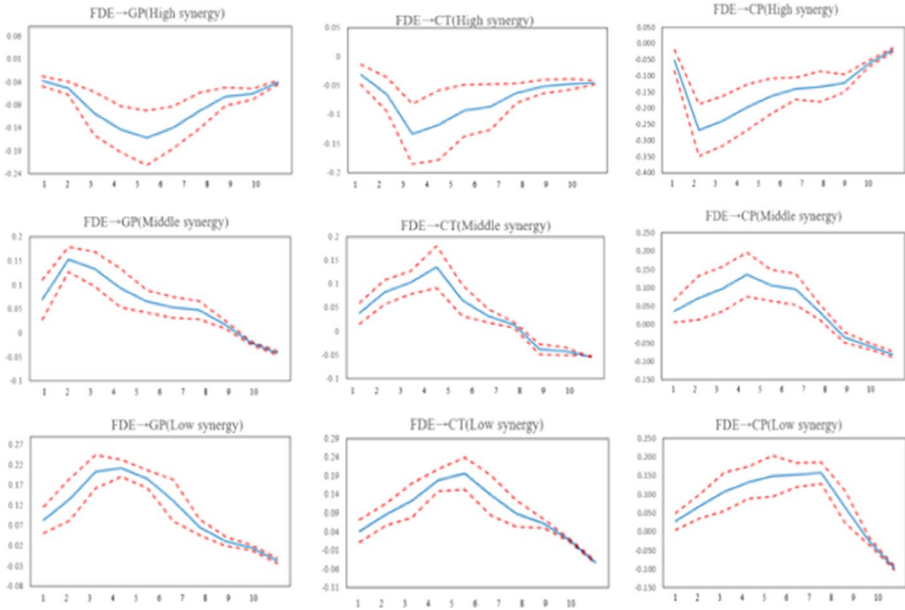


Fig. 11 The pulse effects of FDE on GP , CT , and CP

which shows that the degree of regional synergy plays a regulatory role. As shown in Fig. 11, the characteristics of the effect of fiscal expenditure decentralization on regional emission reduction in regions with different degree of synergy are compared. (1) For urban agglomerations with high synergy, fiscal expenditure decentralization has a negative inhibitory effect on regional carbon emissions, and the impulse peaks of GP , CT , and CP are -0.16 , -0.13 , and -0.26 , respectively. The cleaner production policy is most effective. (2) For urban agglomerations with middle synergy, the effect of fiscal expenditure decentralization on regional carbon emissions is positive first and then become negative, and the impulse peaks of GP , CT , and CP are 0.15 , 0.13 , and 0.13 , respectively. The executive order policy is most effective. (3) For urban agglomerations with low synergy, the effect of fiscal revenue decentralization on regional carbon emissions is positive first and then become negative, and the impulse peaks of GP , CT , and CP are 0.21 , 0.19 , and 0.15 , respectively. The executive order policy is most effective. The reason for this is that fiscal expenditure decentralization directly determines government investment, which in turn determines the effectiveness of regional emission reduction policies. These three results are consistent with the results in Sect. 4.1. The main reason is that regional synergy prompts local governments to favor long-term sustainable development strategies in terms of fiscal expenditures. Therefore, cleaner production is often implemented in regions with high synergy, and the administrative orders are often chosen in regions with low synergy.

Fourth, we analyze the effect of financial decentralization on regional emission reduction. The impulse responses are different in regions with different degree of synergy, which shows that the degree of regional synergy plays a regulatory role. As shown in Fig. 12, the characteristics of the effect of financial decentralization on regional emission reduction in regions with different degree of synergy are compared. (1) For urban agglomerations with high synergy, financial decentralization has a negative inhibitory effect on regional carbon

(4) $FD \rightarrow GP$, $FD \rightarrow CT$ and $FD \rightarrow CP$

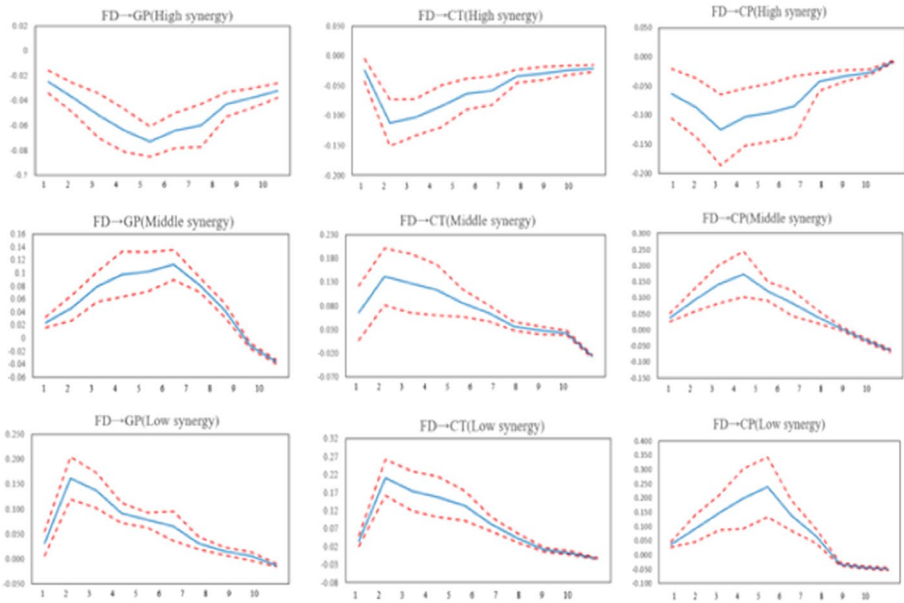


Fig. 12 The pulse effects of FD on GP , CT , and CP

emissions, and the impulse peaks of GP , CT , and CP are -0.07 , -0.11 , and -0.12 , respectively. The carbon tax policy and the cleaner production policy are more effective, and the cleaner production policy is most effective in the long term. (2) For urban agglomerations with middle synergy, the effect of financial decentralization on regional carbon emissions is positive first and then become negative, and the impulse peaks of GP , CT , and CP are 0.11 , 0.14 , and 0.17 , respectively. The cleaner production policy is most effective. (3) For urban agglomerations with low synergy, the effect of financial decentralization on regional carbon emissions is positive first and then become negative, and the impulse peaks of GP , CT , and CP are 0.16 , 0.21 , and 0.23 , respectively. The cleaner production policy is most effective. The potential space of emission reduction in urban agglomerations with low synergy is greater than that of urban agglomerations with middle synergy. These three results are consistent with the results in Sect. 4.1. The main reason is that, financial resources can circulate more freely in regions with high synergy, and the carbon tax policies can be better implemented. In regions with low synergy, the financial factor market hinders the implementation of carbon emission reduction policies under the effect of local government competition, and the administrative orders are more suitable for these regions.

5 Policy improvement

5.1 Design of policy improvement

According to the analysis in Sect. 3, Chinese-style decentralization affects regional carbon emissions through factor market distortion, investment bias, and environmental regulation,

and all of these three paths influence carbon emissions through energy structure, energy efficiency, and technological progress. Therefore, the improvement of emission reduction policy is designed from the aspect of avoiding factor market distortion, investment bias, and the biased implementation of environment policies.

As for political decentralization, the key point is regional development integration and the smooth circulation of information, which is conducive to realize the joint prevention and control of regional carbon emissions and avoid being affected by the substitution effect of industrial structure adjustment. As for fiscal revenue decentralization, the main consideration is land finances. The “enclave economy” is implemented in many regions. Through constructing industrial parks cross-region, the industrial structure can be optimized, the energy consumption can be reduced, and the behavior of “free riding” in environmental governance can be avoided. Then, the effect of fiscal revenue decentralization can be inhibited effectively. As for fiscal expenditure decentralization, through increasing fiscal expenditures in infrastructure (culture, education, and health) and regional business environment, investment bias can be effectively suppressed. As for financial decentralization, local governments promote the regional technological progress mainly through increasing green credit and equity investment, thereby suppressing the influence of financial decentralization.

LS represents the degree of regional integration. Referring to the evaluation system of integration in the research of (Zhang et al., 2021), we calculate the degree of regional integration of 12 urban agglomerations. *IP* represents the industrial park economy, and we use the proportion of investment in industrial park in regional GDP to describe it. *BL* represents the investment bias of local governments in business environment, and we use the amount of investment in regional business environment to describe it. *TECH* represents the investment bias of local government in culture, education, and healthy, and we use the amount of investment in regional culture, education, and healthy to describe it. *DF* represents the green debt capital, and we use the proportion of green debt capital in regional overall debt capital to describe it. *EF* represents the equity capital, and we use the ratio of regional equity capital to the regional overall debt to describe it. All of these indicators have dimensions and cannot be compared directly. Learning from the research of Lin and Du (2013), we use the formula $X = \frac{[\max(x)-x]}{\max(x)} \times 100\%$ to nondimensionalize them, where X is the value of x after nondimensionalizing.

5.2 Simulation test

Based on the analysis in Sect. 3.1, we have the relationship between carbon emission intensity and the driving factors, as shown in Table 3.

In order to compare the effectiveness of regional emission reduction policies before and after the redesign, we use the formula in Table 3 to calculate the increase in carbon emission intensity. The data in Table 3 are derived from the empirical estimation results of the following model:

$$CQ = \beta_{j0} + \sum_{j=1}^{13} \sum_{i=1995}^{2019} \beta_{ji} x_{ji} + \mu_t$$

$$\mu \sim IID(0, \sigma^2); j : 1 - 3; t : 1 - 25;$$

$$x_1 - x_{11} : I, Fac, Regu, PD, FDI, FDE, FD, LS, IP, BL, TECH, DF, EF, GP, CT, CP$$

Table 3 The calculation formula of the effect of driving factors

	Effect of carbon emission changes
Effect of energy structure	$Y_{k,\tau}^i \times (CI_{k,\tau}^i - CI_{k,t}^i) \times \eta_{k,\tau}^i, \eta_k^i = \Delta CI_{i,k}^{ec} / \Delta CI_k^i$
Effect of economic structure	$Y_{k,\tau}^i \times (CI_{k,\tau}^i - CI_{k,t}^i) \times \rho_{k,\tau}^i, \rho_k^i = \Delta CI_{i,k}^y / \Delta CI_k^i$
Effect of the substitution of production factors	$Y_{k,\tau}^i \times (CI_{k,\tau}^i - CI_{k,t}^i) \times \varsigma_{k,\tau}^i, \varsigma_k^i = \Delta CI_{i,k}^{pe} / \Delta CI_k^i$
Effect of energy intensity	$Y_{k,\tau}^i \times (CI_{k,\tau}^i - CI_{k,t}^i) \times \xi_{k,\tau}^i, \xi_k^i = \Delta CI_{i,k}^{eff} / \Delta CI_k^i$
Effect of technological progress	$Y_{k,\tau}^i \times (CI_{k,\tau}^i - CI_{k,t}^i) \times \gamma_{k,\tau}^i, \gamma_k^i = \Delta CI_{i,k}^{te} / \Delta CI_k^i$

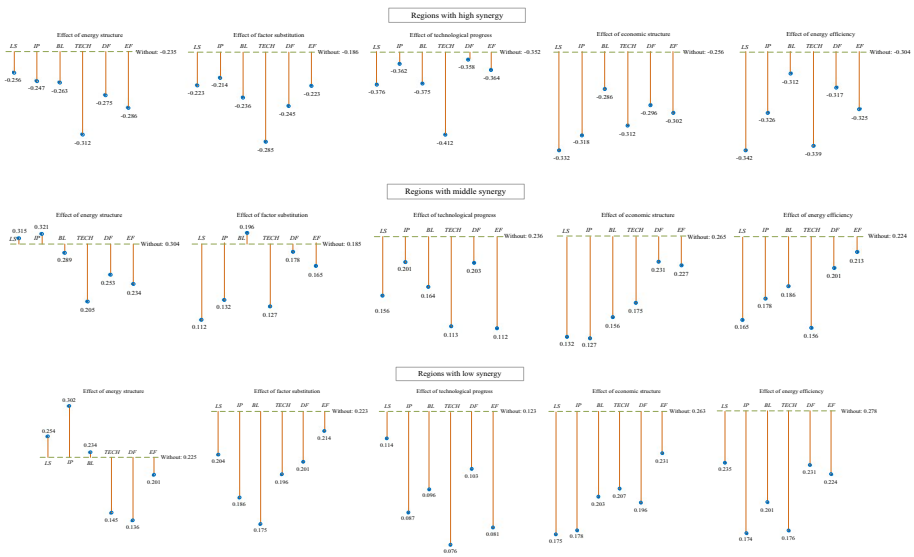


Fig. 13 Simulation results of the implementation of emission reduction policies

Model-LS, IP, BL, TECH, DF, and EF are the estimation results considering these variables, and Model-Without is the estimation result without considering these variable. The increase in carbon emission intensity of urban agglomerations with high, middle, and low synergy is shown in Fig. 13.

For regions with high synergy, regional integration and technological progress are the best measures for improving regional emission reduction policies. 1% increase in the degree of regional integration and technological progress would bring a 1.4% and 6% increases in emission reduction, respectively. Specifically, the best policy for improving the effect of energy structure, the effect of substitution effect of production factors, and the effect of technological progress is increasing the investment in cultural, education, and R&D, and the elasticity is 0.067, 0.09, and 0.058, respectively. The best policy for improving the effect of economic structure and the effect of energy intensity is regional integration, and the elasticity is 0.072 and 0.038, respectively.

For regions with middle synergy, regional integration development and technological progress are the best measures for improving regional emission reduction policies. 1%

increase in the degree of regional integration and regional equity investment would bring a 13.8% and 12.4% increases in emission reduction, respectively. Specifically, the best policy for improving the effect of energy structure is increasing the investment in cultural, education, and R&D, and the elasticity is 0.099. The best policy for improving the effect of the substitution effect of production factors is regional integration development, and the elasticity is 0.073. The best policy for improving the effect of technological progress is increasing regional equity investment, and the elasticity is 0.124. The best policy for improving the effect of economic structure is regional integration development, and the elasticity is 0.101. The best policy for improving the effect of energy intensity is increasing the investment in cultural, education, and R&D, and the elasticity is 0.068.

For regions with low synergy, regional integration development and increasing green-credit are the best measures for improving regional emission reduction policies. 1% increase in the degree of regional integration and regional green-credit would bring a 10.4% and 8.9% increases in emission reduction, respectively. Specifically, the best policy for improving the effect of energy structure is accelerating the increase in regional green-credit, and the elasticity is 0.089. The best policy for improving the effect of the substitution effect of production factors is increasing investment in regional business environment, and the elasticity is 0.048. The best policy for improving the effect of technological progress is increasing the investment in cultural, education, and R&D, and the elasticity is 0.047. The best policy for improving the effect of economic structure is regional integration development, and the elasticity is 0.088. The best policy for improving the effect of energy intensity is regional integration development, and the elasticity is 0.104.

6 Conclusions and policy suggestions

6.1 Conclusions

China is at the stage of rapid new urbanization, and Chinese-style decentralization is the essential reason of “green paradox.” Analyzing the effect of Chinese-style decentralization on regional carbon emissions, testing the effectiveness of emission reduction policies, calculating the potential space of regional emission reduction, and redesigning emission reduction policies could help local governments to formulate precise emission reduction policies. The research results are as follows:

First, Chinese-style decentralization is the main reason for the increase in regional carbon emissions in the process of new urbanization. It affects regional carbon emissions mainly through three paths: factor market distortion, investment bias, and environment regulation. All of these three paths influence carbon emissions through energy structure, energy efficiency, and technological progress, and their effects have significant regional heterogeneity and spatial interaction. For regions with high synergy, it is mainly the fiscal decentralization and the financial decentralization that affect regional carbon emissions. For regions with middle synergy, it is mainly the fiscal revenue decentralization and the fiscal expenditure decentralization that affect regional carbon emissions. For regions with low synergy, it is mainly the political decentralization and the fiscal revenue decentralization that affect regional carbon emissions.

Second, as for the executive order policy, 1% increase in political decentralization and fiscal expenditure decentralization causes 8.9% and 7.5% decrease in the effectiveness of executive order policy, respectively. As for the carbon tax policy, 1% increase

in financial decentralization and fiscal revenue decentralization causes 6.6% and 7.1% decrease in the effectiveness of carbon tax policy, respectively. As for the cleaner production policy, 1% increase in financial decentralization and fiscal expenditure decentralization causes 10.6% and 11.2% decrease in the effectiveness of the cleaner production policy, respectively.

Third, for regions with high synergy, 1% increase in the degree of regional integration and technological progress would bring 1.4% and 6% increases in emission reduction, respectively. For regions with middle synergy, regional integration development and technological progress could improve the effectiveness of regional emission reduction policies effectively. 1% increase in the degree of regional integration and regional equity investment would bring 13.8% and 12.4% increases in emission reduction, respectively. For regions with low synergy, regional integration development and increasing green-credit could improve the effectiveness of regional emission reduction policies effectively. 1% increase in the degree of regional integration and regional green-credit would bring 10.4% and 8.9% increases in emission reduction, respectively.

6.2 Policy suggestions

The performance assessment of local governments, which based on regional GDP, should not be used any more, and the “green GDP” should be introduced in the performance assessment system. The performance evaluation mechanism of local governments that combines the “foot voting” and the “hand voting” should be encouraged which could effectively suppress the promotion effect of Chinese-style decentralization on regional carbon emissions.

For regions with high synergy, the emission reduction policies should be redesigned and improved based on regional integration and technological progress. Local governments should encourage and support the technological innovation of enterprises and the development of high-tech industries, which is conducive to the agglomeration of high-tech enterprises, the innovation and diffusion of science and technology, and then the decrease in carbon emissions.

For regions with middle synergy, the emission reduction policies should be redesigned and improved based on regional coordinated development and technological progress. On the one hand, local governments should transform traditional industries through government investment and policy guidance and promote the use of high-efficiency technologies and clean energies. This could improve the energy efficiency, optimize the energy structure, and reduce the carbon emissions. On the other hand, local governments should increase their investment in environment protection, which could increase the enthusiasm of enterprises in environment governance and reduce regional carbon emissions.

For regions with low synergy, the emission reduction policies should be redesigned and improved based on regional coordinated development and green credit. In these regions, the direct carbon emissions decreased by regional integration development and industrial parks would be offset by the energy rebound effect. There exists the “race to the bottom” and the “free riding” behaviors in environment regulation between local governments. The executive order of local governments is the most effective way. However, its emission reduction effect is also the least.

7 Limitations and future research directions

The decentralization system in this study is mainly the authorization system between the central and local governments in politics and decision-making rights. For the local governments at the same level, the authorization from the central government is the same. However, because of the principal–agent relationship between the central and local governments, the degree of decentralization and the implementation boundaries are related with the characteristics of the incumbent officials and the location of the regions. In this study, considering the availability and traceability of data, the influence of the characteristics of officials is not included. In the future research, the tenure and characteristics of officials, the geography location, and the economic development strategies of regions should be connected with the emission reduction goals, by which the effect of decentralization on regional emission reduction can be better explained. Especially, the mediating effect of local government decision-making competition in the new urbanization process should be considered.

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References

- Ahmed, Z., Asghar, M. M., Malik, M. N., & Nawaz, K. (2020). Moving towards a sustainable environment: the dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China-Science Direct. *Resources Policy*, *67*, 101677.
- Ang, B. W. (2005). The LMDI approach to decomposition analysis: A practical guide. *Energy Policy*, *33*(7), 867–871.
- Cai, W., & Zhou, X. (2017). Dual effect of Chinese environmental regulation on green total factor productivity. *Economist*, *09*, 27–35.
- Cao, J., Dai, H., Li, S., Guo, C., & Zhang, X. (2021). The general equilibrium impacts of carbon tax policy in china: a multi-model comparison. *Energy Economics*, *99*(6), 105284.
- Chen, B., & Deng, X. (2017). Fiscal decentralization, financial decentralization and the growth of local debt. *Public Finance Research*, *05*, 38–53.
- Chen, J., Gao, M., Li, D., et al. (2020). Analysis of the rebound effects of fossil and non-fossil energy in China based on sustainable development. *Sustainable Development*, *28*(1), 235–246.
- Chen, L., Li, X., Xue, S., Qu, L., & Wang, M. (2019). Carbon intensity and emission reduction potential in China: Spatial measuring method. *Journal of Economic Structures*, *8*(1), 1–12.
- Chen, X., & Chang, C. P. (2020). Fiscal decentralization, environmental regulation, and pollution: A spatial investigation. *Environmental Science and Pollution Research*, *27*(1), 31946–31968.
- Chen, Y., Cheng, L., Lee, C. C., & Wang, C. S. (2021). The impact of regional banks on environmental pollution: evidence from china's city commercial banks. *Energy Economics*, *2*, 105492.
- Cheng, S., Fan, W., Chen, J., Meng, F., Liu, G., Song, M., & Yang, Z. (2020). The impact of fiscal decentralization on CO₂ emissions in China. *Energy*, *192*, 116685.
- Du, J., & Sun, Y. (2021). The nonlinear impact of fiscal decentralization on carbon emissions: From the perspective of biased technological progress. *Environmental Science and Pollution Research*, *28*, 29890–29899.
- Du, L., Zhao, Y., Tao, K., et al. (2019). Compound effects of environmental regulation and governance transformation in enhancing green competitiveness. *Economic Research Journal*, *10*, 106–120.
- Fang, J., & Wen, Z. (2018). A comparison of three methods for testing multilevel mediation. *Journal of Psychological Science*, *41*(04), 962–967.
- Farajzadeh, Z. (2018). Emissions tax in Iran: Incorporating pollution disutility in a welfare analysis. *Journal of Cleaner Production*, *186*, 618–631.

- Feng, Y., Wei, Y. D., Gao, J., & Chen, W. (2019). Water crisis, environmental regulations and location dynamics of pollution-intensive industries in China: A study of the Taihu Lake watershed. *Journal of Cleaner Production*, 216, 311–322.
- He, A., & An, M. (2019). Competition among local governments, environmental regulation and green development efficiency. *China Population, Resources and Environment*, 03, 21–30.
- He, Q. (2015). Fiscal decentralization and environmental pollution: Evidence from Chinese panel data. *China Economic Review*, 36, 86–100.
- Ji, X., Umar, M., Ali, S., Ali, W., Tang, K., & Khan, Z. (2021). Does fiscal decentralization and eco-innovation promote sustainable environment? A case study of selected fiscally decentralized countries. *Sustainable Development*, 29, 79–88.
- Khan, Z., Ali, S., Dong, K., & Li, R. (2021). How does fiscal decentralization affect CO₂ emissions? The roles of institutions and human capital. *Energy Economics*, 94, 105060.
- Khan, Z., Sisi, Z., & Siqun, Y. (2018). Environmental regulations an option: Asymmetry effect of environmental regulations on carbon emissions using non-linear ARDL. *Energy Sources Part a: Recovery Utilization and Environmental Effects*, 41(2), 1–19.
- Kuai, P., Yang, S., Tao, A., Zhang, S., & Khan, Z. D. (2019). Environmental effects of Chinese-style fiscal decentralization and the sustainability implications. *Journal of Cleaner Production*, 239, 118089.
- Li, D., & Deng, X. (2018). Research on the policy subject in China's reform of scientific research institutes. *Studies in Science of Science*, 36(04), 654–661.
- Li, J., Zhang, D., & Su, B. (2019). The impact of social awareness and lifestyles on household carbon emissions in China. *Ecological Economics*, 160, 145–155.
- Li, L., & Liu, B. (2020). Prospect for major issues of China's regional economic development during the 14th five-year plan period. *Management World*, 05, 36–51+8.
- Li, X., & Xu, H. (2020). Effect of local government decision-making competition on carbon emissions: Evidence from China's three urban agglomerations. *Business Strategy and the Environment*, 6(29), 2418–2431.
- Lin, B., & Du, K. (2013). The energy effect of factor market distortion in China. *Economic Research Journal*, 48(09), 125–136.
- Liu, L., Ding, D., He, J., et al. (2019). Fiscal decentralization, economic growth, and haze pollution decoupling effects: A simple model and evidence from China. *Computational Economics*, 54(4), 1423–1441.
- Liu, Y., Luo, N., & Wu, S. (2019). Nonlinear effects of environmental regulation on environmental pollution. *Discrete Dynamics in Nature and Society*, 4, 1–10.
- Lu, F., & Yang, H. (2019). Environmental decentralization, local government competition and China's ecological environment pollution. *Industrial Economics Research*, 04, 113–126.
- Luo, N., & Wang, Y. (2017). Fiscal decentralization, environmental regulation and regional eco-efficiency: Based on the dynamic spatial Durbin model. *China Population, Resources and Environment*, 27(04), 110–118.
- Lyu, Y. (2020). Accounting for the declining economic effects of oil price shocks. *Energy Economics*. <https://doi.org/10.1016/j.eneco.2020.105015>
- Ouyang, X., Shao, Q., Zhu, X., He, Q., Xiang, C., & Wei, G. (2019). Environmental regulation, economic growth and air pollution: Panel threshold analysis for OECD countries. *Science of the Total Environment*, 657, 234–241.
- Ouyang, Z., & Peng, F. (2018). The common trend and the codependent cycle of china's economic growth by the two-wheel drive. *Economic Research Journal*, 04, 32–46.
- Pan, F., Xi, B., & Wang, L. (2015). Equilibrium model of local government environmental regulation under the Chinese style decentralization. *Collected Essays on Finance and Economics*, 03, 105–113.
- Pan, X., Cao, Y., Pan, X., & Uddin, M. K. (2021). The cleaner production technology innovation effect of environmental regulation policy: Evidence from China. *Management of Environmental Quality: An International Journal*. <https://doi.org/10.1108/MEQ-10-2020-0227>
- Peng, K., Song, Y., Tao, A., Zhang, S., & Khan, Z. D. (2019). Environmental effects of Chinese-style fiscal decentralization and the sustainability implications. *Journal of Cleaner Production*, 239, 118089.
- Qu, Z., Liu, T., & Zhu, Y. (2021). Does R&D input matter the impact of financial resources allocation on green production in China's energy sectors. *E3S Web of Conferences*, 236(5), 02013.
- Renner, S., Lay, J., & Greve, H. (2018). Household welfare and CO₂, emission impacts of energy and carbon taxes in Mexico. *Energy Economics*, 72, 222–235.
- Shen, K., & Zhou, L. (2020). Local government competition, vertical environmental regulation and the pollution backflow effect. *Economic Research Journal*, 03, 35–49.
- Shi, B., & Shen, K. (2013). The government intervention, the economic agglomeration and the energy efficiency. *Management World*, 10, 6-18+187.

- Song, K., Bian, Y., Zhu, C., & Nan, Y. (2020). Impacts of dual decentralization on green total factor productivity: Evidence from China's economic transition. *Environmental Science and Pollution Research*, 27(32), 14070–14084.
- Song, Y., Chen, S., & Zhang, M. (2020). Local government heterogeneity and regional environmental cooperation-evolutionary game analysis based on Chinese decentralization. *Chinese Journal of Management Science*, 28(01), 201–211.
- Sun, Y. H., Du, J. T., & Wang, S. H. (2020). Environmental regulations, enterprise productivity, and green technological progress: Large-scale data analysis in China. *Annals of Operations Research*, 290(1–2), 369–384.
- Taylor, C. M., Gallagher, E. A., Pollard, S. J. T., et al. (2019). Environmental regulation in transition: Policy officials' views of regulatory instruments and their mapping to environmental risks. *Science of the Total Environment*, 646, 811–820.
- Tian, J., & Wang, Y. (2018). Spatial spillover effects between fiscal decentralization, local governments competition and carbon emissions. *China Population, Resources and Environment*, 28(010), 36–44.
- Usman, M., Yaseen, M. R., Kousar, R., & Makhdam, M. (2021). Modeling financial development, tourism, energy consumption, and environmental quality: Is there any discrepancy between developing and developed countries? *Environmental Science and Pollution Research*, 28, 58480–58501.
- von Hobe, C.-F., & Musshoff, O. (2021). On the effectiveness of restricted tendering as a form of policy intervention on agricultural land markets. *Land Use Policy*, 103, 105343.
- Wu, H., Hao, Y., & Ren, S. (2020). How do environmental regulation and environmental decentralization affect green total factor energy efficiency: Evidence from China. *Energy Economics*, 91, 104880.
- Wu, Y. (2017). Distorted investment under Chinese style decentralization. *Economic Research Journal*, 52(06), 137–152.
- Xia, S., You, D., Tang, Z., & Yang, B. (2021). Analysis of the spatial effect of fiscal decentralization and environmental decentralization on carbon emissions under the pressure of officials' promotion. *Energies*, 14(7), 1–21.
- Xiong, H., & Shen, K. (2019). The impact of financial decentralization on the efficiency of corporate investment. *Research on Economics and Management*, 40(02), 27–46.
- Yang, M., Yang, F., & Sun, C. (2018). Factor market distortion correction, resource reallocation and potential productivity gains: An empirical study on china's heavy industry sector. *Energy Economics*, 69, 270–279.
- Yang, R., Tang, W., & Zhang, J. (2021). Technology improvement strategy for green products under competition: the role of government subsidy. *European Journal of Operational Research*, 289, 553–568.
- Yang, X., Yan, J., Tian, K., Yu, Z., Li, R. Y., & Xia, S. (2021). Centralization or decentralization? The impact of different distributions of authority on China's environmental regulation. *Technological Forecasting and Social Change*, 173, 121172.
- Yang, Y., Yang, X., & Tang, D. (2021). Environmental regulations, Chinese-style fiscal decentralization, and carbon emissions: From the perspective of moderating effect. *Stochastic Environmental Research and Risk Assessment*, 35, 1985–1998.
- Zang, J., & Liu, L. (2020). Fiscal decentralization, government environmental preference, and regional environmental governance efficiency: Evidence from China. *The Annals of Regional Science*. <https://doi.org/10.1007/s00168-020-00989-1>
- Zhang, A., Wen, L., Lioudmila, C., & Gao, X. (2021). Reduction of carbon emissions through resource-saving and environment-friendly regional economic integration: Evidence from Wuhan metropolitan area China. *Technological Forecasting and Social Change*, 166, 120590.
- Zhang, C., & Chen, L. (2018). A dynamic study on the impact of local government competition on environmental regulation: based on chinese decentralization perspective. *Nankai Economic Studies*, 04, 137–157.
- Zhang, K., Zhang, Z., & Liang, Q. (2017). An empirical analysis of the green paradox in China: From the perspective of fiscal decentralization. *Energy Policy*, 103, 203–211.
- Zhang, W., Li, J., Li, G., & Guo, S. (2020a). Emission reduction effect and carbon market efficiency of carbon emissions trading policy in China. *Energy*, 196, 117117.
- Zhang, X., Cheung, M. W., Sun, Y., & Tan, J. (2019). Political decentralization and the path-dependent characteristics of the state authoritarianism: An integrated conceptual framework to understand China's territorial fragmentation. *Eurasian Geography and Economics*, 60(5), 548–581.
- Zhao, C., Feng, F., Chen, Y., & Li, X. (2021). Local government competition and regional innovation efficiency: From the perspective of China-style fiscal federalism. *Science and Public Policy*. <https://doi.org/10.1093/scipol/scab023>

Zhou, A., & Li, J. (2020). The nonlinear impact of industrial restructuring on economic growth and carbon dioxide emissions: A panel threshold regression approach. *Environmental Science and Pollution Research*, 27(12), 14108–14123.

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