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Does the marketization of land transfer have an impact on carbon emissions? Evidence from China

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Excessive carbon emissions caused by extensive economic development are the key to the current government's carbon emission reduction goals. In the process of market-oriented reform of land transfer, alleviating the contradiction between land use and low-carbon development is an essential problem in achieving the purpose of carbon peaking and carbon neutrality. The impact of land transfer marketization on regional economic development is complex, and the final effect on carbon emissions needs to be further examined. Based on China's provincial panel data from 2008 to 2017, this paper uses a double fixed effect model to conduct an empirical analysis. The lag effect of the initial regression results is tested, and the quantitative test of the mediating effect and moderating effect of fixed asset investment is also carried out. The following conclusions are drawn: Firstly, the improvement of the marketization of land transfer will promote carbon emissions; secondly, the promotion effect of the degree of marketization of land transfer on carbon emissions will become inhibited with the delay of the lag effect years. Moreover, fixed asset investment will play a masking effect and an adjustment effect; thirdly, the impact of the degree of marketization of land transfer on carbon emissions is different in the eastern and western regions divided by the degree of marketization, and the strength of government control will also have a significant impact on the impact. The research results of this paper enrich the economic impact theory of land transfer marketization and have certain value for regional land policy management in the context of carbon emission reduction.

KEYWORDS

land transfer, carbon emission, marketization, mechanism inspection, heterogeneity

1 Introduction

Since the Industrial Revolution, a series of climate changes, such as climate warming and frequent extreme weather caused by human activities have become one of the most severe challenges for humanity. Since the Reform and Opening-up, China has made remarkable achievements in economic construction and has become the second largest economy in the world since 2010. From the data of the China Statistical Yearbook and the World Bank Open Data, it can be seen that before the Covid-19 epidemic appeared, China's total GDP increased by 35.8 times compared with 1978 after deducting price factors, with an average annual growth rate of nearly 9.7%, however, what supports the rapid economic growth is an extensive economic development model characterized by high energy consumption and high emissions (Zhang et al., 2013). According to relevant research, at least 18% of China's economic growth GDP is obtained by the "overdraft" of resources and ecological environment, and this part still exists in the current economic development (Shi et al., 2011). On the one hand, in the context of tightening resource and environmental constraints, it is hard for traditional economic development methods to maintain high-speed GDP growth, so in recent years, the growth rate of China's GDP has gradually slowed down and has entered the stage of improving the quality of supply and adjusting the economic structure; on the other hand, the ecological and environmental problems accumulated by the extensive long-term development have gradually emerged (Yu et al., 2016), and the environmental and climate issues are progressively getting more social attention. Finding the key points to change the traditional economic development mode is of great significance to implementing sustainable economic and social development and realizing China's carbon cycle (Jia et al., 2022).

According to the report of the International Energy Agency, in recent years, China's carbon emissions have continued to increase globally, reaching 33% in 2021, ranking first in the world. To achieve the goal of achieving carbon balance by 2060, which was put forward by China at the United Nations in 2020, making good use of land resources is a fundamental issue. The land is the essential production factor and space carrier. In the context of global warming, land management policies such as land use planning, land development and improvement, and low-carbon urban planning have become important means for countries to implement low-carbon economies and achieve sustainable development strategies (Bryan et al., 2016; Gao and Bryan, 2017). The Chinese government is the sole provider of land sales according to the design of China's land system, and local governments can adjust the pricing of the land transfer market, which makes the subsequent evolution of land transfer gradually become the result of the natural selection of the market during the economic development of various regions (Yuan et al., 2019). Some pieces of literature have demonstrated a view that local governments may have the bureaucracy of "moving umbrellas," attracting investment through land sales, and finally driving regional economic growth. (Shi et al., 2021), at the same time, the government can improve the regional environment by raising the pollutant discharge threshold (Ma et al., 2021). Therefore, the land transfer has also become an essential way for local governments to promote marketization and environmental governance. Given China's unique land system design, along with the low-carbon pilot policy, will the government's promotion of the marketization of land transfer affect changes in carbon emissions? By what kind of mechanism does it affect carbon emissions? Is this effect heterogeneous across regions? Answers to these questions will help clarify the actual effect of the marketization of land transfer and the actual impact of policies under carbon emission reduction targets.

According to the current research results, the influencing factors of carbon emissions are mainly attributed to the aspects of economy, structure and emission reduction intervention. The first is the economic aspect, mainly the impact of economic output and factor inputs that drive economic growth. The most famous is the Environmental Kuznets Curve (EKC), proposed by Grossman and Krueger. They argue that when economic development is low, carbon dioxide emissions are also low. With economic growth, carbon dioxide emissions will increase sharply. After a certain critical point, carbon dioxide emissions will gradually slow down with the growth trend of economic growing, thus improving environmental quality (Grossman and Krueger, 1995). After the EKC curve was proposed, more and more scholars have proved an inverted U-shaped relationship between per capita carbon emissions and income (Selden and Song, 1995; Galeotti et al., 2006; Dogan et al., 2019). There are also many other conclusions from an economic perspective. For example, using GDP per capita to measure economic growth, it is found that economic growth has a significant role in promoting carbon emissions (Sharma, 2011; Begum et al., 2015); the increase in energy consumption brought about by the expansion of economic scale is the main reason for the increase in China's carbon emissions at this stage (Wang and Feng, 2020). Per capita demand levels and investment are also significant contributors to the increase in carbon emissions. For example, Cui et al. (2020) research proves that per capita demand will eventually promote the increase of carbon emissions; in the process of economic production, such as fixed asset investment, will form a production scale effect and finally improve the local economic effect and increase the social demand for energy consumption (Wang and Qi, 2021). Studies from the structural aspect mainly discussed the impact of changes in the output share of different industries, mainly including the industrial structure and energy structure as the starting point of the research. Overall, there is a strong correlation between industrial structure and carbon emissions (Dong et al., 2020). Among them, the increase in the proportion of heavy industry structure will increase regional carbon emissions but will significantly reduce the performance of industrial carbon emissions (Ouyang et al., 2020). The energy structure reflects the proportion of various energy sources in the energy consumption system. Many scholars have indicated that the proportion of high-carbon energy sources such as coal and other fossil fuels will have a more significant impact on total carbon emissions (Xu et al., 2014; Xu et al., 2016). There are also some views that using clean energy to improve the high-carbon energy consumption structure can restrain regional carbon emissions to a certain extent (Granados and Spash, 2019). In terms of carbon emission reduction intervention, it mainly includes the impact of technological progress and government governance. Energy technology progress includes independent innovation technology, which is generally measured by the number of patents or reflected in other indicators related to GDP. Advances in energy technology mean that energy efficiency can be improved and energy intensity reduced (Zhang et al., 2016). In addition, the energy consumption per unit of GDP can also reflect the technical level, especially in the industrial field (Jin et al., 2015). Technological progress is also considered an important factor in achieving carbon emission reduction, but different types of patents have different effects on carbon emissions (Cheng et al., 2021). Government intervention and environmental regulation also significantly impact regional carbon emissions. Government intervention and environmental regulation will not only affect carbon emissions through direct channels but also indirectly affect carbon emissions by affecting regional industrial structures (Zhang et al., 2020b; Lin and Huang, 2022). Specifically, government intervention measures such as pollutant discharge restrictions and pollutant discharge fees, will also impact regional carbon emissions. For example, in economically developed provinces, the sewage fee system will drive the manufacturing industry to innovate green technology, thereby reducing regional carbon emissions (Metcalf, 2009).

In the past, the way of dealing with land transfer by local governments in China was mainly to implement differentiated supply: on the one hand, through the "land hunger" policy, combined with land transfer methods such as bidding, auction, and listing, the commercial and residential service land is sold at high prices; on the other hand, there is an excessive supply of industrial land or even a "zero land price" supply through agreement transfer (Cai et al., 2013). This difference in supply mode is formed because of the policy combination made by the local government after weighing the maximization of fiscal revenue and the goal of political promotion to ensure the maximization of the overall interests of the local government. This differentiated land transfer can meet the needs of local governments to expand fiscal revenue and promote economic development in the early stage of development. However, with the development of the economy and society, and the gradual improvement of the marketization degree, many scholars believe that the land transfer behavior controlled by the government will have many negative effects. For example, local governments would rely excessively on land finance to achieve policy goals (Wang and Hui, 2017), real estate prices will continue to rise (Wang et al., 2018), and there will be duplication of infrastructure construction and disorderly waste of production resources (Anas, 2020). There are other serious consequences, that is, to attract investment, the local government has increased the intervention of land transfer and introduced a large number of low-quality and high-energy-consumption investment projects, which will eventually lead to excessive regional carbon emissions, and finally restrict the sustainable development of society and ecology (Ji and Bao, 2020). The marketization of land transfer is a policy tool for allocating urban land resources. Market orientation means changing land elements from planning allocation to market allocation. There are apparent differences in resource utilization efficiency between these two land element allocation methods. Some studies have concluded that the allocation of land elements under the condition of maximizing social benefits should follow the market price mechanism (Lopez et al., 1994). There is also a view that the land market can improve the utilization efficiency of land resources (Messner, 2008; Jiang et al., 2021).

From the perspective of China's land system, both parties to the agreement are single, the land transfer process lacks openness and transparency, and it is easy to breed corruption. Therefore, many scholars are more supportive of land transfer in the form of bidding, auction and listing (Yang et al., 2015; Zeng et al., 2022). The impact of these two methods of carbon emissions requires further empirical research. First, regions with different levels of development have different preferences for industries. The less developed areas pay more attention to the industrial sector of economic output, and the developed areas pay more attention to the technology and pollution of the industry (Jing and Gu, 2008). Secondly, the competitive pricing mechanism of market-oriented land transfer will increase the land price level and the entry barriers of enterprises in the region, thus forcing some traditional industries with low productivity to move out (Chunxiang et al., 2022; Li et al., 2022). For example, for labor-intensive enterprises, the increase in the degree of marketization of land sales will lead to rising real estate prices and increase the burden on enterprises. Therefore, enterprises with low output and high energy consumption will move out of the region due to the improvement of the land transfer market, which will impact regional carbon emissions. However, at the same time, some large-scale enterprises with high energy consumption still have the opportunity to choose and even take the opportunity to expand the scale and increase production (Jing and Gu, 2008) and then upgrade the industry according to the policy, which brings more complexity to the identification of the impact of carbon emissions (Wu et al., 2021a). Therefore, more empirical research is needed on how the degree of marketization of land transfer affects regional carbon emissions.

The possible contributions of this paper include: Taking the local government's land use as the starting point, it studies the effect, mechanism and action path of the degree of marketization of land transfer on carbon emissions. The influence of the heterogeneity of marketization degree and government control between regions in this study is also investigated to help local governments make rational use of land elements and choose appropriate policy implementation priorities when dealing with

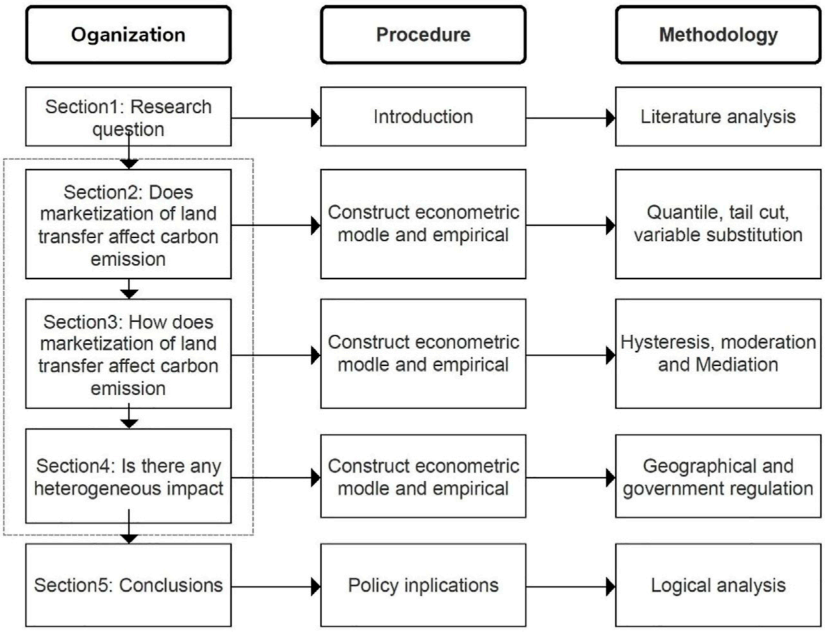

FIGURE 1
The logical framework of this paper.

policy goals to reduce carbon emissions to achieve the goal of green and coordinated development of the regional economy.

The structure of the rest of this paper is as follows: the second part puts forward research hypotheses based on analyzing the relationship between the degree of marketization of land transfer and carbon emissions; the third part introduces the model and data of the empirical research in this paper, and conducts benchmark regression and robustness test; the fourth part conducts multiple mechanism tests and heterogeneity analysis; the fifth section gives conclusions and policy recommendations, the research logic and research method used in this paper are shown in Figure 1.

2 Research hypotheses

From the perspective of regional economic activities, according to Grossman and Krueger (Grossman and Krueger, 1995), the scale effect brought by marketization lowers the threshold of economic behavior so that in the short term, higher economic growth is prioritized and technological progress is more difficult to achieve. Therefore, the increase in the degree of marketization of land transfer will increase the regional land economic activities, including the construction of infrastructure, the expansion of production enterprises and the gathering of the urban population, which will eventually lead to an increase in carbon emissions and a particular threat to the local ecological environment. The scale of capital in the production sector has the most significant promoting effect on carbon emissions, which is related to the persistent capital deepening phenomenon in extensive production (Xu et al., 2014). In the process of land marketization reform, the government introduced a market competition mechanism and selected the highest bidder among eligible transferees. While forming the government's best performance; it also reflects the relative importance of land elements in the buyer's decision-making model. Those who bid high have higher value expectations for the economic benefits of land elements. Therefore, in the subsequent land development, the value of the acquired land will be maximized. In the early stage of land development, a large amount of factor input and energy consumption is required. According to the principles of game theory, due to financial pressure, the assignee may choose maximization of production rather than pollution prevention as the primary strategy in the initial stage. Therefore, this paper proposes the hypothesis:

H1. The increase in the degree of marketization of land transfer will promote regional carbon emissions.

Since the financial crisis, China has issued a two-year economic plan of four trillion yuan and adopted ten measures to stimulate the recovery of the national economy (Bo et al., 2014; Wang et al., 2022), enabling the implementation of China's most extensive fixed asset investment plan (Li and Liu, 2013). Consequentially, the consumption of energy is accelerated. As a developing country, China's rapid economic growth is inseparable from large-scale investment in infrastructure.

Moreover, some low-tech, high-polluting and high-energy-consumption fixed asset investment projects in industry and manufacturing will also increase energy consumption and pressure on carbon emission reduction policies. The government often hedges by introducing a series of carbon emission reduction policies, such as environmental and energy tax, which are commonly used methods (Hou et al., 2022). At the same time, adjusting the proportion of funds for fixed asset investment projects and improving investment approval standards are also ways. On the one hand, the increase in fixed asset investment will affect the investment structure, promote economic growth and per capita income (Hou et al., 2017), and ultimately increase energy consumption will increase carbon emissions; on the other hand, economic growth will bring about technological progress, improve energy efficiency, and reduce carbon emissions in conjunction with the government's macro-control policies. However, due to the profit-seeking nature of capital and the needs of local government performance, the choice of fixed asset investment projects for technological growth and policy support is often passive and has a certain masking effect. Therefore, this paper proposes the hypothesis:

H2. The marketization of land sales will promote carbon emissions by affecting fixed asset investment.

Since the different geography, economic status and social culture of each province in China, there are differences in the degree of development, industrial structure and marketization of the regions (Zhang et al., 2020a), so the marketization of land transfer and carbon emissions are different. As analyzed above, under China's existing mechanism, the core mechanism that drives the government to intervene in the land transfer is the performance appraisal of officials. Different regions have different stages of economic development, macro-strategic positioning and other factors, and thus different regions have different focuses on performance evaluation, prompting local officials to adopt different land transfer intervention behaviors and environmental supervision systems (Wu et al., 2020; Hu and Liu, 2022), which ultimately affect carbon emissions. Therefore, this paper proposes the hypothesis:

H3. The relationship between the degree of marketization of land transfer and carbon emissions is affected by the heterogeneity of the level of regional marketization and government control.

3 Variable definition and model construction

3.1 Sample selection and data sources

For the availability and completeness of the data, this paper adopts the panel data of 30 provinces, autonomous regions or municipalities in China from 2008 to 2017 (In the following text, they are regarded as provincial-level units, Tibet, Hong Kong, Macao and Taiwan regions whose data are missing are excluded.) for an empirical quantitative test. The data of the dependent variables in this paper come from China Emission Accounts and Datasets (CEADs), which is a multi-scale carbon emission inventory in China jointly supported and compiled by authoritative research institutions in many countries; it is also one of the more authoritative and commonly used carbon emission databases. The independent variable data are from China Land and Resources Statistical Yearbook. The manual data for other variables mainly comes from the China Statistical Yearbook and China Urban Statistical Yearbook published by the National Bureau of Statistics of China. In the process of data sorting, this paper adopts the linear interpolation method to fill in the missing data of individual indicators in a few years, and the variables measured in currency are all based on the 2007 price index to eliminate the impact of prices.

3.2 Variable definition

3.2.1 Independent variable

Carbon Emissions (CE). This paper adopts the provincial carbon emission values published in the CEADs database, and the calculation is based on the carbon emission of fossil fuel energy consumption. The calculation process is shown in Eq. 1:

$$\begin{aligned} \boldsymbol{CE} &= \sum\nolimits_{m}\sum\nolimits_{n}\boldsymbol{CE_{mn}} \\ &= \sum\nolimits_{m}\sum\nolimits_{n}\boldsymbol{AD_{mn}} \times \boldsymbol{NCV_{m}} \times \boldsymbol{EF_{n}} \times \boldsymbol{O_{mn}}, \boldsymbol{m} \in [\mathbf{1}, \mathbf{17}], \boldsymbol{n} \in [\mathbf{1}, \mathbf{47}] \end{aligned} \tag{1}$$

Among them, $\boldsymbol{CE_{mn}}$ is the total carbon emissions of different sectors and types of energy. $\boldsymbol{AD_{mn}}$ is the adjusted energy consumption (apparent consumption). $\boldsymbol{NCV_{m}}$ is the net calorific value of different energy types. $\boldsymbol{EF_{m}}$ is the emission factor for the corresponding fossil fuel. $\boldsymbol{O_{mn}}$ is the oxygenation efficiency for different sectors and types of energy. CEADs measured 602 coal samples from 100 large coal mining areas and found that emission factors suggested by the Intergovernmental panel on climate change (IPCC) and the National Development and Reform Commission were often higher than actual emission factors, so this carbon emission data adopts the IPCC (2006) sectoral method to calculate carbon dioxide emissions, which research institutions widely use. Carbon emissions are calculated based on emissions from 17 fossil fuels and 47 socio-economic fuel sectors, and the emission parameters associated with fossil fuel combustion are shown in Table 1.

3.2.2 Dependent variable

The degree of marketization of land transfer (MLT). According to Jiang et al. (2019) calculation method of the degree of marketization of land transfer, after a total of three kinds of land transfers of state-owned construction land in each province,

TABLE 1 Correlation coefficients of various energy sources.

Energy type	Standard coal conversion factor	Carbon emission coefficient	Energy type	Standard coal conversion factor	Carbon emission coefficient
Raw coal	0.7143	0.7559	Kerosene	1.4714	0.5714
Coke	0.9714	0.8550	Diesel fuel	1.4571	0.5921
Gasoline	1.4714	0.5538	Fuel oil	1.4286	0.6185
Crude	1.4286	0.5857	Natural gas	1.3300	0.4483

TABLE 2 Variable definition.

Variable type	Variable name	Variable measurement
Independent variable	CE	Carbon emissions from fossil fuels
Dependent variable	MLT	Degree of marketization of land transfer
Control variables	PD	Population density
	ECS	Energy consumption structure
	GDP	annual GDP
	MI	Marketization index
	UB	Urbanization level
	GP	Number of patents granted

TABLE 3 Descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
CE	300	300.77	192.30	24.80	842.20
MLT	300	0.88	0.10	0.34	0.99
PD	300	2797.48	1199.97	649.00	5967.00
ECS	300	0.43	0.15	0.044	0.724
GDP	300	18780.74	16063.67	896.90	91648.70
MI	300	6.25	1.83	2.33	10.29
UB	300	0.55	0.13	0.29	0.90
GP	300	36128.36	55684.48	228.00	332652.00

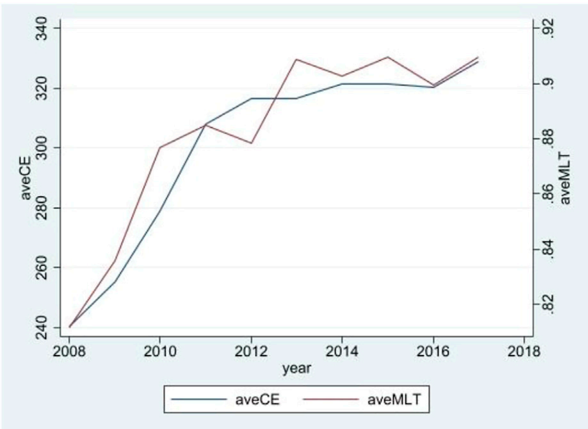

FIGURE 2
Annual average trend line of CE and MLT.

including bidding, auction, and listing, are divided by !the total land transferred each year in each province to obtain the percentage value of the degree of marketization of land transfer. The data comes from the China Land and Resources Statistical Yearbook. In arranging the data, duplicate records were deleted, and individual null values were supplemented by linear interpolation.

3.2.3 Control variables

Based on the IPAT model, this paper selects population density, energy consumption structure, and per capita GDP as the main control variables. In order to prevent omissions, this paper also selects some variables to control. All variables are shown in Table 2, and descriptive statistics of the variables are shown in Table 3.

This paper adopts the panel data model for processing. Since the Hausman test indicated that the two-way fixed-effects model (FE) with robust standard errors was preferable and there were significant differences between provinces, the FE model was used for regression. Before the empirical analysis, the multicollinearity diagnosis of the benchmark OLS model was carried out using the variance inflation factor method (VIF). The results show that the VIF value of each variable is lower than 10, and the mean value is 3.42, so there is no severe multicollinearity problem. Because the

TABLE 4 Basic empirical regression results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	CE	CE	CE	CE	CE	CE	CE
MLT	81.9965**	65.4312**	68.3945**	74.6259**	73.7591**	67.7537**	69.3660**
	(31.6606)	(31.1875)	(30.7659)	(29.8001)	(29.1526)	(28.3724)	(28.4689)
PD		−0.0169***	−0.0184***	−0.0201***	−0.0193***	−0.0156***	−0.0155***
		(0.0045)	(0.0044)	(0.0043)	(0.0042)	(0.0042)	(0.0042)
ECS			133.3224***	164.5679***	162.4788***	169.9141***	166.4998***
			(45.8888)	(44.9822)	(44.0072)	(42.8099)	(43.0647)
GDP				0.0016***	0.0019***	0.0018***	0.0015***
				(0.0004)	(0.0004)	(0.0004)	(0.0006)
MI					−14.7780***	−12.4727***	−13.7569***
					(4.1696)	(4.0930)	(4.4133)
UB						438.2607***	450.1381***
						(109.4601)	(110.5926)
GP							0.0001
							(0.0001)
_cons	173.6248***	232.4564***	169.5344***	137.0382***	215.9977***	−20.2557	−16.4097
	(26.2190)	(29.9241)	(36.5990)	(36.1997)	(41.8369)	(71.6593)	(71.8826)
N	300	300	300	300	300	300	300
r2	0.5602	0.5833	0.5965	0.6237	0.6413	0.6626	0.6634
F	33.1179	32.9533	31.7785	32.7735	32.6988	33.3795	31.2837

Notes: *, **, *** stand for significant levels of 10%, 5%, and 1%, respectively, and the values in brackets are *T*-values.

number of variables N is more than the sample time span T, to ensure the stationarity of the panel data and the reliability of the regression results, LLC and Fisher-ADF unit root tests were performed. Both tests reject the null hypothesis of the existence of a unit root, indicating that the sample data belongs to a stationary series. It can be seen that the differences between the mean, maximum and minimum values of multiple variables are quite large, which indicates that there may be heterogeneity between provincial samples.

3.3 Basic regression analysis

Before returning to the benchmark, this paper first analyzes the overall trend of national carbon emissions and land transfer levels. It can be seen from Figure 2 that the trend line of the average value of carbon emissions is visibly close to the average trend line of the marketization degree of land transfer, and there seems to be some lag effect in the changing trend of the two curves, so the lag effect analysis will be carried out after the benchmark regression.

Then, this paper adopts a double fixed effect model of time and province and gradually adds control variables for regression analysis to ensure the robustness of the measurement test results. The benchmark regression model is shown in Eq. 2, and the regression results are shown in Table 4.

$$\boldsymbol{CE_{it} = a_0 + a_1 MLT_{it} + a_2 PD_{it} + a_3 ECS_{it} + a_4 PGDP_{it} + a_5 MI_{it} + a_6 UB_{it} + a_7 GP_{it} + Year_t + Province_i + \varepsilon_{it}} \tag{2}$$

In the benchmark regression model with control variables added one by one, the adjusted R-square value increased from 0.5602 to 0.6634, indicating that the fitting degree of the benchmark model gradually increased. The correlation coefficient $\boldsymbol{a_1}$ of the marketization of land transfer has always been significantly positive, indicating that the degree of marketization of land transfer has a significant positive effect on carbon emissions. The regression results in column 7) show that the influence coefficient of the degree of marketization of land transfer on carbon emissions is 69.3660, which indicates that the carbon emission level of the province will increase by 69.3660 standard units when the marketization degree of land transfer increases by 1 standard unit. The benchmark regression model's primary conclusion is that land transfer marketization significantly promotes regional carbon emissions.

Among the control variables that promote carbon emissions, the energy consumption structure, GDP, and urbanization are

TABLE 5 Robustness test 1: quantile regression test.

	(1)	(2)	(3)
	CE	CE	CE
	Q25	Q50	Q75
MLT	195.9357***	166.0053**	−1.2e + 02
	(53.1188)	(66.1493)	(157.0601)
PD	0.0182***	−0.0053	−0.0381***
	(0.0038)	(0.0085)	(0.0067)
ECS	435.3743***	340.5984***	957.5659***
	(30.3260)	(35.5414)	(132.7008)
GDP	0.0071***	0.0115***	0.0323***
	(0.0011)	(0.0015)	(0.0031)
MI	3.9997	−36.0465***	−1.3e + 02***
	(4.6104)	(8.2912)	(17.7503)
UB	44.7023	199.4463**	1.5e + 03***
	(67.5892)	(76.6974)	(330.3018)
GP	−0.0008***	−0.0007*	−0.0030***
	(0.0002)	(0.0003)	(0.0007)
_cons	−4.0e + 02***	−1.1e + 02*	−2.9e + 02
	(58.0192)	(59.5450)	(198.6188)
N	300	300	300
r2	0.4101	0.3954	0.5177
F	2.4e + 03	474.0109	288.4034

Notes: *, **, *** stand for significant levels of 10%, 5%, and 1%, respectively, and the values in brackets are *T*-values.

TABLE 6 Robustness test 2–3: tail cut, variable substitution.

	(1)	(2)	(3)
	CE	CC	EC
MLT	73.8796**	3.8e + 03**	2.0e + 03**
	(29.4993)	(1.9e + 03)	(837.6163)
PD	−0.0152***	−0.9101***	−0.6902***
	(0.0042)	(0.2785)	(0.1240)
ECS	166.8883***	1.7e + 04***	2.3e + 03*
	(42.8550)	(2.8e + 03)	(1.3e + 03)
GDP	0.0014**	−0.0451	0.0852***
	(0.0006)	(0.0374)	(0.0167)
MI	−13.6472***	−2.0e + 02	−2.0e + 02
	(4.3901)	(291.7017)	(129.8501)
UB	452.1568***	3.0e + 04***	1.4e + 04***
	(110.0532)	(7.3e + 03)	(3.3e + 03)
GP	0.0001	0.0098	0.0073**
	(0.0001)	(0.0083)	(0.0037)
_cons	−22.0529	−1.1e + 04**	3.6e + 03*
	(71.7969)	(4.8e + 03)	(2.1e + 03)
N	300	300	300
r2	0.6634	0.4771	0.8246
F	31.2840	14.4828	74.6103

Notes: *, **, *** stand for significant levels of 10%, 5%, and 1%, respectively, and the values in brackets are *T*-values.

prominent. If the proportion of coal consumption in the energy consumption structure continues to increase, it will promote carbon emissions, which proves from the side that coal consumption is still the main source of carbon emissions (Wang et al., 2019); the growth of GDP represents the improvement of the economic level and will increase the overall carbon emissions, which is consistent with the relevant research conclusions (Zang et al., 2018); rising levels of urbanization mean a net influx of people into cities, which increases the demand for infrastructure and the overall demand for energy, thereby increasing carbon emissions (Zhou et al., 2021).

Among the control variables that have an inhibitory effect on carbon emissions, the most significant ones are population density and marketization index. For population density, different population density stages have different effects on carbon emissions; firstly, for areas with low population density, the inflow of population will bring about the concentration and increase of various production factors, which could increase carbon emissions (Mclarren, 1992); secondly, after the population density of a province increases to a certain extent, the agglomeration economy and scale effect will significantly improve the efficiency of economic activities; moreover, the compactness of the urban spatial structure can improve the efficiency of energy utilization and reduce the intensity of carbon emissions in general; thirdly, when the population is concentrated to the second critical point, the excessive concentration of the population will bring about an adverse "crowding effect." Population density puts pressure on infrastructure such as urban transport, adversely affecting energy use (Akcin et al., 2016). For China with uneven population distribution and high industrial concentration, the regression of population density in this paper may just reflect that the effect of population aggregation and economies of scale in China's provinces on carbon emissions is at an average level. The impact of the marketization index may be the result of the rational allocation of resources and efficient use of energy by the market mechanism, which is conducive to the reduction of carbon emission reduction (Acheampong et al., 2020).

3.4 Robustness test

First, this paper conducts carbon emission quantile regression as the first step of robustness testing. On the one hand, the linear regression model obtains a conditional mean and does not consider the dependent variable's overall distribution characteristics. Linear regression presents its drawbacks when information on the location of the dependent variable is required. Compared with the general linear regression model, the quantile regression model has broader conditions and can describe the global characteristics of the dependent variable, not just the mean value. On the other hand, estimates from quantile regression models are generally not affected by outliers. From this point of view, the quantile regression has strong robustness, and the results of the quantile regression test are shown in Table 5.

From the results in Table 5, it can be seen that the impact of the degree of marketization of land transfer on carbon emissions has a significant promoting effect at the place of Q25 and Q50, and the value is larger than the benchmark regression. In addition, the correlation coefficient at the place of Q25 is larger, indicating that the marketization of land transfer in areas with a lower degree has a greater role in promoting carbon emissions. In the areas with low and intermediate degrees of land transfer marketization, the effect of the independent variable is significant. However, at the place of Q75, the value of the correlation coefficient presents an abnormally negative number, which shows that the results of this paper need to be further tested for the robustness of tail reduction to remove the influence of extreme values.

Second, this paper deals with the extreme value samples that may affect the conclusion. There are large differences between Chinese provinces; for example, the carbon emission sample of Shandong region in individual years is 30 times that of Qinghai region, in 2017, the degree of land transfer marketization of most provinces exceeded 90%, while the lowest degree of land transfer marketization in the sample was only close to 33%. Therefore, to prevent the significance of the extreme value influence coefficient, this paper carries out the outlier tail cut treatment of the sample as the second step of the robustness test. The regression results are shown in column 1) of Table 6.

Third, due to the variety of measurement methods for CO2 emission data, there are already many methods for measuring carbon emission values. Carbon emission indicators are also directly related to many factors, the most important of which is coal consumption. In order to ensure the reliability of the results, this paper chooses to replace the carbon emission values published by CEADs with the total coal consumption (CC) published by Qianzhan.com and the total energy consumption (EC) published by China Energy Statistical Yearbook. The regression results are shown in column 2) and column 3) in Table 6.

As can be seen from column 1) of Table 6, although the regression result after the tail reduction treatment does not become more significant, the impact of the marketization of land transfer on the carbon emission value has increased, and the results are still significant, indicating that extreme values do not affect the robustness of the regression results. As can be seen from columns 2) and 3) of Table 6, when the dependent variable carbon emission is replaced by coal consumption and total energy consumption, the impact of the marketization of land sales is still significant, which is in line with our expectations, this shows that the promotion effect of the degree of marketization of land transfer on carbon emissions has not changed due to the change of the measurement indicators of dependent variables.

In general, the degree of marketization of land transfer has a promoting effect on carbon emissions, and preliminary regression results have passed the robustness test from multiple perspectives. However, in terms of data description, numerical observation and regression results, other aspects need to be supplemented, such as lag effects, mechanism testing and considerable heterogeneity across provinces, so further heterogeneity research is warranted.

4 Further research

4.1 Mechanistic studies

It can be seen from Figure 2 that there may be a lag effect on carbon emissions due to changes in the degree of marketization of land sales. Analyzing the factors of carbon emissions from the lag effect may more easily reflect the influence of many factors, such as the degree of marketization of land transfer, innovation, and population density. From the perspective of time lag, when the degree of marketization of land increases, it will take a considerable period for various production factors and construction to complete the construction of infrastructure. Therefore, it is necessary to test the lag effect in this research.

Since the reform and opening-up, investment, consumption and export have been the troika that drove China's economic development. After acquiring land, enterprises generally need to invest in fixed assets to build factories or purchase production equipment to put various economic factors into production as soon as possible. Fixed investment is divided into construction, renovation, real estate development, and other fixed asset investments. It is believed that if the supply of infrastructure cannot meet the needs of economic development, it will encounter a "bottleneck" of economic growth (Liu and Su, 2021). Moreover, to get through the economic crisis in 2008, China invested a lot of fixed asset investment in infrastructure to alleviate the impact of the economic crisis (Bo et al., 2014). The government infrastructure includes many railways, highways, real estate and other projects, which will consume a lot of energy and cause a lot of carbon emissions. What role does the fixed asset investment play in the relationship between the degree of marketization of land sales and carbon emissions? After the benchmark regression, this paper will look for the impact of fixed asset investment from the perspective of the mediating effect and the moderating effect.

TABLE 7 Hysteresis analysis.

	(1)	(2)	(3)	(4)	(5)
	CE	CE	CE	CE	CE
	L.1	L.2	L.3	L.4	L.5
MLT	80.1067**	31.6969	−56.4395	−86.3835*	−59.7447
	(33.4856)	(39.8056)	(42.9039)	(46.7652)	(55.5652)
PD	−0.0122***	−0.0085*	−0.0047	0.0009	0.0004
	(0.0046)	(0.0050)	(0.0053)	(0.0060)	(0.0065)
ECS	65.5384	65.4110	18.4368	33.9976	−3.8861
	(46.6033)	(52.9115)	(60.2827)	(69.8106)	(80.7310)
GDP	0.0020***	0.0028***	0.0024***	0.0024***	0.0031***
	(0.0006)	(0.0007)	(0.0007)	(0.0008)	(0.0009)
MI	−8.4360*	−3.5188	−5.9418	−7.7547	−9.4951
	(4.8367)	(5.5356)	(6.0560)	(7.1795)	(7.7449)
UB	467.4042***	481.2209***	527.3721***	546.1152***	620.9880***
	(128.8475)	(156.1765)	(176.4922)	(204.4959)	(229.6528)
GP	−0.0001	−0.0005***	−0.0004**	−0.0003*	−0.0002
	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
_cons	−34.4694	−51.6758	19.6138	17.7638	−44.7815
	(80.8566)	(96.4773)	(111.7826)	(130.4796)	(147.4758)
N	270	240	210	180	150
r2	0.6546	0.6595	0.6848	0.6995	0.7391
F	28.4247	27.1202	27.9122	26.7674	28.0765

Notes: *, **, *** stand for significant levels of 10%, 5%, and 1%, respectively, and the values in brackets are *T*-values.

4.1.1 Hysteresis effect

As we all know, after the land is transferred, the transferee must go through certain economic activities to recover the cost of the land investment. Taking a production-oriented enterprise as an example, in the early stage of its establishment, it not only has to deal with substantial operating pressure and debt pressure, but also needs to do various preparations before factors of production can be put into production. For example, a standardized production enterprise needs workshops, office complexes, canteens, substations, purchasing production equipment, recruiting employees, so it will take a certain amount of time to enter production finally. For the research in this paper, whether the impact of the degree of marketization of land transfer on carbon emissions will change due to the different stages of land use requires further research. This paper uses a 1-year to 5-year lag effect to test the mechanism. The first reason is that the sample covers 10 years; the second reason is that industrial, manufacturing and other enterprises will fail because they cannot be put into operation for a long time, which may not have a significant impact on carbon emissions in the end, at the same time, lag effects that are too short may not reflect meaningful results. The results of the lag effect test are shown in Table 7.

From the regression results, it can be seen that for the first and fourth years of carbon emission lag, the direction of the impact of the degree of marketization of land transfer on carbon emissions has changed, and the results are significant. The empirical test results show that: first, the impact of the marketization degree of land transfer on carbon emissions has a lagging effect, and it is still a promoting effect in the first year and a suppressing effect in the fourth year; second, the innovation variables that have been insignificant all the time have a significant inhibitory effect on carbon emissions in the lag effect, which is in line with theoretical expectations. First of all, the increase in the degree of marketization of land transfer will increase carbon emissions at the beginning due to the processing and aggregation of production factors; however, the equipment used by new entrants is often more advanced and environmentally friendly (Su et al., 2021), and corporate management will pay more attention to energy conservation in all aspects so that carbon emissions will be curbed in the end. Second, the inhibitory effect of innovation on corporate carbon emissions occurred after a 2-year lag, and innovation improved energy efficiency.

4.1.2 Mediation effect

In order to test the mediation effect mechanism of fixed asset investment, the stepwise regression method proposed by Baron and Kenny (1986) was used to verify each hypothesis by constructing a recursive model. The benchmark process of the explanatory variable MLT affecting the explained variable CE through the mediating variable STA is as follows, according to the suggestions of Aiken and West (Aiken et al., 1991), in order to make the coefficient of the regression equation more explanatory, this paper centralizes the variable STA and calculates the mediation effect.

$$\boldsymbol{Y = cX + e_1} \tag{3}$$

$$\boldsymbol{M = aX + e_2} \tag{4}$$

$$\boldsymbol{Y = c'X + bM + e_3} \tag{5}$$

In the above benchmark formula, Eq. 3 reflects the effect of X on Y; Eq. 4 reflects the effect of X on M, and Eq. 5 reflects the effect of X on Y after the intervention of M. If both c' and b are significant and c' is lower than c', it means that M plays a partial mediating effect in the model; if c' is not significant but b is significant, it means that M plays a full mediating effect. In this research scenario, the corresponding mediation model is extended to the following regression model, as shown in Eqs 6, 7, which reflects the impact path of the degree of marketization of land transfer on carbon emissions. In addition, to exclude unobserved bias caused by individual and time factors, individual fixed effects and time fixed effects were still controlled. The results of the mediation effect test are shown in column (1), column 2) and column 3) of Table 8. In order to ensure the robustness of the mediation effect model, SOBEL and bootstrap

TABLE 8 Mechanistic analysis: mediation and moderation.

	(1)	(2)	(3)	(4)	(5)
	CE	STA	CE	CE (SOBEL)	CE
MLT	69.3660**	0.5371***	81.2570***	81.2570***	119.4146***
	(28.4689)	(0.1906)	(28.6476)	(28.6476)	(32.8819)
PD	−0.0155***	−0.0000	−0.0164***	−0.0164***	−0.0156***
	(0.0042)	(0.0000)	(0.0042)	(0.0042)	(0.0042)
ECS	166.4998***	0.2973	173.0824***	173.0824***	178.8579***
	(43.0647)	(0.2883)	(42.7623)	(42.7623)	(42.4768)
GDP	0.0015***	0.0000	0.0015***	0.0015***	0.0011*
	(0.0006)	(0.0000)	(0.0006)	(0.0006)	(0.0006)
MI	−13.7569***	0.0640**	−12.3392***	−12.3392***	−14.1137***
	(4.4133)	(0.0295)	(4.4135)	(4.4135)	(4.4436)
UB	450.1381***	6.1782***	586.9244***	586.9244***	531.2899***
	(110.5926)	(0.7404)	(123.6985)	(123.6985)	(125.0127)
GP	0.0001	−0.0000	0.0001	0.0001	0.0001
	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0001)
STA			−22.1403**	−22.1403**	−72.6311***
			(9.2870)	(9.2870)	(23.7705)
MLTSTA					59.0961**
					(25.6491)
_cons	−16.4097	−4.7069***	−1.2e + 02	−4.5e + 02***	−1.2e + 02
	(71.8826)	(0.4812)	(83.5726)	(119.3602)	(82.8725)
N	300	300	300	300	300
r2	0.6634	0.8932	0.6708	0.9857	0.6776
F	31.2837	132.8175	30.3207	378.0176	29.4188

Notes: *, **, *** stand for significant levels of 10%, 5%, and 1%, respectively, and the values in brackets are *T*-values.

tests (5,000 times) are performed in this paper, and the SOBEL test result is shown in column 4).

$$\begin{aligned} STA_{it} &= \beta_0 + \beta_1 MLT_{it} + \beta_2 PD_{it} + \beta_3 ECS_{it} + \beta_4 PGDP_{it} \\ &\quad + \beta_5 MI_{it} + \beta_6 UB_{it} + \beta_7 GP_{it} + Year_t + Province_i + \varepsilon_{it} \end{aligned} \tag{6}$$

$$\begin{aligned} CE_{it} &= \gamma_0 + \gamma_1 MLT_{it} + \gamma_2 STA_{it} + \gamma_3 PD_{it} + \gamma_4 ECS_{it} + \gamma_5 PGDP_{it} \\ &\quad + \gamma_6 MI_{it} + \gamma_7 UB_{it} + \gamma_8 GP_{it} + Year_t + Province_i + \varepsilon_{it} \end{aligned} \tag{7}$$

First, as shown in columns 2), the degree of marketization of land transfer has a significant role in promoting fixed asset investment. After adding the intermediary variable in columns 3), the impact of the marketization of land transfer on carbon emissions is still significant; this shows that fixed assets mainly play a masking role rather than an intermediary role in the impact of the marketization of land transfer on carbon emissions. From a numerical point of view, although the correlation coefficient of fixed assets is negative, the influence coefficient of the degree of marketization of land transfer on carbon emissions has improved dramatically.

On the one hand, the degree of marketization of land transfer has a significant positive impact on fixed asset investment, which is in line with the theoretical analysis above. The increase in the degree of marketization of land transfer will promote fixed asset investment, and more companies will speed up the pace of construction and use the benefits of economic growth and technological spillovers to increase production to form economies of scale. On the other hand, since the improvement of the marketization of land transfer, more advanced enterprises will be introduced, which will have better performance in the aspects of energy control, pollution control, and rational urban planning, which will eventually reduce the local carbon emission value. Hence, fixed asset investment is a "double-edged sword." If it is not controlled reasonably, it will play a masking mediating effect in promoting the degree of land transfer marketization on carbon emissions.

The results of the Sobel test indicated that the results of the mediation effect were robust. Through 5,000 repeated sampling tests, it can be seen from Table 9 that the confidence interval of bs_2 is (24.57857, 137.9354) and does not contain 0, indicating

TABLE 9 Bootstrap test for mediating effect.

Bootstrap	Observed coefficient	Bootstrap std. err	z	P>|z|	Normal-based [95% conf. Interval]	
bs_1	−11.89093	7.85088	−1.51	0.130	−27.27837	3.49651
bs_2	81.25697	28.91808	2.81	0.005	24.57857	137.9354

Notes: *, **, *** stand for significant levels of 10%, 5%, and 1%, respectively, and the values in brackets are T-values.

that the masking effect exists and is significant at the 95% level. Hence, the test result of the original effect model is still significant. However, the results of the two robustness tests of SOBEL and bootstrap can only prove the robustness of the correlation coefficient, not causality. The result that the correlation coefficient of STA is negative is still worthy of further exploration. Therefore, this paper continues to test the moderating effect, hoping to find the role of fixed asset investment in the impact of the marketization of land transfer on carbon emissions from a causal point of view.

4.1.3 Moderating effect

In this paper, the method to test whether fixed asset investment has an adjustment effect is mainly to form the multiplication item with the independent variable and check whether the regression coefficient of the multiplication item is significant to judge the adjustment effect. Its benchmark regression model is shown in Eq. 8.

$$Y = c''X + b'M + dXM + e_4 \tag{8}$$

Through the above test, it is found that fixed asset investment would produce a masking effect. In order to promote the understanding of the causal relationship between the degree of marketization of land transfer and carbon emissions, this paper continues to conduct a more substantial causal relationship test from the perspective of regulating utility. The expanded moderating utility model is shown in Eq. 9, and the regression results of the moderating utility model are shown in column 5) of Table 8.

$$\begin{aligned} CE_{it} = {} & \rho_0 + \rho_1 MLT_{it} + \rho_2 STA_{it} + \rho_3 MLT*STA_{it} + \rho_4 ECS_{it} \\ & + \rho_5 PGDP_{it} + \rho_6 MI_{it} + \rho_7 UB_{it} + \rho_8 GP_{it} + Year_t \\ & + Province_i + \varepsilon_{it} \end{aligned} \tag{9}$$

The regression results show that the correlation coefficient between the multiplication term and carbon emissions is significantly positive. This shows that fixed asset investment has played a positive regulating role. That is to say, increasing the marketization degree of land transfer and increasing fixed asset investment will further increase the level of carbon emissions. According to the investment multiplier theory, fixed asset investment will increase GDP and drive local economic growth (Wang et al., 2020). After the marketization of land transfer is improved, production units have the opportunity to expand their scale. For example, companies will have more opportunities to open branches and factories. Although some funds will be occupied, companies can increase their turnover by obtaining more financing. Increased production, energy consumption, and new and refurbished infrastructure all increase carbon emissions. Ultimately, empirical results validate this theory.

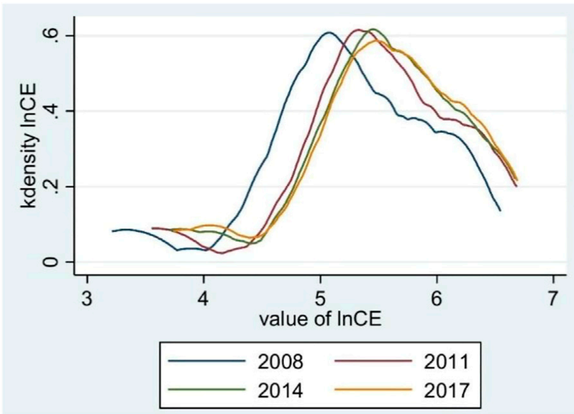

FIGURE 3
Carbon emission nuclear density curve.

4.2 Heterogeneity analysis

As shown in Figure 3, The carbon emission values were taken logarithmically, and a nuclear density analysis was performed. It can be seen from the nuclear density chart that from 2008 to 2017, the overall curve moved to the right, but the speed of movement was slowing down. It shows that in this decade, the value of carbon emissions had continued to grow at diminishing marginal effects; the peak change in the curve first increased and then experienced a more considerable decrease in 2017; it shows that after 2014, the government implemented effective

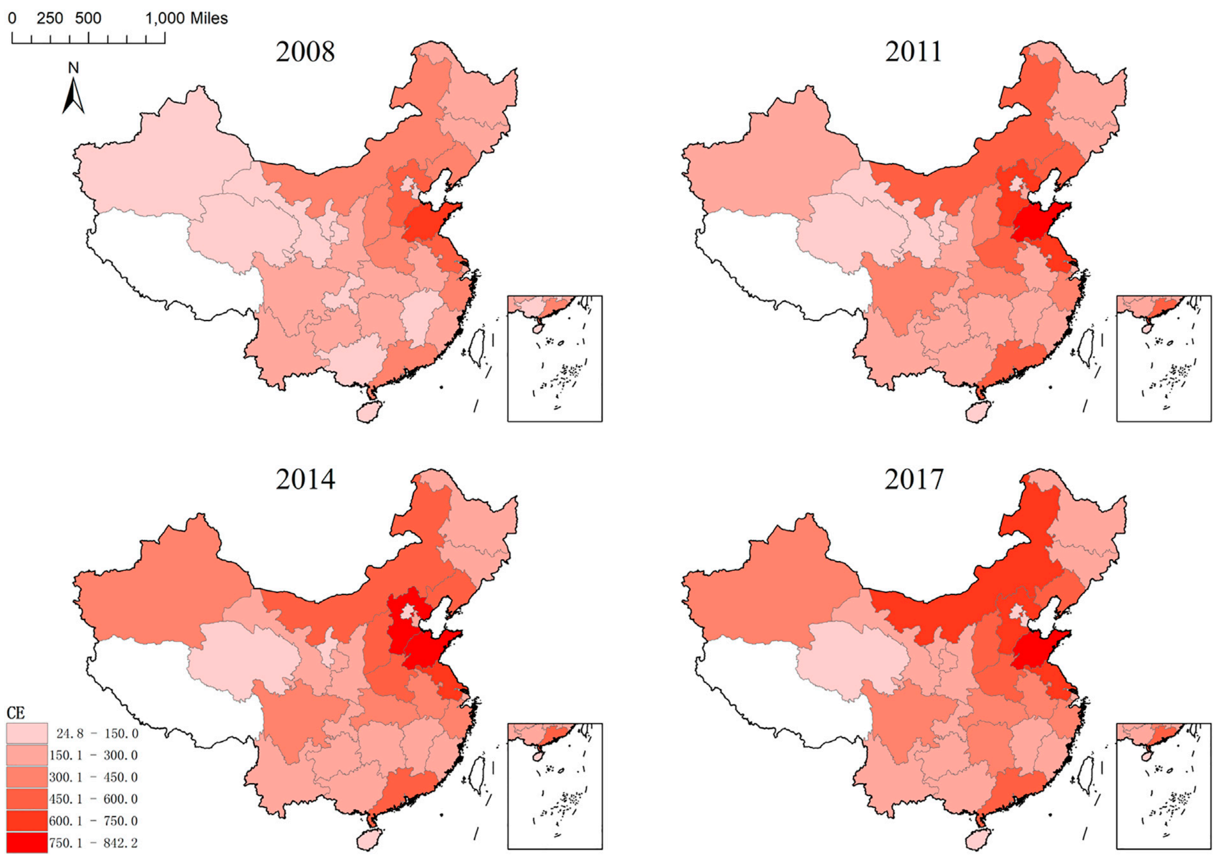

FIGURE 4
Evolution map of carbon emissions (excluding Tibet, Hong Kong, Macao, and Taiwan).

management and control on regions with high carbon emission values, which had reduced the extreme value gap of regional carbon emission values; the overall curve also gradually transitioned from bimodal to unimodal, and the distribution ductility shows a broadening trend to a certain extent, indicated that the difference in carbon emission values between provinces had been gradually increasing. Therefore, this paper conducts further heterogeneity analysis from provincial heterogeneity and government control perspectives.

4.2.1 Heterogeneity of market competition

This paper first analyzes provincial heterogeneity. Since ancient times, China's topography has been complex and diverse, with high in the west and low in the east, and distributed in a ladder shape. The eastern region has vast plains, a humid climate and fertile land, which is favorable for the development of the planting industry; in addition, the eastern region has developed transportation, communication, education, numerous cities and abundant human resources, which provide important conditions for industrial development. There is a shortage of mineral and energy resources in the east, and severe industrial pollution also plagues the development of the eastern region. The western inland region has vast areas of plateaus and mountains, rich grassland resources, developed animal husbandry, and rich mineral resources. However, the climate is arid, and the natural conditions for developing farming operations are poor. Compared with the east, the west has a big gap in social and economic conditions such as capital, technology, talent, market, and transportation. As shown in Figure 4, from the geographic evolution map of carbon emissions, the changes in carbon emissions in the same regions are also similar. In contrast, the evolution of carbon emissions in different regions has different trends.

Therefore, it is necessary to analyze the heterogeneity of carbon emissions in different regions. According to the division of provinces and regions by the Chinese government before 2018, this paper conducts a marketization heterogeneity analysis on the eastern, middle and western regions of China. The empirical test results are shown in Table 10.

From Table 10, it can be seen that the promotion effect of the marketization degree of land transfer on carbon emissions is significant in the eastern and western regions. In contrast, the

TABLE 10 Heterogeneity analysis: marketization level.

	(1)	(2)	(3)
	CE	CE	CE
	EAST	MIDDLE	WEST
MLT	122.2633**	75.8043	80.7396*
	(46.6644)	(51.3343)	(42.8923)
PD	0.0081	−0.0083	−0.0330***
	(0.0128)	(0.0077)	(0.0057)
ECS	17.1096	240.2509***	5.0913
	(88.2179)	(54.9429)	(86.8071)
GDP	0.0017**	−0.0046***	−0.0016
	(0.0007)	(0.0014)	(0.0022)
MI	−26.2973***	−26.1739***	13.9655*
	(7.3425)	(8.9122)	(8.1328)
UB	790.7304***	1.3e+03***	−9.8e+02**
	(157.1614)	(246.0050)	(389.6538)
GP	0.0001	0.0014***	−0.0005
	(0.0001)	(0.0005)	(0.0008)
_cons	−1.5e+02	−3.4e+02**	502.6659***
	(127.5247)	(138.9565)	(150.3676)
N	110	100	90
r2	0.7663	0.8251	0.7465
F	17.0119	21.8141	11.9626

Notes: *, **, *** stand for significant levels of 10%, 5%, and 1%, respectively, and the values in brackets are *T*-values.

TABLE 11 Heterogeneity analysis: government regulation intensity.

	(1)	(2)	(3)	(4)
	CE	CE	CE	CE
	Tight int	Flexible int	Tight reg	Flexible reg
MLT	32.2112	110.1264**	9.2706	110.4879*
	(56.2550)	(48.4498)	(20.2268)	(56.5063)
PD	−0.0044	−0.0165***	0.0052	−0.0209***
	(0.0099)	(0.0055)	(0.0044)	(0.0068)
ECS	265.5788***	53.5009	198.7015***	314.5526***
	(67.4048)	(73.1825)	(38.7688)	(65.0836)
GDP	0.0008	0.0032	0.0010	0.0003
	(0.0008)	(0.0030)	(0.0009)	(0.0007)
MI	−31.6467***	18.3488*	2.2326	−36.5533***
	(7.9909)	(9.2906)	(3.3546)	(8.3168)
UB	563.7059***	−2.4e+02	452.1131***	630.4500**
	(164.9947)	(278.4788)	(92.1210)	(265.6452)
GP	0.0002	−0.0015	0.0001	0.0003*
	(0.0002)	(0.0010)	(0.0002)	(0.0002)
_cons	92.0450	140.5101	−2.2e + 02***	59.9535
	(112.5589)	(146.3328)	(67.2516)	(133.9585)
N	120	120	145	146
r2	0.5251	0.4686	0.6603	0.7867
F	6.7923	5.4790	13.1210	25.5824

Notes: *, **, *** stand for significant levels of 10%, 5%, and 1%, respectively, and the values in brackets are *T*-values.

middle regions with more complex terrain and industry categories do not pass the significance test. At the same time, the promotion effect of the marketization degree of land transfer in the eastern region is significantly higher than that in the western region. On the one hand, for the output value of the technology-intensive eastern developed regions, the improvement of the marketization of land transfer will lead to a better economic Pareto situation, such as less hunger and poverty, but it may not be environmentally friendly (Jia et al., 2021). The eastern cities are more crowded, and the improvement of the marketization of land sales will bring more advanced and large-scale enterprises to settle in. These new entrants will quickly raise funds to build in order to cope with capital turnover and profit; heavy energy use and more congested traffic, putting pressure on carbon emission control. Industries with more minor energy demands and lower output value are not easily developed in the eastern region (Wu et al., 2021b). On the other hand, the terrain and resources of the western region determine that the industries in the western region are mainly resource-intensive and labor-intensive, and the industries are more diversified, mainly energy development, manufacturing and tourism. The carbon emissions produced by these industries are relatively limited, and the improvement of the degree of marketization of land transfer does not promote carbon emissions as much as in the eastern region with a highly developed marketization level. The competition intensity, capital flow rate and development pressure of enterprises in the western region are lower than those in the eastern region, and various government documents in China are motivating the western region to better utilize its characteristic advantages rather than the region's GDP. Therefore, the improvement of the marketization degree of land transfer will promote carbon emissions in the western region to be much lower than that in the eastern region.

4.2.2 Heterogeneity of government regulation intensity

Both government intervention and environmental regulation will have an impact on local economic activities and affect carbon emissions. Due to the different industrial structures, and economic and social conditions in different regions, the intensity of government control is also different. Therefore, this paper first takes the median level of government intervention in each region as the cut-off point and divides the two sides of the cut-off point into tight intervention and flexible intervention, and then carries out a quantitative test analysis of heterogeneity. The government intervention coefficient is derived from the ratio of fiscal expenditure to GDP, excluding education and science. The regression results are shown in columns 1) and 2) of Table 11. Then, the median of the environmental regulation coefficient is taken as the cut-off point, and the two sides of the cut-off point are divided into tight environmental regulation and flexible environmental regulation. The regression results are shown in columns 3) and 4) of Table 11. The environmental regulation factor is: first, the three pollutants of industrial wastewater discharge, industrial SO2 discharge and industrial soot discharge are standardized, then the weight of each pollutant is calculated, and finally, the environmental regulation index is obtained by multiplying the weight and the standardization. The above data come from China Statistical Yearbook, China Environmental Statistical Yearbook and China Urban Statistical Yearbook removing outliers and vacancies.

The results in the table above show that, compared with the benchmark regression results, under flexible government intervention and environmental regulation, the degree of marketization of land transfers will have a more substantial effect on carbon emissions. Although the results did not pass the significance test, numerically speaking, under the tight government intervention and environmental regulation, the correlation coefficient between the degree of marketization of land transfer and carbon emissions has dropped significantly. The reason for insignificant results may be that high-intensity government control affects changes in other variables. On the one hand, from the perspective of game theory, flexible government intervention gives profit-oriented enterprises more room to make profits. Corporations can get more loans because they get more land being sold and choose to maximize production. The better use of land resources brings more carbon emissions. On the other hand, tighter regulations will lead to less newly acquired land being acquired by polluting enterprises, but it has not reversed the promotion effect of the marketization of land transfer on carbon emissions.

5 Conclusion and implications

This paper uses multi-dimensional indicators to calculate the carbon emissions and the degree of marketization of land sales in China's 30 provincial-level administrative units from 2008 to 2017; their correlations, mechanisms of action, and heterogeneity effects were analyzed. We find the following conclusions: On the one hand, the improvement of the degree of marketization of land transfer will optimize the allocation of resources, bring in the influx of labor force and increase the population density, increasing the demand for energy consumption, thereby increasing carbon emissions; on the other hand, the assignee with scale advantage will increase the construction of facilities and expand production in the early stage of land development, which will eventually lead to an increase in carbon emissions. Then, the robustness test of the empirical benchmark results is carried out from three perspectives: quantile test, tail reduction test and replacement of measurement indicators, and it is found that the lower the marketization of land transfer, the stronger the promotion effect on carbon emissions. Second, a mechanism inspection from multiple angles was conducted. The first is the test of the lag effect, the regression results show that with the delay of the lag period, the effect of the marketization of land transfer on carbon emissions has changed from promotion to inhibition, and the inhibition effect of technological innovation has become more significant; secondly, from the perspective of fixed asset investment, this paper tests the mediation effect and the adjustment effect, and finds that the fixed asset exerts a masking effect and a moderating effect, that is to say, the improvement of marketization degree does not promote carbon emissions by increasing the investment in fixed assets, but the improvement of marketization degree of land transfer combined with the investment in fixed assets will further expand the level of carbon emissions; finally, the empirical results are analyzed from the perspectives of marketization degree and government control. The empirical results show that the degree of marketization of land transfer has a significant role in promoting carbon emissions in the less developed western region and the more developed eastern region. Furthermore, the impact on the western region is even more significant. Using the two perspectives of government intervention and environmental regulation to represent the influence of government control factors, it is found that with flexible government control, the improvement of the marketization degree of land transfer will have a more substantial role in promoting carbon emissions.

Based on the empirical test results of this paper, the following policy implications are drawn: first, change the economic growth model, especially in highly developed areas, while improving regional economic benefits; we should resolutely resist the introduction of low-efficiency and high-polluting enterprises, increase investment in research and development, promote industrial upgrading, and gradually form a low-energy, green and energy-saving investment development route. Second, to reasonably control the investment structure of fixed assets and eliminate outdated production capacity, environmental factors need to be considered in the process of increasing investment in fixed assets. The problem of excessive carbon emissions caused by fixed asset investment-driven economic growth requires the gradual realization of carbon neutrality by relying on subsequent innovation improvements. The third is to coordinate the spatial distribution of regional land transfer marketization. For economically developed regions, cooperating with tight government control, the ratio of land bidding, auctions and listings for sale can be increased to squeeze out companies with high energy consumption but low economic benefits; for less developed western regions, more ways to balance the pressure of carbon emissions must be found, for example, encourage energy innovation or vigorously develop characteristic industries to reduce industrial and manufacturing carbon emissions.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization, RY; data curation, RZ and RY; formal analysis, RZ; funding acquisition, RZ; investigation, RZ; methodology, RY; project administration, RZ; resources, RZ; software, RY; supervision, YH; validation, YH; visualization, RZ writing-original draft, RY; writing-review and editing, RY, RZ, and YH. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Acheampong, A. O., Amponsah, M., and Boateng, E. (2020). Does financial development mitigate carbon emissions? Evidence from heterogeneous financial economies. *ENERGY Econ.* 88, 104768. doi:10.1016/j.eneco.2020.104768

Aiken, L. S., West, S. G., and Reno, R. R. (1991). *Multiple regression: Testing and interpreting interactions*. London: Sage.

Akcin, M., Kaygusuz, A., Karabiber, A., Alagoz, S., Alagoz, B. B., Keles, C., et al. (2016). "Opportunities for energy efficiency in smart cities," in Proceeding of the 2016 4th international istanbul smart grid congress and fair (ICSG), Istanbul, Turkey, April 2016 (IEEE).

Anas, A. (2020). The cost of congestion and the benefits of congestion pricing: A general equilibrium analysis. *Transp. Res. Part B Methodol.* 136, 110–137. doi:10.1016/j.trb.2020.03.003

Baron, R. M., and Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. personality Soc. Psychol.* 51 (6), 1173–1182. doi:10.1037/0022-3514.51.6.1173

Begum, R. A., Sohag, K., Abdullah, S. M. S., and Jaafar, M. (2015). CO2 emissions, energy consumption, economic and population growth in Malaysia. *Renew. Sustain. Energy Rev.* 41, 594–601. doi:10.1016/j.rser.2014.07.205

Bo, H., Driver, C., and Lin, H. C. M. (2014). Corporate investment during the financial crisis: Evidence from China. *Int. Rev. financial analysis* 35, 1–12. doi:10.1016/j.irfa.2014.07.002

Bryan, B. A., Nolan, M., McKellar, L., Connor, J. D., Newth, D., Harwood, T., et al. (2016). Land-use and sustainability under intersecting global change and domestic policy scenarios: Trajectories for Australia to 2050. *Glob. Environ. Change* 38, 130–152. doi:10.1016/j.gloenvcha.2016.03.002

Cai, H. B., Henderson, J. V., and Zhang, Q. H. (2013). China's land market auctions: Evidence of corruption? *Rand J. Econ.* 44 (3), 488–521. doi:10.1111/1756-2171.12028

Cheng, C., Ren, X. H., Dong, K. Y., Dong, X. C., and Wang, Z. (2021). How does technological innovation mitigate CO2 emissions in OECD countries? Heterogeneous analysis using panel quantile regression. *J. Environ. Manag.* 280, 111818. doi:10.1016/j.jenvman.2020.111818

Chunxiang, A., Shen, Y., and Zeng, Y. (2022). Dynamic asset-liability management problem in a continuous-time model with delay. *Int. J. control* 95 (5), 1315–1336. doi:10.1080/00207179.2020.1849807

Cui, P., Zhao, Y., Zhang, L., Xia, S., and Xu, X. (2020). Spatio-temporal evolution and driving mechanism of per capita indirect carbon emissions based on different demand levels from urban residents′ consumption in China. *Acta Ecol. Sin.* 40 (4), 1424–1435. doi:10.5846/stxb201812242794

Dogan, B., Saboori, B., and Can, M. (2019). Does economic complexity matter for environmental degradation? An empirical analysis for different stages of development. *Environ. Sci. Pollut. Res.* 26 (31), 31900–31912. doi:10.1007/s11356-019-06333-1

Dong, B. Y., Xu, Y. Z., and Fan, X. M. (2020). How to achieve a win-win situation between economic growth and carbon emission reduction: Empirical evidence from the perspective of industrial structure upgrading. *Environ. Sci. Pollut. Res.* 27 (35), 43829–43844. doi:10.1007/s11356-020-09883-x

Galeotti, M., Lanza, A., and Pauli, F. (2006). Reassessing the environmental Kuznets curve for CO2 emissions: A robustness exercise. *Ecol. Econ.* 57 (1), 152–163. doi:10.1016/j.ecolecon.2005.03.031

Gao, L., and Bryan, B. A. (2017). Finding pathways to national-scale land-sector sustainability. *NATURE* 544 (7649), 217–222. doi:10.1038/nature21694

Granados, J. A. T., and Spash, C. L. (2019). Policies to reduce CO2 emissions: Fallacies and evidence from the United States and California. *Environ. Sci. policy* 94, 262–266. doi:10.1016/j.envsci.2019.01.007

Grossman, G. M., and Krueger, A. B. (1995). Economic growth and the environment. *Q. J. Econ.* 110 (2), 353–377. doi:10.2307/2118443

Hou, J. Y., Huo, X. X., and Yin, R. S. (2017). Land rental market participation and its impact on fixed investment and household welfare: Evidence from Chinese apple production sites. *sustainability* 9 (11), 1961. doi:10.3390/su9111961

Hou, S. H., Chen, X., and Qiu, R. (2022). Sustainable biofuel consumption in air passenger transport driven by carbon-tax policy. *Sustain. Prod. Consum.* 31, 478–491. doi:10.1016/j.spc.2022.03.016

Hu, Y. F., and Liu, D. Y. (2022). Government as a non-financial participant in innovation: How standardization led by government promotes regional innovation performance in China. *Technovation* 114, 102524. doi:10.1016/j.technovation.2022.102524

Ji, F., and Bao, S. (2020). Local government competition, transfer payment and land finance. *China Soft Sci.* 11, 100–109.

Jia, S. S., Qiu, Y. S., and Yang, C. Y. (2021). Sustainable development goals, financial inclusion, and grain security efficiency. *Agron. (Basel).* 11 (12), 2542. doi:10.3390/agronomy11122542

Jia, S. S., Yang, C. Y., Wang, M. X., and Failler, P. (2022). Heterogeneous impact of land-use on climate change: Study from a spatial perspective. *Front. Environ. Sci.* 10, 840603. doi:10.3389/fenvs.2022.840603

Jiang, X., Lu, X., and Gong, M. (2019). Land leasing marketization, industrial structure optimization and urban green total factor productivity: An empirical study based on hubei province. *China Land Sci.* 33, 50–59.

Jiang, X., Lu, X. H., Liu, Q., Chang, C., and Qu, L. L. (2021). The effects of land transfer marketization on the urban land use efficiency: An empirical study based on 285 cities in China. *Ecol. Indic.* 132, 108296. doi:10.1016/j.ecolind.2021.108296

Jin, J., Xu, J., and Yi, L. (2015). Dynamic relationships among industrial structure, technological progress and energy saving in beijing. *Res. Environ. Sci.* 28 (11), 1781–1788. doi:10.13198/j.issn.1001-6929.2015.11.17

Jing, R. Z., and Gu, M. (2008). "On selection of leading industries in new regional industrialization: A case study of jiangsu province of China," in proceedings of the 5th international conference on innovation & management, vols I and II.

Li, F. Y., and Liu, W. D. (2013). "Impact of global economic crisis on China's energy consumption during 2008~ 2010," in *Advanced materials research* (Zurich: Trans Tech Publ), 1578–1584.

Li, P. Z., Yang, D. C., and Huang, D. Z. (2022). How does the fintech sector react to signals from central bank digital currencies? *Finance Res. Lett.* 50, 103308. doi:10.1016/j.frl.2022.103308

Lin, B. Q., and Huang, C. C. (2022). Analysis of emission reduction effects of carbon trading: Market mechanism or government intervention? *Sustain. Prod. Consum.* 33, 28–37. doi:10.1016/j.spc.2022.06.016

Liu, T. Y., and Su, C. W. (2021). Is transportation improving urbanization in China? *SOCIO-ECONOMIC Plan. Sci.* 77, 101034. doi:10.1016/j.seps.2021.101034

Lopez, R. A., Shah, F. A., and Altobello, M. A. (1994). Amenity benefits and the optimal allocation of land. *Land Econ.* 70, 53–62. doi:10.2307/3146440

Ma, A. H., He, Y. Y., and Tang, P. (2021). Understanding the impact of land resource misallocation on carbon emissions in China. *land* 10 (11), 1188. doi:10.3390/land10111188

Mclarren, D. (1992). *Compact or Disposed? Dilution is no Solution*, 18. London: Built Environment.

Messner, E. (2008). Cities without land markets: A case study from st. Petersburg, Russia. *Real Estate Rev.* 37 (2), 31.

Metcalf, G. E. (2009). Designing a carbon tax to reduce US greenhouse gas emissions. *Rev. Environ. Econ. POLICY* 3 (1), 63–83. doi:10.1093/reep/ren015

Ouyang, X. L., Fang, X. M., Cao, Y., and Sun, C. W. (2020). Factors behind CO2 emission reduction in Chinese heavy industries: Do environmental regulations matter? *ENERGY POLICY* 145, 111765. doi:10.1016/j.enpol.2020.111765

Selden, T. M., and Song, D. Q. (1995). Neoclassical growth, the j-curve for abatement, and the inverted U-curve for pollution. *J. Environ. Econ. Manag.* 29 (2), 162–168. doi:10.1006/jeem.1995.1038

Sharma, S. S. (2011). Determinants of carbon dioxide emissions: Empirical evidence from 69 countries. *Appl. ENERGY* 88 (1), 376–382. doi:10.1016/j.apenergy.2010.07.022

Shi, M. J., Ma, G. X., and Shi, Y. (2011). How much real cost has China paid for its economic growth? *Sustain. Sci.* 6 (2), 135–149. doi:10.1007/s11625-011-0133-5

Shi, X. Y., Xi, T. Y., Zhang, X. B., and Zhang, Y. F. (2021). Moving Umbrella": Bureaucratic transfers and the comovement of interregional investments in China. *J. Dev. Econ.* 153, 102717. doi:10.1016/j.jdeveco.2021.102717

Su, Y. Y., Li, Z. H., and Yang, C. Y. (2021). Spatial interaction spillover effects between digital financial technology and urban ecological efficiency in China: An empirical study based on spatial simultaneous equations. *Int. J. Environ. Res. Public Health* 18 (16), 8535. doi:10.3390/ijerph18168535

Wang, Y. L., Yu, Y. Z., and Su, Y. Q. (2018). Does the tender, auction and listing system in land promote higher housing prices in China? *Hous. Stud.* 33 (4), 613–634. doi:10.1080/02673037.2017.1373750

Wang, B. J., Zhao, J. L., Wu, Y. F., Zhu, C. Q., He, Y. N., and Wei, Y. X. (2019). Allocating on coal consumption and CO2 emission from fair and efficient perspective: Empirical analysis on provincial panel data of China. *Environ. Sci. Pollut. Res.* 26 (18), 17950–17964. doi:10.1007/s11356-018-1937-y

Wang, R., Qi, Z. Y., and Shu, Y. M. (2020). Multiple relationships between fixed-asset investment and industrial structure evolution in China-Based on Directed Acyclic Graph (DAG) analysis and VAR model. *Struct. CHANGE Econ. Dyn.* 55, 222–231. doi:10.1016/j.strueco.2020.09.001

Wang, W., Muravey, D., Shen, Y., and Zeng, Y. (2022). Optimal investment and reinsurance strategies under 4/2 stochastic volatility model. *Scand. Actuar. J.*, 1–37. doi:10.1080/03461238.2022.2108335

Wang, M., and Feng, C. (2020). The impacts of technological gap and scale economy on the low-carbon development of China's industries: An extended decomposition analysis. *Technol. Forecast. Soc. CHANGE* 157, 120050. doi:10.1016/j.techfore.2020.120050

Wang, R., and Qi, Z. Y. (2021). "The relationship between fixed-asset investment and carbon emissions by three strata of industry in China," in Proceeding of the ICCREM 2021:Challenges of the construction industry under the pandemic, Beijing, China, October 2021.

Wang, Y., and Hui, E. C. M. (2017). Are local governments maximizing land revenue? Evidence from China. *CHINA Econ. Rev.* 43, 196–215. doi:10.1016/j.chieco.2017.02.005

Wu, H. T., Hao, Y., and Ren, S. Y. (2020). How do environmental regulation and environmental decentralization affect green total factor energy efficiency: Evidence from China. *ENERGY Econ.* 91, 104880. doi:10.1016/j.eneco.2020.104880

Wu, H., Xia, Y., Yang, X., Hao, Y., and Ren, S. (2021a). Does environmental pollution promote China's crime rate? A new perspective through government official corruption. *Struct. Change Econ. Dyn.* 57, 292–307. doi:10.1016/j.strueco.2021.04.006

Wu, H., Xue, Y., Hao, Y., and Ren, S. Y. (2021b). How does internet development affect energy-saving and emission reduction? Evidence from China. *energy Econ.* 103, 105577. doi:10.1016/j.eneco.2021.105577

Xu, S. C., He, Z. X., and Long, R. Y. (2014). Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI. *Appl. energy* 127, 182–193. doi:10.1016/j.apenergy.2014.03.093

Xu, S. C., He, Z. X., Long, R. Y., and Chen, H. (2016). Factors that influence carbon emissions due to energy consumption based on different stages and sectors in China. *J. Clean. Prod.* 115, 139–148. doi:10.1016/j.jclepro.2015.11.050

Yang, Z., Ren, R. R., Liu, H. Y., and Zhang, H. (2015). Land leasing and local government behaviour in China: Evidence from Beijing. *URBAN Stud.* 52 (5), 841–856. doi:10.1177/0042098014529342

Yu, C., de Jong, M., and Cheng, B. D. (2016). Getting depleted resource-based cities back on their feet again the example of Yichun in China. *J. Clean. Prod.* 134, 42–50. doi:10.1016/j.jclepro.2015.09.101

Yuan, F., Wei, Y. D., and Xiao, W. Y. (2019). Land marketization, fiscal decentralization, and the dynamics of urban land prices in transitional China. *LAND USE POLICY* 89, 104208. doi:10.1016/j.landusepol.2019.104208

Zang, Z., Zou, X. Q., Song, Q. C., Wang, T., and Fu, G. H. (2018). Analysis of the global carbon dioxide emissions from 2003 to 2015: Convergence trends and regional contributions. *CARBON Manag.* 9 (1), 45–55. doi:10.1080/17583004.2017.1418594

Zeng, L. J., Wang, Y. D., and Deng, Y. J. (2022). How land transactions affect carbon emissions: Evidence from China. *LAND* 11 (5), 751. doi:10.3390/land11050751

Zhang, X. H., Zhang, R., Wu, L. Q., Deng, S. H., Lin, L. L., and Yu, X. Y. (2013). The interactions among China's economic growth and its energy consumption and emissions during 1978-2007. *Ecol. Indic.* 24, 83–95. doi:10.1016/j.ecolind.2012.06.004

Zhang, C., Zhang, Z., and Qin, M. (2016). Research on energy resources, technology advance and carbon emission intensity -based on spatial panel econometric model. *Syst. Eng.* 34 (11), 47–53.

Zhang, H., Geng, Z. R., Yin, R. S., and Zhang, W. (2020a). Regional differences and convergence tendency of green development competitiveness in China. *J. Clean. Prod.* 254, 119922. doi:10.1016/j.jclepro.2019.119922

Zhang, W., Li, G. X., Uddin, M. K., and Guo, S. C. (2020b). Environmental regulation, Foreign investment behavior, and carbon emissions for 30 provinces in China. *J. Clean. Prod.* 248, 119208. doi:10.1016/j.jclepro.2019.119208

Zhou, Y., Chen, M. X., Tang, Z. P., and Mei, Z. A. (2021). Urbanization, land use change, and carbon emissions: Quantitative assessments for city-level carbon emissions in Beijing-Tianjin-Hebei region. *Sustain. CITIES Soc.* 66, 102701. doi:10.1016/j.scs.2020.102701