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Modeling the Impact of Foreign Direct Investment on China's Carbon Emissions: An Economic and Environmental Paradigm

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Under the background of high-quality development, the impact of foreign direct investment on carbon emissions has attracted increasing attention. This research studies the impact of foreign direct investment on carbon emissions under the effect of institutional quality regulation. Specifically, this study uses China's provincial panel data from 2010 to 2019, taking political system quality, economic system quality, and legal system quality as the external environment of system quality, this research studies the threshold effect of foreign direct investment on carbon emissions. The results show that foreign direct investment can effectively restrain the increase in carbon emissions. The impact of FDI on China's carbon emissions has an obvious economic threshold effect: with the increase of regional corruption, the political quality is gradually declining, and the inhibition effect of foreign direct investment on carbon emissions is declining. With the increase of marketization and intellectual property protection, the regional economic system and legal system have gradually improved, and the role of foreign direct investment in carbon emissions has been further increased. Therefore, China should create a good institutional environment for FDI technology spillovers.

Keywords: foreign direct investment, carbon emissions, institutional quality, econimic, environmental paradigm

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INTRODUCTION

Since the reform and opening up, China has introduced foreign direct investment (FDI) to develop its export-oriented economy (Rauf et al., 2021; Abbasi et al., 2022; Fang et al., 2022), which has made the domestic economic development a great success (Hao et al., 2021a; Iqbal et al., 2021; Irfan et al., 2021), and is known as "China's growth miracle" (Lan et al., 2012; Wu et al., 2019; Zhu et al., 2019). According to the report of the Ministry of Commerce of the People's Republic of China, in 2020, China's foreign direct investment reached 999.98 billion yuan, making it the largest FDI recipient country in the world that year. The contribution of FDI to China's economic growth is unquestionable, but behind it is at the expense of the environment (Wu et al., 2021a; Shao et al., 2021; Shi et al., 2022). In recent years, China's carbon emissions continue to increase, and the environmental quality continues to deteriorate (Hao et al., 2021b; Li et al., 2021; Irfan and Ahmad 2022). The State Council issued the "Comprehensive Work Plan for Energy Conservation and Emission Reduction in the 14th Five-Year Plan" (hereinafter referred to as the "Plan"), proposing that by 2025, the national energy consumption per unit of GDP will be reduced by 13.5% compared with 2020. The total energy consumption has been reasonably controlled, and the total emissions of

chemical oxygen demand, ammonia nitrogen, nitrogen oxides, and volatile organic compounds have decreased by 8%, 8%, more than 10% and more than 10% respectively compared with 2020 (Li et al., 2020). At the same time, it is necessary to achieve remarkable results in air pollution prevention and control, and the situation of carbon emission reduction in China is extremely severe (Hao et al., 2020; Jinru et al., 2021; Khan et al., 2021; Wu et al., 2021b).

Under the background of frequent cross-border investment and high voice of environmental protection, the impact of FDI on the host country's environment has become the focus of many scholars' attention. One view is that FDI not only brings advanced management experience and production technology to the host country through the technology spillover effect, but also improves the energy utilization efficiency of local enterprises, and it also improves the degree of global specialized division of labor through the transnational flow of funds. Making production activities and pollution control activities produce scale-increasing effects, which are beneficial to the reduction of carbon emissions (Rezza, 2013; Chandio et al., 2021; Ren et al., 2022; Wang et al., 2022). Another view is that, in order to evade domestic environmental regulations, developed countries have transferred high-energy and high-pollution enterprises to developing countries with relatively loose environmental regulations (Tanveer et al., 2021; Ahmad et al., 2022), and the inflow of FDI has exerted tremendous pressure on the carbon emissions of the host countries (Hoffmann et al., 2005; Lee, 2009; Singhania and Saini, 2021). It makes developing countries become shelters for the transfer of polluting industries to developed countries. With the deepening of research, some scholars have begun to pay attention to the nonlinear relationship between FDI and carbon emissions. Because the threshold regression model can break through the limitation of linear analysis in previous studies, it can examine the different directions and degrees of action of explanatory variables on the explained variables in different ranges. This model has been widely used in nonlinear relationship verification. Scholars have confirmed that FDI has an obvious threshold effect on carbon emissions from the perspectives of income level, human capital level, financial development level, and industry technology level (Hoffmann et al., 2005; Chai et al., 2021).

In recent years, the political, economic, and legal environment of various countries has been changing constantly, and the impact of traumatic direct investment on carbon emissions may be influenced by economic externalities. Unfortunately, few scholars deeply and systematically analyzed the impact mechanism of FDI on carbon emissions from the perspective of the economic system environment, ignoring the important promoter in the transformation of China's economic growth mode (Hoffmann et al., 2005). So it is difficult to truly describe the impact of FDI on carbon emissions. In view of this, based on the panel data of 30 provinces in China from 2010 to 2019, this study examines the threshold effect of FDI on China's carbon emissions from three externalities of politics, economy, and law, and answers the following three questions: First, does the impact of FDI on China's carbon emissions have a flat threshold effect of economic externalities? Second, if it exists, what channel or mechanism does the threshold effect mainly occur? Third, how to formulate corresponding carbon emission reduction policies according to different thresholds and influencing mechanisms? It is expected to provide a theoretical reference for the rational introduction of foreign direct investment in the region and the realization of green and low-carbon sustainable development.

RESEARCH DESIGN

Basic Model Design

According to the aforementioned analysis, this study uses the research of Grossman and Krueger (1995) to construct the basic econometric model of this study from three aspects: scale, technology, and structure.

$$CO_2 = GDP \cdot TECH \cdot IND. \tag{1}$$

Among them, CO_2 Represents carbon emissions, GDP represents economic scale, TECH represents the technical level, and IND represents industrial structure. In order to test whether there is an "environmental Kuznets curve (EKC)" relationship between the level of economic development and carbon emissions, this study introduces the square of GDP into the economic scale (Wu et al., 2020; Tang et al., 2021). In an open economy, technological progress is influenced by international technology spillover (FDI) and R&D investment (RD). Consider comprehensively transforming model (1) into:

$$CO_2 = F\left(GDP, GDP^2\right) \cdot H\left(FDI, RD\right) \cdot IND. \tag{2}$$

By taking logarithms on both sides of formula **(2)** at the same time, the basic econometric model of this study is obtained:

$$\begin{aligned} LNCO_{2_{it}} = {} & \beta_0 + \beta_1 LNFDI_{it} + \beta_2 LNGDP_{it} + \beta_3 LNGDP_{it}^2 \\ & + \beta_4 LNIND_{it} + \beta_5 LNRD_{it} + e_{it}, \end{aligned} \tag{3}$$

where I represents the province (I = 1, 2, 3 ... 30), and T represents the time, CO_{2it} indicates carbon emissions, FDI_{it} indicates the actual utilization of foreign direct investment, GDP_{it}, GDP_{it}^2, IND_{it}, and RD_{it} represents the level of economic development, the quadratic term of the level of economic development, the industrial structure adjustment index, and the R&D investment intensity, respectively, e_{it} said random disturbance term, LN said logarithm, β_0 and β_1,β_2, ...,β_5 represent constant items and parameters to be estimated.

Dynamic Threshold Panel Model

In order to study the impact of FDI on carbon emissions under the condition of economic externalities and solve the endogenous problems, this study introduces the dynamic threshold panel model and further transforms the model (3) into the following dynamic threshold model by referring to the research of Wu et al. (2020):

$$\begin{aligned} lnco_{2_{it}} = {} & \beta_0 + \beta_1 lnco_{2_{it-1}} + \beta_2 \ln fdi_{it} I\left(q_{it} \leqq c\right) + \beta_3 \ln fdi_{it} I\left(q_{it} > c\right) \\ & + \beta_n x_{it} + \alpha_i + e_{it}. \end{aligned} \tag{4}$$

Among them, $lnco_{2_{it-1}}$ a lag term represents carbon emissions, q_{it} for simplicity, we assume that the threshold variable does not change with time and is exogenous, i (·) indicates the index function, and c is the specific threshold value. x_{it} represents a series of control variables, α_i indicates the individual fixation effect, e_{it} is a random error term.

Explanation and Explanation of Variables

Explained Variable

Emissions of carbon (CO_2. at present, China's carbon emissions mainly come from fossil fuel combustion and industrial production. Fossil fuels mainly include coal, coke, petroleum (divided into fuel oil, gasoline, kerosene, and diesel oil), and natural gas. The emission of CO_2 in industrial production mainly includes CO_2 produced in cement, lime, calcium carbide, and other production processes. Among them, CO_2 produced in the cement production process accounts for the largest proportion. Considering the availability and integrity of data, only the carbon emissions released in the cement production process are considered.

The carbon emissions from fossil fuel combustion can be obtained by multiplying various energy consumption (standard tons of coal) by the carbon dioxide emission coefficient, and the specific calculation formula is as follows:

$$TCO_2 = \sum_{i=1}^{7} CO_{2i} = \sum_{i=1}^{7} Q_i \times CF_i \times CC_i \times COF_i \frac{44}{12}. \quad (5)$$

In the aforementioned formula, TCO_2 represents the total amount of carbon dioxide released by various fossil energy consumption, Q_i represents the final consumption of the I energy in 30 provinces (regions and municipalities directly under the Central Government) (except Tibet), CF_i represents the calorific value released by each energy consumption, CC_i I represents the carbon content in energy, COF_i stands for carbon oxidation factor, $CF_i \times CC_i \times COF_i$ stands for carbon emission coefficient, and $CF_i \times CC_i \times COF_i \times \frac{44}{12}$ represents carbon dioxide emission coefficient. The calculation formula of carbon emission in the cement production process is:

$$CCO_2 = QC \times EC_{cement}. \quad (6)$$

Among them, CCO_2 represents the release during cement production. CO_2 represents the total amount, QC represents the total amount of cement produced in industry, EC_{cement} represents the cement production process. CO_2 represents emission coefficient. The data mainly come from China Energy Statistical Yearbook, China Statistical Yearbook, and wind database.

Core Explanatory Variables

Foreign direct investment (FDI). With the deepening of China's opening to the outside world, foreign direct investment has become a key factor to promote China's rapid economic development. Many scholars at home and abroad have studied whether China will become a "pollution refuge" in developed countries. FDI plays a role in promoting or inhibiting the green development of China's economy and the green adjustment of its industrial structure. The conclusion is controversial. The data on actual foreign direct investment (USD 10,000) in each province comes from the China Statistical Yearbook.

Threshold Variables

This study adopts the quality of the political system, economic system, and the legal system as threshold variables. Follow the research of Ren et al. (2022). This research adopts regional corruption, marketization index, and intellectual property protection to represent the quality of the political system, economic system, and legal system, respectively. Relevant data come from the official website, National Bureau of Statistics, State Intellectual Property Protection Bureau, and China Legal Yearbook.

Control Variables

Economic development level (GDP). Since the revolution, throughout the history of world economic development, the economic development of major countries has always been accompanied by environmental pollution. Although most developed countries have crossed the turning point of "environmental Kuznets," most developing countries still advocate high-speed economic development at the expense of the environment. To study the relationship between economic development level and carbon emissions, the inter-provincial industrial GDP is used as an explanatory variable to reflect the regional economic development level. In order to test whether there is an "environmental Kuznets curve" relationship between the level of economic development and carbon emissions, the square of GDP is introduced, and in order to eliminate the influence of price fluctuations, it is reduced in 2005 as the base period. Source: China Statistical Yearbook.

Industrial structure adjustment index (IND). The optimization of industrial structure is conducive to the improvement of environmental quality, so this study selects the ratio of the added value of the tertiary and secondary industries in each province to measure the industrial adjustment. When the ratio is greater than one, it means that the increased proportion of tertiary industry is greater than that of secondary industry, and the larger the industrial structure adjustment index is, the lower the carbon dioxide emissions will be. On the other hand, the higher the carbon emissions. The industrial adjustment index is calculated, and the added value of the secondary and tertiary industries comes from the China Statistical Yearbook.

R&D intensity (RD). R&D intensity directly reflects the level of regional investment in science and technology. The more R&D investment and the higher R&D intensity in a region, the more resources the region will use for scientific and technological innovation, and the faster the technological progress and the transformation of the economic development mode will be. If these resources are used in the development of environmental protection technology, they can directly promote the reduction of pollution emissions. The R&D intensity of this study is expressed by the proportion of regional R&D expenditure to regional GDP, and the data comes from the China Science and Technology Statistics Yearbook 2. For the convenience of analysis, the term

TABLE 1 | Statistical description of table variables.

Variable name	code	Sample size	Average/mean value	Standard deviation	Minimum value	Maximum
Carbon dioxide emission	co2	300	2.616993	1.785305	0.188	8.745
Foreign direct investment (FDI)	fdi	300	626247.3	998450.4	2044	1.31E+07
Level of economic development	gdp	300	43887.81	554903.1	543.32	9621381
Industry restructuring	ind	300	0.8491735	0.401726	0.4909	2.831642
Research and development intensity	rd	300	0.847091	0.404499	0.000795	2.831642
Economic system	Economic	300	7.835733	2.254093	3.09	14.45
Political system	Politic	300	24.71402	6.854427	7.909968	46.32269
Property right system	Law	300	1.600317	0.8346874	0.6957681	5.210585

TABLE 2 | Self-sampling test of dynamic threshold effect.

Institutional variable	Threshold value	Wald statistics	*p* value	BS times	95% confidence interval	
Political system	3.8903179***	14.905822	0.000	1,000	2.0202796	5.8528128
Economic system	10.395***	20.127274	0.000	1,000	4.6599998	12.28
Property right system	2.8689389***	18.111161	0.000	1,000	0.89472002	3.5456843

** * *, * *, and * are significant at the levels of 1, 5, and 10%, respectively (the same below). The* p*-value and critical value are obtained by repeated sampling of the GMM threshold panel regression program 1,000 times. Wald statistics are used to judge whether the threshold features are obvious, and the smaller the corresponding probability, the more obvious the threshold features are.*

"province" is utilized to represent all provincial administrative units in China, including provinces, municipalities, and minority autonomous regions. Descriptive statistics of variables are shown in **Table 1**.

RESULTS AND EMPIRICAL ANALYSIS

Threshold Effect Test and Determination of Threshold Value

Using stata14.0, based on the dynamic threshold panel model Wald test self-sampling method (Bootstrap), the significance of the threshold effect of the political system (political), economic system (economic), and legal system (law) is tested under the assumption of no threshold effect. The results show that, according to Wald statistics and its *p*-value, The level of infrastructure construction, regional marketization, regional innovation capability, and intellectual property protection all rejected the original hypothesis of no threshold effect at the significance level of 1%, and the threshold value is obvious. See **Table 2** for its threshold value and confidence interval. This shows that the impact of foreign direct investment on China's carbon emissions varies with the quality of inter-provincial systems.

Parameter Estimation and Result Analysis of GMM Threshold Model

GMM Threshold Model Correlation Test

Table 3 reports the relevant test results of the two-step GMM threshold model regression, in which models (1–3) respectively represent the models constructed with the political system, economic system, and legal system as threshold variables. According to the correlation test of residual sequence, the difference GMM has no strict requirements for AR (1) test, but strict requirements for the AR (2) test, and the *p*-values of the AR (2) test are all greater than 10% significance level. Accept the original assumption (H_0: random error term, e_{it}: no second-order autocorrelation), therefore, there is no second-order autocorrelation in the difference of random error terms, and differential GMM can be used; according to the Sargan test results, the p-values of all model test results are greater than 0.1, and the original assumption that "all tool variables are valid" cannot be rejected, so the selection of model tool variables is valid; Wald statistics also show that the overall model is highly significant.

Parameter Estimation and Result Analysis

(1) Regional corruption

Model (1) reports the regression results with regional corruption as the threshold variable, from which it can be seen that the impact of foreign direct investment on China's carbon emissions also has a significant threshold effect. Specifically, with the increase in corruption, the energy-saving, and emission-reducing effect of FDI on carbon emissions weaken. The possible reason is that local officials, some foreign capital with high pollution, high energy consumption, and high emissions may be introduced. These FDI aggravated environmental pollution and weakened the proportion of technology-intensive FDI (Welsch, 2004; Cole, 2007; Ren et al., 2021).

(2) Regional marketization

Model (2) reports the regression results with the marketization index as the threshold variable, from which it can be seen that the

TABLE 3 | Dynamic threshold regression results.

Explanatory variable	Model (1)	Model (2)	Model (3)
lnco2	0.3742747***	0.302053***	0.502367***
	[3.35]	[4.08]	[6.34]
lngdp1	0.8959271***	0.801279***	0.623692***
	[4.45]	[3.77]	[4.27]
lngdp2	−0.0351378***	−0.02513**	−0.01682**
	[−3.77]	[−2.13]	[−2.13]
lnrd	−0.053452**	−0.04408	−0.08551***
	[−2.45]	[−1.35]	[−3.04]
lnind	−0.002231	−0.00203	−0.00155
	[−1.07]	[−0.91]	[−0.8]
lnfdi1	−0.0640822***	−0.0792***	−0.04545**
	[−4.52]	[−3.19]	[−2.51]
lnfdi2	−0.060112***	−0.08285***	−0.05014***
	[−4.22]	[−3.54]	[−2.87]
Constant term	0.0125395	0.009669	−0.00149
	[0.92]	[0.37]	[−0.08]
AR(1)	−2.20	−1.26	−1.32
	(0.028)	(0.209)	(0.188)
AR(2)	1.00	0.54	0.96
	(0.316)	(0.59)	(0.335)
Sargan test	26.34	24.81	24.77
	(0.285)	(0.36)	(0.362)
Wald statistics	7204.41***	36542.67***	12088.07***
	(0.000)	(0.000)	(0.000)
Sample size	240	240	240

[] indicates Z value, () indicates p*-value, and the aforementioned results are obtained according to xtabond2 two-step GMM threshold model regression.*

impact of foreign direct investment on China's carbon emissions also has a significant marketization index threshold effect. When the marketization index value is less than the threshold value, the impact of FDI on carbon emissions is negative at a 1% confidence level. When the marketization index is greater than the threshold value, the estimated coefficient of foreign direct investment is further reduced. This result shows that the level of marketization plays an important role in the impact of foreign direct investment on the environment. The negative coefficient of FDI on the environment indicates that the hypothesis of the environmental "pollution halo" is established in China, and the inhibition effect of FDI on carbon emissions is more obvious in areas with high marketization. Areas with a high degree of marketization usually have relatively complete public facilities, better government execution, a relatively mature market of elements and products, and human resources platform that encourages innovation, which injects vitality into the economy, thus creating conditions for foreign-invested enterprises to carry out technology research and development and technology diffusion, and continuously improving environmental pollution problems. A good institutional environment can even overcome problems such as poor foreign investment structure, insufficient economic openness, and policy failure. Therefore, to expand the technology spillover effect of FDI on local enterprises, it is necessary to improve the degree of marketization in this region (Lopez and Mitra, 2000; Biswas et al., 2012).

(3) Level of intellectual property protection

It can be seen from the model (4) that when the level of intellectual property protection is taken as the threshold variable, the impact of FDI on China's carbon emissions also have a significant threshold effect on the intellectual property protection level. When the level of intellectual property protection is lower than the threshold value, the elasticity coefficient of FDI to carbon emissions is small. This result shows that the level of intellectual property protection plays an important role in the impact of foreign direct investment on the environment, and the negative coefficient of FDI on the environment shows that the hypothesis of the environmental "pollution halo" is established in China. When the level of intellectual property protection is higher than the threshold value, the elasticity coefficient of FDI to carbon emissions becomes larger, and it passes the significance test of 5% confidence level. In areas with a low level of intellectual property protection, FDI has a weak inhibitory effect on carbon emissions. Only in areas with a high level of intellectual property protection, does FDI has a significant inhibitory effect on carbon emissions. The possible reasons are: 1) On the one hand, the protection of intellectual property rights in the host country can affect the quantity and quality of inflow, thus affecting the spillover. 2) On the other hand, it affects the absorptive capacity of the host country to technology spillovers through its independent innovation and technology stock (Irfan et al., 2021a; Irfan et al., 2021b).

The economic development of areas with a low level of intellectual property protection is relatively backward, people's legal awareness is weak, and law enforcement intensity is relatively low, which leads to a lower level of intellectual property protection than the eastern and central regions of China. The strong protection of intellectual property rights in these areas has increased the difficulty of imitation, resulting in the waste of resources and frustration of imitation. A lot of resources are wasted on imitation, while few resources are left for production, thus crowding out FDI (Rezza, 2013). As far as the western region of China is concerned, the ownership advantage and location advantage are not obvious, and the internalization advantage plays a greater role. From the analysis of internalization advantage, the level of intellectual property protection not only affects FDI but also affects the technology transfer in this region. The more perfect the intellectual property protection system in these areas, the better the multinational companies can control their intellectual assets and reduce the implementation cost of technology licensing, so that more enterprises can switch from FDI to technology licensing, and then the inflow of FDI will decrease. In areas with a high level of intellectual property protection, all aspects of the system are relatively perfect, people's comprehensive quality and legal awareness have also improved obviously. Therefore, the more perfect the intellectual property system in these areas, the more the ownership of multinational companies in these areas are protected, and the ownership advantage of international enterprises in the local area is enhanced. At the same time, with the deepening of international economic integration in these areas, multinational enterprises are paying more and more attention to the soft environment such as information,

TABLE 4 | Number of provinces crossing the threshold.

Threshold variable	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Political system	19	18	14	16	15	12	10	10	12	9
Market	0	0	1	3	4	5	6	6	8	10
Protect	2	2	2	2	2	2	3	3	3	3

TABLE 5 | Number of provinces in different threshold intervals in 2019.

Threshold variable	$q_{it} > C$	$q_{it} \leq C$
Political system	Jilin, Anhui, Fujian, Henan, Hubei, Guangxi, Chongqing, Yunnan, and Ningxia	Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia Liaoning, Heilongjiang, Shanghai, Jiangsu, and Zhejiang Jiangxi, Shandong, Hunan, Guangdong, and Hainan Sichuan, Guizhou, Shanxi, Gansu, Qinghai, and Xinjiang
Economic system	Beijing, Tianjin, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Chongqing	Shanxi, Hebei, Inner Mongolia, Jilin, and Heilongjiang Anhui, Jiangxi, Henan, Hubei, and Hunan Guangxi, Hainan, Sichuan, Guizhou, and Yunnan Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang
Legal system quality	Beijing, Tianjin, and Shanghai	Shanxi, Hebei, Inner Mongolia, and Liaoning Jilin, Heilongjiang, Jiangsu, and Zhejiang Anhui, Fujian, Jiangxi, Shandong, and Henan Hubei, Hunan, Guangdong, Guangxi, and Hainan Chongqing, Sichuan, Guizhou, and Yunnan Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang

services, and laws to ensure the effective operation of the enterprise management system, which means that the protection of intellectual property rights also strengthens the regional advantages of these areas. Therefore, the higher the level of intellectual property protection in these areas, the more it can promote the inflow of local FDI.

Further Discussion

Taking the quality of the political system, economic system, and legal system of 30 provinces in 2010–2019 as research samples, this study divides them into two different regions according to the threshold variable values. **Table 4** reports the number of provinces crossing the threshold area each year during the inspection period, and **Table 5** reports the specific provinces in different threshold areas in 2019. It can be seen from the following results that in the area where the threshold value is not crossed, the international technology spillovers brought by FDI have little ability to restrain China's carbon emissions, and the pollution halo effect is also relatively small. For the provinces that have crossed the threshold, the absolute value of the influence coefficient of FDI on carbon emissions increases and is significantly negative. It shows that the international technology spillover effect is restricted by external conditions, and the external production conditions of foreign-funded enterprises are improved. It is conducive to the generation of international technology spillover effects. Therefore, local governments should fully consider the external conditions of foreign direct investment when promoting energy conservation and emission reduction through international technology spillovers.

The Robustness Test

In order to further study the relationship between FDI and China's carbon emissions under externalities, this study uses the whole sample interaction test to verify the robustness of the above dynamic threshold regression results. In **Table 6**, models (5–7) respectively show the estimated results of the interaction between FDI and regional corruption, marketization index, and intellectual property protection.

It can be seen from model (5) that the coefficient of FDI is significantly negative at the level of 1%, and the cross-term coefficient is also significantly positive at the level of 1%. Therefore, after the interaction between FDI and regional corruption is added, the effect of FDI on carbon emission reduction in China is weakened. It shows that when the degree of regional corruption is relatively high, the positive externalities that foreign-funded enterprises can get are relatively small. Therefore, the effect of FDI on carbon emission reduction is weak. With the further reduction of corruption level, foreign-funded enterprises get more and more positive external effects, and FDI has more and more inhibitory effects on carbon emissions. The regression results of model (6) show that the interaction coefficient between FDI and marketization index and intellectual property protection level is significantly negative. It shows that with the enhancement of market-oriented level and knowledge-based protection level, FDI

TABLE 6 | All-sample interaction test.

Explanatory variable	Model (4)	Model (5)	Model (6)	Model (7)
lnco2	0.262868***	0.241671***	0.277647***	0.250681***
	[5.56]	[4.8]	[9.26]	[4.8]
lnfdi	−0.00826***	−0.01554***	0.058878***	−0.00683***
	[−2.82]	[−3.85]	[9.34]	[−2.98]
lngdp1	1.238112***	1.215369***	1.181667***	1.20392***
	[10.9]	[10.14]	[11.93]	[9.7]
lngdp2	−0.04982***	−0.04788***	−0.03927***	−0.04399***
	[−8.62]	[−7.85]	[−7.14]	[−7.29]
lnrd	−0.00187	−0.00654	−0.02212	−0.01111
	[−1.04]	[−0.4]	[−1.37]	[−0.7]
lnind	−0.01312	−0.00133	0.000668	−0.00351*
	[−0.96]	[−0.72]	[0.39]	[−1.73]
lnpolitic*lnfdi		0.001806**		
		[2.48]		
lnarket*lnfdi			−0.03507***	
			[−10.03]	
lnprotect*lnfdi				−0.01007***
				[−4.14]
constant term	−6.14656***	−6.06878***	−6.37139***	−6.23739
	[−11.48]	[−10.56]	[−13.99]	[−10.28]
AR(1)	−0.86244	−0.52984	−1.0804	−0.72395
	(0.3884)	(0.5962)	(0.28)	(0.4691)
AR(2)	−0.25856	−0.56677	−0.00354	−0.26832
	(0.796)	(0.5709)	(0.9972)	(0.7885)
Sargan test	29.26565	27.81628	26.09099	28.77939
	(0.7408)	(0.8008)	(0.8621)	(0.7617)
Wald statistics	4675.79***	6883.64***	6433.26***	7304.51***
	(0.000)	(0.000)	(0.000)	(0.000)
sample size	240	240	240	240

[] indicates Z value and () indicates p*value. The aforementioned results are obtained by two-step differential GMM regression.*

will play a more and more important role in inhibiting carbon emissions, and the "pollution halo" effect will gradually appear. In addition, the coefficients and symbols of other control variables are not much different from the threshold regression results. The level of economic development promotes the rise of carbon emissions, and its quadratic term is negatively correlated with carbon emissions. "environmental Kuznets curve" still exists in China, and the industrial structure adjustment index and R&D investment intensity have promoted the reduction of carbon emissions, which is consistent with the previous conclusion of dynamic threshold regression. To sum up, the threshold regression results in this study are robust.

CONCLUSION AND ENLIGHTENMENT

Based on China's provincial panel data from 2010 to 2019, this study examines the threshold effect of FDI on China's carbon emissions from the perspective of external conditions (political system quality, economic system quality, and legal system quality) of foreign-funded enterprises in the host country. The results show that foreign direct investment can effectively restrain the increase in carbon emissions. FDI has an obvious economic threshold effect on China's carbon emissions: with the increase of regional corruption, the quality of the political system gradually declines, and the inhibition effect of foreign direct investment on carbon emissions declines. With the increase in marketization and intellectual property protection, the regional economic system and legal system have gradually improved. The role of foreign direct investment in carbon emissions has been further increased. In view of this, in order to achieve the goal of energy conservation and emission reduction in China, this study puts forward the following suggestions:

1. Promote the process of marketization and improve the degree of market opening. At present, China is still in the process of marketization, and the market structure is still unreasonable and imperfect, which to some extent restricts the development of China's technology market and affects the innovation, transfer, digestion, and absorption of China's technology. The Third Plenary Session of the 18th CPC Central Committee clearly pointed out that, we should make the market play a decisive role in resource allocation, constantly push forward the marketization process, fully release the reform dividend, and promote sustained and healthy economic and social development. While continuing to introduce FDI, constantly promoting market-oriented reform and perfecting laws and regulations will provide more ways for China to obtain FDI technology spillovers, so that the spillover effect of FDI technology can be brought into greater play. In the end, it will play a great role in promoting China's energy conservation and emission reduction.
2. Increase investment in scientific research and technological transformation to improve the independent innovation capability of local enterprises.

The improvement of local enterprises' independent innovation capability and the technology spillover of acquiring technology-based FDI are effective ways to promote energy conservation and emission reduction in China. In view of this, from the national level, government investment should focus on basic research, national defense, aviation, and other fields, increase investment in high-tech industries with higher risks, and ensure the formation of an effective investment mechanism in the country. It directly improves China's scientific and technological level in some fields; in addition, enterprises should become the main body of R&D investment, but although the comprehensive strength of large enterprises represented by the top 50 Chinese enterprises is still following the extensional development road characterized by expanding scale. Therefore, we should improve the policy system to encourage enterprises to invest in R&D as soon as possible, such as: increasing the fiscal and tax incentives for enterprise R&D, giving more tax incentives for enterprise R&D links, increasing the pre-tax deduction ratio of enterprise R&D investors, and introduce new tax incentives such as enterprise R&D reserve and accelerated depreciation of R&D equipment as soon as possible to reduce the cost of enterprise R&D.

In recent years, China has emphasized the improvement of independent innovation capability, with increasing R&D investment, technology introduction, and patent applications. However, the empirical research results show that the coefficient of R&D investment on technological progress in China is small, and the effect of technology spillover caused by the quality of foreign capital on technological progress is limited, which is related to China's low absorptive capacity. Although China's R&D investment is increasing year by year, the proportion of R&D investment in enterprises is also increasing year by year. However, due to the low capability of independent innovation, the input-output performance of R&D investment is not high, and the proportion of R&D investment used for digestion and absorption is small, so it can't effectively absorb foreign capital spillovers. Therefore, policies should be guided, a certain proportion or even most of R&D investment will be used for the digestion and absorption of spilled technology and imported technology, so as to improve the level of independent innovation, save R&D resources and make foreign technology spillovers promote technological progress more effectively.

3. Improve the level of regional intellectual property protection and improve laws and regulations.

The empirical results show that the improvement of intellectual property protection level can produce positive externalities to the technology spillover effect of FDI, so the government should consider strengthening intellectual property protection while promoting the goal of energy conservation and emission reduction through FDI technology spillover channels. Specifically, on the one hand, we should improve the legislation on intellectual property protection and formulate different levels of intellectual property protection according to the characteristics of different industries.

When formulating intellectual property protection policies, we should comprehensively consider the role of intellectual property protection in innovation and diffusion, formulate different intellectual property protection efforts for different industries, and establish high-intensity intellectual property protection for technology-intensive industries, so as to promote large-scale foreign investment in China's high-tech fields and further improve the quality of foreign investment. Promote the upgrading of the overall industrial structure. On the other hand, we should improve the law enforcement level of intellectual property protection, train professionals engaged in intellectual property protection, intensify publicity on intellectual property protection, and enhance the awareness of intellectual property protection in the whole society. We should strengthen the professional training of relevant law enforcement personnel in a planned way, and constantly improve the effectiveness and transparency of law enforcement. There are laws to be followed and laws to be followed, so that China's intellectual property protection legislation and law enforcement are in line with international standards, thus promoting the quality of foreign capital introduction.

Although this study uses the provincial level data of China to study the impact of foreign direct investment on carbon emissions, it still has some limitations, which we hope to solve in our future research. First, we can use microdata to study the relationship between them in the future. Second, the instrumental variable estimation may be a good method to solve potential endogenous problems.

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 authors.

AUTHOR CONTRIBUTIONS

YX: conceived the idea and contribute to the writing of the manuscript. KG: performed the data collection and statistical analysis. RS: proofread the manuscript and gave guidance throughout the process of this study. All authors have read and agreed to the published version of the manuscript.

REFERENCES

Abbasi, K. R., Shahbaz, M., Zhang, J., Irfan, M., and Lv, K. (2022). Analyze the Environmental Sustainability Factors of China: The Role of Fossil Fuel Energy and Renewable Energy. *Renew. Energy* 187, 390–402. doi:10.1016/j.renene.2022.01.066

Ahmad, B., Irfan, M., Salem, S., and Asif, M. H. (2022). Energy Efficiency in the Post-COVID-19 Era: Exploring the Determinants of Energy-Saving Intentions and Behaviors. *Front. Energy Res.* 9, 824318. doi:10.3389/fenrg.2021.824318

Biswas, A. K., Farzanegan, M. R., and Thum, M. (2012). Pollution, Shadow Economy and Corruption: Theory and Evidence. *Ecol. Econ.* 75, 114–125. doi:10.1016/j.ecolecon.2012.01.007

Chai, J., Hao, Y., Wu, H., and Yang, Y. (2021). Do constraints Created by Economic Growth Targets Benefit Sustainable Development? Evidence from China. *Bus. Strategy Environ.* 30 (8), 4188–4205. doi:10.1002/bse.2864

Chandio, A. A., Jiang, Y., Akram, W., Adeel, S., Irfan, M., and Jan, I. (2021). Addressing the Effect of Climate Change in the Framework of Financial and Technological Development on Cereal Production in Pakistan. *J. Clean. Prod.* 288, 125637. doi:10.1016/j.jclepro.2020.125637

Cole, M. A. (2007). Corruption, Income and the Environment: an Empirical Analysis. *Ecol. Econ.* 62 (3-4), 637–647. doi:10.1016/j.ecolecon.2006.08.003

Fang, Z., Razzaq, A., Mohsin, M., and Irfan, M. (2022). Spatial Spillovers and Threshold Effects of Internet Development and Entrepreneurship on Green Innovation Efficiency in China. *Technol. Soc.* 68, 101844. doi:10.1016/j.techsoc.2021.101844

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

Hao, Y., Ba, N., Ren, S., and Wu, H. (2021a). How Does International Technology Spillover Affect China's Carbon Emissions? A New Perspective through Intellectual Property Protection. *Sustain. Prod. Consum.* 25, 577–590. doi:10.1016/j.spc.2020.12.008

Hao, Y., Gai, Z., Yan, G., Wu, H., and Irfan, M. (2021b). The Spatial Spillover Effect and Nonlinear Relationship Analysis between Environmental Decentralization, Government Corruption and Air Pollution: Evidence from China. *Sci. Total Environ.* 763, 144183. doi:10.1016/j.scitotenv.2020.144183

Hao, Y., Guo, Y., Guo, Y., Wu, H., and Ren, S. (2020). Does Outward Foreign Direct Investment (OFDI) Affect the Home Country's Environmental Quality? the Case of China. *Struct. Change Econ. Dyn.* 52, 109–119. doi:10.1016/j.strueco.2019.08.012

Hoffmann, R., Lee, C. G., Ramasamy, B., and Yeung, M. (2005). FDI and Pollution: a Granger Causality Test Using Panel Data. *J. Int. Dev. J. Dev. Stud. Assoc.* 17 (3), 311–317. doi:10.1002/jid.1196

Iqbal, W., Tang, Y. M., Chau, K. Y., Irfan, M., and Mohsin, M. (2021). Nexus between Air Pollution and NCOV-2019 in China: Application of Negative Binomial Regression Analysis. *Process Saf. Environ. Prot.* 150, 557–565. doi:10.1016/j.psep.2021.04.039

Irfan, M., and Ahmad, M. (2022). Modeling Consumers' Information Acquisition and 5G Technology Utilization: Is Personality Relevant? *Personal. Individ. Differ.* 188, 111450. doi:10.1016/j.paid.2021.111450

Irfan, M., Elavarasan, R. M., Hao, Y., Feng, M., and Sailan, D. (2021a). An Assessment of Consumers' Willingness to Utilize Solar Energy in China: End-Users' Perspective. *J. Clean. Prod.* 292, 126008. doi:10.1016/j.jclepro.2021.126008

Irfan, M., Hao, Y., Ikram, M., Wu, H., Akram, R., and Rauf, A. (2021b). Assessment of the Public Acceptance and Utilization of Renewable Energy in Pakistan. *Sustain. Prod. Consum.* 27, 312–324. doi:10.1016/j.spc.2020.10.031

Jinru, L., Changbiao, Z., Ahmad, B., Irfan, M., and Nazir, R. (2021). How Do Green Financing and Green Logistics Affect the Circular Economy in the Pandemic Situation: Key Mediating Role of Sustainable Production. *Econ. Res.-Ekonomska Istraživanja*, 1–21. doi:10.1080/1331677x.2021.2004437

Khan, I., Hou, F., Irfan, M., Zakari, A., and Le, H. P. (2021). Does Energy Trilemma a Driver of Economic Growth? the Roles of Energy Use, Population Growth, and Financial Development. *Renew. Sustain. Energy Rev.* 146, 111157. doi:10.1016/j.rser.2021.111157

Lan, J., Kakinaka, M., and Huang, X. (2012). Foreign Direct Investment, Human Capital and Environmental Pollution in China. *Environ. Resour. Econ.* 51 (2), 255–275. doi:10.1007/s10640-011-9498-2

Lee, C. G. (2009). Foreign Direct Investment, Pollution and Economic Growth: Evidence from Malaysia. *Appl. Econ.* 41 (13), 1709–1716. doi:10.1080/00036840701564376

Li, Y., Wu, H., Shen, K., Hao, Y., and Zhang, P. (2020). Is Environmental Pressure Distributed Equally in China? Empirical Evidence from Provincial and Industrial Panel Data Analysis. *Sci. Total Environ.* 718, 137363. doi:10.1016/j.scitotenv.2020.137363

Li, Y., Yang, X., Ran, Q., Wu, H., Irfan, M., and Ahmad, M. (2021). Energy Structure, Digital Economy, and Carbon Emissions: Evidence From China. *Environ. Sci. Pollut. Res.* 28 (45), 64606–64629.

Lopez, R., and Mitra, S. (2000). Corruption, Pollution, and the Kuznets Environment Curve. *J. Environ. Econ. Manag.* 40 (2), 137–150. doi:10.1006/jeem.1999.1107

Rauf, A., Ozturk, I., Ahmad, F., Shehzad, K., Chandiao, A. A., Irfan, M., et al. (2021). Do Tourism Development, Energy Consumption and Transportation Demolish Sustainable Environments? Evidence from Chinese Provinces. *Sustainability* 13 (22), 12361. doi:10.3390/su132212361

Ren, S., Hao, Y., and Wu, H. (2021). Government Corruption, Market Segmentation and Renewable Energy Technology Innovation: Evidence from China. *J. Environ. Manag.* 300, 113686. doi:10.1016/j.jenvman.2021.113686

Ren, S., Hao, Y., and Wu, H. (2022). The Role of Outward Foreign Direct Investment (OFDI) on Green Total Factor Energy Efficiency: Does Institutional Quality Matters? Evidence from China. *Resour. Policy* 76, 102587. doi:10.1016/j.resourpol.2022.102587

Rezza, A. A. (2013). FDI and Pollution Havens: Evidence from the Norwegian Manufacturing Sector. *Ecol. Econ.* 90, 140–149. doi:10.1016/j.ecolecon.2013.03.014

Shao, L., Zhang, H., and Irfan, M. (2021). How Public Expenditure in Recreational and Cultural Industry and Socioeconomic Status Caused Environmental Sustainability in OECD Countries? *Econ. Res.-Ekonomska Istraživanja*, 1–18. doi:10.1080/1331677x.2021.2015614

Shi, R., Irfan, M., Liu, G., Yang, X., and Su, X. (2022). Analysis of the Impact of Livestock Structure on Carbon Emissions of Animal Husbandry: A Sustainable Way to Improving Public Health and Green Environment. *Front. Public Health* 145, 835210. doi:10.3389/fpubh.2022.835210

Singhania, M., and Saini, N. (2021). Demystifying Pollution Haven Hypothesis: Role of FDI. *J. Bus. Res.* 123, 516–528. doi:10.1016/j.jbusres.2020.10.007

Tang, C., Xu, Y., Hao, Y., Wu, H., and Xue, Y. (2021). What Is the Role of Telecommunications Infrastructure Construction in Green Technology Innovation? A Firm-Level Analysis for China. *Energy Econ.* 103, 105576. doi:10.1016/j.eneco.2021.105576

Tanveer, A., Zeng, S., Irfan, M., and Peng, R. (2021). Do perceived Risk, Perception of Self-Efficacy, and Openness to Technology Matter for Solar PV Adoption? an Application of the Extended Theory of Planned Behavior. *Energies* 14 (16), 5008. doi:10.3390/en14165008

Wang, J., Wang, W., Ran, Q., Irfan, M., Ren, S., Yang, X., and Ahmad, M. (2022). Analysis of the Mechanism of the Impact of Internet Development on Green Economic Growth: Evidence from 269 Prefecture Cities in China. *Environ. Sci. Pollut. Res.* 29 (7), 9990–10004. doi:10.1007/s11356-021-16381-1

Welsch, H. (2004). Corruption, Growth, and the Environment: a Cross-Country Analysis. *Environ. Dev. Econ.* 9 (5), 663–693. doi:10.1017/s1355770x04001500

Wu, H., Ba, N., Ren, S., Xu, L., Chai, J., Irfan, M., and Lu, Z. N. (2021a). The Impact of Internet Development on the Health of Chinese Residents: Transmission Mechanisms and Empirical Tests. *Socio-Econ. Plan. Sci.* 81, 101178. doi:10.1016/j.seps.2021.101178

Wu, H., Hao, Y., and Ren, S. (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., Hao, Y., and Weng, J. H. (2019). How Does Energy Consumption Affect China's Urbanization? New Evidence from Dynamic Threshold Panel Models. *Energy policy* 127, 24–38. doi:10.1016/j.enpol.2018.11.057

Wu, H., Xue, Y., Hao, Y., and Ren, S. (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

Zhu, L., Hao, Y., Lu, Z. N., Wu, H., and Ran, Q. (2019). Do economic Activities Cause Air Pollution? Evidence from China's Major Cities. *Sustain. Cities Soc.* 49, 101593. doi:10.1016/j.scs.2019.101593

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