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Research article

Unravelling the moderating roles of environmental regulations on the impact of foreign direct investment on environmental sustainability

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ABSTRACT

In the era of economic globalization, China attracts significant foreign direct investment (FDI) to accelerate economic prosperity. FDI inflows could have ramifications on environmental degradation (ED) despite the enactment of different environmental regulations (ERs) such as market-incentive, command-and-control as well as informal regulations. Though some studies have shown that FDI and ED have significant relationship, the moderating roles of different ERs on the environmental impact of FDI has not been empirically unraveled. This study fills this research gap by analyzing the direct impact of FDI on ED (i.e., carbon dioxide emissions, ecological footprint) using the provincial panel data. Second, it unravels the moderating roles of different ERs on the environmental impact of FDI in the provinces and regions. The results indicate that FDI directly mitigates ED, verifying the pollution halo hypothesis while ERs directly alleviate ED in China. However, the interaction between FDI and ERs do not alleviate ED in China albeit regional heterogeneity exist. The economic implication is that FDI is not a channel through which ERs enhance environmental sustainability in China. This study recommends some policy options arising from the findings.

1. Introduction

The global sustainable development agenda has garnered increasing attention in the last decades particularly with the establishment of the United Nations Sustainable Development Goals (SDGs). Against this backdrop, it has become imperative for policy makers to balance economic activities with environmental sustainability. In addition, economic growth serves as the foundation for national development, yet it inevitably leads to environmental degradation (ED) and resource depletion issues (Ehigiamusoe et al., 2023). In a rapidly developing economy like China, the continuous influx of foreign direct investment (FDI) has intensified the relationship between economic activities and environmental conservation. Concurrently, formulating and implementing environmental regulations (ERs) is crucial to ensure economic development and environmental sustainability.

With sustained economic growth and deepening integration into the global economy, China has emerged as a key player in shaping its economic landscape through FDI. China's prominence as a favored destination for global foreign investment is due to its expansive consumer market, improving business environment, and government policies promoting foreign investment (Zhang et al., 2022). Against economic globalization, cross-border investments as well as mergers and acquisitions have experienced rapid growth. Aligned with the trend of global economic integration, China has expanded opportunities for foreign investors by implementing preferential policies and accumulating substantial capital. Furthermore, the inflow of FDI has significantly influenced the economic growth of the host country, addressing issues such as foreign exchange shortages and saving deficits.

In today's context, where global environmental issues are increasingly prominent, ED has become a core concern of the international community. Issues such as climate change, air pollution, and resource depletion have prompted reflections on sustainable development and environmental protection (Siripi et al., 2024). Against this backdrop, China, as one of the world's largest developing countries, is under intense scrutiny, and its environmental condition is deemed crucial. The rapidly developing Chinese economy is escalating environmental

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problems, which has made it necessary for the country to prioritize both economic and environmental sustainability. In 2022, China's carbon emissions constituted 30% of the world's emissions (WDI, 2024). As environmental issues gain prominence, Chinese public attention to environmental concerns has increased, making environmental protection a societal priority.

Though China has formulated different ERs such as market-incentive, command-and-control as well as informal regulations, the country faces issues in the implementation and supervision of these regulations (Li and Ramanathan, 2018). The unclear relationship between Environmental Department and other regulatory bodies weakens the effectiveness of ERs, with vertical supervision often compromised due to complex superior-subordinate relationships (Sun et al., 2020). Public environmental awareness is increasing, with higher income levels and living standards leading residents to demand better environmental quality. Social groups with high environmental awareness promote corporate social responsibility through negotiations, reporting, and media exposure, pressuring polluting enterprises to reduce pollution.

Empirically, though some analysts have studied the effect of FDI on ED, the results have been mixed. For example, one strand of the literature noted that FDI mitigates ED thereby supporting the pollution halo hypothesis (Abid et al., 2022; Mert and Caglar, 2020). Conversely, another strand of the literature posited that FDI contributes to ED, thereby confirming the pollution haven hypothesis (Shahbaz et al., 2018; Viglioni et al., 2024). Specifically, Grimes and Kentor (2003) posited that FDI can aggravates ED if the investment is mostly concentrated in the energy-intensive industries and/or if multinational corporations relocate pollution-intensive plants to host nations with lax environmental regulations. FDI inflows can also worsen ED if the generation of power is less efficient in the host country, and if the movement of output and inputs (caused by dispersion of production worldwide) are more energy-expensive in nations that have poorer infrastructure. Thus, it is important to employ ERs to alleviate the adverse environmental impact of FDI inflows. This is fundamental since some studies have shown that ERs can mitigate ED (Ahakwa and Tackie, 2024; Li and Ramanathan, 2018). Moreover, some studies have established a significant link between FDI and ERs (Chung, 2014; Dong et al., 2021). But one vital issue that has not received much investigation is whether ERs can favourably moderate the environmental impact of FDI. Our study fills this research gap using data from a country with high FDI inflows, ED and ERs.

Therefore, the specific objectives of this research are to: (i) analyze the direct impact of FDI inflows on ED (carbon emissions, ecological footprint) in the 30 provinces. (ii) unravels the moderating roles of different ERs (market-incentive, command-and-control, informal regulations) on the environmental impact of FDI in the provinces and regions. This study's motivation arises from the rising levels of FDI inflows and economic growth amid severe ED in China. Specifically, carbon dioxide emissions rose from 1.91 to 7.76 metric tons per capita while ecological footprint soared from 1.35 to 3.53 gha during 1990–2020 (WDI, 2024; GFN, 2024). FDI inflows rose from 0.97% to 1.72% while per capita GDP soared from US$905 to US$10,358 (WDI, 2024). Moreover, there has been a remarkable increase in different ERs such as market incentive, command-and-control, as well as informal regulations (China Statistical Yearbook on Environment). Given the trend in these variables, it is crucial to analyze how these ERs moderate the environmental impact of FDI in China. The outcomes of this investigation could enhance policy decisions on how to combat the menace of ED in China.

This study's contributions to extant literature are highlighted as follows; First, unlike past research that usually deploy carbon dioxide emissions, this study unravels the direct impact of FDI on both ecological footprint as well as carbon dioxide emissions, which enables us to capture different dimensions of ED. This is important because the link between FDI and ED could be sensitive to the proxy used for ED. Second, unlike prior works that often solely investigate the direct environmental impacts of FDI or ERs (Li and Ramanathan, 2018; Mert and Caglar, 2020), this study represents an innovative idea the unravels how different ERs moderate the environmental impact of FDI in the provinces and regions. We analyze the marginal effects of FDI on ED at diverse levels of ERs, which display how a simultaneous increase in FDI inflows and ERs influence ED. Unlike past studies, our study uses three kinds of ERs (market-incentive, command-and-control, informal regulations) to aptly capture the ERs in China. Finally, to obtain robust evidence that can aid the formulation of the requisite policies, we deploy the empirical techniques that handle endogeneity, autocorrelation, as well as cross-sectional dependence.

2. Literature review

2.1. Foreign direct investment and environmental degradation

This study's theoretical foundation is based on the pollution haven hypothesis (PHH) and pollution halo hypothesis (PHoH). The PHH posits that FDI leads to the deterioration of environmental quality since international companies prefer to relocate their pollution-intensive production plants to lower-cost areas thereby bringing pollutant output into developing countries (Balsalobre-Lorente et al., 2019). They can also inhibit local technological advancement to certain extent, leading to the host nations' lock-in at the low end of the global value chain. Empirically, the PHH has been analyzed and confirmed in some countries or regions albeit other views exist. For instance, Sapkota and Bastola (2017) investigated the impact of FDI on ED in 14 Latin American nations and showed that FDI contributes to ED thereby supporting the PHH. Chaudhry et al. (2021) investigated the impact of FDI on ED in BRICS and revealed that FDI intensifies ED. Musah et al. (2022) analyzed the impact of FDI on carbon emissions for some G20 nations, and the results highlighted that increased FDI inflows lead to a surge in carbon emissions. Bhat and Ikram (2024) analyzed the impact of FDI on ED in the Asia Pacific region and reported that FDI contributes to ED possibly because of their lax environmental regulations. Siripi et al. (2024) reported that FDI aggravates ED in long-run in Ghana. However, some studies argued that the PHH prevails at a lower level of FDI inflows but if FDI inflows rise beyond a certain threshold level, the PHoH will prevail (Abbasi et al., 2023).

The PHoH opines that the entrance of transnational companies brings advanced/efficient technologies to host nation which benefit the environment. Unlike the local companies in developing nations, multinational companies use fewer polluting technologies, and their presence tends to inspire host nations to implement strict ERs (Zugravu-Soilita, 2017). As FDI enters a host country or investment location, it can provide a positive effect through the demonstration of production process technology or management experience. It can introduce green product or output, environmentally friendly products, more stringent environmental standards, diffusion of green technologies as well as technology spillovers to improve the environmental quality of developing countries (Jiang et al., 2018). Empirically, Jiang et al. (2018) analyzed the impact of FDI on ED and revealed that FDI reduces ED in Chinese cities, thereby establishing the PHoH. Wang and Liu (2019) also found evidence to validate the PHoH. Mert and Caglar (2020) analyzed the impact of FDI on ED in Turkey and reported that FDI abates ED. Abid et al. (2022) showed that FDI eases ED while Ehigiamusoe (2023) found that FDI lowers ED in ASEAN. Fu et al. (2024) also found evidence to confirm the PHoH.

Notwithstanding the above empirical outcomes, some scholars have contended that the environmental impact of FDI is insignificant, since they found no evidence to support either the PHH or PHoH (Bulut et al., 2022; Li and Ramanathan, 2018). The review above indicated that previous works have examined the direct influence of FDI on ED though the conclusions are varied. The variations in the outcomes could be due to variations in the datasets, sample periods, countries/regions, empirical strategies as well as failure to control autocorrelation, endogeneity, heterogeneity as well as cross-sectional dependence.

2.2. Environmental regulations and environmental degradation

The porter hypothesis is the theoretical foundation that relates ERs and environmental quality. The hypothesis posits that strict ERs can balance economic activities with environmental protection since it possesses the ability to enhance production efficiency, competitiveness and innovation (Porter and Linde, 1995). Moreover, Race-to-the-bottom hypothesis opines that environmental standards can be lowered by local government officials in attempt to attract greater FDI inflows resulting in ED (Zhang et al., 2020). In contrast, some countries implement stringent ERs (formal, informal) to protect their ecosystems or natural resources, and these ERs could have ramifications for economic activities including FDI inflows (Yu and Liu, 2024). This presents a complex dynamic where the pursuit of environmental protection could potentially conflict with economic growth objectives facilitated by FDI inflows.

Formal ERs (market-incentive, command-and-control) include legally binding laws, regulations, and technical standards that mandate enterprises to enhance resource allocation efficiency to achieve environmental goals. These regulations can compel companies to adopt cleaner technologies and more sustainable practices. However, they can also impose additional costs on businesses, potentially reducing the attractiveness of investing in such regions (Li and Ramanathan, 2018). Informal ERs, in contrast, involves voluntary actions and societal pressures, such as public awareness campaigns, environmental advocacy, and community participation in environmental protection efforts. These informal mechanisms can complement formal regulations by fostering a culture of environmental responsibility and encouraging businesses to go beyond compliance. However, the effectiveness of informal ERs depends heavily on public engagement and the presence of strong civil society institutions.

Critical examination of formal and informal ERs reveals a nuanced interplay. Formal ERs mandatory nature ensures a baseline level of compliance, which is essential for addressing significant environmental issues. However, its rigid structure may stifle innovation and adaptability in businesses. Informal ERs, being flexible and driven by public sentiment, can drive more profound and innovative environmental initiatives, though the impact can be inconsistent and difficult to measure without strong civic participation (Zhang et al., 2020). Studies have shown mixed results regarding the efficacy of formal and informal ERs in China (Li and Ramanathan, 2018). While formal ERs such as environmental taxes and emissions trading systems provides a clear framework for reducing pollution, their implementation and enforcement have been inconsistent. Informal ERs initiatives, such as environmental complaint systems and public petitions, demonstrate high public engagement but lack the enforcement power to bring about substantial change without accompanying formal regulations.

Specifically, Li and Ramanathan (2018) reported that market-incentive regulation has negative impact on environmental performance while the impact of command-and-control and informal regulations are not significant. The non-linear model found evidence of nonlinearity between market-incentive regulation and environmental performance. They added that it takes some years for some ERs to have significant impact on environmental performance. Zhang et al. (2020) reported that command-and-control as well as market-incentive regulations have nonlinear nexus with ED while informal regulation has no impact. Eregha et al. (2023) reported that ERs has insignificant impact on ED in a panel of 11 nations, albeit the country-specific analysis found a mitigating effect in Mexico, Philippines and Turkey.

2.3. Moderating effects

Some studies have examined how the interaction between FDI and other variables (e.g., institutional quality, GDP, financial development, technological innovation) influence ED. For instance, Neequaye and Oladi (2015) proved that the interaction between FDI and corruption intensifies ED in 27 developing nations. Zugravu-Soilita (2017) noted that the environmental impact of FDI could be conditioned on the levels of capital-to-labour ratio, environmental regulations and education. Chaudhry et al. (2021) reported that institutional quality favourably moderates the impact of FDI on ED in BRICS. Uddin et al. (2024) analyzed how the interaction between FDI and GDP affect ED in 115 nations. The results indicated that the interaction term between FDI and GDP contributes to ED while the interaction between FDI and the squared term of GDP abate ED in low-, lower-middle and high-income nations. Bhat and Ikram (2024) revealed that the interaction between FDI and financial development heightens ED in 44 Asia Pacific/Oceania nations. Siripi et al. (2024) showed that the interaction between FDI and technological innovation reduces ED in Ghana while Viglioni et al. (2024) proved that the interaction between FDI and intellectual property rights reduces ED in G20 nations.

Another strand of the literature had analyzed how the interaction between ERs and other variables (e.g., natural resource rents) affect ED. For example, Ahakwa and Tackie (2024) showed that the interaction between ERs and natural resource rents mitigate ED in long-run albeit it raises ED in the short-run in Ghana. However, there are scanty empirical analysis on how the interaction between FDI and different ERs (market-incentive, command-and-control, informal) influence ED. To our best knowledge, Zhang et al. (2020) analyzed how the interaction between FDI and ERs affect ED and reported that ERs abate the impact of FDI on ED. Nevertheless, their study used environmental taxes as proxy for ERs rather than analysing different forms of ERs. Given the dynamic link between FDI and ERs (Dong et al., 2021), it is possible that different ERs could moderate the impact of FDI on ED. In other words, the environmental impact of FDI could vary with the levels of different ERs. Our study fills this research gap using provincial and regional data in China, a country with large FDI inflows, different ERs and severe ED. The findings on the direct/indirect impacts will provide insights into policies that can enhance economic and environmental sustainability.

3. Methodology and data

3.1. Specification of models

The baseline model used to estimate the direct impact of FDI inflows on ED is given as follows (Ehigiamusoe, 2023; Hao et al., 2020):

$$\mathrm{ED}_{it} = \beta_0 + \beta_1 \mathrm{GDP}_{it} + \beta_2 GDP_{it}^2 + \beta_3 \mathrm{FDI}_{it} + \beta_4 \mathrm{IND}_{it} + \beta_5 \mathrm{URB}_{it} + \beta_6 \mathrm{TOP}_{it} + \beta_7 \mathrm{POP}_{it} + \beta_8 \mathrm{TEC}_{it} + \varepsilon_{it}$$

where ED = environmental degradation (measured by carbon emissions, and alternately by ecological footprint), FDI = foreign direct investment inflows, GDP = real GDP per capita, IND = industrial development, URB = urban population, TOP = trade openness, TEC = technical innovation, PD = population density, ε = the error term.

To analyze how ERs moderates the impact of FDI on ED, this study adds the interaction term between FDI and ERs to the model (Hao et al., 2018; Zhang et al., 2020):

$$\mathrm{ED}_{it} = \alpha_0 + \alpha_1 \mathrm{GDP}_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 \mathrm{FDI}_{it} + \alpha_4 \mathrm{ER}_{it} + \alpha_5 (FDI^{*}\mathrm{ER}_{it}) + \alpha_6 \mathrm{IND}_{it} + \alpha_7 \mathrm{URB}_{it} + \alpha_8 \mathrm{TOP}_{it} + \alpha_9 \mathrm{POP}_{it} + \alpha_{10} \mathrm{TEC}_{it} + \varepsilon_{it}$$

where FDI*ER is the interaction term between FDI and ERs. To analyze the marginal effect of FDI on ED at different levels of ERs, this study takes the partial differentiation of Equation (2) with respect to FDI:

$$\frac{\partial \mathrm{ED}_{it}}{\partial \mathrm{FDI}_{it}} = \alpha_3 + \alpha_5 \mathrm{ER}_{it}$$

We focus on the coefficients' sign and significance. Precisely, ERs abate the harmful impact of FDI on ED if $\alpha_3 > 0$ and $\alpha_5 < 0$, while ERs favourably influence the mitigating environmental impact of FDI if $\alpha_3 < 0$ and $\alpha_5 < 0$. Conversely, ERs intensify the adverse impact of FDI on ED if $\alpha_3 > 0$ and $\alpha_5 > 0$ whereas ERs adversely influence the mitigating impact of FDI on ED if $\alpha_3 < 0$ and $\alpha_5 > 0$. To ascertain the total impact, it is essential to compute the marginal effect. A positive marginal effect implies that an increase in both FDI and ERs will increase ED while the opposite is the case if the marginal effect is negative. The associated t-statistics as well as the standard errors need to be calculated to assess whether the marginal effect is statistically significant. A large t-statistic implies a significant marginal effect (Ehigiamusoe et al., 2023).

3.2. Justification

Dependent variables: Environmental degradation (measured by carbon emissions, and alternatively by ecological footprint) is the dependent variable in our model. Carbon emissions are generally seen as the primary greenhouse gases that contribute to the detorioration of the environment, climate change, as well as global warming while ecological footprint assesses the pressure which people's actions place on ecosystem because of their consumption and waste absorption (Balsalobre-Lorente et al., 2019; Shahbaz et al., 2018).

Independent variables: Foreign direct investment (FDI) is the major independent variable in our research. It can be defined as net inflows of investment that obtain a management interest that last in a company functioning in a nation which is not the investor's country. FDI intensifies ED in the host country if it allows multinational firms to relocate pollution-intensive production techniques from developed nations (with strict enforcement of environmental policies to developing nations with weak enforcement of ERs (Mert and Caglar, 2020). Nonetheless, FDI will improve environmental sustainability if it encourages the transfer of advanced or energy-efficient technologies and excellent environmental management practices in the host nations (Grimes and Kentor, 2003; Shahbaz et al., 2018). *A priori*, FDI could have a negative/positive coefficient.

Moderating variables: Environmental regulations (ERs) are the moderating variables in this study, and they can be categorized into formal and informal ERs. The informal ERs consist of the number of environmental letters and petitions, National People's Congress environmental proposals as well as those of the Chinese People's Political Consultative Conference. The formal ERs are further classified into command-and-control ERs (i.e., the number of administrative penalties, environmental regulations, environmental regulatory provisions, and environmental protection standards) and market-based ERs (i.e., the amount of pollutant discharge fee collected, investment in the treatment of industrial pollution sources, operating expenses of industrial wastewater and waste gas treatment facilities). These variables have been deployed in previous research (Wang et al., 2021; Zhang et al., 2020). *A priori,* the direct effect of ERs is expected to be negative, but the moderating effect could be positive or negative.

Control variables: GDP, squared term of GDP, industrial development, urbanization, trade openness, population density and technical innovation are the conditioning variables added to the model in line with prior works (Abid et al., 2022; Viglioni et al., 2024; Zhang et al., 2022). The inclusion of GDP and its' squared term enables us to ascertain the existent of EKC hypothesis. The EKC hypothesis is supported if GDP's coefficient is positive and squared term of GDP coefficient is negative. *A priori,* the coefficient of industrial development is expected to be positive while that of technical innovation is expected to be negative. The coefficients of urbanization, trade openness and population density could be positive or negative.

3.3. Estimation strategies

The empirical strategies of our research proceed thus: First, the research conducts the descriptive statistics and correlations to determine the data characteristics as well as the relationship between the variables. Second, it tests the existence of cross-sectional dependence (CSD) in the variables. Third, it deploys the panel unit root tests developed by Im et al. (2003) and Pesaran (2007) to determines the integration property of the variables. Fourth, it tests the presence of cointegration with the panel cointegration tests developed by Pedroni (1999), Kao (1999) and Westerlund (2007). The use of different unit root as well as cointegration tests enables us to account for CSD. Moreover, to determine the impact of the regressors on the dependent variable, our research deploy the Fully Modified Ordinary Least Squares (FMOLS) model proposed by Pedroni (2001) that accounts for heterogeneity and autocorrelation. For robustness, our research uses the system Generalized Method of Moments (GMM) developed by Arellano and Bover (1995) that addresses potential endogeneity. This study uses EViews 13 for the descriptive statistics, correlations, cross-sectional dependence tests, panel unit root tests, Pedroni and Kao cointegration tests as well as FMOLS estimations. It uses Stata 18 for the Westerlund cointegration test and GMM estimations.

3.4. Data

This analysis utilizes the panel data of 30 provinces/autonomous regions (i.e., Anhui, Beijing, Chongqing, Fujian, Gansu, Guangdong, Guizhou, Hainan, Henan, Hebei, Heilongjiang, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Qinghai, Shaanxi, Shandong, Shanghai, Shanxi, Sichuan, Tianjin, Yunnan, Zhejiang, Ningxia autonomous region, Xinjiang autonomous region, Inner Mongolia autonomous region, Guangxi autonomous region) ranging from 2003 to 2021. Due to significant gaps in relevant statistical data from the Tibet, Macao, Hong Kong, and Taiwan provinces, they were not included in our analysis. Besides, this study conducts regional analysis by categorizing the provinces into eastern region (i.e., Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan), central region (i.e., Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Jilin, Heilongjiang), and western region (Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia autonomous region, Xinjiang autonomous region, Inner Mongolia autonomous region, Guangxi autonomous region). This categorization enables us to juxtapose the moderating roles of ERs on the environmental impact of FDI in different regions in China. Since China was enlisted in World Trade Organization (WTO) in 2001, most statistical data are available after 2003, marking the starting point for this study. Appendix 1 summarizes the data description and sources.

4. Empirical results

4.1. Preliminary analysis

The statistics displayed in Table 1 reveals large disparities between the variables. The standard deviations show the dispersion of the variables around their averages. The correlation analysis reveals that FDI and market-incentive regulation have negative relationships with carbon emissions/ecological footprint while command-and-control as well as informal regulations are positively correlated with carbon emissions/ecological footprint.

Before commencing the empirical analysis, this study conducts CSD test, and the outcomes shown in Appendix 2 reject the null hypothesis (i.e., no CSD) at 1 percent significant level, suggesting the existence of CSD in the variables. Consequently, it is essential to account for CSD in the analysis.

To ascertain the variables' stationarity property, this research deploys different unit root tests, including the CIPS that accounts for CSD. The results of the tests displayed in Table 2 reject the null hypothesis (i.e., no unit root) at 1 percent significant level, implying that unit root exists in the variables. However, all the variables become stationary after first differenced.

Since the variables are integrated in order one, it is essential to verify whether the variables have cointegration. Hence, this study employs different panel cointegration tests including the tests developed by Westerlund (2007) that control for CSD. The results shown in Table 3

Table 1
Results of descriptive statistics and correlations.

Variables	CO_2	EFP	FDI	CER	MER	IER	GDP	IND	POP	TEC	URB	TOP
Max	68.25	16.11	2257	100.0	99.92	99.99	183.9	55.94	82.75	65.29	89.60	163.3
Mean	9.938	3.966	438.4	93.21	88.66	86.99	42.81	34.08	54.43	14.82	53.92	30.22
Min	1.416	0.679	0.207	42.48	31.77	32.43	3.686	10.07	20.00	1.749	13.89	0.749
Std. Dev.	8.244	2.485	484.4	7.329	10.21	10.76	29.89	8.571	12.75	11.01	14.84	33.44
CO_2	1											
EFP	0.908	1										
FDI	−0.108	−0.112	1									
CER	0.092	0.057	−0.436	1								
MER	−0.112	−0.167	−0.665	0.408	1							
IER	0.210	0.146	−0.659	0.399	0.700	1						
GDP	0.236	0.152	0.561	−0.153	−0.414	−0.270	1					
IND	−0.017	−0.037	0.223	−0.152	−0.225	−0.343	−0.272	1				
POP	−0.248	−0.288	0.579	−0.232	−0.350	−0.392	0.411	0.203	1			
TEC	−0.053	−0.207	0.525	−0.180	−0.319	−0.273	0.723	−0.143	0.605	1		
URB	0.265	0.167	0.488	−0.113	−0.296	−0.168	0.842	−0.230	0.436	0.736	1	
TOP	−0.069	−0.170	0.571	−0.193	−0.275	−0.329	0.369	0.250	0.585	0.443	0.515	1

Notes: CO_2= Carbon dioxide emission, EFP = Ecological footprint, FDI= Foreign direct investment inflows, GDP = Gross domestic product per capita, CER = command-and-control environmental regulations, MER = market incentive environmental regulations, IEF = informal environmental regulations, IND= Industrial development, POP = Population density, TOP = Trade openness, TEC =Technical innovation, URB=Urbanization.

Table 2
Results of panel unit root tests.

Variables	IPS	ADF	CIPS
CO_2	1.628	48.80	−1.876
EFP	1.289	54.79	−1.821
FDI	−0.380	75.98	−1.578
CER	−1.155	33.36	−1.987
MER	−0.454	62.98	−1.879
IER	−0.288	54.49	−1.870
GDP	3.571	39.180	−0.952
IND	1.993	49.104	−1.361
URB	1.872	6.3171	−0.945
TOP	−0.263	57.649	−1.181
POP	2.922	45.028	−1.212
TEC	−1.210	71.215	−1.833
△CO_2	−10.81***	224.1***	−4.245***
△EFP	−21.36***	433.4***	−4.384***
△FDI	−11.34***	242.4***	−3.558***
△CER	−21.18***	389.5***	−5.630***
△MER	−13.03***	255.7***	−4.910***
△IER	−16.61***	317.0***	−4.910***
△GDP	−7.902***	179.0***	−3.122***
△IND	−5.264***	131.1***	−3.346***
△URB	−17.78***	237.7***	−2.826***
△TOP	−15.13***	365.3***	−3.485***
△POP	−4.751***	124.8***	−2.880***
△TEC	−12.79***	253.6***	−3.975 ***

Notes: *** indicate statistically significance at 1% level.

Table 3
Results of panel cointegration tests.

	(1)	(2)	(3)	(4)
Pedroni (1999) cointegration tests				
Panel V-statistic	3.952***	1.852**	1.249	1.405*
Panel Rho-Statistic	−2.207***	−0.404	1.312	0.395
Panel PP-Statistic	−4.580***	−4.5***	−3.47***	−4.87***
Panel ADF-Statistic	−9.197***	−4.6***	−3.79***	−5.07***
Group Rho-Statistic	2.024	3.917	3.825	4.650
Group PP-Statistic	−2.895***	−2.16**	−3.23***	−1.297*
Group ADF-Statistic	−4.137***	−2.32**	−5.38***	−3.33***
Kao (1999) cointegration test				
ADF	3.002***	3.126**	2.865***	3.027***
Westerlund (2007) cointegration tests				
Group-τ	−2.052	−2.001	−6.211**	−1.446
Group-α	−7.167	−0.673	−0.423	−4.008
Panel-τ	−13.536	−2.924	−0.024	−2.204
Panel-α	−10.675*	−1.049	−0.005	−2.426*

Notes: *, **, and *** indicate significant at 10%, 5%, and 1% levels.

reject the null hypothesis (i.e., no cointegration) at 1 percent significant level, indicating that the variables are cointegrated.

4.2. Estimation results

The estimations presented in Table 4 (Column 1) reveal that the coefficient of FDI is significantly negative at 1% level, implying that a rise in FDI abates carbon emissions in China. Precisely, holding other variables constant, a 1% rise in FDI is accompanied with a 0.003% decrease in carbon emissions in China. This finding confirms the PHoH in China, and aligns with some prior works (Hao et al., 2020; Yu and Xu, 2019; Wang et al., 2021). The plausible justification for this finding can

Table 4
Results of FMOLS estimations in China.

Variables	(1)	(2)	(3)	(4)
FDI	−0.003***	−0.007***	−0.010***	−0.008***
	(0.000)	(0.000)	(0.017)	(0.001)
CER		−0.030***		
		(0.007)		
FDI*CER		0.004***		
		(0.000)		
MER			−0.104***	
			(0.017)	
FDI*MER			0.007***	
			(0.001)	
IER				−0.034**
				(0.016)
FDI*IER				0.006***
				(0.001)
GDP	0.307***	0.308***	0.280***	0.305***
	(0.011)	(0.008)	(0.008)	(0.009)
GDP^2	−0.131***	−0.131***	−0.121***	−0.135***
	(0.004)	(0.003)	(0.003)	(0.009)
IND	0.141***	0.142***	0.146***	0.145***
	(0.025)	(0.019)	(0.019)	(0.021)
URB	0.098***	0.098***	0.098***	0.097***
	(0.010)	(0.008)	(0.007)	(0.009)
TOP	−0.015***	−0.019***	−0.035***	−0.031***
	(0.004)	(0.003)	(0.003)	(0.004)
POP	0.267**	0.238**	0.289***	0.282***
	(0.120)	(0.104)	(0.098)	(0.100)
TEC	−0.362***	−0.357***	−0.344***	−0.310***
	(0.022)	(0.018)	(0.018)	(0.020)
Marginal effects				
Maximum		0.452	0.709	0.591
Mean		0.421	0.628	0.513
Minimum		0.187	0.218	0.186

Notes: ***, **, and * indicate statistically significance at 1%, 5%, and 10% level.

be attributed to the fact that FDI often introduces advanced technology and management practices, which enhance production efficiency. Huang and Chang (2019) demonstrated that advanced technology brought by FDI reduces environmental pollution.

Regarding the control variables, GDP's coefficient is positive whereas the squared term of GDP has a negative coefficient, supporting the EKC hypothesis. This suggests that as a country grows, carbon emissions also rises but beyond a certain economic threshold, a continuous economic growth causes a reduction in carbon emissions. This finding aligns with the inverted U-shaped trend of the EKC in some previous studies (Ehigiamusoe, 2023; Liu et al., 2024). The results further indicate that industrial development, urbanization, and population density contribute to carbon emissions while trade openness and technical innovation mitigate carbon emissions. These findings align with some past studies (Abid et al., 2022; Hao et al., 2020; Yu and Xu, 2019).

In Columns 2, we added command-and-control regulations (CER) as well as the interaction term between FDI and CER to the model. The results indicate that both FDI and CER enter with negative coefficients while the interaction term's coefficient is positive. Specifically, a 1% rise in CER is linked with a 0.030% decline in carbon emissions. These imply that CER mitigate carbon emissions in China. This is consistent with some past studies (Du and Li, 2020). However, the positive coefficient of the interaction term suggest that CER has unfavourable moderating role on the environmental impact of FDI in China. In other words, though CER directly mitigates carbon emissions, but FDI is not a channel through which CER reduces emissions. To capture the total impact of both variables on carbon emissions, we computed the marginal effect of FDI on carbon emissions at various levels of CER. The marginal effect of FDI on carbon emissions at the minimum, mean and maximum levels of CER are 0.187, 0.421 and 0.452, correspondingly. Though Zhang et al. (2020) argued that ERs can abate the impact of FDI on carbon emissions, Uddin et al. (2024) reported that the interaction term between FDI and growth contributes to carbon emissions.

In Columns 3, market-incentive regulation (MER) as well as the interaction term between FDI and MER were added to the model. The outcomes show that MER enter with a negative coefficient, implying that MER alleviate carbon emissions in China. Particularly, a 1% rise in MER is linked with a 0.104% reduction in carbon emissions. The coefficient of the interaction term is positive, indicating that MER have unfavourable moderating role on the environmental impact of FDI in China. The marginal effect of FDI on carbon emissions at the minimum, mean and maximum levels of MER are 0.218, 0.628 and 0.709, correspondingly. Chaudhry et al. (2021) reported that the interaction term between FDI and institutional quality mitigates ecological footprint in BRICS.

In Columns 4, informal environmental regulations (IER) as well as the interaction term between FDI and IER were included in the models. The results reveal that a 1% rise in IER is linked with a 0.034% reduction in carbon emissions. This evidence agreed with some past studies (Lin and Wang, 2022; Zhang et al., 2020). As for interaction term, the coefficient is positive demonstrating that IER have unfavourable moderating effect on the impact of FDI on carbon emissions. The marginal effect of FDI on carbon emissions at the minimum, mean and maximum levels of IER are 0.186, 0.513 and 0.591 correspondingly. Abid et al. (2022) reported that the interaction between FDI and technological innovation cannot mitigate carbon emissions in G-8 countries.

4.3. Alternative proxy

To capture other dimensions of ED, this study uses ecological footprint and redo the estimation. The results displayed in Table 5 indicate that FDI abates ecological footprint in China. Though CER, MER and IER mitigate ecological footprint, the interaction term between these ERs and FDI do not reduce ecological footprint. These findings align with the results of the carbon emissions model. As for the control variables, the EKC is upheld in the ecological footprint model. Urbanization raises the level of ecological footprint while trade openness and technological innovation lower it.

Table 5
Results of FMOLS estimations in China using Ecological footprint.

Variables	(1)	(2)	(3)	(4)
FDI	−0.001***	−0.003***	−0.005***	−0.004***
	(0.000)	(0.000)	(0.005)	(0.000)
CER		−0.015***		
		(0.002)		
FDI*CER		0.002***		
		(0.000)		
MER			−0.073***	
			(0.005)	
FDI*MER			0.005***	
			(0.000)	
IER				−0.030***
				(0.006)
FDI*IER				0.003***
				(0.000)
GDP	0.091***	0.091***	0.076***	0.088***
	(0.003)	(0.003)	(0.002)	(0.003)
GDP^2	−0.040***	−0.041***	−0.035***	−0.041***
	(0.001)	(0.001)	(0.001)	(0.001)
IND	−0.002	−0.002	−0.004	−0.001
	(0.009)	(0.008)	(0.005)	(0.008)
URB	0.034***	0.035***	0.036***	0.035***
	(0.003)	(0.003)	(0.002)	(0.003)
TOP	−0.008***	−0.010***	−0.017***	−0.014***
	(0.001)	(0.001)	(0.001)	(0.001)
POP	−0.010	−0.023	−0.033	−0.003
	(0.041)	(0.037)	(0.034)	(0.035)
TEC	−0.115***	−0.112***	−0.104***	−0.094***
	(0.008)	(0.007)	(0.006)	(0.007)
Marginal effects				
Maximum		0.226	0.503	0.335
Mean		0.211	0.446	0.291
Minimum		0.094	0.156	0.106

Notes: ***, **, and * indicate statistically significance at 1%, 5%, and 10% level.

4.4. Alternative estimation technique

To account for possible endogeneity and autocorrelation, this study deploys alternative estimation technique namely the GMM estimator. The outcomes reported in Appendix 3 are like the FMOLS estimations regarding the coefficients' sign and significance. This outcome suggest that our findings are robust and reliable. The coefficient of lagged carbon emissions is positive, demonstrating persistence in carbon emissions. The diagnostic tests indicate that the instruments are valid, and the models have no autocorrelation.

4.5. Regional analysis

To provide greater insights into these issues in different regions in China, this study conducted regional analysis. The results of the ecological footprint model presented in Table 6 indicate that the coefficient of interaction term between FDI and IER is positive in all regions, aligning with the national trend that IER has unfavourable moderating role on the environmental impact of FDI. In these regions, the results show that FDI and IER directly lower ED. However, the coefficient of the interaction term between FDI and CER is positive in the central and western regions albeit negative in the eastern region. These imply that CER has unfavourable moderating role on the environmental impact of FDI in the western and central regions albeit plays a favourable moderating role in the eastern region. The negative coefficient of FDI and IER directly reduce ED in the western and central regions but have the opposite impact in the eastern region. The strict CER in the eastern region encourages foreign enterprises to adopt more environmental-friendly production technologies thereby mitigating the environmental

Table 6
Results of FMOLS estimations in regions.

	Eastern region			Central region			Western region		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
FDI	0.001***	−0.001***	−0.001***	−0.022**	−0.003**	−0.008***	−0.004**	0.007***	−0.004**
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.002)	(0.001)
CER	0.019***			−0.092**			−0.006**		
	(0.003)			(0.004)			(0.002)		
FDI*CER	−0.001**			0.017***			0.004***		
	(0.000)			(0.001)			(0.001)		
MER		−0.008**			−0.022**			0.035***	
		(0.003)			(0.009)			(0.006)	
FDI*MER		0.001***			0.002***			−0.008**	
		(0.000)			(0.000)			(0.002)	
IER			−0.009**			−0.037***			−0.020**
			(0.003)			(0.008)			(0.004)
FDI*IER			0.001***			0.003***			0.004*
			(0.000)			(0.000)			(0.002)
GDP	0.026***	0.191***	0.062***	0.032***	0.091***	0.031***	0.116***	0.202***	0.174***
	(0.005)	(0.002)	(0.002)	(0.007)	(0.008)	(0.006)	(0.014)	(0.014)	(0.025)
GDP^2	−0.009**	−0.080***	−0.027***	−0.087**	−0.063**	−0.066***	−0.053**	−0.084**	−0.065**
	(0.002)	(0.001)	(0.001)	(0.007)	(0.006)	(0.005)	(0.008)	(0.015)	(0.027)
IND	−0.010	−0.059***	−0.040***	−0.087**	−0.036**	−0.082***	0.017**	−0.002	0.003
	(0.007)	(0.006)	(0.006)	(0.005)	(0.007)	(0.004)	(0.007)	(0.007)	(0.011)
URB	−0.001	0.003*	0.001	0.367***	0.024	0.320***	−0.060**	−0.057**	−0.051**
	(0.001)	(0.001)	(0.002)	(0.013)	(0.017)	(0.012)	(0.010)	(0.010)	(0.017)
TOP	0.001	0.032***	0.005***	−0.166**	−0.225**	1.397***	−0.019**	−0.022**	−0.024**
	(0.001)	(0.001)	(0.001)	(0.009)	(0.100)	(0.070)	(0.003)	(0.002)	(0.005)
POP	−0.014	−1.439***	−0.630***	1.614***	0.026***	−0.095***	−0.272**	−0.155	−0.256
	(0.055)	(0.033)	(0.030)	(0.067)	(0.007)	(0.009)	(0.073)	(0.101)	(0.169)
TEC	0.043***	0.039***	0.012*	0.082***	0.127***	−0.001	0.014	0.048***	0.061**
	(0.007)	(0.007)	(0.006)	(0.015)	(0.009)	(0.011)	(0.016)	(0.014)	(0.025)

Notes: ***, **, and * indicate statistically significance at 1%, 5%, and 10% level.

impact of FDI. As for market-incentive regulation (MER), the coefficient of the interaction term between FDI and MER is positive in the eastern and central regions but negative in the western regions. These signify that MER can favourably moderate the environmental impact FDI in the western region only. Despite the relatively slower economic development in the western region, MER incentivizes foreign enterprises to implement green technologies, enhancing FDI's positive role in environmental protection. These findings agreed with some past works (Fu et al., 2024; Sun et al., 2020)

This outcome underscores the differentiated effects of environmental regulations across regions, illustrating that well-designed and effectively enforced policies can optimize FDI's environmental impact in specific areas. Zhang et al. (2020) demonstrated that regional variations in factor endowments can affect how FDI under ERs influences carbon emissions, leading to varying outcomes across regions. Wang et al. (2021) found that both formal and informal ERs reduce air pollution albeit informal regulations have a stronger effect. Thus, the moderating influence of ERs on the FDI-carbon emissions relationship varies regionally due to differences in economic development and population density.

5. Discussion, policy implications and conclusion

We summarize this study's findings: First, FDI has a mitigating effect on carbon emissions and ecological footprint, thereby ensuring environmental sustainability. This finding confirms the PHoH, which contended that multinational companies could bring advanced and energy-efficient technologies to the host country which improve environmental sustainability. FDI will not contribute to ED if the host country formulates and implements the requisite ERs to guide the operations of multinational companies. This outcome aligns with some prior works (Hao et al., 2020; Wang et al., 2021; Zhang et al., 2020). Essentially, Yu and Liu (2024) revealed that FDI enhances the efficiency of urban green development. The plausible justification for this empirical outcome is that foreign investors use advanced and energy-efficient technologies in the process of production as well as adhere to environmental regulations. FDI inflows will not contribute to ED if the investments are predominant in the industries that require less energy consumption, and/or if the host country formulate and strictly implement environmental policies that prohibit multinational firms from using emissions-intensive methods. The policy implication of this finding is that enhancing the quality of FDI is crucial. Policies that encourage FDI should continue to be implemented to improve investment quality while optimizing the investment environment. It is advisable for the government to grant greater fiscal autonomy to local governments to regulate their investment attraction activities. It may be necessary to strengthen environmental policies to ensure that multinational corporations adhere to environmental standards.

Second, this study indicates that different ERs such as market-incentive, command-and-control, as well as informal regulations have direct mitigating impact on ecological footprint and carbon emissions in China. These finding are consistent with some previous studies (Du and Li, 2020; Li and Ramanathan, 2018). The plausible justification for this outcome is that the implementation of ERs can balance economic activity with environmental sustainability by improving production efficiency, competitiveness and innovation. The policy implication of this finding is that optimizing environmental regulations is essential. The government should adjust the content and form of ERs according to the actual situation, crafting more flexible and targeted environmental policies. This includes setting differentiated environmental standards and emissions reduction targets and implementing tailored environmental supervision policies based on the varying environmental impacts and emissions reduction potentials of different industries and enterprises. Implementing more flexible and precise ERs can minimize the adverse effects on economic activities while ensuring the achievement of environmental protection.

Third, this study revealed that different ERs cannot abate the impact of FDI on ecological footprint and carbon emissions in China. This suggests that ERs have not been effective in reducing the impact of FDI on ED. In other words, ERs cannot screen the environmental impact of

FDI inflows (i.e., cannot restrict the entry of high-energy or emissions transnational firms). This conclusion highlights the challenges facing environmental management in China, emphasizing the need for comprehensive and effective policies to balance economic development and environmental protection. Fu et al. (2024) noted that the market-incentive regulations suppress the PHoH while the command-and-control regulations enhance it. Hao et al. (2018) posited that the interaction between FDI and ERs reduce wastewater and SO2 emissions, whereas Sun et al. (2020) reported that the interaction between FDI and ERs abates industrial pollution.

The probable justification for this outcome is that higher levels of command-and-control regulations increase resource and environmental costs, leading to the closure of financially strained companies. Since local governments are often evaluated based on GDP performance, they would want to prioritize short-term economic gains over environmental standards, compromising pollution control efficiency in FDI inflows. The ineffectiveness of the market-incentives regulations in boosting the PHoH could be due to imperfect market mechanisms, information asymmetry, regulatory loopholes, stakeholder influences, and market competition pressures. Excessive market supervision leads companies to opt for paying pollution fees over investing in environmental governance, thereby reducing the efficiency of pollution control (Wang et al., 2021). Moderate regulations will enhance air pollution control effectively, as stringent supervision may not sufficiently incentivize cleaner technologies. Wu and Gao (2021) argued that command-and-control as well as market-incentive regulations struggle to mitigate the environmental impact of FDI, suggesting limitations in the current regulatory approaches. The policy implication of this finding is that though FDI and ERs can directly mitigate ED, their interaction cannot abate ED. In other words, ERs do not amplify the favourable environmental impact of FDI in China.

Fourth, the regional analysis suggests that the three kinds of ERs have adverse moderating roles on the environmental impact of FDI in the central region, which align with the national findings reported above. However, market-incentive regulation favourably moderates the environmental impact FDI in the western region albeit command-and-control as well as informal regulations have adverse moderating roles. Besides, command-and-control regulation favourably moderates the environmental impact of FDI in the eastern region albeit market-incentive as well as informal regulations have adverse moderating roles. The plausible justification for the favourable moderating effect is that environmental regulations in these regions raise the cost of polluting FDI, thereby restraining the entry of pollution-intensive multinational plants. ERs can support the PHoH if it has the capacity to screen FDI inflows with a view to abating the environmental consequences of raising FDI. Conversely, the unfavourable moderating effect in some regions implies that environmental regulations influenced by FDI, have not effectively improved environmental conditions. Environmental regulations can restrain FDI's spillover and capital accumulation effects, hindering technological progress, economic development, and carbon emissions reduction (Wang and Liu, 2019).

Finally, this study indicates that China can grow out of ED as postulated by the EKC hypothesis, which aligns with some past works (Ehigiamusoe, 2023; Jiang et al., 2018; Liu et al., 2024). However, some determinants of economic growth such as industrialization, urbanization, and population contribute to ED albeit trade openness and technical innovation are friendly to the environment in China. These findings align with some past research (Ehigiamusoe et al., 2024). The plausible justification for this empirical outcome is that China employed emissions-intensive method of production at the early stage of economic development, but as awareness about environmental protection and technological development increases, ED started to reduce. Nevertheless, the activities associated with industrialization, urbanization and population density still contribute to ED, emphasizing the need for cleaner production in China. Trade openness mitigates ED in China because it facilitates the importation of cleaner products that are friendly to the environment. Similarly, technical innovation reduces ED because it facilitates energy efficiency, green productivity and the transition from fossil fuels energy (natural gas, oil, coal) to clean energy sources (wind, solar, hydro power).

The policy implication is that policies (monetary, fiscal, external) that can enhance green economic growth should be prioritized in the country development agenda. Human capital development, physical capital accumulation, infrastructural development and stable macroeconomic indicators which are fundamental for economic growth should be vigorously pursued to attain the EKC's inflection point. Greater investment should be directed to research and development on how to adopt renewable energy resources in industrialization and urbanization. Incentives (e.g., subsidies) should be provided to encourage individuals and firms to utilize clean technology while punishment (e.g., carbon tax) should be imposed on individuals and firms using emissions-intensive methods. It may be essential to intensify environmental education on the need to protect the environment. Since maintaining environmental sustainability is paramount, the government should ensure strict enforcement of environmental protection policies, involving intensifying supervision of environmental performance and rigorously enforcing environmental laws and regulations.

In conclusion, this paper provides insights into the impacts of FDI inflows and ERs as well as their interaction on ED in China. It revealed that though FDI inflows and ERs can mitigate ED, but FDI inflows is not a channel through which ERs abate ED. This analysis provides the following crucial policy options.

- Since FDI mitigates ED in China, it may be necessary for the country to prioritize policies that would attract clean foreign investment into the country.
- Since ERs directly reduce ED in China, the country should continue to adopt formal and informal regulations to tackle environmental problems in the country.
- The inability of ERs to mitigate the impact of FDI on ED in China stresses the need for the country to evaluate the relationship between FDI and different ERs.
- The confirmation of the EKC hypothesis in China implies that the country can grow out of ED. Hence policies (e.g., monetary, fiscal, external) and factors (e.g., human capital development, physical capital accumulation, green productivity growth) that accelerate economic growth should be vigorously pursued to attain the EKC's inflection point. Greater investment should be directed to research and development on how to utilize renewable energy resources in industrialization and urbanization.

Finally, our analysis has provided insights into the moderating roles of different ERs on the environmental impact of FDI in China. However, our analysis did not unravel the relationship between FDI and ERs in China, an issue that should be investigated in future research. Since our study focused on a developing country with large FDI inflows, different ERs and severe ED, it may be essential for future study to conduct comparative analysis between countries with diverse levels of ED, ERs and FDI inflows for further insights.

CRediT authorship contribution statement

Kizito Uyi Ehigiamusoe: Writing – original draft, Data curation. **Danqing Chen:** Writing – original draft, Methodology. **Eyup Dogan:** Supervision, Software. **Rima H. Binsaeed:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. Summary of data description and sources

Variables	Meaning	Measurement	Source
EVD	Environmental degradation	Carbon dioxide emission per capita Ecological footprint per capita	China Statistical Yearbook on Environment
Formal ERs	Command-and-control regulations (CER)	Number of administrative penalties Number of environmental regulations Number of environmental regulatory provisions Number of environmental protection standards	
	Market-incentive regulations (MER)	Amount of pollutant discharge fee collected Investment in the treatment of industrial pollution sources Operating expenses of industrial wastewater treatment facilities Operating expenses of industrial waste gas treatment facilities	
Informal ERs	Informal regulations (IER)	Number of environmental letters and petitions Number of environmental proposals of the National People's Congress (NPC) Number of environmental proposals of the Chinese People's Political Consultative Conference (CPPCC)	
FDI	Foreign direct investment	Foreign direct investment Inflows	China Statistical Yearbook
GDP	Gross domestic product	Gross domestic product per capita	
IND	Industrial development	Added value of secondary industry/GDP	
URB	Urbanization	The proportion of the urban population in the total population	
TOP	Trade openness	The ratio of total import and export trade to the GDP of the area	
POP	Population density	The number of people per square kilometer.	
TEC	Technical innovation	The proportion of R&D in GDP	

Appendix 2. Results of cross-sectional dependence tests

Variables	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
CO_2	5626***	176.0***	175.1***	60.30***
EFP	5399***	168.3***	167.4***	60.78***
FDI	2813***	80.64***	79.81***	33.30***
CER	736.75***	10.23***	9.396***	9.466***
MER	3265***	95.95***	95.12***	54.09***
IER	1609***	39.82***	38.99***	27.62***
GDP	7685***	245.8***	244.9***	87.57***
IND	3665***	109.5***	108.6***	40.90***
URB	7056***	224.4***	223.6***	83.24***
TOP	2444***	68.13***	67.30***	21.50***
POP	4552***	139.5***	138.7***	32.71***
TEC	5078***	157.4***	156.5***	65.39***

Notes: *** indicate statistically significance at 1% level and a rejection of the null hypothesis of no cross-section dependence.

Appendix 3. Results of GMM estimations of China

Variables	(1)	(2)	(3)	(4)
Lagged dependent variable	1.069***	1.038***	0.972***	1.062***
	(0.020)	(0.046)	(0.097)	(0.066)
FDI	−0.001**	−0.008*	0.013*	−0.0149*
	(0.000)	(0.004)	(0.007)	(0.008)
CER		−0.126**		
		(0.061)		
FDI*CER		0.009**		
		(0.005)		
MER			0.212***	
			(0.065)	
FDI*MER			0.0143*	
			(0.007)	
IER				−0.186*
				(0.097)
FDI*IER				0.0181*
				(0.009)
GDP	0.015*	−0.039	0.176*	−0.071
	(0.008)	(0.025)	(0.101)	(0.046)
GDP^2	−0.007**	0.022	−0.062**	0.0320
	(0.003)	(0.014)	(0.030)	(0.039)

(*continued on next page*)

(*continued*)

Variables	(1)	(2)	(3)	(4)
IND	0.018**	0.033	0.158	−0.002
	(0.008)	(0.036)	(0.129)	(0.030)
URB	0.010	0.065	−0.024	0.0535
	(0.012)	(0.058)	(0.105)	(0.063)
TOP	−0.0001	0.0001	−0.024	−0.015
	(0.003)	(0.019)	(0.039)	(0.028)
POP	−0.002	−0.0455	0.055	−0.014
	(0.011)	(0.050)	(0.121)	(0.097)
TEC	−0.003	−0.045	−0.132	−0.003
	(0.004)	(0.073)	(0.271)	(0.180)
Constant	−0.438	12.765	21.46***	17.093*
	(0.862)	(8.469)	(7.795)	(10.24)
2nd order autocorrelation (p-value)	0.51 (0.612)	0.40 (0.690)	−1.58 (0.114)	0.83 (0.405)
Hansen test (p-value)	26.41 (0.999)	19.42 (0.677)	14.36 (0.642)	0.68 (0.712)
Observations	570	570	570	570
No of provinces	30	30	30	30

Notes: ***, **, and * indicate statistically significance at 1%, 5%, and 10% level.

Data availability

Data will be made available on request.

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