Journal of Asian Economics 87 (2023) 101634

Contents lists available at ScienceDirect

Journal of Asian Economics

journal homepage: www.elsevier.com/locate/asieco

Is environmental regulation a powerful weapon to mitigate China's $PM_{2.5}$ emissions? The role of human capital

Jun Zhao [a], Kangyin Dong [b,*]

[a] School of Economics and Management, Beijing University of Chemical Technology, Beijing 100029, China
[b] School of International Trade and Economics, University of International Business and Economics, Beijing 100029, China

ARTICLE INFO

JEL classification:
C33
J24
Q53
R10

Keywords:
Environmental regulation
Haze emissions
Human capital
Moderating effect
Mediation effect

ABSTRACT

The continuous introduction of environmental governance policies aims to control the deteriorating ecological environment, which has been highly concerned by scholars. To re-assess the regulation-haze nexus for the case of China, by incorporating the effect of human capital, this study first analyzes the channels through which environmental regulation (ER) influences haze emissions and then conducts a series of empirical checks on the regulation-haze nexus by using the provincial data covering 2003–2017. The empirical findings show that: (i) strengthened ER is not a valid strategy to alleviate haze pollution; (ii) the integration of enhancing environmental supervision and actively introducing talents can drastically mitigate haze emissions; and (iii) human capital has been established as the conduction path of ER affecting haze pollution; although ER can accelerate human capital accumulation, it cannot effectively solve haze emissions at present. Therefore, several targeted policy implications, such as combining multiple ER tools and gradually cultivating talents, are highlighted.

1. Introduction

China's economic aggregate, growing continuously and rapidly during the past few decades, has achieved remarkable and unparalleled achievements (Dong et al., 2022a; Li & Wei, 2021). Against this background, the use of primary energy surges (Ren et al., 2022a, 2022b). As the statistical data of former British Petroleum (BP, 2021) suggest, the total energy use grew from 1.36 billion tonnes oil equivalent (Btoe) in 2003 to 3.14 Btoe in 2017. Given the substantial increase of energy consumption dominated by traditional fossil energy and low allocation of resource utilization efficiency, China's environmental pollution issues have garnered widespread attention, particularly haze pollution (Hao et al., 2021). Notably, fine particulate matter with a diameter less than or equal to 2.5 μm ($PM_{2.5}$) is the primary component of haze pollution. Moreover, the analysis of rolling average $PM_{2.5}$ from 2010 to 2012 in Columbia University's Socioeconomic Data and Applications Center (SEDAC) emphasizes the seriousness of haze pollution in China (Zhou et al., 2019b). Since the winter of 2012, haze pollution has spread to the whole country, which profoundly damages the health of citizens and the fast development of society (Dong et al., 2021). The spacial pattern of haze emission across different areas in China is posted in Fig. 1. Obviously, haze pollution in a region or province is directly correlated with the economic situation of the region or province. Given the great damage caused by haze pollution to residents' health and daily life, it is imperative to explore preventive methods for haze governance (Khan et al., 2021).

With the increasing intensification of $PM_{2.5}$ pollution, a series of strategies have been constructed by local governments to

* Corresponding author.
E-mail address: dongkangyin@uibe.edu.cn (K. Dong).

https://doi.org/10.1016/j.asieco.2023.101634
Received 4 August 2022; Received in revised form 4 May 2023; Accepted 23 May 2023
Available online 24 May 2023
1049-0078/© 2023 Elsevier Inc. All rights reserved.

strengthen environmental regulation (ER), promote ecological civilization, and benefit the harmonious development of humans and nature (Pan et al., 2021; Shen et al., 2022). Given the typical public product attributes of haze pollution, it will be difficult to achieve the goal of haze control only through market supervision; therefore, the role of government is particularly crucial. To solve the haze pollution, the regional governments must introduce many local air pollution prevention regulations, demonstrating the determination and confidence to control and mitigate haze emissions (Zhao et al., 2020). The statistics of China Statistical Yearbook (CSY) in 2018 indicate that the investment in environmental pollution treatment was 953.9 billion RMB, which accounts for 1.16% of gross domestic product (GDP) (CSY, 2018).

Additionally, human capital has been introduced for efficient policy in recent years, which is regarded as a valid means to address haze pollution (Bano et al., 2018). Some scholars believe that human behavior and activities are the decisive factors affecting regional pollutant emissions (Salim et al., 2017). Specifically, the increased provincial human capital level can provide effective guarantee for green technology innovation and improving energy efficiency, thus decreasing dependence on fossil fuels and mitigating pollution emissions. Thus, some issues deserve our consideration: (i) In what ways does ER influence $PM_{2.5}$ emissions; by implication, what is the transmission mechanism in China's regulation-haze nexus? (ii) Can human capital effectively adjust the specific relationship between these two variables? (iii) Can human capital be an effective mediating factor of ER affecting $PM_{2.5}$ emissions? In this respect, this paper proceeds to creatively analyze the causal regulation-$PM_{2.5}$ nexus by incorporating the impact of human capital to answer the above three doubts. In addition, how talent capital adjusts the regulation-haze nexus and whether it is a transmission route through ER affects haze emissions are also explored by adopting the provincial data. We find that although ER can enhance the gradual accumulation of talents, it is not a favorable strategy to alleviate haze emissions. However, the synergy of official policy supervision and talent gathering is the best way to solve the haze issue.

The primary innovations and contributions of our paper are threefold, which not only helps to supplement existing literature

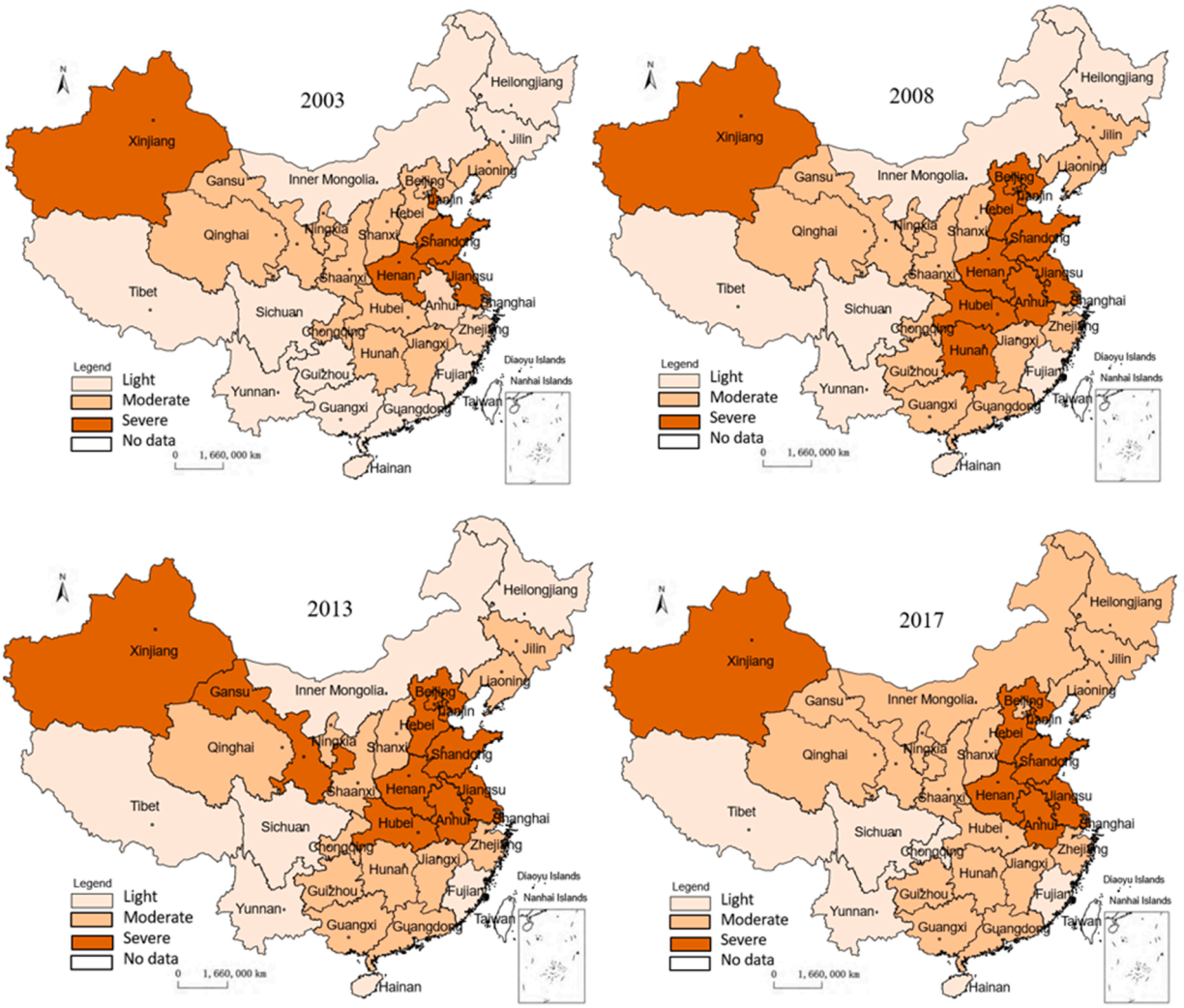

Fig. 1. The spatial pattern of haze emissions in 2003, 2008, 2013, and 2017, respectively.

research deficiencies, but also provides support for the accuracy and scientificity of governmental ER policy implementation.

First, although various methods are adopted to check the role of ecological governance in solving the haze problem, the potential effect of human capital has been ignored; thus, the underlying influence of ER on haze is creatively examined in our study from the perspective of human capital, which can offer a major breakthrough in the field of haze governance.

Second, the interaction of environmental supervision and actively introducing talents, that is, the moderating effect, has been deeply explored. This examines the effectiveness of coordination between ER and talent introduction in addressing the haze problem from a completely new perspective.

Third, whether human capital is the impact pathway through which ecological governance influences haze emissions has been profoundly verified. This can provide new insights and ideas for local governments to solve $PM_{2.5}$ emission problems by incorporating the roles of human capital accumulation and talent introduction.

We organize the structure of our paper as follows. Section 2 reviews the current literatures and analyzes the transmission channel, followed by the methodology posted in Section 3. Section 4 reports the regression results. Section 5 further explores whether accumulated human capital can affect the linkage between the core variables. Section 6 summarizes the whole paper.

2. Literature review and influence mechanism

During the past years, the effectiveness of ecological governance policies has been the focus of many scholars. For example, Wang et al. (2019) indicated that ER aims to regulate economic activities, control negative externalities of pollutants, and achieve socio-economic harmonious evolution. As some scholars devoted to the research of environmental governance have implied that ER aims to restrain the pollutant discharge behavior of economic subjects for protecting and improving ecological environment, and the most commonly classifications for ER are formal and informal (Li & Wu, 2017). Among them, formal regulation mainly reflects the initiative of the government and the market to address pollutant discharge, which refers to the government using its power to initiate environmental policies or set standards to mitigate pollutants (Ouyang et al., 2019). While the informal ER first advanced by Hettige et al. (1996) mainly lays stress on the consciousness of the public and residents to protect the ecological environment (Cole et al., 2005). Notably, although the subjects and means of formal and informal ER are significantly different, they have the same goals. Accordingly, this study tends to review the related literature from two dimensions (i.e., direct and indirect impacts) to summarize the underlying influence mechanism.

2.1. Direct effect analysis

As an essential component of social regulation, ER denotes the governance of enterprises' and households' activities through the formulation of measures and systems, thus realizing the goal of optimizing the ecological environment. The analysis of the formal and informal ER suggests that the ER tools mainly compose of three aspects: official command, market control, and public agreement. Among them, the first type of regulation corresponds to economic incentives and indicates the application of emission standards or some regulations to meet environmental objectives. Regulatory strategies mainly include shutting down highly polluting enterprises, limiting the private cars with odd and even numbers, and restricting the heating of high-polluting fuels. This mandatory requirement can drastically address the issues of haze emissions (Li et al., 2019). Market control ER can incorporate externalities into enterprises and reduce pollution control costs by effectively distributing pollution emission reduction among polluters; furthermore, this control greatly increases the operating costs of enterprises, which can further encourage and motivate enterprises to actively engage in technical innovation activities, improve the utilization rate of equipment for production factors, and reduce the level of haze emissions. The main means of this regulation include emission trade system, emission charge system, and subsidy and deposit return system (Ren et al., 2018; Saltari & Travaglini, 2011). In addition, with the gradual evolution of urbanization, educational resources are increasingly concentrated, the public has more opportunities to receive education, and the level of citizens' education is widely permeated, which has gradually increased the demand for excellent living environment. The public will consciously establish a mechanism for monitoring pollution emissions or sign environmental agreements with surrounding pollution enterprises to reduce haze pollution (Li & Wu, 2017).

2.2. Indirect effect analysis

Except for the direct effect mentioned above, numerous scholars have discussed the indirect transmission pathways of ER on $PM_{2.5}$ emissions by affecting technological innovation (Hussain et al., 2022), energy use structure (Zhang et al., 2019), industrial transition (Zhou et al., 2017, 2013, 2019b), and foreign direct investment (FDI) (Zhang et al., 2019; Zhou et al., 2019a). Notably, very few researches concerned about the intermediary influence of human capital yet. In recent years, many studies have shown that talent capital, as a crucial invested parameter in the productive and business process, can be used to reduce the consumption of high-pollution fossil fuels (Fang & Chang, 2016). This is because human capital associated with higher education level usually maintains a relative high pursuit of superior residential environment and quite strong consciousness of protecting ecological environment and has the ability to improve energy efficiency and conduct research and development (R&D) of pollution mitigation skills, which is conducive to haze reduction (Salim et al., 2017). This implies that accumulated human capital is of great importance for improving environmental conditions. Importantly, knowledge based on human capital is the core of the concept of economizing energy and alleviating pollutants, and the technology mastered by talents is the key content of haze emission reduction (Ma et al., 2022). Currently, the improvement of human capital quality provides the necessary cultural flow, talent flow, and technology flow for the

construction of low-pollution economy, which can effectively break the bottleneck of natural resource scarcity (Zhang et al., 2022). In this regard, the specific transmission channels between ER and haze pollution is presented in Fig. 2, and the hypothesis is shown as follows:

Hypothesis 1. Human capital as the transmission path of environmental regulation influencing haze pollution is established; put differently, environmental regulation can indirectly alleviate $PM_{2.5}$ emissions by accelerating human capital accumulation while mitigate it directly.

3. Model and data

3.1. Model

To accurately test the underlying influence of ER in impacting $PM_{2.5}$ pollution in China, human capital, foreign investment, economic growth, and technical innovation are introduced in the model, and the quadratic item of economic growth is added to detect the environmental Kuznets curve (EKC) hypothesis. The regression frame for $PM_{2.5}$ concentrations is constructed as follows:

$$PM_{it} = f(ER_{it}, Huma_{it}, Pgdp_{it}, Pgdp_{it}^2, Open_{it}, Tec_{it}) \tag{1}$$

where i and t are the cross-section unit and time unit, respectively. *PM* denotes the $PM_{2.5}$ concentrations for 31 Chinese provinces, *ER* is environmental regulation. *Huma*, *Open*, *Pgdp*, and *Tec* refer to human capital, foreign investment, economic growth, and technical innovation, respectively.

In addition, all variables in Eq. (1) are processed by natural logarithm to effectively eliminate the potential effects of heteroscedasticity and data fluctuation; thus, Eq. (1) can be re-written in the following equation:

$$\ln PM_{it} = \alpha_0 + \alpha_1 \ln ER_{it} + \sum_{i=2}^{6} \alpha_i \ln Ctrl_{it} + \nu_i + \eta_t + \varepsilon_{it} \tag{2}$$

where α_0, ν_i, η_t and ε_{it} represents the intercept item, the province effect, the time effect, and the error item. ln is the logarithmic form of all variables. *Ctrl* is a vector that contains *Huma*, *Pgdp*, $Pgdp^2$, *Open*, and *Tec*. $\alpha_i (1 \leq i \leq 6)$ refer to the estimated coefficients. According to the impact mechanism, we anticipate the empirical parameters of *ER*, *Huma*, *Open*, and *Tec* to be negative, while the estimated parameters of *Pgdp* and $Pgdp^2$ are anticipated to be positive and negative, respectively.

3.2. Data

A panel dataset for Chinese 31 provinces covering 2003–2017 is applied in this study to empirically explore the regulation-haze nexus. Other provinces are excluded due to the statistics unavailability. The relevant measures are as follows:

(1) Haze pollution (*PM*). This indicator is mainly composed of PM_{10} and $PM_{2.5}$; based on previous studies, this article selects $PM_{2.5}$ pollution as the main research goal (Li et al., 2019). However, the statistics of the density of $PM_{2.5}$ in China have only been collected since 2013 (Xie et al., 2019). Considering the time span of the research, the data on $PM_{2.5}$ in China are insufficient (Dong et al., 2019; Du et al., 2018). Accordingly, the statistics of $PM_{2.5}$ used in this study come from the Socio-Economic Data and Application Center of Columbia University and are following the results of aerosol optical depth (AOD) measurement of satellite-borne equipment and converted into global haze concentration monitoring data in the form of raster data (Van et al., 2014).

(2) Environmental regulation (*ER*). This study aims to reflect the government's strength and determination in controlling pollutants in terms of formal ER. Following the works of Wang and Tan (2017) and Zhou et al. (2019b), three indicators — sulfur dioxide (SO_2)

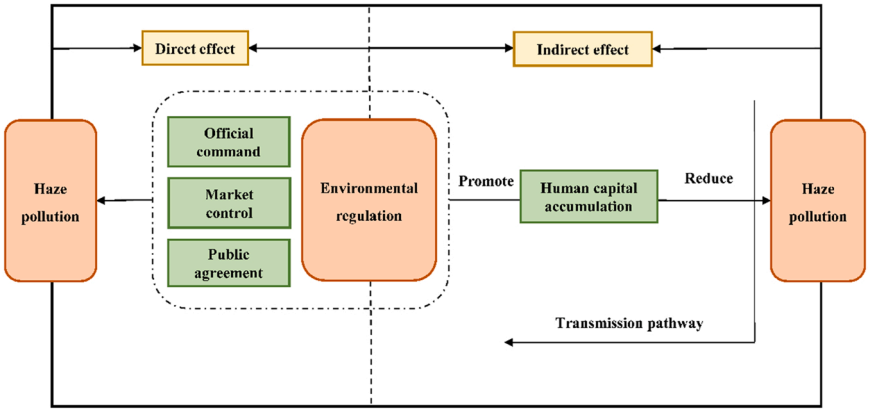

Fig. 2. The influence mechanism of the regulation-haze nexus.

emission, wastewater discharge, and waste and solid emission of industry — are utilized to gauge ER comprehensive index based on the entropy technique, which assigns weights to different pollutants. According to Zhao et al. (2020)'s measure of ER, the share of the investment in solving industrial pollutant required to produce a unit of GDP (input side) to pollution composite index (output side) is employed to assess ER. Notably, the statistics of three pollutant indicators originate from China Environment Statistical Yearbook (CESY, 2018), while CSY (2018) offers the statistics of pollution control investment and output value.

(3) Human capital (*Huma*). Many scholars have discussed the influence of gradual accumulation of human capital on various types of pollutants, and confirmed its active role in mitigating ecological pollution (Azam, 2019; Li & Ouyang, 2019). Therefore, this study uses the share of employed people with a college degree or above to all employed people to assess human capital (Chi, 2008); the data are from China City Statistics Yearbook (CCSY, 2018).

(4) Economic growth (*Pgdp*). Rapid economic evolution produces serious ecological pollution initially and then alleviates pollutants after reaching the highest value (Ouyang et al., 2019; Shen & Balezentis, 2023; Wang & Xu, 2015). To this end, we introduce the degree of economic growth gauged by per capita GDP and its square term as control variables.

(5) Foreign investment level (*Open*). Numerous studies have concerned about the FDI-haze nexus, mainly including the direct (Cheng et al., 2020) and mediation effect (Li et al., 2019; Zhang et al., 2019). This indicator can be gauged by the share of total invested amount by foreign companies in domestic companies to GDP.

(6) Technical innovation (*Tec*). The active effects of technical innovation on various pollutants are proved by numerous studies (Yi et al., 2020); thus, this indicator evaluated by the amount of domestic patent application authorization is added into the model. The statistical descriptions of the variables are highlighted in Table 1.

4. Empirical findings and discussions

4.1. Preliminary checks

Before performing baseline regression, this study first empirically checks the correlation between selected variables. The consequential outcomes are posted in Table 2. Clearly, both ER and $PM_{2.5}$ show substantial active linkage, while provincial human capital accumulation is also positively associated with haze pollution; these findings go against our expectations. Thus, it is imperative for us to select more reliable and complicated econometric models for accurate estimate.

Table 2 also posts the outcomes of multicollinearity. This is a vital prerequisite to avoid false regression (Feng & Yuan, 2022; Song et al., 2019). The test statistics of the variance inflation factor (VIF) for all variates, including the mean VIF, are smaller than 10. This insists that no multicollinearity is found between the independent variables we choose during the regression process.

4.2. Baseline estimate

To more scientifically assess the concrete impacts of strengthened environmental governance and gradual introduction of talents on $PM_{2.5}$ emissions, this study selects three classical estimated methods — ordinary least square (OLS), fixed effect (FE), and two-step system generalized method of moments (Sys-GMM) approaches, and lists the outcomes with or without control variables simultaneously in Table 3. In this regard, which method can be applied to assess the actual effect of ER and Huma on $PM_{2.5}$ pollution becomes a crucial issue. To this end, in accordance with the research of Ullah et al. (2018), we check the applicability of these three methods in the following three steps: (1) performing the empirical analysis by using the OLS method and checking whether endogeneity exists within the model; (2) conducting the FE regression; and (3) solving the issue of endogeneity by using the rigorous two-step Sys-GMM technique.

4.2.1. OLS regression

Owing to the wide use of OLS strategy in previous studies, we first check the effect of *ER* and *Huma* on haze emissions based on the OLS method. Notably, some explanatory variables may be omitted from the model and are significantly correlated with the core variable, which means that this variable will automatically be included in the disturbance term, that is, the core research variable may be correlated with the disturbance term, leading to serious endogeneity problems. To this end, to test whether the empirical model constructed has the endogeneity issue, the endogeneity within the sample data is examined by applying the share of added value in the secondary industry as instrumental variable. In the bottom of this table, we can find that the test values of *K-P rk LM* and Durbin-WU-

Table 1
Statistical descriptions of the variables.

Variables	Definitions	Mean	Std. Dev.	Min.	Max.	Data source
ln*PM*	Haze pollution	3.563234	0.5160755	1.866951	4.436747	Socio-Economic Data and Application Center of Columbia University
ln*ER*	Environmental regulation	-2.717181	0.1365305	-3.15738	-2.424676	CESY (2018),CSY (2018)
ln*Huma*	Human capital	2.333463	0.7059321	-1.371181	4.023028	CCSY (2018)
ln*Pgdp*	Economic growth	10.21691	0.72133189	8.216358	11.76752	CSY (2018)
ln*Open*	Foreign investment	1.311155	0.8530772	-0.4423974	4.317905	CSY (2018)
ln*Tec*	Technical innovation	8.849137	1.802074	2.772589	12.71485	CSY (2018)

Table 2
Test outcomes of the multicollinearity and correlation checks.

Variable	VIF	ln*PM*	ln*ER*	ln*Huma*	ln*Pgdp*	ln*Open*	ln*Tec*
ln*PM*		1.0000					
ln*ER*	1.25	0.2884*	1.0000				
ln*Huma*	2.70	0.3656*	-0.0826*	1.0000			
ln*Pgdp*	4.09	0.2260*	-0.3367*	0.7689*	1.0000		
ln*Open*	1.23	0.0823*	-0.1746*	0.3497*	0.3974*	1.0000	
ln*Tec*	2.01	0.4118*	-0.1859*	0.5383*	0.6991*	0.3738*	1.0000
Mean VIF	2.26						

Notes: * indicates $p < 0.1$.

Table 3
Estimated findings of the baseline regression.

Variable	OLS estimate		FE estimate		Sys-GMM estimate	
	No	Yes	No	Yes	No	Yes
L.ln*PM*					0.641***	0.633***
					(45.26)	(43.30)
ln*ER*	0.191***	0.189***	0.014	0.025**	0.048***	0.063***
	(8.04)	(7.48)	(1.35)	(2.33)	(14.22)	(9.84)
ln*Huma*	0.287***	0.240***	0.011	-0.040**	0.046***	-0.024*
	(10.78)	(5.74)	(0.89)	(−2.17)	(10.33)	(−1.75)
ln*Pgdp*		-0.647		0.205		-0.642**
		(−0.97)		(0.92)		(−2.45)
ln$Pgdp^2$		0.024		-0.002		0.030**
		(0.72)		(−0.20)		(2.20)
ln*Open*		-0.044*		0.0004		0.067***
		(−1.82)		(0.02)		(5.21)
ln*Tec*		0.136***		-0.057***		0.066***
		(8.15)		(−2.70)		(5.29)
_*Cons*	3.668***	6.709**	3.593***	2.420**	1.375***	4.358***
	(32.27)	(2.01)	(86.46)	(2.17)	(24.60)	(3.32)
K-P rk LM	75.487 [0.0000]					
K-P rk Wald F	88.760{16.38}					
DWH test	28.774 [0.0000]					
AR (1)					0.0012	0.0016
AR (2)					0.9485	0.8159
Sargan					0.9776	0.9988
Obs.	465	465	465	465	434	434

Note: ***, **, and * are $p < 0.01$, 0.05, and 0.1; t- or z-statistics in parentheses.

Hausman (DWH) are both substantial, while the statistic of *K-P rk Wald F* is evidently larger than 16.38; these test results suggest that there is significant endogeneity within the econometric model. Thus, it is inappropriate to use OLS as the baseline estimation technique to analyze the impacts of *ER* and *Huma* on $PM_{2.5}$ emissions.

4.2.2. FE regression

Except for the OLS regressor, this study further employs the FE method to explore the nexus between variables due to the inapplicability of the OLS estimate. Notably, FE regression can effectively eliminate the time effect between variables (Hamilton & Nickerson, 2003; Yan et al., 2022); however, the successively introduction of formal ER policies and the gradual recruitment of talents have conspicuous time-lag influences on haze mitigation. Due to the existence of endogeneity and hysteresis between the variables, the use of pooled OLS and FE techniques is not appropriate.

4.2.3. Two-step Sys-GMM regression

After checking the irrationality of OLS and FE methods, the two-step Sys-GMM technique is applied in this section to deal with the endogenous issue (Zhao et al., 2021). The test values of the Arellano-Bond (A-B) test (i.e., AR (1) and AR (2)) and the Sargan test obviously confirm the scientificity of applying this approach.

The outcomes of Table 3 denote that the estimated parameters of ln*ER* and ln*Huma* are 0.063 and − 0.024, respectively. These findings suggest that strengthened regulation of environment is not an effective strategy to mitigate haze emissions, while accumulated human capital and talent introduction in a region can be conducive to reducing haze pollution. To be specific, strengthened ER forces regional governments to implement some measures (e.g., closing high-polluting enterprises, levying taxes and fees on pollution emissions, or subsidizing the emission reduction technologies) to control haze emissions, thus meeting the national advocacy and demand for saving energy and alleviating pollutants (Zhou et al., 2021). Notably, these mandatory measures, while temporarily and substantially curbing haze emissions, will also decrease enterprises' enthusiasm for production and constrain regional economic

growth (Zhong et al., 2022). This will not only damage the residents' quality of life, but also inhibit social harmony and stability (Zhang et al., 2020). Meanwhile, under the premise of GDP as the main assessment mechanism in the past, government officials tend to lower regulation standards impacted by promotion incentives and fiscal income incentives. In addition, to complete the performance review order issued by the central government, local authorities and stakeholders are easy to ignore the emission behavior of polluting firms in the production process, resulting in the conclusion that government-mandated ER policy is not a powerful means to promote haze emission reduction. In the long run, these measures are not effective strategies for maintaining harmonious and sustainable urban development. Thus, local authorities should consider regional development when laying down ER strategies, effectively grasp the intensity of regulation, and support the green transition of enterprises.

Regarding the negative human capital-haze nexus, human capital with higher education not only has a strong self-awareness of protecting the ecological environment, but also has the ability to innovate technology, which can help alleviate pollutant emissions (Lan et al., 2012). Furthermore, the estimated parameters of ln*Pgdp* and ln$Pgdp^2$ are − 0.642 and 0.030, which imply that both *Pgdp* and *PM* appear a typical U-shaped nexus. In addition, foreign investment and technical innovation influence haze emissions positively. Foreign investment aims to maximize profits, and the introduction of a large amount of capital can effectively improve enterprises' production and transaction activities, thus consuming massive fossil energy and exacerbating haze emissions. This positive foreign investment-haze link is also proved by Tang et al. (2016) and Wang et al. (2022a, 2022b). However, the viewpoint that strengthening the capital flows from foreign firms can efficiently alleviate $PM_{2.5}$ in our nation due to its advanced management experience and technical innovation capabilities is supported by Guan et al. (2022). Moreover, the statistics from China's National Bureau of Statistics show that China's technical innovation to speed up production and operation has outperformed those to reduce pollutant emissions; therefore, it is imperative to prompt firms to reinforce the R&D of clean and low-emission technologies (Wen et al., 2023).

4.3. Sensitivity checks

4.3.1. Adopting the proxy variable of environmental regulation

Notably, the positive regulation-haze nexus does not meet our expectations. Thus, to check whether the estimated outcomes are robust and reliable, the investment in solving industrial pollutant required to produce a unit of GDP (expressed as *ER_I*) is chosen to gauge China's environmental regulation to further perform the empirical analysis (see Table 4). It is evident that the symbols and meanings of ln*ER* and ln*Huma* stay the same with those in Table 3; this substantially proves the robustness of the benchmark findings.

4.3.2. Excluding the impact of 2008 financial crisis

To further examine the reliability of regression findings, we remove the statistics of 2008 and 2009 in the full sample to exclude the potential impact of financial crisis. The outcomes are posted in Table 5. Clearly, the parameters of ln*ER* and ln*Huma* are substantially positive and negative, respectively, with all control variables in the model. These findings verify the scientificity of the impacts.

4.3.3. Removing the influence of four municipalities

Following the regional pattern of haze emissions in Fig. 1, prominent regional heterogeneity exists in haze emissions. In particular, the role of economically developed and representative urban environmental governance on haze emissions may affect the overall assessment. To this end, the statistical data of four municipalities in China (i.e., Beijing, Tianjin, Shanghai, and Chongqing) are

Table 4
Robust findings of applying the proxy variable.

Variable	OLS estimate		FE estimate		Sys-GMM estimate	
	No	Yes	No	Yes	No	Yes
L.ln*PM*					0.642***	0.634***
					(45.85)	(48.90)
ln*ER_I*	0.191***	0.185***	0.026**	0.032***	0.044***	0.063***
	(7.88)	(7.19)	(2.47)	(2.94)	(12.22)	(9.79)
ln*Huma*	0.271***	0.240***	0.012	-0.042**	0.039***	-0.025*
	(10.21)	(5.56)	(1.02)	(−2.31)	(9.78)	(−1.90)
ln*Pgdp*		-0.888		0.154		-0.725***
		(−1.31)		(0.69)		(−2.56)
ln$Pgdp^2$		0.035		-0.0001		0.034**
		(1.01)		(−0.01)		(2.27)
ln*Open*		-0.035		0.004		0.073***
		(−1.42)		(0.17)		(5.42)
ln*Tec*		0.137***		-0.054**		0.069***
		(8.06)		(−2.55)		(5.94)
_Cons	4.224***	8.533**	3.708***	2.783**	1.497***	4.978***
	(23.98)	(2.48)	(53.70)	(2.48)	(24.71)	(3.53)
AR (1)					0.0012	0.0016
AR (2)					0.9129	0.7864
Sargan					0.9769	0.9988
Obs.	465	465	465	465	434	434

Note: ***, **, and * are $p < 0.01$, 0.05, and 0.1; t- or z-statistics in parentheses.

Table 5
Robust findings excluding the 2008 financial crisis and the special value of municipalities.

Variables	The 2008 financial crisis		The special value of municipalities	
	(1)	(2)	(3)	(4)
L.ln*PM*	0.468***	0.413***	0.692***	0.650***
	(34.93)	(27.33)	(87.26)	(40.83)
ln*ER*	0.026***	0.035***	0.041***	0.066***
	(10.18)	(5.53)	(15.52)	(7.93)
ln*Huma*	0.102***	-0.148***	0.041***	-0.043***
	(15.47)	(−11.84)	(10.19)	(−2.74)
Control variables	No	Yes	No	Yes
_*Cons*	1.760***	2.169	1.159***	5.899***
	(29.22)	(1.22)	(31.74)	(3.79)
AR (1)	0.0021	0.0023	0.0052	0.0069
AR (2)	0.8893	0.9192	0.5575	0.4540
Sargan	0.3740	0.3910	0.9942	0.9940
Obs.	341	341	378	378

Note: *** $p < 0.01$; z-statistics in parentheses; the control variables are the same with Table 3.

removed from the full panel and re-estimation is performed to exclude the interference of specific values (see the last two columns of Table 5 for specific results). Obviously, the active and negative influences of *ER* and *Huma* on $PM_{2.5}$ emissions are confirmed.

4.4. How human capita moderates the regulation-haze nexus?

In this section, we further check whether human capital can effectively adjust the regulation-haze nexus. On the basis of Eq. (2), the interaction of *ER* and *Huma* is added into the estimation model; notably, while adding the interaction term, we remove human capital from the model to avoid multicollinearity. The test equation is built as follows:

$$\ln PM_{it} = \beta_0 + \beta_1 \ln ER_{it} + \beta_2 \ln ER_{it} * \ln Huma_{it} + \sum_{i=3}^{6} \beta_i \ln Z_{it} + \nu_i + \eta_t + \varepsilon_{it} \quad (3)$$

where β_0 represents the interaction term, and $\beta_i (i \geq 1)$ refer to parameters that need to be assessed. Among them, β_2 indicates the coefficient of the interactive item. Z is a vector that contains *Pgdp*, $Pgdp^2$, *Open*, and *Tec*.

By applying the FE and two-step Sys-GMM technique simultaneously, we show the empirical outcomes in Table 6. Also choosing Sys-GMM technique, this study finds that the regression parameter of ln*ER* is active, while that of the interactive item is substantially

Table 6
Regression outcomes of the moderating role of human capital.

Variable	ER measured by the composite index		ER gauged by pollution investment	
	FE estimate	Sys-GMM estimate	FE estimate	Sys-GMM estimate
L.ln*PM*		0.634***		0.635***
		(48.36)		(29.65)
ln*ER*	0.065***	0.086***		
	(2.96)	(6.39)		
ln*ER**ln*Huma*	-0.040**	-0.023*		
	(−2.17)	(−1.75)		
ln*ER_I*			0.091***	0.082***
			(4.13)	(7.53)
ln*ER_I**ln*Huma*			-0.060***	-0.022**
			(−3.20)	(−2.33)
ln*Pgdp*	0.205	-0.644**	0.050	-0.787**
	(0.92)	(−2.44)	(0.22)	(−2.43)
ln$Pgdp^2$	-0.002	0.030**	0.005	0.036**
	(−0.20)	(2.18)	(0.42)	(2.18)
ln*Open*	0.0004	0.067***	0.009	0.074***
	(0.02)	(5.25)	(0.44)	(6.12)
ln*Tec*	-0.057***	0.067***	-0.050**	0.068***
	(−2.70)	(5.81)	(−2.40)	(5.72)
_*Cons*	2.420**	4.364***	3.486**	5.363***
	(2.17)	(3.30)	(−2.40)	(3.40)
AR (1)		0.0015		0.0017
AR (2)		0.8167		0.7702
Sargan		0.9988		0.9987
Obs.	465	434	465	434

Note: ***, **, and * are $p < 0.01$, 0.05, and 0.1; t- or z-statistics in parentheses.

negative. Furthermore, the estimation outcomes of ER gauged by *EP_I* in the last two columns verify the validity of the empirical conclusions.

Due to the positive coefficient of ER, we can conclude that, under the background of the local government's active introduction of environmental supervision policies, accelerating human capital accumulation and the introduction of talents, and actively cultivating capable and intelligent talents are the key content and effective means to solve the haze pollution problem. In the context and premise that the government vigorously advocates environmental protection and emission reduction, improved human capital can greatly contribute to the national R&D of clean and green technologies (Hu, 2021). In other words, the combination of policies and talents can lay a solid foundation for accelerating haze emission reduction.

5. Further discussion

5.1. Model specification

As the influence mechanism insists that, gradual talents introduction may be the underlying transmission path of ER on $PM_{2.5}$. Accordingly, the mediating effect model is used to conduct the relevant empirical analysis (Dong et al., 2022b; Zhao et al., 2022a, 2022b). This model has the following two test procedures:

(i) The first procedure is to calculate the total impact between the primary variables; the concrete equation is posted as follows:

$$\ln PM_{it} = \gamma_0 + \gamma_1 \ln ER_{it} + \sum_{i=2}^{6} \gamma_i \ln Z_{it} + \nu_i + \eta_t + \varepsilon_{it} \tag{4}$$

where $\gamma_0$stand for intercept term. Notably, the estimated coefficient (i.e., γ_1) reflects the total effect between variables.

(ii) Another procedure lays stress on testing the direct and intermediary impacts; the models are built in the following equations:

$$\ln Huma_{it} = \eta_0 + \eta_1 \ln ER_{it} + \sum_{i=2}^{6} \eta_i \ln Z_{it} + \nu_i + \eta_t + \varepsilon_{it} \tag{5}$$

$$\ln PM_{it} = \varphi_0 + \varphi_1 \ln ER_{it} + \varphi_2 \ln Huma_{it} + \sum_{i=3}^{7} \varphi_i \ln Z_{it} + \nu_i + \eta_t + \varepsilon_{it} \tag{6}$$

where η_0 and φ_0 are intercept terms. $\eta_i (i = 1, 2, ., 7)$ and $\varphi_i (i = 1, 2, ., 7)$ are the parameters that require to be evaluated. The parameter of *ER* in Eq. (6) (i.e., φ_1) denotes the direct impact, while the indirect impact of *ER* on *PM* exists if η_1 and φ_2 are significant

Table 7
Regression outcomes of the mediation effects.

Variables	ER measured by the composite index			ER gauged by pollution investment		
	(1)	(2)	(3)	(1)	(2)	(3)
ln*ER*	0.230***	0.170***	0.189***			
	(9.36)	(7.13)	(7.50)			
ln*ER_I*				0.227***	0.177***	0.185***
				(9.18)	(7.42)	(7.25)
ln*Huma*			0.240***			0.240***
			(5.15)			(5.09)
ln*Pgdp*	-1.365**	-2.987***	-0.647	-1.659**	-3.221***	-0.888
	(−1.98)	(−4.45)	(−0.94)	(−2.39)	(−4.81)	(−1.28)
ln$Pgdp^2$	0.069**	0.189***	0.024	0.082**	0.199***	0.035
	(2.03)	(5.68)	(0.70)	(2.40)	(6.00)	(1.00)
ln*Open*	-0.039	0.020	-0.044*	-0.028	0.030	-0.035
	(−1.47)	(0.79)	(−1.70)	(−1.04)	(1.15)	(−1.34)
ln*Tec*	0.132***	-0.016	0.136***	0.133***	-0.016	0.137***
	(8.43)	(−1.06)	(8.90)	(8.42)	(−1.08)	(8.89)
_Cons	10.041***	13.855***	6.709*	12.279***	15.638***	8.533**
	(2.88)	(4.09)	(1.94)	(3.50)	(4.62)	(2.44)
Sobel test		0.041*** (4.174)		0.042*** (4.195)		
Total effect		0.230*** (9.361)		0.227*** (9.185)		
Direct effect		0.189*** (7.499)		0.185*** (7.247)		
Indirect effect		0.041*** (4.174)		0.042*** (4.195)		
Proportion of indirect effect		17.8%		18.67%		
Bootstrap test						
_bs_1		0.041*** (2.97)		0.042*** (2.98)		
		[0.012 0.067]		[0.016 0.070]		
_bs_2		0.189*** (7.29)		0.185*** (6.99)		
		[0.138 0.240]		[0.132 0.233]		

Notes: ***, **, and * are p < 0.01, 0.05, and 0.1; t statistics in parentheses.

simultaneously; more specifically, η_1 α_2 highlights the indirect impact (i.e., mediation effect) between the variables.

5.2. Regression findings

Table 7 posts the regression outcomes of the direct and intermediary influences of *ER* on *PM* by using human capital as transmission channel. In this table, (1)-(3) denote the estimated results corresponding to Eqs. (4)–(6). The coefficient of ln*ER* in (1) of Table 7 is 0.230, which suggests that the total effect between the primary variables is 0.230. In the estimation process, the statistic of the Sobel test (i.e., 0.041) is substantial; put differently, human capital has been proved as a valid and vital transmission pathway for environmental governance to influence $PM_{2.5}$ emissions. In addition, we find that the regression parameters of direct and intermediary impacts are 0.189 and 0.041, and the intermediary impact accounts for 17.8% of the total effect. That is, human capital contributes 17.8% to the influence of ER policies on haze emissions. In respect to the bootstrap sampling test, 0 is not included in the confidence intervals of *_bs_1* and *_bs_2*. This result highlights the validity of the intermediary impact of human capital.

Notably, in these three equations, the parameters of ln*ER* are all substantially positive, while that of human capital in Eq. (3) is also positive. This insists that although strengthened regulation of environment can facilitate human capital accumulation (Ma et al., 2019), talent introduction and improved human capital are not valid strategies to solve haze pollution. The positive ER-Huma nexus is also proved by Wen and Dai (2020). They believe that the demand for senior talent and high-quality human capital improves rapidly when researching and developing reduction technologies; furthermore, highly educated human capital and elites usually have a high pursuit of quality life and a strong sense of environmental protection awareness.

As Bano et al. (2018) and Fang and Chang (2016) emphasize, introducing talents with the features of innovation and creativity can rationally allocate limited resource endowments and make suggestions for green evolution of enterprises, thus facilitating $PM_{2.5}$ emission reduction; however, in the estimated results, the positive nexus between *Huma* and *PM* is contrary to their conclusions. The reason may be that, despite the tremendous improvement in the education level of residents and employees, enterprises face high technical barriers in the R&D of clean and green technologies, and it is difficult for domestic human capital to overcome these technologies in a short time. It is proved that the role of talent introduction in haze emission reduction will be highlighted in the near future.

6. Conclusions and policy recommendations

To systematically discuss the potential influence of ER is solving China's $PM_{2.5}$ problem, this study creatively analyzes the transmission channel and impact mechanism of regulation on $PM_{2.5}$ by incorporating the underlying role of human capital. Moreover, the moderating and mediation impacts between variables are also explored. This study presents the primary conclusions in the following points:

(1) The outcomes of the baseline regression prove that continuous implementation of environmental governance policies is positively correlated with haze emissions, while human capital affects haze emissions negatively. Put differently, ER is not a valid means to promote haze reduction, and accumulated human capital can effectively accelerate haze reduction.

(2) The active combination of the execution of ER policies and the continuous recruitment of talents has played a prominent role in haze control. By implication, when local governments actively introduce environmental control policies, increasing education investment, vigorously cultivating talents, and establishing and improving talent introduction mechanism are effective ways to solve the local haze dilemma.

(3) The intermediary effect of human capital in influencing regulation-haze link is established; specifically, although ER can effectively boost human capital accumulation, human capital, however, cannot exerts its underlying role in alleviating haze dilemma in the current context.

Following the empirical findings of the above discussions, two policy suggestions are proposed as follows. First, the empirical results underline the ineffective role of current environmental governance policies in solving haze emissions, which is contrary to our positive expectation of environmental regulation. In other words, the current ER policies that are continuously advancing may have certain drawbacks in the implementation stage. To exert the strength of policy control, the local governments should not create shelter for the preservation of pillar industries; instead, they should actively provide technical and capital support for the development and transition of local industries. In addition, considering the coordinated and optimal combination of multiple ER tools to solve the haze problem is crucial. Specifically, in the regions with relatively severe haze pollution, official command ER policies can effectively contribute to haze reduction; in highly market-oriented regions, the transition from official command to market-control supervision should be gradually achieved, and the government should try to avoid excessive administrative intervention in the activities of economic entities. Therefore, local governments should realize the target of reducing pollutant emissions through the optimized combination of various ER strategies.

Second, the empirical results on the further discussion imply that strengthened ER intensity is a powerful accelerator to facilitate human capital accumulation, which is also verified by the moderating effect analysis of human capital. Consequently, further strengthening environmental supervision and subsidizing and supporting companies that value innovative technologies can effectively promote the accumulation of talents. Thus, clean technological innovation, vigorously introducing technological talents, and promoting the accumulation of talent dividends should be highly concerned by local authorities; more specifically, it is indispensable to focus on the cultivation and education of talents and actively promote reform of the education system. Furthermore, local authorities should pay close attention to its leading role in environmental protection technologies, and provide capital subsidies, reasonable tax reductions & exemptions, as well as technical guidance to enterprises committed to the R&D of clean technologies when formulating

relevant policies to create an environment for firms, thus ensuring the enthusiasm and confidence of enterprises' R&D from the perspective of policy and capital.

The current discussion on the regulation-human capital-haze nexus only checks their underlying effects and impact channel in China; however, existing research still has some shortcomings. One is substantially related to the empirical approach. At present, this study only detects the regulation-haze nexus by using the GMM technique. In the future studies, we tend to investigate the spatial effect in the relationship. Another is associated with sample data. It is imperative for us to apply the municipal data to specifically and deeply discuss the causal regulation-haze nexus.

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.

Data Availability

Data will be made available on request.

Acknowledgements

The article is sponsored by the National Social Science Foundation of China (Grant No. 20VGQ003). The authors gratefully acknowledge the helpful reviews and comments from the editors and anonymous reviewers, which improved this manuscript considerably. Certainly, all remaining errors are our own.

References

Azam, M. (2019). Relationship between energy, investment, human capital, environment, and economic growth in four BRICS countries. *Environmental Science and Pollution Research, 26*, 34388–34400. https://doi.org/10.1007/s11356-019-06533-9

Bano, S., Zhao, Y., Ahmad, A., Wang, S., & Liu, Y. (2018). Identifying the impacts of human capital on carbon emissions in Pakistan. *Journal of Cleaner Production, 183*, 1082–1092. https://doi.org/10.1016/j.jclepro.2018.02.008

BP (2021). BP Statistical Review of World Energy 2021. http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html.

CCSY (2018). National Bureau of Statistics, China City Statistical Yearbook. http://www.tjcn.org/.

CESY (2018). National Bureau of Statistics, China Environment Statistical Yearbook. http://www.tjcn.org/tjnj/HHH/36980.html.

Cheng, Z., Li, L., & Liu, J. (2020). The impact of foreign direct investment on urban $PM_{2.5}$ pollution in China. *Journal of Environmental Management, 265*, Article 110532. https://doi.org/10.1016/j.jenvman.2020.110532

Chi, W. (2008). The role of human capital in China's economic development: Review and new evidence. *China Economic Review, 19*(3), 421–436. https://doi.org/10.1016/j.chieco.2007.12.001

Cole, M. A., Elliott, R. J. R., & Shimamoto, K. (2005). Industrial characteristics, environmental regulations and air pollution: An analysis of the UK manufacturing sector. *Journal of Environmental Economics and Management, 50*(1), 121–143. https://doi.org/10.1016/j.jeem.2004.08.001

CSY (2018). National Bureau of Statistics, China Statistical Yearbook. http://www.stats.gov.cn/tjsj/ndsj/.

Dong, F., Zhang, S., Long, R., Zhang, X., & Sun, Z. (2019). Determinants of haze pollution: An analysis from the perspective of spatiotemporal heterogeneity. *Journal of Cleaner Production, 222*, 768–783. https://doi.org/10.1016/j.jclepro.2019.03.105

Dong, K., Jiang, Q., Shahbaz, M., & Zhao, J. (2021). Does low-carbon energy transition mitigate energy poverty? The case of natural gas for China. *Energy Economics, 99*, Article 105324. https://doi.org/10.1016/j.eneco.2021.105324

Dong, K., Shahbaz, M., & Zhao, J. (2022a). How do pollution fees affect environmental quality in China? *Energy Policy, 160*, Article 112695. https://doi.org/10.1016/j.enpol.2021.112695

Dong, K., Taghizadeh-Hesary, F., & Zhao, J. (2022b). How inclusive financial development eradicates energy poverty in China? The role of technological innovation. *Energy Economics, 109*, Article 106007. https://doi.org/10.1016/j.eneco.2022.106007

Du, G., Liu, S., Lei, N., & Huang, Y. (2018). A test of environmental Kuznets curve for haze pollution in China: Evidence from the penal data of 27 capital cities. *Journal of Cleaner Production, 205*, 821–827. https://doi.org/10.1016/j.jclepro.2018.08.330

Fang, Z., & Chang, Y. (2016). Energy, human capital and economic growth in Asia Pacific countries—Evidence from a panel cointegration and causality analysis. *Energy Economics, 56*, 177–184. https://doi.org/10.1016/j.eneco.2016.03.020

Feng, W., & Yuan, H. (2022). The pain of breathing: How does haze pollution affect urban innovation? *Environmental Science and Pollution Research, 29*(28), 42664–42677. https://doi.org/10.1007/s11356-021-18279-4

Guan, Y., Zhai, Z., Wang, Y., Wu, D., Yu, L., & Lei, Z. (2022). Foreign direct investment, environmental regulation, and haze pollution: Empirical evidence from China. *Environmental Science and Pollution Research, 29*(18), 27571–27584. https://doi.org/10.1007/s11356-021-17841-4

Hamilton, B. H., & Nickerson, J. A. (2003). Correcting for endogeneity in strategic management research. *Strategic Organization, 1*(1), 51–78. https://doi.org/10.1177/1476127003001001218

Hao, Y., Niu, X., & Wang, J. (2021). Impacts of haze pollution on China's tourism industry: A system of economic loss analysis. *Journal of Environmental Management, 295*, Article 113051. https://doi.org/10.1016/j.jenvman.2021.113051

Hettige, H., Huq, M., Pargal, S., & Wheeler, D. (1996). Determinants of pollution abatement in developing countries: Evidence from South and Southeast Asia. *World Development, 24*(12), 1891–1904. https://doi.org/10.1016/S0305-750X(96)00076-9

Hu, G. G. (2021). Is knowledge spillover from human capital investment a catalyst for technological innovation? The curious case of fourth industrial revolution in BRICS economies. *Technological Forecasting and Social Change, 162*, Article 120327. https://doi.org/10.1016/j.techfore.2020.120327

Hussain, J., Lee, C. C., & Chen, Y. (2022). Optimal green technology investment and emission reduction in emissions generating companies under the support of green bond and subsidy. *Technological Forecasting and Social Change, 183*, Article 121952. https://doi.org/10.1016/j.techfore.2022.121952

Khan, Z., Ali, S., Dong, K., & Li, R. Y. M. (2021). How does fiscal decentralization affect CO_2 emissions? The roles of institutions and human capital. *Energy Economics, 94*, Article 105060. https://doi.org/10.1016/j.eneco.2020.105060

Lan, J., Kakinaka, M., & Huang, X. (2012). Foreign direct investment, human capital and environmental pollution in China. *Environmental and Resource Economics, 51*, 255–275. https://doi.org/10.1007/s10640-011-9498-2

Li, B., & Wu, S. (2017). Effects of local and civil environmental regulation on green total factor productivity in China: A spatial Durbin econometric analysis. *Journal of Cleaner Production, 153*, 342–353. https://doi.org/10.1016/j.jclepro.2016.10.042

Li, G., & Wei, W. (2021). Financial development, openness, innovation, carbon emissions, and economic growth in China. *Energy Economics, 97*, Article 105194. https://doi.org/10.1016/j.eneco.2021.105194
Li, L., Liu, X., Ge, J., Chu, X., & Wang, J. (2019). Regional differences in spatial spillover and hysteresis effects: A theoretical and empirical study of environmental regulations on haze pollution in China. *Journal of Cleaner Production, 230*, 1096–1110. https://doi.org/10.1016/j.jclepro.2019.04.248
Li, P., & Ouyang, Y. (2019). The dynamic impacts of financial development and human capital on CO_2 emission intensity in China: An ARDL approach. *Journal of Business Economics and Management, 20*(5), 939–957. https://doi.org/10.3846/jbem.2019.10509
Ma, M., Feng, W., Huo, J., & Xiang, X. (2022). Operational carbon transition in the megalopolises' commercial buildings. *Building and Environment, 226*, Article 109705. https://doi.org/10.1016/j.buildenv.2022.109705
Ma, S., Dai, J., & Wen, H. (2019). The influence of trade openness on the level of human capital in China: On the basis of environmental regulation. *Journal of Cleaner Production, 225*, 340–349. https://doi.org/10.1016/j.jclepro.2019.03.238
Ouyang, X., Shao, Q., Zhu, X., He, Q., Xiang, C., & Wei, G. (2019). Environmental regulation, economic growth and air pollution: panel threshold analysis for OECD countries. *Science of the Total Environment, 657*, 234–241. https://doi.org/10.1016/j.scitotenv.2018.12.056
Pan, X., Cao, Y., Pan, X., & Uddin, M. K. (2021). The cleaner production technology innovation effect of environmental regulation policy: Evidence from China. *Management of Environmental Quality: An International Journal, 32*(4), 737–751. https://doi.org/10.1108/MEQ-10-2020-0227
Ren, S., Li, X., Yuan, B., Li, D., & Chen, X. (2018). The effects of three types of environmental regulation on eco-efficiency: A cross-region analysis in China. *Journal of Cleaner Production, 173*, 245–255. https://doi.org/10.1016/j.jclepro.2016.08.113
Ren, X., Li, Y., Qi, Y., & Duan, K. (2022a). Asymmetric effects of decomposed oil-price shocks on the EU carbon market dynamics. *Energy, 254*, Article 124172. https://doi.org/10.1016/j.energy.2022.124172
Ren, X., Li, Y., Wen, F., & Lu, Z. (2022b). The interrelationship between the carbon market and the green bonds market: Evidence from wavelet quantile-on-quantile method. *Technological Forecasting and Social Change, 179*, Article 121611. https://doi.org/10.1016/j.techfore.2022.121611
Salim, R., Yao, Y., & Chen, G. (2017). Does human capital matter for energy consumption in China? *Energy Economics, 67*, 49–59. https://doi.org/10.1016/j.eneco.2017.05.016
Saltari, E., & Travaglini, G. (2011). The effects of environmental policies on the abatement investment decisions of a green firm. *Resource and Energy Economics, 33*(3), 666–685. https://doi.org/10.1016/j.reseneeco.2011.02.001
Shen, Z., & Balezentis, T. (2023). Devising evidence-based strategies for progress towards zero-carbon energy at the country level: The by-production approach. *Journal of Environmental Management, 340*, Article 117974. https://doi.org/10.1016/j.jenvman.2023.117974
Shen, Z., Wu, H., Bai, K., & Hao, Y. (2022). Integrating economic, environmental and societal performance within the productivity measurement. *Technological Forecasting and Social Change, 176*, Article 121463. https://doi.org/10.1016/j.techfore.2021.121463
Song, Y., Zhou, A., Zhang, M., & Wang, H. (2019). Assessing the effects of haze pollution on subjective well-being based on Chinese General Social Survey. *Journal of Cleaner Production, 235*, 574–582. https://doi.org/10.1016/j.jclepro.2019.07.021
Tang, D., Li, L., & Yang, Y. (2016). Spatial econometric model analysis of foreign direct investment and haze pollution in China. *Polish Journal of Environmental Studies, 25*(1), 317–324. https://doi.org/10.15244/pjoes/60856
Ullah, S., Akhtar, P., & Zaefarian, G. (2018). Dealing with endogeneity bias: The generalized method of moments (GMM) for panel data. *Industrial Marketing Management, 71*, 69–78. https://doi.org/10.1016/j.indmarman.2017.11.010
Van, Donkelaar, A., Martin, R. V., Brauer, M., & Boys, B. (2014). Use of satellite observations for long-term exposure assessment of global concentrations of fine particulate matter. *Environmental Health Perspectives, 123*(2), 135–143. https://doi.org/10.1289/ehp.1408646
Wang, F., He, J., & Niu, Y. (2022a). Role of foreign direct investment and fiscal decentralization on urban haze pollution in China. *Journal of Environmental Management, 305*, Article 114287. https://doi.org/10.1016/j.jenvman.2021.114287
Wang, S., & Tan, F. (2017). Environment regulation and haze decoupling effect: Base On the perspective of heavy pollution industrial transformation. *Journal of Beijing Institute of Technology (Social Sciences Edition), 19*, 1–7. https://doi.org/10.15918/j.jbitss1009-3370.2017.2262
Wang, S., & Xu, Y. (2015). Environmental regulation and haze pollution decoupling effect: Based on the perspective of enterprise investment preferences. *China Industrial Economics, 4*, 18–30.
Wang, X., Li, J., & Ren, X. (2022b). Asymmetric causality of economic policy uncertainty and oil volatility index on time-varying nexus of the clean energy, carbon and green bond. *International Review of Financial Analysis, 83*, Article 102306. https://doi.org/10.1016/j.irfa.2022.102306
Wang, Y., Sun, X., & Guo, X. (2019). Environmental regulation and green productivity growth: Empirical Evidence on the Porter Hypothesis from OECD industrial sectors. *Energy Policy, 132*, 611–619. https://doi.org/10.1016/j.enpol.2019.06.016
Wen, H., Chen, S., & Lee, C. C. (2023). Impact of low-carbon city construction on financing, investment, and total factor productivity of energy-intensive enterprises. *The Energy Journal, 44*(2). https://doi.org/10.5547/01956574.44.2.hwen
Wen, H., & Dai, J. (2020). Trade openness, environmental regulation, and human capital in China: Based on ARDL cointegration and Granger causality analysis. *Environmental Science and Pollution Research, 27*, 1789–1799. https://doi.org/10.1007/s11356-019-06808-1
Xie, Q., Xu, X., & Liu, X. (2019). Is there an EKC between economic growth and smog pollution in China? New evidence from semiparametric spatial autoregressive models. *Journal of Cleaner Production, 220*, 873–883. https://doi.org/10.1016/j.jclepro.2019.02.166
Yan, R., Xiang, X., Cai, W., & Ma, M. (2022). Decarbonizing residential buildings in the developing world: Historical cases from China. *Science of The Total Environment, 847*, Article 157679. https://doi.org/10.1016/j.scitotenv.2022.157679
Yi, M., Wang, Y., Sheng, M., Sharp, B., & Zhang, Y. (2020). Effects of heterogeneous technological progress on haze pollution: Evidence from China. *Ecological Economics, 169*, Article 106533. https://doi.org/10.1016/j.ecolecon.2019.106533
Zhang, M., Liu, X., Ding, Y., & Wang, W. (2019). How does environmental regulation affect haze pollution governance?—An empirical test based on Chinese provincial panel data. *Science of the Total Environment, 695*, Article 133905. https://doi.org/10.1016/j.scitotenv.2019.133905
Zhang, M., Liu, X., Sun, X., & Wang, W. (2020). The influence of multiple environmental regulations on haze pollution: Evidence from China. *Atmospheric Pollution Research, 11*(6), 170–179. https://doi.org/10.1016/j.apr.2020.03.008
Zhang, S., Ma, M., Xiang, X., Cai, W., Feng, W., & Ma, Z. (2022). Potential to decarbonize the commercial building operation of the top two emitters by 2060. *Resources, Conservation and Recycling, 185*, Article 106481. https://doi.org/10.1016/j.resconrec.2022.106481
Zhao, J., Jiang, Q., Dong, X., & Dong, K. (2020). Would environmental regulation improve the greenhouse gas benefits of natural gas use? A Chinese case study. *Energy Economics, 87*, Article 104712. https://doi.org/10.1016/j.eneco.2020.104712
Zhao, J., Jiang, Q., Dong, X., Dong, K., & Jiang, H. (2022a). How does industrial structure adjustment reduce CO_2 emissions? Spatial and mediation effects analysis for China. *Energy Economics, 105*, Article 105704. https://doi.org/10.1016/j.eneco.2021.105704
Zhao, J., Shahbaz, M., & Dong, K. (2022b). How does energy poverty eradication promote green growth in China? The role of technological innovation. *Technological Forecasting and Social Change, 175*, Article 121384. https://doi.org/10.1016/j.techfore.2021.121384
Zhao, J., Shahbaz, M., Dong, X., & Dong, K. (2021). How does financial risk affect global CO_2 emissions? The role of technological innovation. *Technological Forecasting and Social Change, 168*, Article 120751. https://doi.org/10.1016/j.techfore.2021.120751
Zhong, Q., Wen, H., & Lee, C. C. (2022). How does economic growth target affect corporate environmental investment? Evidence from heavy-polluting industries in China. *Environmental Impact Assessment Review, 95*, Article 106799. https://doi.org/10.1016/j.eiar.2022.106799
Zhou, J. Q., Liang, W. G., & Zhang, Y. (2019a). Foreign direct investment, environmental regulation, and haze pollution: theoretical analysis and experience from China. *Journal of Beijing Institute of Technology (Social Sciences Edition), 21*(01), 37–49. https://doi.org/10.15918/j.jbitss1009-3370.2019.5296
Zhou, Q., Zhang, X., Shao, Q., & Wang, X. (2019b). The non-linear effect of environmental regulation on haze pollution: empirical evidence for 277 Chinese cities during 2002–2010. *Journal of Environmental Management, 248*, Article 109274. https://doi.org/10.1016/j.jenvman.2019.109274

Zhou, Q., Zhong, S., Shi, T., & Zhang, X. (2021). Environmental regulation and haze pollution: neighbor-companion or neighbor-beggar? *Energy Policy, 151*, Article 112183. https://doi.org/10.1016/j.enpol.2021.112183

Zhou, X., Zhang, J., & Li, J. (2013). Industrial structural transformation and carbon dioxide emissions in China. *Energy Policy, 57*, 43–51. https://doi.org/10.1016/j.enpol.2012.07.017

Zhou, Y., Zhu, S., & He, C. (2017). How do environmental regulations affect industrial dynamics? Evidence from China's pollution-intensive industries. *Habitat International, 60*, 10–18. https://doi.org/10.1016/j.habitatint.2016.12.002