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Trade Openness and Haze Pollution in China: The Moderating Role of Environmental Regulation

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Abstract: Using panel data from 30 Chinese provinces spanning 2003-2019, the relationship between trade openness and haze pollution, moderated by environmental regulation, was investigated through spatial econometric models. It was observed that the effect of trade openness on haze pollution was negative, albeit insignificant, suggesting that trade openness alone did not markedly influence haze reduction in China. Contrarily, environmental regulation, while intensifying haze pollution, displayed a significant moderating role. When combined with environmental regulations, trade openness showed potential in mitigating haze pollution, thus enhancing environmental quality. Although trade openness did not display significant regional variance in its impact on haze pollution, considerable regional disparities were found in the effects of environmental regulation on haze pollution and its moderating influence on the trade openness-haze pollution relationship.

Keywords: Trade openness; Environmental regulation; Haze pollution; Moderating effect; Spatial econometric model; China

1. Introduction

Following China's economic reform and open-door policy, sustained economic growth was witnessed. Between 2003 and 2020, China's total import and export volume surged from 85 billion dollars to 465.6 billion dollars, with a reported GDP of 10.1 billion yuan in 2020 (Han et al., 2021). Yet, this remarkable growth was observed to come at a significant environmental expense (Dauda et al., 2021; Liu et al., 2022). Indicators from the World Bank in 2016 elucidated that the persistent environmental deterioration in China remained unchecked. Alarming trends were observed in both traditional environmental pollutants, such as nitric oxide and CO_2 emissions, and emerging pollutants like PM2.5 (Tachie et al., 2020).

The nexus between trade openness and its environmental ramifications has subsequently become a focal point of academic and governmental discourse. A faction of scholars posits that trade openness paves the way for advancements in industrial structures and technology, thus potentially alleviating environmental degradation (Afridi et al., 2019; Ansari et al., 2020; Liu et al., 2022; Tachie et al., 2020; Zafar et al., 2019; Zugravu-Soilita, 2019). Conversely, another set of researchers suggests that it may foster a shift of high-pollution industries from developed regions to their less developed counterparts, thereby inadvertently creating pollution sanctuaries (Van Tran, 2020; Xu et al., 2020; Zhan, 2017). Still, some argue that a direct relationship between the two is ambiguous and likely modulated by various factors, notably environmental regulations (Dauda et al., 2021; Ponce & Alvarado, 2019; Wang & Cheng, 2021). It has been posited that environmental regulation exerts a significant influence on a region or country's degree of trade openness (Yang et al., 2021a). Such regulations have been noted to directly impact foreign direct investment and, by extension, the scope of a region's product exports (Zhan, 2017). Yet, the specific manner in which environmental regulation interplays with trade openness remains under-explored. Hence, an examination was conducted using panel data from 30 provinces in China spanning 2003-2019 to discern the spatial effects of trade openness, environmental regulation, and haze pollution. Additionally, the potential moderating role of environmental regulation in this triad was probed, aiming to furnish a nuanced understanding of the dynamics between trade openness and haze pollution.

2. Literature Review

2.1 Trade Openness and Haze Pollution

The pioneering exploration into the nexus between trade and environmental implications can be traced back to the work of Grossman & Krueger (1995), who assessed the environmental ramifications of the North American Free Trade Agreement (NAFTA) (Grossman & Krueger, 1995). In their work, the concept of the environmental Kuznets curve was introduced, elucidating an inverted U-shaped correlation between income and environmental degradation. Subsequent investigations have consistently delved into the environmental consequences of trade openness, predominantly corroborating the presence of either a pollution haven or pollution halo (Zhan, 2017; Zhao et al., 2023).

Central to this discourse is the pollution haven hypothesis, suggesting that industries characterized by high pollution levels migrate from economically affluent regions to those less developed, primarily due to lenient environmental regulations. Such a transition, it is posited, diminishes pollution levels in wealthier nations, while exacerbating them in less affluent ones (Afridi et al., 2019). Consequently, these underdeveloped regions metamorphose into pollution havens, culminating in escalated ecological deterioration at a societal scale (Allaire & Brown, 2015; Shao et al., 2016b; Zhang et al., 2017). In a study by Dietzenbacher et al. (2012), it was observed that a surge in China's trade exports is associated with a proportionally larger carbon footprint compared to other nations. Gibson (2015) reported that escalating trade-investment cycles contribute to increased air and water pollution. By harnessing PM2.5 data spanning 31 Chinese provinces from 1998 to 2012, Kang (2016) identified, using spatial lag panels, a direct link between trade openness and amplified haze pollution. A similar sentiment was echoed by Liu & Jiang (2017) and Xin & Li (2019), wherein trade liberalization was correlated with increased PM10 concentrations and heightened haze pollution in the Yangtze River Delta, respectively. Zugravu-Soilita (2019) highlighted that trading exclusively in Environmental Goods (EGs) is insufficient to address environmental challenges effectively. The phenomenon of "pollution shelter", as presented by Shahbaz et al. (2019), underscores those countries, in pursuit of bolstered product competitiveness through trade liberalization, might compromise environmental standards, leading to a race-to-bottom. A reduction in trade volumes was advocated by Ansari et al. (2020) as a measure to curtail emissions from top CO_2 emitters. This perspective was further corroborated by research from Afridi et al. (2019), Tachie et al. (2020), and Zafar et al. (2019), all emphasizing the detrimental influence of trade openness on CO_2 emissions across various regions. In contrast, Liu et al. (2022) unveiled a positive Environmental Kuznets Curve association between trade, tourism, and environmental health in Pakistan from 1980-2017, suggesting the potential ecological benefits of trade.

The pollution halo hypothesis is predicated on the notion that prior to industrial transfer, advanced technologies, sophisticated methodologies, and rigorous environmental management systems are introduced to less developed regions by their developed counterparts. As a result, technological innovation and environmental stewardship in these underdeveloped areas are bolstered, potentially leading to a reduction in ecological degradation (Grafton et al., 2014; Michielsen, 2014; Zhang et al., 2017).

Findings from Moran et al. (2013) implied that international trade might exert a favorable influence on air quality. Contrarily, Bollen (2015) postulated that trade could circumvent the financial burden of air quality regulations. A sentiment of trade liberalization's environmental benefits is echoed by Al-Mulali et al. (2015) in the context of Europe's long-term CO_2 emissions, while Zhan & Yu (2015) and Dai et al. (2015) associate trade liberalization with diminished environmental pollution in China. However, a temporal dichotomy is suggested by Zhan (2017) and Li et al. (2018), who argue that while trade liberalization might be environmentally deleterious in the short term, the resultant income augmentation could elevate societal demand for environmental quality, curbing ecological degradation in the long haul.

Analyzing a broader dataset spanning 66 developing economies from 1971 to 2017, Van Tran (2020) discerned that the relationship between trade openness and environmental pollutants is not straightforward, with trade openness potentially being detrimental to environmental health. Contrasting studies from Zhou & Liu (2020) and Xu et al. (2020) ascertained the environmental benefits of both foreign direct investment introduction and trade openness, especially in the context of China's haze pollution and agricultural CO_2 emissions, respectively.

Furthermore, a linear connection between trade openness and haze pollution has been challenged by some academicians. The assertion is that trade openness yields non-linear or threshold effects on haze pollution, contingent on a myriad of factors (Ozatac et al., 2017; Unger, 2012; Zhan, 2017). The selection of specific pollutant indicators yielded disparate outcomes concerning the pollution haven effect (Peng et al., 2013). Similarly, the influence of the pollution haven effect versus the factor endowment effect manifested differently depending on the chosen pollutant index and area of analysis (Zhan & Yu, 2015). Cai & Xu (2018) posited the existence of a threshold effect between trade openness and smog pollution, while research from Dauda et al. (2021), Han et al. (2021), Ponce & Alvarado (2019), Tiba & Belaid (2020), and Wang & Cheng (2021) unveiled the bidirectionality of the trade-environment nexus.

In summation, a clear consensus remains elusive regarding the precise relationship between trade openness and haze pollution. It is surmised that environmental regulation intensity may modulate the influence of trade openness on haze pollution, with heterogeneous effects arising due to variations in this intensity (Li, 2016; Zhan, 2017).

2.2 Environmental Regulation as a Moderating Influence

As a salient mechanism in regional environmental governance, the influence of environmental regulation on trade openness has been substantially explored (Sderholm et al., 2021). Two dominant perspectives emerge from the current literature. The “race to the bottom” hypothesis postulates that in pursuit of economic growth, trade openness incentivizes developing nations to either reduce or sustain minimal levels of environmental regulation, fostering high-carbon industries and exports (Esty, 1998). Although empirical analyses by Asici & Acar (2016) and Rasli et al. (2018) uphold this viewpoint, counterarguments have been raised suggesting its relevance is confined primarily to developing nations. The alternative perspective is the Pollution Paradise Hypothesis, which proposes that trade liberalization triggers a migration of high-carbon industries from nations with stringent environmental oversight to those with lax environmental policies. This migration, in essence, renders developing nations as “pollution paradises,” while more developed countries witness enhanced environmental quality (Walter & Ugelow, 1979). Validations for this paradigm have been discerned in studies by Tang et al. (2016), Eichner & Pethig (2018), Wu et al. (2020), and Destek & Sinha (2020).

Three primary reflections of the influence of environmental regulation on trade openness emerge from a review of extant literature. Firstly, it is documented that environmental regulation governs the direction and velocity of industry transfers across regions (Li et al., 2016; Rezza, 2014; Zhang & Wang, 2014). In the absence of robust regulations, pollution havens are readily established, ushering industries into territories with lenient environmental constraints. Conventional wisdom holds that developed regions would transition their high-emission industries to lesser-developed vicinities, exacerbating haze pollution in the process (Dong et al., 2012; Chung, 2012; Yang et al., 2019). Conversely, with rigorous environmental policies, relocation of such industries becomes an imperative, culminating in their rejection or removal (Shahbaz et al., 2019; Yang et al., 2016). The second dimension pertains to the modulation of technological innovation within trade sectors by environmental regulations (Zhou et al., 2016). Rigorous regulations ostensibly propel enterprises to augment investments in pioneering clean technologies, both to economize and to satisfy environmental benchmarks, culminating in diminished pollution emissions (Jugurnath et al., 2017; Yang et al., 2016). Thirdly, the character and environmental compatibility of choices made by trading sectors are impacted by environmental regulation (Hansen, 1999). In contexts such as China, weak regulatory environments have traditionally fostered predominance of high-emission, energy-efficient products in trade. Consequently, an uptick in export volumes directly escalates pollution emissions (Mulatu, 2017). However, with more exacting environmental standards, trade sectors are observed to gravitate towards sustainable, low-carbon pathways, subsequently dampening environmental pollution (Allaire & Brown, 2015; Yang et al., 2018; Zhang et al., 2017).

While numerous investigations have dissected the interplay between trade openness and haze pollution, and between environmental regulation and haze pollution separately, a lacuna exists in literature that bridges these three facets holistically. Typically, the moderating influence of environmental regulation remains under-explored. Environmental regulation's ability to shape the magnitude and methodology of trade openness, coupled with its sway over technological advancement and product choices in trade, holds implications for haze pollution. Drawing on data spanning 30 Chinese provinces from 2003 to 2019, and accommodating the spatial spillover effect inherent to haze pollution, the moderating role of environmental regulation on the nexus between trade openness and haze pollution is investigated. This study's contributions lie twofold. It provides insights into the interrelationship between trade openness, environmental regulation, and haze pollution, elucidating the nuanced influence of environmental regulations. Furthermore, leveraging spatial econometric and mediation effect models endows the empirical investigation with methodological innovation.

3 Materials and Methods

3.1 Empirical Model Construction

Given the recognized spatial spillover effects of haze pollution, a spatial model was employed for empirical assessment. Classically, such spatial models encompass the spatial lag model (SLM) and the spatial error model (SEM), whose algorithms are articulated in Eqs. (1) and (2).

$$\mathrm{lnPM}_{it} = \rho w \mathrm{lnPM}_{it} + \beta_0 + \beta_1 \mathrm{lnTRE}_{it} + \beta_2 \mathrm{lnER}_{it} + \beta_3 X_{it} + \varepsilon_i, \qquad \varepsilon_{it} \sim N(0,\ \sigma_{it}^2) \tag{1}$$

$$\mathrm{lnPM}_{it} = \alpha_0 + \alpha_1 \mathrm{lnTRE}_{it} + \alpha_2 \mathrm{lnER}_{it} + \alpha_3 X_{it} + \varepsilon_{it},\ \ \varepsilon_{it} = \lambda w_{ij}\, \varepsilon_{it} + u_{it}, \qquad u_{it} \sim N(0, \sigma_{it}^2) \tag{2}$$

In these equations, $lnPM_{it}$ denotes haze pollution, $lnTRE_{it}$ characterizes trade openness, $lnER_{it}$ represents environmental regulation, and X_{it} comprises a set of control variables. The term W signifies the spatial weight matrix. In this research, the adjacency distance matrix, represented by Eq. (3), was utilized:

$$W=\begin{bmatrix} w_{11} & \cdots & w_{1n} \\ \vdots & \cdots & \vdots \\ w_{n1} & \cdots & w_{nn} \end{bmatrix} \tag{3}$$

To probe into the moderating role of environmental regulation, an interaction term integrating trade openness and environmental regulation was incorporated into the model. To ensure the comparability of the primary variables' coefficients both pre- and post-integration of these interaction terms, the moderating effect model proposed by Balli & Sorensen (2012) was adopted. Prior to the introduction of the interaction terms, the variables underwent centering, aligning with the methodology delineated by Aiken et al. (1991) and Balli & Sorensen (2012). The representative equation for this moderating effect is presented as Eq. (4). This foundational model facilitated the evaluation of environmental regulation's mediating influence.

$$y=\gamma_0+\gamma_1 x_1+\gamma_2 x_2+\gamma_3(x_1-\bar{x}_1)(x_2-\bar{x}_2)+\varepsilon_3 \tag{4}$$

3.2 Selection of Variables and Data Characterization

(1) Haze Pollution: Historically, indices such as SO_2, NO_x, CO_2, PM2.5, PM10, and soot have been employed as proxy metrics to denote atmospheric pollution severity. Notably, PM2.5 and PM10 have been predominantly utilized for haze pollution quantification (Feng & Wang, 2020; Shao et al., 2019). As defined by the Chinese Ecological Environment Administration, PM10 corresponds to inhalable particulate matter with an aerodynamic equivalent diameter smaller than 10 microns. Such values represent the concentration of inhalable particulate matter in milligrams per cubic meter of air. Data pertaining to PM10 is consistently monitored and disseminated by China's Ministry of Ecology and Environment (Shao et al., 2016a; Yang et al., 2020a). For the purposes of this study, PM10 was selected as the metric for haze pollution, with PM2.5 employed in further confirmatory analyses.

(2) Trade Openness: This metric elucidates a nation's level of economic openness on the global stage, determined by the ratio of the aggregate import and export volume to the GDP for a given year (Zhan, 2017; Zhan & Yu, 2015). Data corresponding to total goods imports and exports was sourced in US dollars and subsequently converted to RMB, relying on the mean annual exchange rate.

(3) Environmental Regulation: This term encompasses the emission taxes, administrative sanctions, and discharge permit systems instituted by governing bodies to modulate the operational endeavors of manufacturers, thereby fostering sustainable economic trajectories (Chen et al., 2021). Echoing the methods delineated by Zhang (2017), investments earmarked for pollution abatement within each jurisdiction were adopted as proxies for environmental regulation stringency.

(4) Control Variables: Factors such as economic progression, foreign direct investment (FDI), demographic trends, and the industrial matrix critically influence a region's haze pollution dynamics. Adhering to guidelines proposed by Ohno & Thanh (2016), the actual volume of foreign capital introduced in each province was harnessed to quantify the degree of investment. Data was sourced from the "China Statistical Yearbook on Science and Technology", with values in US dollars being converted to RMB via the median annual exchange rate. To negate the price effect, each city's GDP deflator was applied across the temporal spectrum. Based on assessments by Gani (2012) and Zhang et al. (2017), Gross Domestic Product (GDP) was expressed through the real per capita GDP, while population size (PO) was represented by each region's end-of-year populace count. Borrowing insights from Li & Wang (2015), the secondary industry's share in the GDP served as a gauge for the industrial structure. The bulk of this data was extracted from the "China Statistical Yearbook" and "China Statistical Yearbook on Environment". A logarithmic transformation was enacted during analysis to effectively negate the time-series dimension. Comprehensive descriptions of these variables, along with their statistical outcomes, are encapsulated in Table 1.

Table 1. Descriptive statistical overview of variables

Variables	Description	Minimum	Maximum	Mean	Std. Deviation
$lnPM_{10}$	Haze pollution	3.4012	5.7203	4.5497	0.3353
lnTRE	Trade openness	-0.0062	6.9166	2.9273	1.1065
lnER	Environmental regulation	1.2809	7.2557	4.8357	1.0876
lnGDP	The level of economic development	8.0886	12.0090	10.3187	0.7516
lnFDI	Foreign direct investment	-1.3438	7.7219	5.1224	1.6857
lnIS	Industrial structure	2.4713	4.0817	3.6399	0.2584
lnPS	Population size	6.2804	11.4675	8.1781	0.7617

4. Results

4.1 Spatial Spillover Effects of Haze Pollution Analysis

An examination of the haze pollution distribution characteristics from 2019 revealed contiguous and spatial correlations in the pollution's spatial distribution (Figure 1). As visualized in Figure 2, the Moran's I values for haze pollution spanning from 2003 to 2019 predominantly exhibited positive values, with the exceptions occurring in 2019. Statistically significant results were observed for all years except for 2004 and 2019. This pattern suggests pronounced spatial spillover characteristics inherent to haze pollution.

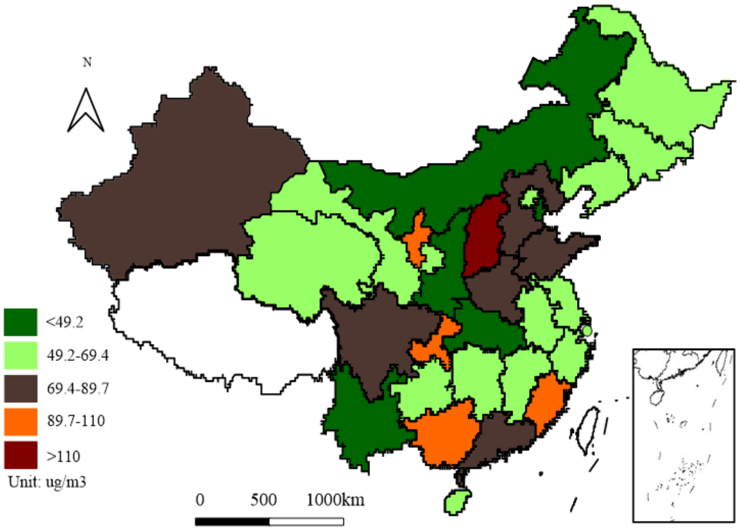

Figure 1. Spatial distribution of haze pollution, 2019

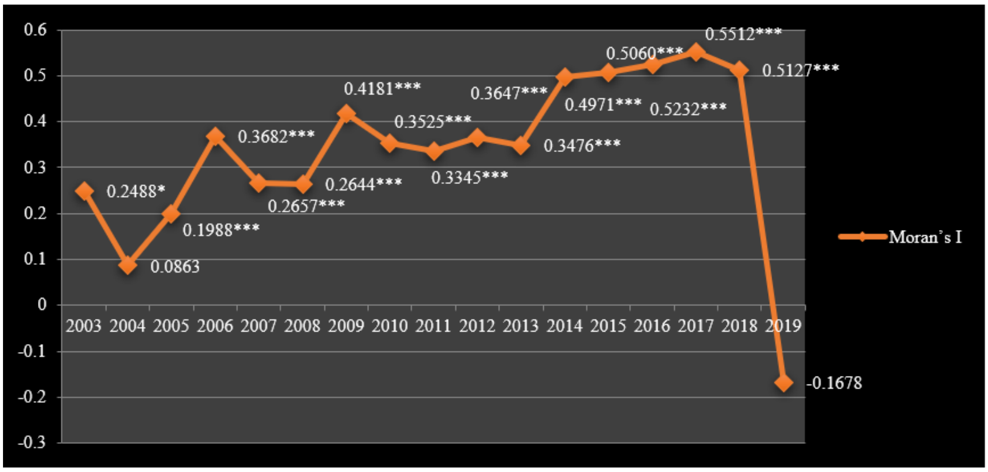

Figure 2. Moran's I value trends for haze pollution in China (2003-2019)
Note: Significance denotations are as follows: * P<0.1, ** P<0.05, *** P<0.01

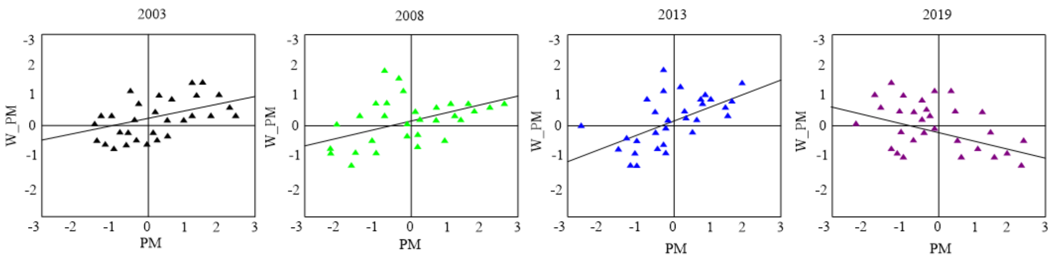

Figure 3. Haze pollution's Moran scatterplots across China
Note: Each triangle in Figure 3 represents a single sample unit among the 30 provinces in China

The Moran scatter plot, depicted in Figure 3, further elaborates on this phenomenon. During the years 2003, 2008, and 2013, a majority of the observation zones were identified within the first and third quadrants, pointing towards a significant positive spatial autocorrelation concerning haze pollution. Contrastingly, in 2019, a shift was observed with the majority of zones transitioning to the second and fourth quadrants. Although this transition indicates a potential negative spatial autocorrelation for haze pollution, it lacks statistical significance. Collectively, these findings reaffirm the substantive spatial spillover effect of haze pollution, in line with the research outcomes presented by Tang et al. (2016), Zhou & Liu (2020), and Wang & Cheng (2021). This consistency across studies underscores the imperative to account for spatial spillover effects in future haze pollution research endeavors.

4.2 Empirical Findings

Prior to delving into the empirical analysis, the suitability of the SLM and SEM models was assessed, as detailed in Table 2. It was determined that the SEM model did not pass the LM robustness test, rendering the SLM model as the more fitting choice for this study. In recent research, it has been posited by Wang et al. (2020) and Shao et al. (2019) that when both the individual and timeframe of the sample under study remain constant, the fixed-effect model exhibits enhanced explanatory power. Given these findings, the SLM fixed-effect model was employed for the empirical investigation.

Table 2. Comparative outcomes of SLM and SEM models

Testing Method	Test Statistics	P-Value
LM test no spatial lag, probability	308.1750	0.000
robust LM test no spatial lag, probability	7.7585	0.005
LM test no spatial error, probability	300.4909	0.000
robust LM test no spatial error, probability	0.0745	0.785

4.2.1 Direct implications of trade openness on haze pollution

A comprehensive exploration of the direct effects of trade openness on haze pollution was conducted, using multiple frameworks: the spatial fixed effect model (SFE), the time fixed effect model (TFE), and the dual time-space fixed effect model (STFE). The findings, encapsulated in Table 3, unveiled that the ρ/λ values across these models successfully underwent the significance test. This provided empirical evidence pointing towards the spatial spillover attributes of China's haze pollution. As a result, the significance of spatial considerations within the spatial econometric model was underscored. With the ρ/λ values consistently appearing positive and successfully passing the 1% significance test, it was inferred that the spatial spillover effect remains steadfast and exhibits significant positive spatial autocorrelation. Interestingly, a comparison revealed that the TFE model's adjusted R^2 significantly eclipsed that of the SFE and STFE models, advocating for the heightened explanatory power of the TFE model. Therefore, subsequent empirical analysis was anchored on the TFE model.

Table 3. Outcomes highlighting the direct impact of trade openness on haze pollution

Variables	SFE	TFE	STFE
$\ln PM_{-1}$	0.3738*** (13.4880)	0.6465*** (27.6059)	0.4000*** (13.8281)
lnTRE	0.0006 (0.5076)	-0.0005 (-0.0691)	0.0040 (0.5791)
lnGDP	-0.03069** (-2.5026)	0.0112 (0.5062)	0.0860* (1.7018)
lnFDI	0.0077 (0.8072)	-0.0138** (-2.0839)	-0.0058** (-2.6383)
lnIS	0.1411*** (3.6111)	0.0654 ** (2.4756)	0.1047* (1.8283)
lnPS	0.0251 (0.5558)	0.0529*** (4.3794)	-0.02561 (-0.5803)
ρ/λ	0.5280*** (14.893)	0.3730*** (11.4101)	0.2380*** (4.7725)
Adjusted R^2	0.5045	0.8290	0.3039
Log-likelihood	389.1760	350.2054	436.2726

Note: Significance metrics are categorized as: * P<0.1, ** P<0.05, *** P<0.01.

An inverse relationship was observed between trade openness and haze pollution, albeit without significance. The TFE model, delineated in Table 3, estimated the coefficient of trade openness at -0.005, but it was not deemed statistically significant. This aligned with the conclusions drawn from earlier research by Li et al. (2018), Van Tran (2020), Zhan (2017), and Zhou & Liu (2020). Several factors contribute to this observation:

(1) The interplay of trade openness is driven by both factor endowment and pollution haven effects. In scenarios where the factor endowment effect surpasses the pollution haven effect, trade openness can potentially bolster environmental quality (Destek & Sinha, 2020; Kang, 2016).

(2) Both the pollution paradise and pollution halo phenomena might concurrently manifest in China. While developed nations often shift pollution-intensive industries to countries with laxer environmental regulations, thereby exacerbating emissions (Wu et al., 2021), international trade can catalyze the transfer of avant-garde production technologies. This can empower nations with lesser technological prowess to elevate their pollution mitigation strategies (Xu et al., 2022; Zhan, 2017).

(3) As trade-driven elevations in per capita income emerge, more rigorous environmental policies are often enacted, reflecting the populace's amplified environmental preferences. Consequently, enterprises are propelled towards cleaner production technologies, curbing pollutant emissions (Han et al., 2021; Zafar et al., 2019).

Analyzing the control variables, it was discerned that Foreign Direct Investment (FDI) actively aids in curbing haze pollution. Such a trend implies the potential positive repercussions of foreign investments, possibly due to the influx of advanced, eco-friendly technologies, consistent with the observations by Yang et al. (2019) and Tang et al. (2022). Conversely, both the industrial structure and population size were found to be positively correlated with heightened haze pollution, echoing the perspectives of Shao et al. (2019) and Yang et al. (2020a). Notably, the influence of economic development on haze pollution did not exhibit statistical significance.

4.2.2 The moderating role of environmental regulation

Utilizing the TFE model, the potential mediating role of environmental regulation on the nexus between trade openness and haze pollution was rigorously examined. The subsection regression approach was employed to incorporate trade openness, environmental regulation, and their interaction terms into the model. The resultant empirical findings are depicted in Table 4.

Table 4. Outcomes of environmental regulation's moderating influence

Variables	Coefficient	Coefficient	Coefficient
$lnPM_{-1}$	0.6465*** (27.6059)	0.6365*** (26.7922)	0.6435*** (27.3440)
lnTRE	-0.0005 (-0.0691)		
lnER		0.0336*** (2.7862)	
lnTRE*lnER			-0.0087* (-1.7215)
lnGDP	0.0112 (0.5062)	-0.0186 (-0.8390)	0.0105 (0.5333)
lnFDI	-0.0138** (-2.0839)	-0.0144** (-2.1774)	-0.0139** (-2.0995)
lnIS	0.0654 ** (2.4756)	0.0641** (2.5408)	0.0663** (2.5834)
lnPS	0.0529*** (4.3794)	0.0266* (1.7654)	0.0534*** (4.4461)
ρ/λ	0.3730*** (11.4101)	0.3580*** (10.9384)	0.3790*** (11.7017)
Adjusted R^2	0.8290	0.8322	0.8289
Log-likelihood	350.2054	354.2012	350.0984

Note: Significance: * P<0.1, ** P<0.05, *** P<0.01.

It was discerned that environmental regulation bore a significant positive correlation with haze pollution. This implies that elevated environmental regulations might be exacerbating haze pollution levels, a finding that aligns with the research conclusions drawn by Shao et al. (2019), Yang et al. (2021b), and Zhao et al. (2020). Counterintuitively, these results indicate that environmental regulations, in their current form, may not be directly mitigating haze pollution. Two primary reasons are postulated for this observation. Firstly, it is surmised that environmental regulations, rather than having a direct mitigating effect on haze pollution, influence other variables that in turn influence environmental quality. For instance, research has indicated that while the direct impact of environmental regulations on carbon emissions might be negligible, such regulations can indeed bolster energy conservation and emission reductions by spurring technological innovation (Wang & Xu, 2015; Yang et al., 2020b). Moreover, environmental regulations might moderate haze pollution indirectly through their impact on FDI and trade openness (Zhan, 2017). Secondly, the substantial presence of a hidden economy in China is highlighted. Rigorous environmental regulations might inadvertently expand this hidden economy, leading to an upsurge in overall pollution levels (Zhan, 2017). It is suggested that heightened regulations might compel firms to shift export production to clandestine, under-regulated sectors to economize on production costs, thus exacerbating emissions due to poor regulation in these areas (Afridi et al., 2019). Furthermore, the imposition of stringent pollutant emission fees might encourage some firms to bypass environmental obligations through illicit means, such as graft (Feng & Li, 2020; Fu et al., 2021), subsequently amplifying overall emission levels.

Interestingly, a significant moderating effect of environmental regulation on the relationship between trade openness and haze pollution was observed. As delineated in Table 4, the coefficient of the interaction term between environmental regulation and trade openness was found to be negatively significant at the 10% level. This suggests that as environmental regulations are implemented, the effects of trade openness on haze pollution undergo notable alterations. The interaction term's negative coefficient indicates that trade liberalization, in conjunction with environmental regulations, can potentially ameliorate haze pollution and enhance environmental quality. On the one side, stricter implementation of environmental regulations in recent years is believed to have curtailed the influx of high-emission industries from developed countries into China (Zhan, 2017). Simultaneously, advancements in both domestic and international environmental regulations have obligated firms to innovate, thereby aligning exported product quality with international environmental and trade standards (Su et al., 2020). Complementary to these regulations, the Chinese government is reported to have introduced measures to bolster enterprise compliance (Zhang et al., 2019). Incentives and financial aid have been proffered to firms, fostering innovation in eco-friendly technologies and pollution management, which in turn fuels enthusiasm for energy conservation and emission reductions in the context of international trade.

In summation, while environmental regulations appear to amplify haze pollution levels, their significant moderating influence on the relationship between trade openness and haze pollution cannot be overlooked. Such regulations, by screening out high-emission industries and necessitating enterprise innovation in green technologies, render trade openness a positive agent in the combat against haze pollution.

4.3 Robustness Assessment

In a bid to delve deeper into potential regional variations in the nexus between trade openness and haze pollution, the study region was segmented into three distinct zones: western, central, and eastern (Table 5). The western zone encompasses provinces such as Chongqing, Gansu, Guangxi, and eight others. The central zone is constituted of provinces like Anhui, Heilongjiang, and six additional provinces. Conversely, the eastern zone integrates provinces including Beijing, Fujian, Guangdong, and eight more. Observations spanning 2003-2019 were compiled, with the eastern and western regions accounting for 187 observations across 11 provinces, and the central region amassing 136 observations from 8 provinces.

Interestingly, the influence of trade openness on haze pollution was determined to be insignificant across the eastern, central, and western regions, mirroring the findings observed at a national scale. Such a discovery underscores the absence of a pronounced regional divergence in the effects of trade liberalization on haze pollution, reaffirming the robustness of preceding research outcomes. Furthermore, environmental regulation was ascertained to notably mitigate haze pollution in the eastern zone while intensifying it in the western area. As for the central area, the effects of environmental regulation on haze pollution were deemed inconsequential. Such outcomes hint at pronounced regional disparities in how environmental regulation modulates haze pollution. It is postulated that the root of such regional differences lies in the disparities in economic advancement, environmental regulatory intensity, and the potency of environmental governance across these zones. In regions like the east, where economic ascension is pronounced and environmental statutes are robustly enforced, environmental governance manifests robustly, leading environmental regulations to play a pivotal role in enhancing environmental quality (Yang et al., 2020b).

Table 5. Regional variations in the moderating impact of environmental regulation

Variables	Eastern Region	Central Region	Western Region
	Coefficient	Coefficient	Coefficient
$\ln PM_{-1}$	0.8304***	0.8729***	0.3293***
lnTRE	-0.0004	-0.0075	-0.0146
lnER	-0.0383*	0.0495	0.1942***
lnTRE*lnER	-0.0154*	-0.0077	-0.0447**
lnGDP	-0.0115	-0.1278	-0.2984***
lnFDI	-0.0109**	-0.0232	-0.0059
lnIS	-0.0148	0.0208	0.1301
lnPS	0.0070**	-0.0066	1.0705*
ρ/λ	0.0900***	-0.2361***	-0.2360***
Adjusted R^2	0.9254	0.7089	0.4556
Log-likelihood	157.8812	136.9025	187.9190

Note: Significance levels are as follows: * P<0.1, ** P<0.05, *** P<0.01.

Moreover, it was discerned that significant regional variations exist in how environmental regulation moderates the relationship between trade openness and haze pollution. Both eastern and western regions exhibited significant moderating effects. In the presence of environmental regulations, the manner in which trade openness impacts haze pollution was found to be markedly different. A negative cross-term coefficient was estimated, signifying that trade openness, when accompanied by environmental regulations, potentially curtails haze pollution levels. In contrast, the central region did not exhibit any significant moderating influence of environmental regulation. This can potentially be attributed to the environmental regulation in the eastern region setting a more rigorous benchmark for trade openness (Li, 2016). In areas like the east, stringent environmental regulations have been observed to curb or oversee industries with high pollution emissions (Li & Liu, 2013). However, in the pursuit of economic upliftment in the central zone, relaxation in environmental regulations might have inadvertently facilitated the influx of industries notorious for significant pollution emissions.

5. Conclusions and Policy Implications

In the unfolding chapter of economic globalization, striking a harmonious balance between ecological sustainability and trade has emerged as a pivotal societal challenge. This research probed the moderating impact of environmental regulation on the nexus between trade openness and haze pollution. Panel data spanning 2003-2019, encompassing 30 Chinese provinces, were employed, with the application of various spatial econometric and moderating effect models to delineate the nuanced interplay between environmental regulation, trade openness, and haze pollution. The principal findings can be synthesized as:

(1) A negative yet statistically non-significant relationship was observed between trade openness and haze pollution. While the liberalization of trade was perceived to possibly facilitate the transference of high-pollution industries to China, it was concurrently linked to the introduction of advanced technological and productive processes, leading to a discernible enhancement in China's environmental benchmarks.

(2) An amplification of haze pollution was associated with environmental regulation. It was inferred that these regulations might not effectively oversee myriad discrete economies within China, culminating in augmented environmental degradation. Notwithstanding this, it was also posited that the right environmental regulations have the potential to curtail haze emissions by galvanizing technological innovations that underscore energy conservation and pollution abatement.

(3) A prominent moderating effect of environmental regulation on the dynamic between trade openness and haze pollution was identified. Trade liberalization, when integrated with stringent environmental mandates, can potentially reduce haze pollution levels and augment environmental health. Such regulations are envisioned to sieve out high-pollution trade endeavors while simultaneously compelling enterprises to pivot towards low-carbon technological solutions and emission reductions.

(4) With respect to spatial disparities, pronounced regional variances were detected in terms of the impacts of environmental regulation on haze pollution, and how it influences the nexus of trade liberalization and haze pollution. Yet, a uniform trend was discerned, suggesting no palpable regional differentiation concerning the repercussions of trade openness on haze pollution.

In light of these insights, several policy interventions are suggested. Primarily, the amplification of environmental mandates is regarded as a critical vector for governance bodies aiming to rein in haze pollution and elevate environmental quality standards. However, it remains paramount for policymakers to discern between the direct and tangential ramifications of environmental regulations on haze deterioration. It is imperative that governmental bodies recognize the modulatory role of environmental decrees in bridging trade liberalization and haze pollution and be attuned to the pivotal threshold function these regulations play. A profound comprehension of these regulatory thresholds could engender a scenario where industries with a heavy pollution footprint are deterred, whilst simultaneously incentivizing the integration of cutting-edge, eco-friendly production methodologies. This scenario has the potential to architect a duality of progressive economic strides coupled with enhanced environmental stewardship.

Author Contributions

Conceptualization, formal analysis, funding acquisition, writing-review and editing: Guohua Niu. Data curation, methodology, validation, software, writing-original draft preparation: Yuanhua Yang.

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Data Availability

The [data927.xlsx] data used to support the findings of this study have been deposited in the [https://pan.baidu.com/s/197aswMeJNMBVj9Wkje7STA (password: my3l)].

Conflicts of Interest

The authors declare no conflict of interest.

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