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Evaluating the Synergistic Effects of Urban Environmental Governance: Achieving Pollution Mitigation and Economic Growth

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Abstract— Under the dual constraints of economy and environment, whether and how to exploit the synergistic effect of urban environmental governance achieves has garnered considerable attention but remains understudied. This study examines the synergistic impacts and green development mechanism of urban environmental governance in China, drawing on theoretical analyses and empirical evidence. Specifically, we focus on the perspectives of pollution reduction and economic growth, we endeavors to integrate pollution, governance and economic growth into a unified research framework, and empirically examines policy effects and mechanisms of China's urban environmental governance, and analyzes the direct and indirect channels of the synergistic impacts, and discusses green development mechanisms and paths. We can find that: (1) the effectiveness of urban environmental governance in reducing haze pollution and its contribution to economic growth remains significant even after conducting a series of robustness tests on a quasi-natural experiment. (2) an inverted "U" curve relationship exists between urban environmental governance and Green total factor productivity (GTFP), namely, with the gradual increase in the level of urban environmental governance, GTFP rises firstly and then falls. (3) significant heterogeneity exists among the cities with different levels of development and geographical location, more significant in eastern regions and economically developed cities. This study would contribute to understanding policy effect of urban environmental governance in China, and enriching the theoretical foundation of environmental economics and the empirical evidence from China.

Index Terms—Environmental governance; Synergies; Green development; Heterogeneity.

I. INTRODUCTION

How to achieve the dual goals of environmental improvement and economic development is a classical theoretical proposition, also an unresolved problem globally, and it remains uncertain whether urban environmental governance can play a key role to solve it. In the era context characterized by profound transformations of the worldwide economy and the accelerated changes of global climate warming, most countries and economies are dedicated to promote the strategic choice of high-quality economic development and high-level environmental protection. A broad consensus has been emerged that excellent environment quality and sustainable economic growth are both considered the basic requirements of human well-being and social stability, with abundant evidences that air pollution not only penetrates deep into human respiratory system and causes serious adverse health effects (Graff & Neidell, 2013), but may also raises serious public environmental concerns (Qin et al., 2020), and further exacerbates the gap between the rich and poor and social inequities, as some studies proposed the hypothesis of 'environmental health poverty trap', indicating that haze pollution can affect income inequality. Despite the rapid economic growth, trade globalization and the social wealth accumulation, no country has been immune from severe air pollution with the rapid industrialization and urbanization. As we all know that the "Eight major pollution incidents" such as "London Great Smog of 1952" has ever shocked the world (Davis, 2002), and air pollution has been a common environmental problem in most of the countries and regions around the world within different period, such as 1930 Meuse Valley fog in Belgium, Los Angeles photochemical smog in the United States, Yokkaichi asthma Incident in Japan and so on (Xu et al., 2022). On above basis, prevention and control of regional haze pollution has been a prominent environmental issue, therefore, various countries and territories have implemented different regulations and policies of urban environmental governance to address it. For instance, the Clean Air Act of 1956, which for the first time obtained royal assent of United Kingdom in July 1956, was enacted to combat smog and air pollution arising from coal burning and industrial activities. Another significant milestone was the Clean Air Act of 1970 in the United States, along with its subsequent amendments in 1977 and 1990, leading to a substantial transformation in the federal government's involvement in air pollution control (Longhurst et al., 2016). In recent years, great efforts involved with air pollution governance has been made in China, such as 'The air pollution prevention and control plan in 2013' and 'The three-year action plan for winning the "blue sky defense war" in 2018', notable progress have been made to enhance air quality in key regions and reduce haze pollution emissions in significant industries. Yu et al.(2015) indicated two opposite effects of environmental regulation on environmental pollution due to the existence of a hidden economy and its effects, and conclude that environmental regulation does not have a significant impact on the improvement of environmental quality. As the main body for policy formulation and implementation, the government plays an extremely important role in economic growth and environmental protection, thus, whether and how urban environmental governance achieve a win-win outcome for haze abatement and economic growth has garnered significant attention from various sectors, consequently, and this topic has become a research subject which is highly deserved investigating and discussing, so it is also the focus of this research and the core issue urgently needs to be addressed.

To sum up, as shown in Figure 1, the research innovation and contribution of this paper can be concluded in the following threefold: First, unlike the previous literatures which aims to examine the effects and mechanisms of economic development on haze pollution and its environmental governance, this paper attempts to integrate environmental governance, haze pollution and economic development into a unified theoretical framework, and systematically investigate the interactive effect and mechanisms of haze abatement and economic growth under the influence of urban environmental governance; Second, employing the panel data of 282 prefecture-level cities in China, this paper empirically analyzes the environmental and economic effects of urban environmental governance, and identifies the mediating effects and transmission channels with the a series of testing checks in variables endogeneity, robustness and heterogeneity of regression results, which can enrich the empirical evidence on a win-win outcome for haze abatement and economic growth; Finally, it deviates most literature that uses a single variable to measure core variables, this paper quantify the core variables adopting a variety of indicators and measures to measure, thus it enriches the conceptual understanding and measurement techniques of urban environmental government and its green development mechanism, providing a more realistic and effective depiction, moreover, it could effectively mitigates the endogeneity issue in core variables and minimizes potential biases in the empirical results.

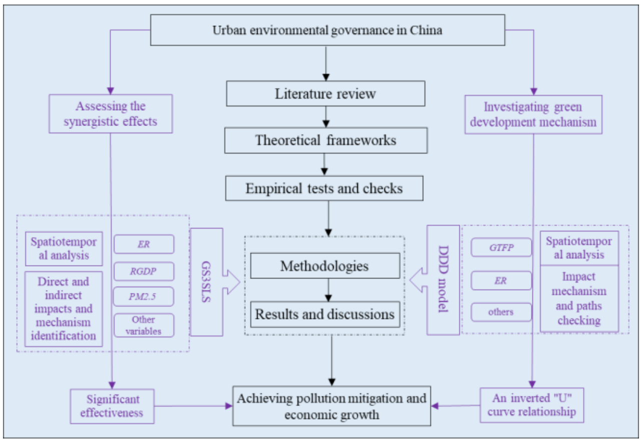

Fig.1 The overall framework of this research article

II. RESEARCH FRAMEWORK AND THEORETICAL ANALYSIS

Theoretical analysis framework

On the above basis, the nexus among environmental governance, haze abatement, and economic growth is regarded as complex and variable, and it is assumed that effective environmental governance is both critical in mitigating pollution and achieving a trade-off between environmental protection and economic growth, and numerous studies have examined and discussed the inter relationship between them, however, the interaction and mechanism paths is complex and multifaceted, on one hand, stringent environmental governance may increase compliance costs for businesses, potentially reducing economic productivity and hindering growth, and the expenses associated with pollution control measures can impose financial burdens on industries, on the other hand, environmental governance can also promote innovation and technological advancements in production process and energy conservation, so it can improve productivity, resource efficiency, and promote the green transformation and sustainable development of traditional industries, these positive effects can contribute to long-term economic growth and enhance competitiveness. Above all, the impact of environmental governance on haze abatement and economic growth relies on the multiple influencing factors, and mechanism and channels also cover the direct effect of environmental governance on haze abatement, and the indirect effect of economic growth. Effective environmental governance contributes to the reduction of haze pollution by enforcing emission standards and promoting cleaner production practices. It also facilitates sustainable economic growth by encouraging innovation, improving resource efficiency, and ensuring the long-term viability of industries. Thus, as Figure 2 shows that the impact mechanism of environmental governance on haze abatement and economic growth will analyzed from the following aspects

Direct effect and mechanism of environmental governance on haze abatement.

As is known that industrial activities and energy utilization have been identified as the primary causes of haze pollution in China, necessitating the pursuit of green product and cleaner energy as a direct and pragmatic approach to reduce haze pollutant emission(Zhang et al., 2019), and the production of green products benefits from enterprises to improve the level of green technology innovation, and utilization of cleaner energy depends largely on the energy structure transition (Zhou et al., 2019). Existing research indicates that environmental governance not only promotes activities of green technological innovation by enterprises, but aslo contributes to the transformation and upgrading of the energy structures (Du etal., 2021), and Liu & Xu (2017) found that environmental regulation acts on haze control through both direct and indirect paths, starting from the intermediary effect, in addition, Zhou et al., (2021) indicated an “inverted-U” relationships between environmental regulation and haze pollution, and also shown neighbor-companion mode, namely different environmental regulations have different mechanisms on haze pollution. Thus, the direct effect and mechanism of environmental governance on haze abatement can be discussed based on the significant mediating role and influencing mechanism of green technological innovation and energy structure optimization. The 'Porter hypothesis' suggests that stricter regulation can drive firms to invest in technological innovation to improve energy efficiency and optimate energy structure. However, the second hypothesis proposes that it may lead to more technological progress in pollution abatement, resulting in energy rebound effect. The third hypothesis, based on 'induced innovation,' posits that rising fossil energy costs stimulate firms to develop non-fossil energy sources using backstop technology, leading to energy savings.

Indirect effect and mechanism of environmental governance on economic growth

Effective environmental governance can incentivize industries and businesses activities to adopt cleaner production processes and green technologies and eco-friendly infrastructures, so it can foster urbanization processing, improve resource utilization efficiency, enhance industry competitiveness, and contribute to sustainable economic growth (Li et al., 2020). Environmental governance can affect economic growth through various factors, such as environmental costs, technological progress, and resource utilization, as Revesz (1997) for the earlier time indicated that environmental governance could compel firms to improve their technological progress by incentivizing innovation, leading to increased total factor productivity and enhanced environmental competitiveness. Firstly, environmental governance increase product costs, lower corporate profits, and may hinder business activities, which can be a challenge for sustained economic development. Secondly, Under the constraints of environmental regulation, companies invest in research and development to maximize their profits. Lastly, it could encourage the efficient of resources utilization and promote the development of a circular economy (Cao et al., 2020). Thus, the indirect effect and mechanism of environmental governance on economic growth can be discussed based on the significant mediating role and influencing mechanism of urbanization improvement and resource utilization effectiveness.

Green development effect and mechanism of environmental governance

This study posits the presence of a substantial environmental governance-induced green development effect, which has the potential to influence the technological innovation capacities of firms and their green total-factor productivity (GTFP). Porter et al., (1991) introduced the "Porter Hypothesis" which posits that the implementation of environmental governance measures has the potential to incentivize corporations to allocate greater resources towards research and development activities, hence fostering advancements in technological innovation. Ambec et al., (2013) indicated that the implementation of environmental regulations may lead to a rise in corporate profits, which can help mitigate the associated costs. Furthermore, research on technological innovation has demonstrated that environmental governance plays a crucial role in enhancing enterprises' overall productivity by facilitating technological advancements. Li and Chen (2021) found that there exists a non-linear link between environmental governance and GTFP across industries, characterized by a "U" shape. However, the inflection point was found to be statistically insignificant. Environmental governance requires manufacturing firms to actively participate in technological innovation, which has a greater impact on their overall productivity, known as the GTFP. Consequently, the advancement of business technology is hindered, resulting in a decrease in corporate profit margins. As a result, the influence of environmental governance on the progress of GTFP is perceived as negative.

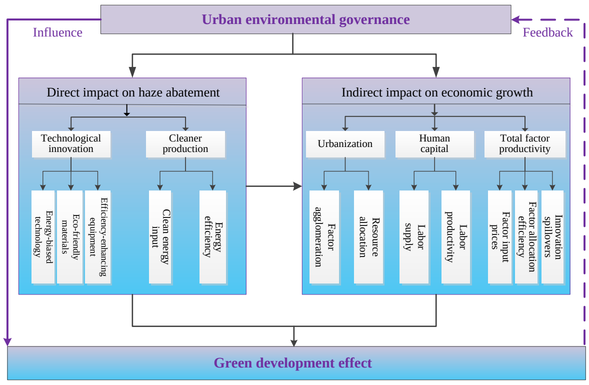

Fig.2 Theoretical mechanism and analytical framework

III. METHODOLOGIES AND DATA CHARACTERISTICS

Empirical strategies

Baseline regression model The current literatures have predominantly focused on two primary approaches in formulating empirical models to identify the nexus between environmental governance, pollution emissions, and economic output, the first was to incorporate pollution emissions as an environmental factor input into the production function of the enterprise, and the other treated the pollution emissions as a by-product of the enterprise's production, and adopted it to a conventional production function (Hanna & Oliva, 2015). Thus, the article aims to examine the environmental and economic impact of urban environmental governance, thus the baseline regression models are constructed by integrating environmental governance, haze pollution and economic growth into a unified research framework. Distinguished from other studies, a generalized spatial three-stage least squares (GS3SLS) method is established based on the construction of spatial associative equations, and is utilized to address the potential endogeneity problem from single-equation model may suffer, and the spatial panel model is selected mainly considering the spatial autocorrelation and spillover effects (Liu et al., 2022;)

$$PM2.5_{it} = \rho_1 \cdot \sum w_{it} \cdot PM2.5_{it} + \phi_1 \cdot \sum w_{it} \cdot rgdp_{it} + \alpha_1 ER_{it} + \alpha_2 ER_{it}{}^2 + \alpha_3 rgdp_{it} + \alpha_4 rgdp_{it}{}^2 + \alpha_n control_{it} + \mu_{it} \quad (1)$$

$$rgdp_{it} = \rho_2 \cdot \sum w_{it} \cdot rgdp_{it} + \phi_2 \cdot \sum w_{it} \cdot PM2.5_{it} + \beta_1 ER_{it} + \beta_2 ER_{it}{}^2 + \beta_3 rgdp_{it} + \beta_4 rgdp_{it}{}^2 + \beta_n control_{it} + \varepsilon_{it} \quad (2)$$

Where, i denotes the prefecture-level city, t denotes the detailed year.w_{it} is the spatial weigh matrix, and this study mainly employs a traditional symmetric geographical distance weight matrix to identify the spatial spillover effect and employs a novel symmetric geography-economy weight matrix for robustness testing (Gao et al., 2022). $rgdp$ indicates the level of economic growth, ER indexes the level of urban environmental governance, and $PM2.5$ indexes the level concentration level of haze pollution. Besides, $control$ denotes a series of control variables of haze pollution, such as industrial structure (second), foreign direct investment (fdi), government expenditure (gov), technology innovation (tech), financial development (finance), population density (pop) and infrastructure (infra). Additionally, $control$ denotes the a series of control variables of economic growth, such as industrial structure (second), foreign direct investment (fdi), governanment expenditure (gov), investment in fixed assets (invest), finanical development (finance), consumption level (consume) and infrastructure (infra). Furthermore, μ denotes the fixed effect of urban, λ denotes the fixed effect of time ， ε denotes the stochastic error term. Above all, the β_1 indexes the impact and extent to which haze pollution affects economic development, and this coeffective and its economic implication is the focus and core parameter.

Estimation model of green development effect Green total factor productivity (GTFP) is selected as a proxy variable for green development, and this paper employs a generalized spatial three-stage least squares (GS3SLS) method to examine the green development effect of urban environmental governance.

$$PM2.5_{it} = \rho_1 \cdot \sum w_{it} \cdot PM2.5_{it} + \phi_1 \cdot \sum w_{it} \cdot GTFP_{it} + \varphi GTFP_{it} + \alpha_1 ER_{it} + \alpha_2 ER_{it}{}^2 + \alpha_3 rgdp_{it} + \alpha_4 rgdp_{it}{}^2 + \alpha_n control_{it} + \mu_{it} \quad (3)$$

$$GTFP_{it} = \rho_2 \cdot \sum w_{it} \cdot GTFP_{it} + \phi_2 \cdot \sum w_{it} \cdot PM\,2.5_{it} + \beta_1 ER_{it} + \beta_2 ER_{it}^{\ 2} + \beta_3 rgdp_{it} + \beta_4 rgdp_{it}^{\ 2} + \beta_n control_{it} + \varepsilon_{it} \quad (4)$$

Investigation of the policy effects and robustness of urban environmental governance. To further conduct the robustness check, this paper assessed the policy effects of urban environmental governance employing a DDD model (Qi et al., 2021), and it indicated that industrial wastewater emissions are not affected by cross-regional haze pollution governance, so that the differences between the second experimental group and the control group originate from the effects of other environmental policies. The difference between the first experimental group and the control group originates from the effects of cross-regional haze pollution management policies and other environmental policies. Their difference is the net effect of cross-regional haze pollution control policies. Considering the atmospheric and water policies, such as the "Air Pollution Prevention and Control Action Plan(APPCAP)"or "Water Pollution Control Action Plan (WPCAP)", the DDD model is further transformed into a three-dimensional fixed-effect model and construct a quasi-natural experiment, and it is used as a complement to the robustness testing.

Variables and data description

The core variables mainly include haze pollution, economic growth, urban environmental governance and green development. Haze pollution is measured by the annual average value of PM2.5 concentration on urban surface (ug/m³), and the variable is logarithmically processed to eliminate the heteroscedasticity bias that exists (Gan et al., 2021). The data's accuracy and credibility are enhanced through the mutual calibration of satellite detection data and ground monitoring data, and these datasets are processed using latitude and longitude raster methods and are aligned with vector maps of specific regions. Economic growth selects the per capital gross domestic product (GDP) to measure, and the data is converted using the GDP deflator based on 2003 period, and the square term of per capital GDP are added to model to explore whether there exist the EKC characters in China (Liu, et al.,2022). Urban environmental governance is constructed based on industrial dust (or smoke) emissions, industrial sulfur dioxide emissions and the added value of the secondary industry output in GDP (Song & Cai, 2018). Green development: green total factor productivity is selected as a proxy variable. Drawing on Fare R et al. (2007) adopt the non-radial, non-angle SBM directional distance function to measure the Malmquist-Luenberger productivity (index), and use the index to measure the chain growth rate of green total factor productivity in 282 cities above prefecture level in China. In this paper, labor force, capital stock and electricity consumption are selected as the input factors of cities, real GDP is the desired output, and industrial wastewater emission, industrial sulfur dioxide emission and industrial smoke (dust) emission are the non-desired outputs. In addition, a set of control variables are introduced to the regression equation based on the existing studies and our theoretical analysis to alleviate the endogeneity and estimation errors. This paper mainly selects the panel data of 282 prefecture-city in China during the period form 2003 to 2018 as the testing samples due to the data completeness, availability and statistical calibers, and the dataset covers the vast majority of the city sample studied.

IV. Results and Discussion

Baseline regression results for spatial associative equation

Tables 1 present the estimation results for Eqs. (1) and (2) , and results of different groups are estimated based on data for the whole sample as well as for different regional samples. Taking the whole sample (.1) as an example, the model (1.1) matches Eqs.(1) and demonstrates the pollution equation, the model (2.1) matches Eqs.(2) and demonstrates the economic growth function. First, the estimation results of model (1.1) show that the coefficient ρ_1 of $w \cdot PM_{2.5}$ is 1.436, and it is significantly positive at the 1% level, which demonstrates that there exists a spatial correlation of haze pollution among neighboring prefecture-level city in China, and haze pollution concentrations level in the local city will also increase by 1.436%, for every 1% increase in the haze pollution level in the neighboring cities. The coefficient estimate ϕ_1 of $w \cdot rgdp_{2.5}$ is 0.000401, and also passes the 1% significance level testing, indicating that a 1% increase in the economic development level of neighboring cities raises local haze pollution by approximately 0.000401%. Additionally, the coefficients α_1 and α_2 exhibit a negative correlation between urban environmental governance and haze pollution, which is significantly positive at the 1% level. The coefficient estimates of $rgdp$ and $rgdp^2$, which measure the level of economic growth, are negative and positive respectively, and they both pass the 1% significance level test. Furthermore, there exists a negative relationship between technological innovation and haze pollution, passing the 1% significance test, which highly confirms the "innovation compensation" effect in China's urban environmental management. Besides, the coefficient estimate of population density is significantly positive, indicating rising population escalates resource demands, straining the environment, and exacerbating haze pollution. and the coefficient estimate of industrial structure are significantly positive, and the coefficient estimates of financial development level (infinance) and transportation infrastructure are also significantly positive. Further analysis of model (2.1) shows that an inverted U-shaped relationship exists between economic development and urban environmental governance, which suggests that as urban environmental governance improves, economic growth first increases and then declines. The coefficient estimates of $PM_{2.5}$ exhibit significant negativity, indicating haze pollution hampers economic growth during the study period. Notably, the positive estimate for second suggests its promotion of economic development. Likewise, a positive estimate for infra suggests its role in fostering urban economic development. On the above basis, urban environmental governance can exert both direct and indirect influences, impacting haze pollution and economic growth. Firstly, urban environmental governance holds the capability to directly diminish haze pollution. Furthermore, since haze pollution and economic development exhibit a notable negative correlation, local governments can enhance economic growth by elevating urban environmental governance standards, thus decreasing haze pollution.

Further analysis about regional heterogeneity, referring to the National Bureau of Statistics of China (NBSC) and the National Statistical Yearbook of China (NSYC), the sample of 282 cities in China is divided into three sub-samples, namely, the eastern, the central and the western region. The regression results correspond to (.2), (.3) and (.4), respectively. First, model (1.2), (1.3) and (1.4) are analyzed that the coefficient of $w \cdot PM_{2.5}$ in the eastern, central and western regions are 2.040, 2.095 and 1.788, respectively, which all pass the 1% significance level test, and it indicates the spatial spillover effect of haze pollution in the eastern and central regions is larger than that in the western region. Further analysis of model (2.2), (2.3) and (2.4) shows that the estimated values and significance levels of the parameters of ER and ER^2 show an inverted "U"-shaped relationship between urban environmental governance and economic growth, but the inflection points of the three regions are different.

Estimation results for green development effect of urban environmental governance

Tables 2 present the estimation results for Eqs. (3) and (4) , and results of different groups are estimated based on data for the whole sample as well as for different regional samples. Taking the whole sample (.1) as an example, the model (3.1) matches Eqs.(3) and represents the pollution equation, the model (4.1) matches Eqs.(4) and demonstrates the function of green development effect. Model (3.1) is first analysed that the coefficient of $w \cdot GTFP$ is 2.548 and also passes the 1% significance level test, indicating that the GTFP value in the neighboring cities rises by 1%, the haze pollution in the region rises by about 2.548%. Furthermore, the coefficients and significance levels show that there is a "U"-shaped curve relationship between urban environmental governance and haze pollution, and a "U"-shaped curve relationship between haze pollution and economic growth, of which is highly consistent with the regression results and analyses in the chapter 4.2. Then model (4.1) is analyzed that the regression coefficient of W*PM2.5 is significantly positive, which means that the growth of GTFP in the neighboring cities can promote the growth of GTFP in the region; the regression coefficients and significance levels of ER and ER^2 reveal that there is an inverted "U" curve relationship between urban environmental governance and GTFP, namely, with the gradual increase in the level of urban environmental governance, GTFP rises firstly and then falls. To sum up, urban environmental governance mainly affects GTFP through two paths: on the one hand, the environmental governance behavior of the local government will force the enterprises in the city to improve production technology, technological innovation and use more advanced environmental protection equipment, which will have a direct impact on GTFP. On the other hand, under the effect of urban environmental governance, haze pollution first decreases and then rises, as can be seen from the GTFP equation, haze pollution has a positive effect on GTFP, which in turn makes GTFP first decrease and then increase, and when the inflection point is crossed, the positive contribution of urban environmental governance to GTFP will be sustainable, so the state vigorously pushes forward the governance of haze pollution, which can not only reduce the haze pollution, but also improve the green total factor productivity and realize the green development.

Moreover, the entire sample is subdivided into three sub-samples based on geographical regions: eastern, central, and western. The regression results for these sub-samples are denoted as (.2), (.3), and (.4) respectively. These results indicate that there exists an inverted "U"-shaped relationship between GTFP and urban environmental governance in the eastern region. Conversely, there is a statistically significant positive association between GTFP and urban environmental governance in both the central and western regions. There exists a strong positive correlation between the GTFP and urban environmental governance in the central and western regions. Within the eastern area, a distinct U-shaped correlation can be observed between haze pollution and urban environmental governance. Urban environmental governance in the central area has been shown to have a detrimental impact on haze pollution. However, it has been observed that haze pollution in the central region does not have a substantial influence on GTFP. The link between haze pollution and urban environmental governance in the western area exhibits a "U" shaped curve.

Robustness testing based on a quasi-natural experiment

In this chapter, we propose treating the initiation of cross-regional haze pollution control action as a natural experiment to address potential issues of variable endogeneity and model robustness bias. Specifically, we consider the prefectural-level cities that participate in cross-regional haze pollution control action as the experimental group, while the cities that do not participate serve as the control group. Hence, the utilization of the triple difference model (DDD) becomes imperative in addressing the issue of non-adherence to the parallel trend assumption. As mentioned by Zhao and Wu (2020), the DDD model is formulated by designating industrial wastewater emissions as the control group and haze pollution as the experimental group. Table 6 presents the estimation results of model (5.1), which employs high-dimensional fixed-effects regression on the full sample. Additionally, models (5.2), (5.3), and (5.4) display the regression outcomes of sub grouped samples, specifically the eastern, central, and western regions, respectively. These models also utilize high-dimensional fixed-effects regression and incorporate adjustments for standard errors through clustering at the city level. Based on the findings of the regression analysis, it can be observed that the coefficients associated with the triple difference term (DDD) exhibit significant negative values. Furthermore, all these coefficients pass the 5% significance threshold. This suggests that the implementation of regional haze pollution synergistic management has a notable and negative influence on haze pollution. Specifically, it indicates that urban environmental management plays a significant role in directly reducing haze pollution. Moreover, when considering subregions, the impact of urban environmental management on haze reduction is most pronounced in the western region, followed by the central region, and least prominent in the eastern region.

V. Conclusions and Policy Implications

This study aims to aims to explore whether and how is the synergistic effect of urban environmental governance, and examine the direct influence of urban environmental governance on haze emissions and the indirect influence of economic growth. It proposes an analytical framework model that integrates haze emission reduction and the effects of economic growth on urban environmental management. The study then empirically investigates the relationship and mechanism of these factors using a combination of Exploratory Spatial Data Analysis (ESDA), Generalized Spatial Three-Stage Least Squares (GS3SLS) method, and Dynamic Difference-in-Differences (DDD) models. The panel data of 282 prefecture-level cities in China is utilized for this analysis. Lastly, this paper examines the impact of green development on urban environmental governance and analyses the government's implementation of cross-regional haze governance policies. In conclusion, this study contributes to the advancement of the theoretical framework in the field of environmental economics and enhances the empirical knowledge specific to China. Furthermore, it offers a practical foundation that can be utilized by policy makers in the Chinese government for the development and execution of policies.

First, this paper presents an analytical methodology that aims to evaluate the interrelated impacts of urban environmental governance on the decrease of haze and economic growth. The empirical study demonstrates the presence of regional spillover effects in relation to haze pollution, the level of governmental engagement in haze governance, and the impact of economic growth. Moreover, the analysis reveals a curvilinear association in the form of a "U" shape between haze pollution and environmental governance. Similarly, the correlation between economic growth and environmental governance follows an inverted "U" shape pattern. The U-shaped relationship suggests that improved urban environmental governance has a direct impact on the quality of economic development. Furthermore, the decrease of haze pollution indirectly contributes to the enhancement of urban economic growth. The comprehensive research, which considers both the complete dataset and regional sub-samples, ultimately determines that only a minimal number of cities surpass the threshold required to achieve a mutually beneficial outcome between haze control and economic development. Consequently, it is imperative for the local governments in China to actively promote policies that strive to achieve the harmonisation of haze control and economic growth. However, it is important to recognize the existence of regional discrepancies and subsequently tailor methods to suit certain conditions, while also implementing policies that are distinct.

Secondly, Furthermore, a comprehensive analytical framework is developed to evaluate the impact of urban environmental governance on the promotion of sustainable green development. The initial step is the establishment of a green total factor productivity (GTFP) index through the use of the non-radial, non-angular SBM directional distance function and the Malmquist-Luenberger productivity index. Consequently, a systematic examination of the correlation between the mitigation of haze pollution and the advancement of urban green growth is conducted utilising the GS3SLS model. The findings from the empirical analysis indicate that the Gross Total Factor Productivity (GTFP) of China's prefecture-level cities exhibits a fluctuating rising trend at the national level. Furthermore, there is a notable geographical spillover effect observed for GTFP. There are two influential paths that can be observed in the relationship between urban environmental governance and Green Total Factor Productivity (GTFP). The first path suggests that the level of intensity in the local government's governance of haze directly impacts urban GTFP. The second path indicates that the level of intensity in the local government's governance of haze affects the levels of haze pollution, which in turn influences urban GTFP. Nevertheless, the contribution of the latter route is rather insignificant. At the national level, there exists an inverted "U" shaped link between the Gross Total Factor Productivity (GTFP) of metropolitan areas and the level of intensity in which local governments address the issue of haze governance. In terms of regional variations, the relationship between the GTFP pattern in eastern cities and the intensity of government's haze management may be described as inversely "U"-shaped. Conversely, in central and western areas, there exists a positive correlation between GTFP and the intensity of government's haze management. Regardless of whether the study is conducted using the entire dataset or regional sub-samples, only a limited number of cases have beyond the inflection point of "haze control and GTFP increase." As a result, the state's proactive efforts in promoting measures to control haze pollution not only lead to a reduction in haze pollution but also contribute to the improvement of green total factor production, hence aiding the advancement of green development.

Finally, we construct a DDD model to empirically investigate the synergistic impact of cross-regional haze pollution governance. This approach allows us to address possible issues related to variable endogeneity and model robustness bias. The analysis of the comprehensive dataset reveals that the use of cross-regional management strategies for haze pollution yields substantial reductions in haze levels, as supported by empirical evidence. Taking into account temporal fluctuations, it can be concluded that the reduction of haze had a little influence between the years 2016 and 2017. Nevertheless, there was a notable increase in the aforementioned years of 2013, 2014, 2015, and 2018, with the most dramatic decline observed in 2018. This resulted in an overall drop of 17.34% when compared to the average annual concentration in 2017. The findings of this study contribute to the existing body of empirical research on cross-regional haze pollution control strategies. Additionally, they provide empirical evidence supporting the implementation of these policies on a countrywide scale. This study highlights the significant practical significance of the thorough implementation of cross-regional haze pollution management in China. The phenomena of "bottom-up competition" and the occurrence of a "haze pollution" free-rider scenario are brought about by the interplay of tax changes, decentralized governance structures, and performance evaluation systems within the framework of local governments' involvement in environmental regulation. In the given situation, it is crucial to surpass the limitations imposed by conventional administrative boundaries and attain efficient control of haze pollution across different regions.

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Table 1 The baseline regression and estimation results of spatial associative equation

Model Dep. Var.	The whole sample (.1)		Sample of East region (.2)		Sample of Centrel region (.3)		Sample of West region (.4)	
	(1.1) $PM2.5$	(2.1) $rgdp$	(1.2) $PM2.5$	(2.2) $rgdp$	(1.3) $PM2.5$	(2.3) $rgdp$	(1.4) $PM2.5$	(2.4) $rgdp$
$w \cdot PM2.5$	1.436***	646.6***	2.040***	353.5**	2.095***	-172.8	1.788***	471.2*
	(0.0324)	(68.90)	(0.0949)	(165.1)	(0.0475)	(108.0)	(0.0828)	(268.6)
$w \cdot rgdp$	0.000401***	0.652***	-0.000188***	1.176***	-0.000152	1.804***	0.000305***	1.040***
	(2.31e-05)	(0.0199)	(5.03e-05)	(0.0423)	(9.32e-05)	(0.0570)	(7.86e-05)	(0.127)
ER	-0.000639***	1.162***	-0.00113***	1.118***	-0.00164***	3.268***	-0.00368***	5.710***
	(0.000132)	(0.177)	(0.000148)	(0.208)	(0.000563)	(0.700)	(0.000730)	(1.652)
ER^2	-5.31e-09*	-1.38e-05***	1.30e-08***	-1.83e-05***	2.83e-07***	-0.000251**	3.88e-07**	-0.000944***
	(2.84e-09)	(3.02e-06)	(2.94e-09)	(3.36e-06)	(9.82e-08)	(0.000119)	(1.62e-07)	(0.000366)
$PM2.5$		-424.8***		23.88		-177.1***		-507.8***
		(29.58)		(48.78)		(35.48)		(84.19)
$rgdp$	-0.000658***		-2.00e-05		0.000288***		-0.000247***	
	(3.75e-05)		(4.78e-05)		(7.21e-05)		(6.42e-05)	
$rgdp^2$	7.45e-10***		-6.37e-12		-1.88e-09***		4.55e-10**	
	(7.73e-11)		(7.87e-11)		(4.29e-10)		(2.08e-10)	
tech	-0.00358***		0.000323		0.00326*		-0.00210	
	(0.000993)		(0.00131)		(0.00186)		(0.00416)	
pop	1.844***		1.022***		2.932***		3.062***	
	(0.0673)		(0.0919)		(0.101)		(0.159)	
invest		-126.6***		-148.7***		-35.70***		-88.20***
		(10.36)		(20.49)		(12.29)		(21.00)

consume		-308.1***		-680.1***		-168.3***		-152.2***
		(23.57)		(45.50)		(30.03)		(41.07)
second	0.307***	520.7***	0.0761*	534.1***	-0.124***	386.7***	0.150***	521.8***
	(0.0259)	(28.90)	(0.0461)	(58.20)	(0.0284)	(26.85)	(0.0348)	(57.61)
fdi	0.0703	79.05	-0.872***	-6.502	-0.116	289.6**	-0.00297	222.0
	(0.0656)	(87.54)	(0.113)	(157.6)	(0.109)	(135.8)	(0.0626)	(139.1)
gov	-0.482***	-430.4***	-0.113**	-436.7***	-0.146***	-860.5***	-0.159***	-249.4***
	(0.0283)	(36.61)	(0.0562)	(78.37)	(0.0498)	(51.66)	(0.0307)	(68.86)
finance	0.000186***	0.433***	-3.53e-06	0.456***	-7.13e-05***	0.324***	4.65e-05***	0.294***
	(1.08e-05)	(0.00510)	(1.73e-05)	(0.00710)	(1.12e-05)	(0.00799)	(1.10e-05)	(0.0139)
infra	0.487***	856.1***	0.469***	631.5***	0.0112	140.4***	0.177***	1,450***
	(0.0313)	(35.96)	(0.0480)	(67.07)	(0.0345)	(43.06)	(0.0354)	(61.69)

Notes: Robust standard errors are in parentheses. ***, ** and * denotes significance at 1%, 5% and 10% level, respectively.

Table 2 The estimation results for green development effect of urban environmental governance

	The whole sample (.1)		Sample of East region (.2)		Sample of Centrel region (.3)		Sample of West region (.4)	
	(3.1)	(4.1)	(3.2)	(4.2)	(3.3)	(4.3)	(3.4)	(4.4)
	$PM2.5$	$GTFP$	$PM2.5$	$GTFP$	$PM2.5$	$GTFP$	$PM2.5$	$GTFP$
$w\cdot PM2.5$	1.223***	-0.00436	1.232***	-0.0821***	2.120***	-0.0308***	2.233***	-0.282***
	(0.0329)	(0.00609)	(0.126)	(0.0132)	(0.0511)	(0.0104)	(0.0830)	(0.0297)
$w\cdot GTFP$	2.548***	1.015***	-7.841***	1.158***	-7.328***	1.555***	-1.535	1.799***
	(0.527)	(0.0641)	(1.811)	(0.162)	(1.814)	(0.157)	(1.329)	(0.290)
$GTFP$	3.751***		11.60***		3.042***		3.783***	
	(0.360)		(0.498)		(0.571)		(0.384)	
$PM2.5$		0.00943***		0.0707***		0.00334		0.0707***
		(0.00275)		(0.00303)		(0.00334)		(0.00935)
ER	-0.00171***	0.000143***	-0.00223***	0.000163***	-0.00142**	0.000116*	-0.00515***	0.000599***
	(0.000146)	(1.71e-05)	(0.000219)	(1.92e-05)	(0.000581)	(6.69e-05)	(0.000816)	(0.000194)
ER^2	1.85e-08***	-2.82e-09***	3.55e-08***	-2.99e-09***	3.68e-08	4.16e-08***	4.14e-07**	-4.46e-08
	(2.53e-09)	(2.81e-10)	(3.55e-09)	(3.01e-10)	(9.88e-08)	(1.13e-08)	(1.78e-07)	(4.24e-08)
$rgdp$	-0.000187***		-0.000129***		7.94e-05**		-0.000112***	
	(1.63e-05)		(2.18e-05)		(3.27e-05)		(3.11e-05)	
$rgdp^2$	3.54e-10***		3.03e-10***		-5.81e-10**		1.74e-10*	
	(4.44e-11)		(5.58e-11)		(2.31e-10)		(9.91e-11)	
tech	2.559***		-0.00383***		0.00319*		-0.000946	

	(0.0701)		(0.00115)		(0.00182)		(0.00365)	
pop	-0.00202**		0.534***		2.921***		2.919***	
	(0.000977)		(0.0861)		(0.100)		(0.165)	
invest		-0.000619		0.000321		-0.00213**		-0.00289
		(0.00101)		(0.00121)		(0.00109)		(0.00219)
consume		-0.0282***		-0.00921***		-0.00727**		-0.0454***
		(0.00264)		(0.00272)		(0.00284)		(0.00744)
second	0.0169	-0.00471*	0.390***	-0.0329***	-0.0731***	0.00776***	-0.0335	0.0116
	(0.0206)	(0.00283)	(0.0561)	(0.00503)	(0.0223)	(0.00260)	(0.0307)	(0.00755)
fdi	0.111	-0.0262***	-0.0188	0.00392	-0.0158	0.00218	-0.00164	-0.00684
	(0.0679)	(0.00855)	(0.183)	(0.0163)	(0.111)	(0.0134)	(0.0672)	(0.0159)
gov	-0.261***	-0.00333	-0.329***	0.0226***	-0.0968**	-0.00485	-0.118***	0.00514
	(0.0252)	(0.00345)	(0.0729)	(0.00676)	(0.0388)	(0.00470)	(0.0303)	(0.00786)
finance	-2.40e-05***	9.04e-06***	-9.13e-05***	1.03e-05***	-8.72e-05***	1.25e-05***	-9.54e-07	6.44e-06***
	(6.48e-06)	(4.49e-07)	(1.03e-05)	(5.64e-07)	(1.14e-05)	(7.25e-07)	(8.31e-06)	(1.54e-06)
infra	0.243***	-0.0139***	0.851***	-0.0641***	0.110***	-0.0163***	0.0428	0.00666
	(0.0279)	(0.00329)	(0.0658)	(0.00586)	(0.0356)	(0.00399)	(0.0374)	(0.00715)

Notes: Robust standard errors are in parentheses. ***, ** and * denotes significance at 1%, 5% and 10% level, respectively.

Table 3 The estimation results of the triple difference model

	(5.1)	(5.2)	(5.3)	(5.4)
DDD	-10.59***	-11.72	-14.51***	-24.30*
	(3.785)	(15.15)	(3.508)	(12.46)
$pollution \cdot post$	10.50***	17.52	10.50***	6.662
	(2.958)	(15.06)	(2.202)	(8.632)
$treat \cdot pollution$	7.949***	15.40	11.04***	16.79***
	(2.321)	(12.23)	(2.323)	(5.648)
$treat \cdot post$	9.087**	6.150	11.70***	23.99**
	(3.619)	(12.83)	(3.326)	(11.85)
Control variables	YES	YES	YES	YES
Citied fixed	YES	YES	YES	YES
Year fixed	YES	YES	YES	YES
Pollutant type fixed	NO	YES	YES	YES
Constant	20.76	18.89	1.412	69.38
	(23.37)	(39.25)	(17.15)	(64.90)
Observations	8,460	2,970	3,720	1,770
R-squared	0.058	0.067	0.079	0.061

Notes: Robust standard errors are in parentheses. ***, ** and * denotes significance at 1%, 5% and 10% level, respectively.