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Original Research

Evaluation of the Haze Reduction Effect of Innovative City Construction: Evidence from Pilot Cities in China

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Abstract

This article investigates the impact of innovative urban policies on haze pollution. Based on panel data from 285 prefecture-level cities in China from 2007 to 2018, we use the difference-in-difference method (DID) to estimate the governance effect of innovative city construction on haze pollution. We find that the construction of innovative cities can reduce urban haze pollution, but this effect is mainly reflected in the central region, cities with low innovation capacity, and cities with high FDI and environmental regulation intensity. Further analysis reveals that the construction of innovative cities can indirectly promote the suppression of urban haze pollution by adjusting industrial structure, promoting government policy implementation, improving technological innovation efficiency, and promoting human capital agglomeration. The conclusion of this article provides evidence for the government to implement environmental protection and reduce haze pollution.

Keywords: innovative city construction, haze pollution, DID, environmental protection

Introduction

Since China's reform and opening up, China's economy has grown rapidly and its total economic output has ranked among the top in the world. At the same time, extensive economic growth has brought serious haze pollution. According to the "*China Ecological Environment Status Bulletin in 2020*", only 202 cities have achieved environmental quality standards, accounting for 59.9% of all cities, PM2.5 years with an average annual concentration of up to 33 μG/m^3, far exceeding the standards set by *the World Health Organization*. In recent years, many parts of China have been shrouded in extensive and prolonged haze weather, and pollution emissions have become a shortcoming that hinders the high-quality development of China's economy. Therefore, exploring new urban development models is urgent. The development of innovative cities relies on innovation-driven growth, which can achieve connotative economic growth and create a favorable competitive, supervisory, and innovative environment for urban development. It is of great significance for improving the level of regional urban development, enhancing national innovation capabilities, suppressing the decline in environmental quality, and achieving coordinated economic and environmental development.

Scholars have conducted research on the impact of traditional urban development on the environment. Some scholars believe that although the expansion of urban scale has promoted economic growth, it has led to a series

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of problems such as overcapacity and large population mobility, resulting in imbalanced industrial structure, single energy consumption, population agglomeration, and traffic congestion, further exacerbating urban haze pollution, ultimately leading to a significant "U-shaped" relationship between economic development and haze pollution [1, 2]. However, the latest research differs from the above viewpoint, suggesting that there is heterogeneity in the impact of urban size on haze pollution among cities. Among them, there is a significant "N" curve relationship between the degree of haze pollution in large and medium-sized cities and the quality of urban economic development. For small cities, the EKC hypothesis of haze pollution and economic development is supported, and the degree of development in large and medium-sized cities has a prominent inhibitory effect on haze pollution, while the inhibitory effect of small cities is insufficient [3]. In order to promote high-quality economic development and face the increasingly severe urban haze pollution, we urgently need to find new methods, new ideas, and new measures to jointly resist it. As a result, a large number of scholars have studied the governance measures and effects of haze pollution from the perspectives of fiscal decentralization, environmental regulation, and foreign direct investment. They have found that strengthening these measures is not conducive to effectively reducing urban haze pollution [4–6]. Some scholars also study environmental pollution control from an innovative perspective. From the perspective of technological innovation, although the level of technological innovation will increase with the expansion of industrial agglomeration, and there is a significant synergistic effect between technological innovation and human capital, providing excellent external conditions for innovative industrial agglomeration can reduce environmental pollution [7, 8]. However, the development and implementation of new technologies can lead to new environmental pollution [9]. From the perspective of institutional innovation, environmental management systems can achieve the dual goals of economic growth and environmental governance through three types of institutional innovations: incentives, regulation, and culture.

Although the aforementioned scholars have conducted extensive feasibility studies on the coordinated development of the economy and environment, there is little literature that effectively evaluates the haze control effects of innovative cities. Therefore, this article uses the DID and PSM-DID methods to analyze the environmental governance effects of the policy of building innovative cities, in order to provide empirical experience and theoretical reference for the promotion of the policy.

Based on this, this article collected data from China's innovative city pilot program and matched it with the annual average global PM2.5 concentration grid data released by Columbia University. The causal relationship between innovative cities and haze pollution was investigated. As a pilot city in China, innovative cities can be regarded as a quasi-natural experiment, providing us with assistance in identifying haze pollution between pilot and non-pilot cities. The research results found that the construction of innovative cities can reduce urban haze pollution, and this conclusion still holds after robustness testing by methods such as PSM-DID. This effect is mainly reflected in the central region, cities with low innovation capacity, and cities with high FDI and environmental regulation intensity. Further analysis reveals that the construction of innovative cities can indirectly promote the suppression of urban haze pollution by adjusting industrial structure, promoting government policy implementation, improving technological innovation efficiency, and promoting human capital agglomeration.

Our contributions mainly include the following aspects. First, this study examines the impact of innovative cities on haze pollution, supplementing relevant literature on environmental regulations. Most of the existing literature is based on policies such as emission charging systems, dual control zones, and carbon emission trading rights before 2018, observing their impact on haze pollution. This article takes the latest implementation of innovative cities as the research object, explores the relationship between innovative cities and haze pollution, and supplements relevant literature on environmental regulation.

Second, this study uses the difference-in-difference method (DID) for causal identification, which more accurately estimates the impact of innovative cities on haze pollution. As an exogenous policy shock, innovative cities have effectively alleviated endogeneity issues, and the estimated results are more accurate. Although the treatment of these indicators is gradually being optimized, there still exists a causal relationship between innovative cities and haze pollution.

Third, this study examines the mechanism of innovative cities on haze pollution from four perspectives: upgrading industrial structure, promoting government policy implementation, improving technological innovation efficiency, and promoting the agglomeration of human capital. It clarifies the mechanism of innovative cities on haze pollution, and further examines their policy effects on pollution emissions.

The rest of the paper is structured as follows. Section 2 provides theoretical analysis. Section 3 describes the data, variables, and empirical specifications. Section 4 presents the baseline results and robustness results. Section 5 presents the mechanism analysis, and Section 6 concludes.

Background and Theoretical Analysis

Background

Innovation is one of the important ways of economic growth. As an innovation-driven policy implemented on a city-by-city basis, the pilot policy for national innovative cities is a powerful measure to help China become an innovative country. Through policy analysis, the construction process of innovative cities in China can be divided into three stages.

One is the construction start-up stage (2006–2007). In 2006, the State Council deployed the implementation of the National Medium-and Long-Term Plan for Scientific and Technological Development (2006–2020), which identified enhancing independent innovation capabilities as the central link in adjusting economic structure, transforming growth patterns, and enhancing national competitiveness. It also identified building an innovative country as a major strategic choice for the future. Afterward, cities actively responded to the national call and conducted opinions solicitation, learning, and research on how to promote independent innovation and improve regional innovation systems, and formulated strategies, goals, and tasks for the construction of innovative cities. This series of measures marks the beginning of the construction of innovative cities in China.

The second stage is the construction exploration stage (2008–2015). In October 2007, the Ministry of Science and Technology, the Guangdong Provincial Government, and the Shenzhen Municipal Government jointly supported the pilot work of innovative cities in Shenzhen. In 2010, the National Development and Reform Commission and the Ministry of Science and Technology successively approved 44 cities as pilot areas for innovative cities. In April 2010, the "Guiding Opinions on Further Promoting the Pilot Work of Innovative Cities" and the "Monitoring and Evaluation Indicators for Innovative City Construction" were issued to unify the work requirements and evaluation system for innovative city construction. From 2011 to 2013, 16 cities were successively approved to carry out pilot projects for innovative cities. During this period, each pilot city actively explored and continuously improved its construction plans for innovative cities based on its own conditions.

The third stage is the construction promotion stage (from 2016 to present). According to the relevant deployment requirements of the National Innovation Driven Development Strategy Outline, the Ministry of Science and Technology is required to hold the "2016 Innovative City Construction Training Course" in Beijing. The training class summarized and exchanged the path and mode of achieving innovative development in cities, playing a positive role in continuing to promote the construction of innovative cities. At the end of 2016, the Ministry of Science and Technology and the National Development and Reform Commission issued the "Work Guidelines for Building Innovative Cities", further improving the development requirements for the construction of innovative cities. In 2018, 17 cities were added to the list of innovative city construction. In 2022, 25 cities were approved as a new batch of innovative cities. As of 2022, a total of 103 cities in China have carried out pilot construction of innovative cities.

Theoretical Analysis

Under the new model and mechanism of urban development, government behavior is closely related to the behavior of innovative entities such as enterprises. For innovative entities such as enterprises, the establishment of pilot cities can strengthen their sense of responsibility, regulate their behavior, and guide their innovative development. This can help promote the construction of a new urban model with enterprises as the main body, promote the effective application of intelligent and green technologies in traditional enterprise production, make products conform to environmental purification, and achieve generational upgrading, thereby suppressing the generation of pollutants from the source. For the government, firstly, in order to meet the existing standards of urban innovation level, it is necessary to supervise the process of enterprise innovation technology development and promotion, in order to meet the assessment requirements of innovative cities; Secondly, the government will further increase investment in the field of green innovation, gather green innovation elements from various regions, ensure the supply of various green innovation elements, promote the construction of innovative cities, and ultimately achieve haze control; Finally, governments at all levels provide convenient infrastructure such as telecommunications and public transportation for urban innovation through pilot policies, helping to break down spatial barriers to the flow of innovation factors, reduce the timeliness and asymmetry of information flow in the innovation market, improve resource allocation efficiency, and reduce environmental pollution [10]. Therefore, this article proposes the first hypothesis.

H1: The pilot construction of innovative cities has a significant governance effect on haze pollution.

The construction of innovative pilot cities is conducive to improving urban innovation efficiency and thereby suppressing haze pollution, mainly due to the following four reasons.

Firstly, pilot cities can suppress haze pollution through structural effects. The construction of innovative cities should be based on deepening the reform of the enterprise production system, optimizing energy consumption structure, strengthening the introduction, and development of technological innovation, thereby increasing the use of advanced production equipment by enterprises, suppressing pollution emissions, and improving environmental governance efficiency. The key to achieving the above goals lies in the coordination of industrial structure changes, ultimately achieving a reasonable proportion of industrial structure [11, 12]. The construction of innovative cities has a huge impact on enterprises with backward production capacity and extensive production, prompting them to change their production structure, replace new equipment, and limit the use of traditional energy such as coal. This can not only reduce pollutant emissions from the source, but also limit the unreasonable operation of high-energy consuming industries, guide them to shut down, merge, and transform, improve input-output efficiency, and promote coordinated development of the economy and environment, thereby forcing enterprises to adjust their production methods, optimize their industrial structure [13, 14], and ultimately achieve the effect of reducing haze pollution.

Secondly, pilot cities can suppress haze pollution through government financial support effects. On the one hand, local governments formulate green policies that are conducive to the development of enterprises and set up special funds for green development, strengthen policy guidance for technology-based small and medium-sized innovative enterprises, adhere to the principles of government support, enterprise responsibility, and win-win cooperation, and explore new management and operation mechanisms for the development of innovative cities; On the other hand, local governments invest special innovation funds to play a leading role in the construction of innovative cities and guide enterprises to embark on a reasonable path of innovation. The main ways for the government to lead are as follows: firstly, to establish fiscal special expenditures to provide policy support and guidance for innovative pilot cities; The second is to increase fiscal technology expenditure, improve the innovation efficiency and output of enterprises [15], and thereby strengthen the investment of government funds and social capital in innovative industries; The third is to implement flexible and variable measures to reduce taxes and fees, and increase the tax reduction quota for enterprise innovation technology research and development and the introduction of high-tech equipment; The fourth is to increase subsidies for information infrastructure construction in innovative industries, promote the effective improvement of innovation efficiency in China's high-tech industries, and ultimately apply innovation to green technologies to achieve the goal of efficient governance of haze pollution.

Thirdly, pilot cities can suppress haze pollution through technological innovation effects. Technological innovation has promoted the progress of energy-saving and emission-reduction technologies and production technologies, achieving pollution reduction from the source to the end [16]. In the mainstream development context of stricter environmental regulations, during the implementation of pilot policies, enterprises will integrate green innovative technologies into all aspects of production, producing green and environmentally friendly products. This can not only improve resource utilization efficiency and form front-end governance for enterprises, but also enhance their level of prevention and control of environmental pollution, thereby suppressing haze pollution. In addition, technological innovation helps accelerate the research and development of clean energy by enterprises, promote the widespread use of clean energy, and adjust the energy application structure, thereby reducing energy consumption and reducing haze pollution.

Fourthly, pilot cities can suppress haze pollution through the agglomeration effect of human capital. Talents, as one of the basic elements of innovative city construction, can promote urban technological innovation, research, and development, thereby significantly enhancing regional innovation capabilities [5]. On the one hand, research enterprises and universities are the foothold of national innovation. The Law of the People's Republic of China on Promoting the Transformation of Scientific and Technological Achievements points out that the government needs to support universities and research and development enterprises to jointly establish research and practical work institutions, accelerate the transformation of knowledge and scientific and technological achievements, and provide intellectual support for the construction of innovative cities. Therefore, the pilot policy requires the government to provide strong financial support for the construction of urban innovation bases, the transformation of communication and cooperation models between universities and science and technology innovation enterprises, and the establishment of various entrepreneurial platforms, in order to promote the coordinated development of knowledge and technology. On the other hand, talent is the core driving force for the development of intelligent technology. *The 13th Five Year Plan* has elevated the big data strategy to a national strategy, indicating the urgent need for innovative talents in the country. Under the promotion of innovative city construction, governments at all levels have formulated relevant policies to actively introduce outstanding talents, such as household registration placement, spouse employment, housing subsidies, or tax and fee reductions, to provide guarantees for the introduction of high-quality talents, so that entrepreneurial talents and advanced scientific research teams can gather in cities, help cities attract high-quality FDI, vigorously develop knowledge-intensive industries, and thus leverage the pollution reduction effect of human capital to reduce urban haze pollution [17]. Based on the above analysis, this article proposes a second hypothesis.

H2: The construction of innovative pilot cities can reduce the level of urban haze pollution through four intermediary channels: industrial structure upgrading effect, government financial support effect, technological innovation effect, and human capital agglomeration effect.

Data and Research Design

Data Source

Haze pollution: As PM2.5 is the main factor causing haze pollution, This article refers to the research of Ma et al. (2016), using grid data of global PM2.5 concentration annual averages published by Columbia University [18], and using ArcGIS 10.2 software to re-extract the annual average PM2.5 concentration at the level of 285 prefecture-level cities in China to represent haze pollution.

Innovative cities: This article takes the innovative pilot cities established in 2009 as the treatment group and other non-innovative pilot cities as the control group.

Other city-level data mainly include foreign direct investment, industrial structure, the level of economic development, labor force, human capital, and air flow coefficient. Those variables come mainly from the website of the National Bureau of Statistics and the "China Urban Statistical Yearbook".

Table 1 reports the summary statistics of the above dependent variable, independent variable, control variables, and mechanism analysis variables.

Empirical Strategy

We use a DID model on the full sample to estimate the effects of innovative cities on haze pollution. As an

Table 1. Summary statistics.

Variables	Observations	Mean	Standard deviation	Min	Max
ln PM2.5	3420	3.508	0.502	1.543	4.509
DID	3420	0.034	0.182	0	1
Log foreign direct investment	3420	0.104	1.336	-7.722	3.713
Log industrial structure	3420	3.575	0.244	2.149	4.477
Log pgdp	3420	5.667	0.721	3.505	7.851
Log Employment	3420	6.615	0.923	2.565	9.511
Log human capital	3420	-0.151	1.133	-5.129	2.574
Log hvc	3420	7.362	0.291	6.547	8.242

exogenous policy, innovative cities brought exogenous changes to the haze pollution of the pilot cities, which provides us with a unique quasi-natural experiment. The DID model helps us identify the causal relationship between innovative cities and haze pollution. The specific regression equation is set as follows:

$$Y_{it} = \beta_0 + \beta_1 did_{it} + \sum \gamma X_{it} + year_t + city_i + \varepsilon_{it} \quad (1)$$

In Eq. (1), Y_{it} is the outcome variable used to describe the haze pollution levels of different cities at different times; did_{it} denotes the independent variable, which is a dummy variable used to describe innovative cities. It will be coded 1 in the current and subsequent years if a city i is piloted in year t and 0 otherwise. X_{it} denotes a series of control variables that may affect haze pollution, including foreign direct investment, industrial structure, the level of economic development, labor force, human capital, and air flow coefficient. $year_t$ and $city_i$ are year-fixed effects and city-fixed effects, respectively, and ε_{it} is the error term. The coefficient β on the post-piloted dummy captures the treatment effect of the innovative cities on haze pollution. It is noteworthy that to overcome the possible temporal correlation of random disturbance terms and reduce the risk of underestimating standard error, all regressions in this paper adopt the robust standard error clustered to the city level [19].

Main Results

Baseline Results

We estimated equation (1) using the DID model with PM2.5 data as the dependent variable. In order to accurately estimate the results, while controlling for fixed effects, we used the methods of not adding control variables and adding control variables. The regression results are shown in the (1) and (2) columns of Table 2, respectively. From the results, regardless of whether the control variable is increased or not, the coefficients we are interested in are significantly negative at the 1% level, indicating that the construction of innovative cities has reduced urban haze pollution. Hypothesis H1 in this article has been validated. Specifically, it can be seen from column (2) that the construction of innovative cities has significantly decreased by about 0.269% of the annual average concentration of PM2.5.

Robustness Test

To address concerns about the data assumptions and corroborate the findings, a battery of robustness checks are conducted.

Table 2. Baseline regression results.

Variables	(1)	(2)
DID	-0.477*** (0.053)	-0.269*** (0.041)
Log foreign direct investment		0.025** (0.012)
Log industrial structure		-0.157*** (0.030)
Log pgdp		-0.044*** (0.011)
Log employment		-0.085** (0.038)
Log human capital		0.091*** (0.017)
Log hvc		0.235*** (0.066)
City fixed-effect	YES	YES
Year fixed-effect	YES	YES
Observations	3420	3420
R-squared	0.026	0.137

Notes: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. The city-level clustered standard errors are reported in parentheses.

Firstly, we use the PSM-DID method for robustness testing. Although the construction of innovative cities in China is uniformly implemented and gradually promoted under the national comprehensive planning, the construction of innovative cities is still inevitably affected by factors such as urban location and economic development level. This article selects the PSM-DID method for regression analysis to eliminate the differences in environmental pollution levels among cities as much as possible. Before using the PSM-DID method for estimation, a model validity test is required. Firstly, test whether there is a significant difference in the mean of the covariates between the experimental group and the control group after matching, that is, verify whether the common support hypothesis is met. If there is no significant difference, the PSM-DID method can be used. The first column of Table 3 shows that after eliminating endogeneity issues and adopting the PSM-DID method, the regression coefficient of DID is significantly negative at the 5% level, indicating that the implementation of pilot policies has significantly reduced urban haze pollution, and the conclusion is robust.

Secondly, we tested the robustness of the treatment group and the control group. Due to the establishment of innovative pilot cities at different times and batches by the country, the previous regression used 2009 as the time point for policy implementation, which may lack persuasiveness. Therefore, this article selects 2010 and 2011 as the time nodes for policy implementation and conducts further robustness testing. In order to eliminate the impact of newly established innovative cities on the results, this article deleted pilot cities that appeared after 2010 and used the innovative pilot cities determined in 2010 as the treatment group. Policy and time dummy variables were reset according to the method described earlier. According to this method, process the regression samples for 2011. To meet the common trend assumption of DID and eliminate intercity differences, this paper still uses the PSM-DID method to estimate the two sets of samples in 2010 and 2011. The results are shown in columns (2) and (3) of Table 3. It can be seen from this that after redefining the timing of policy occurrence and adopting the PSM-DID estimation method, the construction of innovative cities still effectively suppressed haze pollution, further verifying the robustness of the previous results.

Thirdly, we tested the robustness of the dependent variable. Given the difficulty in obtaining nitrogen oxide indicators at the prefecture-level city level, industrial exhaust emissions were selected as the indicator for measuring haze pollution, and logarithmic processing was performed. Regression analysis was conducted using the PSM-DID method, and the estimated results are shown in column (4) of Table 3. The regression coefficient of DID is significantly negative at the 1% level, indicating that the implementation of this policy has effectively suppressed urban haze pollution.

Finally, considering the possibility of heterogeneity processing effects in grouping and time dimensions, there may be some bias in the estimation of staggered DID, therefore we used the more robust estimators proposed by Sun and Abraham (2020) for estimation [20], and the estimated results are shown in column (5). In addition, we clustered the estimation results at the provincial level and re-estimated equation (1), and the estimated results are shown in column (6), we found the results to be robust.

The robustness test results of the above three methods indicate that the regression coefficients of innovative pilot city construction on haze pollution are significantly negative. The establishment of innovative pilot cities by the government will be beneficial for the construction of a resource-saving and environmentally friendly society in China. Therefore, the implementation of pilot policies will reduce urban haze pollution.

Heterogeneity Analysis

Since China's reform and opening up, the eastern region has always been the core area of national economic development. Compared to the central and western regions, the eastern region relies on its unique geographical advantages and long-term capital accumulation to introduce cutting-edge foreign technology through international trade. Moreover, the domestic government has formulated relatively loose foreign trade policies for the eastern region, resulting in a significant gap in the economic development level, infrastructure construction, and policy dividends between the central and western regions and the eastern region. Therefore, this article speculates that the haze control effect of innovative pilot city construction varies significantly

Table 3. Robustness test.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
did	-0.246** (0.108)	-0.111** (0.046)	-0.161*** (0.056)	-1.199*** (0.233)	-0.335*** (0.101)	-0.207*** (0.066)
Control variables	YES	YES	YES	YES	YES	YES
County fixed effects	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
Observations	3420	3180	2916	3420	3420	3420
R-squared	0.143	0.118	0.120	0.157	0.165	0.088

Notes: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 4. The results of heterogeneity analysis (1).

Variables	Location			Innovation ability	
	Eastern	Central	Western	High innovation ability	Low innovation ability
DID	-0.131* (0.703)	-0.762*** (0.101)	0.076 (0.061)	-0.219 (0.205)	-1.202*** (0.331)
Control variables	YES	YES	YES	YES	YES
County fixed effects	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES
Observations	1344	1140	936	1710	1710
R-squared	0.202	0.087	0.138	0.147	0.184

Notes: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. The city-level clustered standard errors are reported in parentheses.

among the eastern, central, and western regions. Based on geographical location, this article divides the sample into three groups: east, central, and west for regression analysis. The regression results are shown in the first three columns of Table 4. It can be seen from this that the regression coefficients of DID in the eastern and central regions are significantly negative, but the policy implementation has a greater inhibitory effect on haze pollution in the central region than in the eastern region. The reason may be that in 2004, the implementation of the national strategy to promote the rise of the central region greatly promoted the transformation and upgrading of the industrial structure in the central region, enhanced technological innovation capabilities, and thus helped to reduce the level of haze pollution. The regression coefficient of DID in the western region is positive, but not significant, indicating that the implementation of pilot policies in the western region has not yet achieved the expected effect. The reason may be that the western region has taken over most of the transfer of polluting industries from the eastern and central regions, with high energy consumption and high pollution industries as the main focus.

There are significant differences in resource endowments, factor allocation, and policy implementation among different cities in China, resulting in significant differences in urban innovation levels among different cities. This may lead to heterogeneity in the effectiveness of pilot policies on haze control. Therefore, this article applies the mean grouping method to divide urban innovation capabilities into high and low groups and tests the degree of impact of pilot policies on haze pollution. The regression results are shown in the last two columns of Table 4. Although the construction of innovative pilot cities has a significant haze control effect between the high and low groups, the policy effect of suppressing haze pollution in cities with high innovation capacity is significantly lower than that in cities with low innovation capacity. The possible reason is that cities with high innovation levels concentrate their industries in the tertiary industry and advanced manufacturing, and their own haze pollution is significantly lower than that of cities with backward innovation capabilities. This leads to cities with low innovation levels being more sensitive to policy implementation effects and having a stronger inhibitory effect on haze pollution.

Foreign direct investment is a fundamental factor affecting environmental issues. Some scholars believe that China actively lowers environmental regulatory standards to attract foreign investment in order to develop its economy, becoming a "pollution haven" for developed countries [21]. Other scholars believe that the new technologies provided by foreign direct investment are beneficial for improving environmental quality and unleashing the "pollution halo" effect. Therefore, this article uses the mean grouping method to divide the level of urban foreign direct investment into high and low groups for regression analysis. The regression results are shown in the first two columns of Table 5. According to Table 6, it can be seen that the policy implementation of cities with high levels of foreign direct investment has a positive effect on suppressing haze pollution, but for cities with low levels of foreign direct investment, the haze reduction effect of innovative city construction is not significant. The reason may be that cities with high levels of foreign direct investment actively introduce advanced production technologies and green production equipment, which has a significant promoting effect on reducing haze pollution in the city. However, cities with lower levels of foreign direct investment are mostly underdeveloped areas with insufficient ability to attract foreign investment, and most cities focus on how to promote urban economic construction, often becoming transfer destinations for polluting enterprises. Therefore, policy implementation has little effect on their haze control.

Considering the synergistic effect of environmental regulations on the implementation of pilot policies to suppress haze pollution, this article will examine the heterogeneity of the implementation effects of innovative city construction on urban policies with different levels of environmental regulations from the perspective of environmental

Table 5. The results of heterogeneity analysis (2).

Variables	Foreign direct investment		Environmental regulations	
	High	Low	High	Low
DID	-0.220*** (0.108)	-0.325 (0.193)	-0.308*** (0.088)	-0.367 (0.301)
Control variables	YES	YES	YES	YES
County fixed effects	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	1710	1710	1710	1710
R-squared	0.205	0.084	0.104	0.174

Notes: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. The city-level clustered standard errors are reported in parentheses.

regulations. Due to the difficulty in obtaining data from prefecture-level cities, the intensity of environmental regulations is measured by the per capita nitrogen oxide emissions. The larger the value, the weaker the intensity of environmental regulations. Regression analysis is conducted by dividing the mean into high and low groups, and the regression results are shown in the last two columns of Table 5. For cities with high environmental regulation intensity, policy implementation has a significant effect on reducing haze pollution, while for cities with low environmental regulation intensity, policy implementation has no significant effect on reducing haze pollution. The possible reason is that in cities with high environmental regulation intensity, their governments formulate a large number of policies and measures to protect the environment, incentivizing enterprises to link environmental taxes with their pollution treatment rates in the production process, reducing pollutant emissions from the source. Therefore, the construction of innovative pilot cities can significantly suppress haze pollution in the city.

Mechanism Analysis

To verify that innovative cities may affect urban economic development and environmental governance through industrial structure adjustment, government fiscal policies, technological innovation, and human capital, ultimately manifested as a suppressive effect on haze pollution, this article sets the following econometric model.

$$Y_{it} = \beta_0 + \beta_1 did_{it} + \sum\gamma X_{it} + year_t + city_i + \varepsilon_{it} \quad (2)$$

$$M_{it} = \beta_0 + \beta_1 did_{it} + \sum\gamma X_{it} + year_t + city_i + \varepsilon_{it} \quad (3)$$

$$Y_{it} = \beta_0 + \beta_1 did_{it} + \beta_2 M_{it} + \sum\gamma X_{it} + year_t + city_i + \varepsilon_{it} \quad (4)$$

Among them, M is the mediating variable, representing industrial structure, government financial support, technological innovation, and human capital elements, respectively. The industrial structure (lnstr) is expressed as the ratio of the output value of the tertiary industry to the output value of the secondary industry; Government financial support (lnsci) is expressed as government technology expenditure; The innovation efficiency (lnpat) is represented by the urban innovation performance indicators in the China Urban and Industrial Innovation Power Report; The measurement method of human capital level (lnhum) is described earlier. Perform regression on the above model and verify the existence of mediating effects based on the Sobel test and Bootstrap test. The specific regression results are shown in columns (1)–(9) of Table 6.

The results in column (1) indicate that the total effect of the pilot policy in suppressing haze pollution is 0.434, and is significantly negative at the 1% level. The second and third columns show the regression results of the pilot policies for innovative cities on industrial structure, as well as the regression results of the pilot policies and industrial structure on haze pollution. Among them, the regression coefficient of pilot policies on industrial structure is significantly positive, indicating that innovative pilot policies are conducive to adjusting the industrial structure of prefecture-level cities. The results in column (3) indicate that the pilot policies and industrial structure coefficients are significantly negative at the 1% level, indicating that industrial structure helps to reduce the level of haze pollution in prefecture-level cities. Further analysis shows that the construction of innovative cities can significantly adjust and improve the industrial structure of prefecture-level cities, thereby exerting the haze control effect of policy implementation. The mediating effect is 0.024, which is significantly negative at the 1% level, accounting for 5.53% of the total effect. The Sobel test results are significant at the 5% level and the Bootstrap test results are significant at the 1% level, confirming the existence of the mediating effect of industrial structure.

Columns (4) and (5) respectively represent the regression results of pilot policies on government science and technology expenditure and the regression results

Table 6. The results of the mechanism analysis.

variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	lnPM2.5	lnstr	lnPM2.5	lnsci	lnPM2.5	lnpat	lnPM2.5	lnhum	lnPM2.5
did	-0.434*** (0.105)	0.736*** (0.218)	-0.411*** (0.093)	3.059*** (0.863)	-0.415*** (0.077)	3.743*** (0.933)	-0.326*** (0.088)	1.984*** (0.753)	-0.288*** (0.063)
lnstr			-0.001*** (0.000)						
lnsci					-0.010*** (0.002)				
lnpat							-0.032*** (0.010)		
lnhum									-0.080*** (0.023)
Sobel		-0.024** (0.011)		-0.031* (0.017)		-0.120*** (0.033)		-0.158*** (0.041)	
Observa-tions	3420	3420	3420	3420	3420	3420	3420	3420	3420
R-squared	0.023	0.020	0.026	0.114	0.027	0.149	0.037	0.102	0.056

Notes: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. The city-level clustered standard errors are reported in parentheses.

of pilot policies and government science and technology expenditure on haze pollution. For column (4), the coefficient of the pilot policy is significantly positive at the 1% level, indicating that the construction of innovative cities will stimulate the government to increase technology investment and strengthen the guiding role of prefecture-level city governments. In column (5), the regression coefficients of pilot policies and technology expenditures are significantly negative at the 1% level, indicating that prefecture-level municipal governments will strengthen investment in the technology industry to achieve the effect of suppressing haze pollution. Further analysis shows that the construction of innovative cities can encourage the government to formulate a series of fiscal policies to increase technological investment, thereby promoting green and efficient production by enterprises and achieving the effect of suppressing urban haze pollution. The Sobel test in Table 6 shows that the mediating effect is 0.030, significantly negative, accounting for 6.92% of the total effect. The Bootstrap indirect effect test results are significant at the 5% level, which also verifies the existence of the intermediary effect of technology expenditure by prefecture-level municipal governments.

Columns (6) and (7) respectively represent the regression results of innovative city pilot policies on urban technological innovation and the regression results of pilot policies and technological innovation on haze pollution. In column (6), the regression coefficient of the pilot policy on the innovation performance of prefecture-level cities is significantly positive, indicating that the construction of innovative cities helps to improve the efficiency of urban technological innovation. The results in column (7) indicate that the regression coefficients of pilot policies and technological innovation efficiency of prefecture-level cities on haze pollution are significantly negative, indicating that the improvement of urban technological innovation efficiency can provide a good innovation environment, contribute to the construction of innovative cities, enhance the green innovation efficiency of enterprises, and thus reduce haze pollution. Further analysis shows that the Sobel test and Bootstrap indirect effect test are significantly negative at the 1% level, with an indirect effect proportion of 0.119 and a total effect proportion of 26.82%, confirming the existence of the mediating effect of technological innovation.

Columns (8) and (9) respectively represent the regression results of innovative city pilot policies on human capital, as well as the regression results of pilot policies and human capital on haze pollution in prefecture-level cities. The results in column (8) indicate that the construction of innovative cities has significantly improved the human capital level of prefecture-level cities, providing talent support for reducing haze pollution. In column (9), the regression coefficients of pilot policies and human capital on haze pollution are significantly negative at the 1% level, indicating that the strengthening of talent agglomeration effect helps to suppress haze pollution in prefecture-level cities and also facilitates the smooth implementation of pilot policies. Further analysis shows that the mediating effect of human capital is 0.158, which is significantly negative, and the indirect effect of Bootstrap is also significantly negative at the 1% level, thereby verifying the existence of the mediating effect of human capital factor agglomeration, with a proportion of 35.41%. The above results indicate that the effects of technological innovation and human capital are the two main pathways through which the construction of innovative cities affects haze pollution. In summary, the hypothesis H2 in this article has been validated.

Conclusion and Suggestions

The construction of innovative cities is based on innovative elements such as technology and talent. While promoting China's economic development, it can also coordinate the common development of the urban economy and ecological environment. This article is based on panel data from 285 prefecture-level cities in China from 2007 to 2018, and applies DID and PSM-DID models for robustness testing to verify the effectiveness of innovative urban construction in controlling urban haze pollution. Research has shown that the construction of innovative cities has significantly suppressed urban haze pollution, and this conclusion still holds after a series of tests. Heterogeneity analysis shows that the pilot policies have a significantly higher effect on haze control in the eastern and central regions than in the western regions; the haze control effect of cities with low innovation ability is higher than that of cities with high innovation ability; the pilot policy has a significant haze control effect on cities with high levels of foreign direct investment; the pilot policy has a significant effect on haze control in cities with high environmental regulation intensity. In addition, based on the results of mechanism testing, it was found that the construction of innovative pilot cities indirectly promotes haze governance by promoting industrial structure upgrading, strengthening government financial support, improving technological innovation efficiency, and attracting innovative talents to gather.

Based on the conclusions verified in the previous text, the following suggestions are proposed for China to promote the construction of innovative pilot cities: increase the promotion of innovative pilot cities, and combine the location conditions and existing economic characteristics of cities to build a unique innovation system, so as to effectively play the role of innovative cities in controlling haze pollution. At the same time, relevant government departments should continue to improve the selection system for pilot cities, gradually improve the selection standards for innovative pilot cities that meet the requirements of the new era, construct more scientific selection indicators with more coverage content, and further increase the number of pilot cities in an orderly manner. In addition, government departments also need to strengthen the supervision of the construction quality of pilot cities, such as introducing relevant regulatory regulations and ensuring the construction quality of innovative cities through hard supervision and constraints. At the same time, it is necessary to strengthen the tracking, evaluation, and monitoring of the effectiveness of pilot policies, adjust pilot measures in a timely manner, and if necessary, adopt exit mechanisms to no longer include cities with poor pilot effects in the pilot scope, so as to ensure the effective implementation of haze control effects.

Conflict of Interest

The authors declare no conflict of interest.

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