Analysis of the Impact of Internet Development on Environmental Pollution

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Abstract. With the rapid progress of the Internet, tremendous changes have occurred in enterprises and living standards. However, we are looking forward to the answer about whether internet progress has a prominent inhibiting effect on the discharge of environmental pollutants. Based on 2009–2019 panel data from 295 cities in China, the paper has empirically tested the influence of internet progress on urban pollutant discharge and mediating mechanisms through the fixed-effect model and mediating effect model. Research indicated that internet progress has significantly helped lower urban pollution emissions. This conclusion is valid after soundly testing by replacing core explanatory variables and resolving endogenous problems in fixed provinces. Research pointed out that internet progress plays a different role in restraining the emission of different contaminants. It ranks first in inhibiting the emission of industrial smoke dust and second for industrial sulfur dioxide and wastewater. Analysis result of mediating effect showed that industrial structure supererogation is an essential mechanism that internet progress has reduced the environmental contaminants in cities. Nevertheless, as the development of green innovation does not play a positive role in the contribution of progress on the Internet to bring down pollutants, it has lowered the effectiveness of progress on the Internet on the urban environmental pollutants. Analysis of spatial heterogeneity showed that middle-China cities with a high level of internet progress enjoy a more significant emission reduction effect than cities in the east and west of China. The paper has enriched the relevant research on internet progress and fully supplemented the influencing factors of environmental pollutants. At the same time, the research conclusion has provided reliable empirical evidence for progress in the Internet enhancing the capability of ecological pollution improvement and offered some references related to an emission reduction of environmental pollutants.

Keywords: Internet · environmental pollution · mediation effect · masking effect

1 Introduction

Since the reform and opening-up, China's economy has developed rapidly, but it has long been along the traditional growth route of high energy consumption and pollution. This route has enabled China to achieve tremendous economic growth. However, along with

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the economic growth, some problems in economic development are gradually emerging, such as environmental pollution and insufficient innovation. In October 2021, the State Council published a relevant circular to deploy October 2021, the State Council issued a circular on the main objectives of the 14th Five-Year Plan and the 15th Five-Year Plan, clearly proposing that carbon emissions should be integrated into the whole process. The critical tasks should be all aspects of economic and social development, energy-saving and carbon-reduction initiatives, and industrial carbon emissions initiatives. As of December 2021, the Internet users in China were 1.032 billion, with a penetration rate of 73.0%. Internet development has been dramatically improved, and the Internet has gradually been integrated into various fields such as residents' lives, enterprise production, and government governance. In this context, can the Level of Internet development curb the emission of environmental pollutants? If so, what are the pathways and mechanisms by which this impact is generated? The exploration of the above questions not only helps to enrich the research related to Internet development but also has practical significance in promoting the improvement of the urban environment and the rational development of the economy.

In recent years, environmental problems have become increasingly prominent. The Chinese government has continued to pay attention to energy conservation and emission reduction, focusing on deploying carbon peak and pollution reduction tasks and promoting the development of local green industries. Research on environmental pollution has gradually become a hot topic. Scholars have explored the main influencing factors on ecological pollution from different perspectives. Dongbin Hu and Jing Li believe economic growth could reduce environmental pollution through industrial adjustment and technological innovation [1, 2]. Hosseini and Kaneko noted that regional environmental pollution is also influenced by pollution caused by industrial policies and economic activities in surrounding areas [3]. Feng Ying et al. studied the impact on environmental pollution in terms of population size and technology level, and the results showed that energy consumption and population aggregation due to population size jointly aggravate environmental pollution between regions [4], while technological progress can continue to promote regional resource utilization and promote efficient resource recycling [5]. However, Jun Sun and Yanyan Gao have also found that technological progress can bring negative externalities in the early stages, exacerbating environmental pollution in adjacent regions [6].

There has been a considerable amount of research on Internet development. Most of the studies have confirmed the positive significance of Internet development for various aspects of the economy and society, such as the view that Internet development can promote the transformation of industrial structure [7]; the transfer of labour and labour productivity [8]; the impact on the structure of industrial agglomeration and green innovation efficiency under different conditions [9]. A large body of literature has conducted more detailed research on the measurement of Internet development level, but there is still no authoritative and comprehensive theoretical system and indicator system. In previous studies, Siqi Zheng et al. just used a single indicator to construct the Level of Internet development, such as using the number of regional Internet users to measure the level of Internet development [10] and Juan Qiu and Mingfeng Wang used the number of annual Internet users to measure the Level of Internet development [11]. Some scholars who believe it is difficult to comprehensively and accurately assess a region's absolute Internet development level by a single indicator measurement system adopted comprehensive indicators to build an evaluation system of the Internet development level. Liu Yin and Xiangbing Guan selected indicators such as the number of Internet users and broadband access ports and used fuzzy comprehensive evaluation and hierarchical analysis to build an Internet development evaluation system [12]. Yincheng Xie and Jie Gao selected the number of Internet users, Internet infrastructure and equipment, online retail transactions, and other indicators for constructing the Internet development level system [13]. Furthermore, Xianfeng Han measured the comprehensive development level of the Internet based on the Internet development environment, business applications, and other aspects [14].

As for the impact of Internet development on the emission of environmental pollutants, Wonohardjo and Kusuma had improved more efficient and reliable technical means for the government to regulate environmental quality through the innovation of ecological monitoring means by the advancement of Internet technology [15]; Chunyan Xie et al. had argued that Internet technology has an impact on the environment, and empirically tested that the development of Internet technology can significantly reduce environmental pollution and promote ecological improvement [16]; Ozcan and Apergis believed there is a causal relationship between Internet technology and pollutant emissions, and empirically tested that the expansion of the size of Internet users contributes to the emission reduction effect [17]; and Xianchun Xu pointed out that the development of extensive data technology development can provide more scientific optimization for enterprises' production decisions, enhance the government's environmental regulatory capacity, help energy conservation and emission reduction, and reduce environmental pollution [18].

In summary, although previous studies have adopted different Internet development indicators and methods in the light of varying development realities, most of them only analyzed the impact of Internet development on environmental pollution emissions from a specific entry point without including the indicator of Internet development in the analysis system. Most scholars have constructed a single evaluation system for the level of Internet development, but it is not easy to objectively reflect the actual level of Internet development. The impact of Internet development on environmental pollution has not been included in the analysis system. Given this, this paper focuses on the effect of urban Internet development on environmental pollutant emissions and its underlying mechanisms. It empirically explores the impact of Internet development on urban environmental pollution, the mediating effect, and regional heterogeneity based on panel data of 295 Chinese cities from 2009 to 2019.

This paper attempts to make a marginal contribution in the following aspects: (1) There is little relevant literature on the impact of Internet development on environmental pollution. This paper explores the effect of Internet development on environmental pollution reduction from theoretical and empirical evidence, which enriches the relevant research on Internet development and effectively supplements the factors influencing environmental pollution. (2) This paper incorporates the Internet development into the analytical framework of environmental governance, extending the theoretical framework of this paper from multiple perspectives, and exploring the mediating effect of the Internet on environmental pollution. And then, a heterogeneity analysis is conducted from a spatial perspective to deepen further the theoretical level of the Internet's environmental effects.

2 Mechanistic Analysis

2.1 The Internet and Environmental Pollution

The Internet increasingly combines technological innovation with business model innovation and its ability to transmit information and data concisely, forming a substantial shared network of nodes. This network feature is a significant development opportunity for China. The Chinese government has also been supporting and encouraging the development of the Internet, from infrastructure development to the innovative integration of the Internet with other industries, which has enabled China to take the lead in the global Internet arena. Environmental pollution management is a system project, and with the widespread proliferation and penetration of internet technology into various industries, the sharing, real-time and shared nature of the Internet has brought new concepts of prevention and control and governance to environmental pollution management. Information technologies such as the Internet of Things, big data, cloud computing, and artificial intelligence have been continuously integrated into ecological pollution management, giving powerful new energy to environmental pollution. The Internet has shown a significant role in promoting energy conservation and emission reduction.

Specifically, the impact of Internet development on environmental pollution and emission reduction is mainly reflected in the low carbonization of residents' lifestyles, the construction of green and efficient production models for enterprises, the improvement of government environmental pollution regulation, and the optimization of the supervision system.

Firstly, the rise of the Internet has led to the development of online shopping and e-commerce, which has directly changed the traditional consumption patterns of residents and significantly reduced the energy consumption of their daily travels and the loss of unnecessary logistics energy. At the same time, the transmission of information without relying on the actual material carrier has reduced the energy consumption of residents' daily office commuting and traditional offices, significantly improving the efficiency of material and energy use and thus reducing environmental pollution. Secondly, in the era of the digital economy, various new Internet industries are rapidly emerging. Relying on information technology, enterprises can effectively deal with the considerable information resources in the production decision-making process and the fragmentation and asymmetry of information between various departments. Moreover, companies can efficiently analyze decisions and plan product and resource data to continuously improve production efficiency and lay a solid foundation for green development [19–21].

Thirdly, regarding changes in the government's environmental pollution regulation model. The expanding scale of China's economy and the increasingly complex ecological environment have brought increasing difficulties to the regulatory authorities. The traditional environmental regulatory model has gradually reflected the problems of inadequate regulation and outdated and inefficient regulatory methods. The Internet has given new energy to the regulation of environmental pollution. On the one hand, the continuous upgrading and use of technologies such as big data and cloud computing have enabled government departments to monitor air quality and pollution emissions in real-time and dynamically [23], improving the early warning capability and accuracy of environmental pollution, and thus enhancing the level of environmental pollution regulation. The real-time dynamic data support policy formulation, planning decisions, and other regulatory work. On the other hand, the public has assumed responsibility for environmental regulation, such as supervision, advice, and public opinion. Its tolerance for ecological pollution is gradually decreasing with the increased sharing of information. The public's access to information is also expanding with the development of the Internet, which has built a bridge of information interchange between the government and society [24], thus bringing this has brought about a new way and opportunity for the public to access environmental pollution information. The government has also continued to open online regulatory platforms, giving the public the opportunity and ability to provide a full play to the information communication mechanism, facilitating the continued practise and development of public awareness of environmental protection. So it is easy to achieve synergistic governance among residents, businesses, and the government in environmental protection [25]. In summary, this paper proposes the following hypothesis:

Hypothesis 1: Internet development promotes reduced environmental pollution emissions.

2.2 Internet, Technological Innovation, Industrial Structure, and Environmental Pollution.

It has been shown that the level of interconnection development plays a vital role in technological innovation and industrial structure optimization [26, 27]. At the same time, technological innovation and industrial structure have inhibitory effects on environmental pollution emissions. Therefore, this paper analyses the inhibitory effects of Internet development on environmental pollution emissions in terms of green innovation and industrial structure optimization effects.

With the rapid development of the Internet, information technology such as the Internet continues to accelerate its integration into traditional industries. In the process, traditional industries are constantly improving their production efficiency and optimizing their production processes with the help of emerging information technologies such as blockchain and cloud computing, forming new production models that are more scientific and intelligent. These help them to gain a favourable position in the market. At the same time, traditional industries can also use the new technologies of the Internet to continuously improve their product quality, reduce product production costs, provide quality products and services, and promote the transformation of industries into high-value-added and environment-friendly industries. They reduced environmental pollution by facilitating the transformation of the industrial structure. The technological spillover effect of the Internet also continues to spill over to the information technology sector, thus driving technological progress in the industry as a whole [28]. The industrial structure influences the scale of pollutant emissions and is the "controller of pollutant categories and numbers" in environmental pollution. A reasonable and advanced industrial structure can help enterprises to improve resource utilization and production efficiency and give full play to the value of resources. The optimization of industrial structure mainly works on the emission of environmental pollutants through the optimal allocation of factors and the effect of technological progress [29] . Accordingly, this paper puts forward the hypothesis that:

Hypothesis 2: Internet development reduces environmental pollution emissions through industrial structure optimization.

The Internet industry is a knowledge-intensive industry, and the knowledge spillover effect of the Internet itself contributes to technological innovation. However, previous studies have shown that the relationship between technological progress and environmental pollution is not simply linear but shows an inverted "U" shaped relationship, i.e., technological advancement in the early stage increases environmental pollution [30]. As an essential component of technological progress, green innovation shows a facilitative effect on environmental pollution, probably because green innovation has some negative externalities in the early years, leading to a transfer of pollution to surrounding areas, making the overall appearance of promoting pollutant emissions. As enterprises do not, there is an unavoidable delay in green innovation. Green technology is not used on a large scale for cost control and other reasons. To a certain extent, it does not significantly affect the emission of pollutants. Accordingly, this paper proposes the hypothesis that:

Hypothesis 3: Green innovation has a masking effect on the Internet's impact on environmental pollution.

3 Research Model and Data

3.1 Model Setting

A fixed-effects model is developed to test whether interconnected urban development in China significantly reduces environmental pollutant emissions.

$$Y_{it} = \alpha_0 + \alpha_1 Id + \alpha_2 C_{it} + u_i + v_t + \mu_{it} \tag{1}$$

where i represents the city; t represents the year; Y represents the explanatory variables, which are industrial soot emissions (*lnsm*); industrial sulfur dioxide emissions (*lnso*); and industrial wastewater emissions (*lnsw*); Id represents the urban Internet development level index; C represents a set of control variables; u represents regional effects; μ Represents random error.

In addition to the aggregate effect embodied in Eq. (1), the Level of Internet development may also indirectly affect environmental pollution through some mediating effect mechanism, which is modelled in this paper as follows.

$$M_{it} = \beta_0 + \beta_1 Id + \beta_2 C_{it} + u_i + v_t + \mu_{it} \tag{2}$$

$$Y_{it} = \gamma_0 + \gamma_1 Id + \gamma_2 M_{it} + \gamma_3 C_{it} + u_i + v_t + \mu_{it} \tag{3}$$

where M are denoted mediating variables, which are green patent quality (*lnpgi*), the number of green patents (*lnqgi*) representing green innovation, and industrial structure heightening (*lnhsi*); the rest of the variables are defined in the same way as Eq. (1). In Eqs. (2) and (3) $\beta_1 \times \gamma_2$ denotes the mediating effect, which means that the Level of Internet development impacts environmental pollutant emissions through its influence on the mediating variables and hence on ecological pollutant emissions.

3.2 Definition of Variables

1. Explanatory variables. In previous studies on environmental pollution, the "three waste" indicators have been widely used. However, due to data availability, only industrial sulfur dioxide, industrial soot, and industrial wastewater emissions are published in urban statistical yearbooks. This paper uses these three indicators to measure urban environmental pollution.

2. Core explanatory variables. Internet development level index (*Id*). The level of development of the Internet is reflected in the existing physical industry as a kind of systemic project, and this paper adopts the indicator system method for measuring the Level of Internet development. Since the availability of data, the following six secondary indicators are chosen: the number of telecommunication services per capita (*ttbp*), the number of broadband subscribers per capita (*bsr*), the number of mobile phone subscribers per capita (*cpr*), the proportion of Internet employees (*ier*), the number of Internet users per 100 people (*iu*) and postal business per capita (*pop*) to construct an indicator system that can comprehensively reflect the Level of Internet development (see Table 1 for details).

According to the above evaluation system, the evaluation system is measured using the principal component analysis method. Firstly, the original data is standardized to eliminate the dimension's influence; secondly, the top 6, the first main components, were taken to make their cumulative contribution rate reach 80%. Finally, the number of factors is determined according to the weights to obtain the evaluation system.

3. Mediating variable.① Green innovation development. The development of green innovation includes both "quality" and "quantity," which are the improvement of the quantity of green innovation and the progress of the quality of green innovation, respectively. Therefore, in this paper, the logarithm of the total number of green patent applications in cities is used to represent the quantity of green innovation (*lnqpi*), and the logarithm of the total number of green patents obtained by cities is chosen to represent

Table 1. Comprehensive measurement system of Internet development level in Chinese cities.

Tier 1 indicators	Secondary indicators
Internet applications	*ttbp*
	ier
	pop
The popularity of the Internet	*iu*
	cpr
	bsr

the quality of green innovation (*lnppi*), in order to verify whether the Level of Internet development affects the "quality" and "quantity" of green innovation development and thus the level of urban pollution.

② Industrial structure heightening. In this paper, the logarithm of the ratio of the tertiary industry to secondary industry is used to measure the heightened industrial structure (*lnhsi*), the larger the value, the more significant the proportion of the tertiary sector, the more advanced the industrial structure is implied.

4. Controlling variables Drawing on relevant studies on the factors influencing urban environmental pollutant emissions [31–37], this paper controls the following variables that may have an impact on urban environmental pollution: ① Foreign-to-foreign investment (*fdip*), using the amount of foreign direct investment as a proportion of the actual *GDP* share of foreign direct investment, expressed as the share; ② Fixed investment (*fai*), expressed using the amount of government fixed investment as a share of real GDP; ③ Expenditure on science and technology (*ssp*), expressed using government expenditure on science and technology as a share of fiscal expenditure; ④ Expenditure on education (*esp*), expressed using government expenditure on education as a share of fiscal expenditure; ⑤ Level of economic development (*pcgdp*), expressed using real gross urban product per capita; ⑥ Population density (*pod*) is expressed using the number of people per square kilometre.

3.3 Description of the Sample and Data

To ensure data availability and continuity and consider urban planning adjustments and data deficiencies, the observations of 295 cities from 2009 to 2019 were selected as the sample for this study. Each city's pollutant emission and socio-economic data were obtained from the China Urban Statistical Yearbook. Data related to green patents were obtained from the National Intellectual Property Repository. Finally, cities' green development patent data were aggregated according to the location of enterprises. Some data were logarithmized or standardized in consideration of the influence of the magnitude of some data (see Table 1).

4 Empirical Results

4.1 Baseline Regression Results

Based on Eq. (1), it can be verified whether Internet development can significantly reduce the level of urban pollutant emissions (Table 2). Table 3 reports the estimated results of the Level of Internet development on the emissions of three types of pollutants. In particular, in model (1), the correlation between Internet development and industrial soot emissions (*lnsm*) has a correlation coefficient of −0.130, which is significant at the 1% level. The correlation coefficient between Internet development and industrial sulfur dioxide emissions in model (2) *lnso* has a correlation coefficient of −0.0950, which is significant at the 1% level. The correlation coefficient between Internet development and industrial wastewater emissions in model (3) *lnsw* has a correlation coefficient of −0.0856, which is significant at the 1% level. It can be seen that the Level of Internet

Table 2. Baseline regression results of the Internet Development Level Index affecting environmental pollution.

	(1)	(2)	(3)
VARIABLES	lnsm	lnso	lnsw
Id	−0.130***	−0.0950***	−0.0856***
	(0.0310)	(0.0276)	(0.0279)
fdip	0.705	0.331	−1.026*
	(0.979)	(0.879)	(0.557)
fai	−0.133	−0.184**	−0.157***
	(0.0928)	(0.0837)	(0.0603)
ssp	−0.110	−26.06***	−7.091
	(10.79)	(9.974)	(6.756)
esp	−13.69***	-12.94***	−10.43***
	(1.860)	(1.664)	(1.907)
pcgdp	6.86e-06***	8.44e-06***	−8.27e-07
	(1.16e-06)	(1.05e-06)	(9.15e-07)
pod	−0.000287***	7.34e-05	0.000161
	(6.61e-05)	(5.96e-05)	(0.000406)
Constant	9.882***	10.89***	9.826***
	(0.120)	(0.108)	(0.347)
Observations	2,054	2,049	2,053
R-squared	0.173	0.237	0.879
Controls	YES	YES	YES
Year	YES	YES	YES
Area	YES	YES	YES

Note: Robust standard errors in brackets; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The following tables are identical.

development significantly reduces industrial soot emissions (*lnsm*), industrial sulfur dioxide emissions (*lnso*), and industrial wastewater emissions (*lnsw*). Among them, Internet development has the most significant impact on industrial soot emissions (*lnsm*). Hypothesis 1 is proved.

In terms of control variables, foreign direct investment (*fdip*) does not significantly reduce the emission of pollutants, which may be due to the following reasons. On the one hand, the introduction of foreign investment may introduce more advanced technologies and industries, which effectively improves the technological level of the region through the technology spillover effect and suppresses the emission of pollutants. On the other hand, introducing foreign investors may also bring in some enterprises or industries with high pollution levels, which significantly enhances the emission of pollutants. According

Table 3. Internet development index and mediating variables

	(1)	(2)	(3)
VARIABLES	lnqgi	lnpgi	lnhsi
Id	0.785***	0.827***	0.0745***
	(0.0245)	(0.0247)	(0.00780)
Constant	3.743***	2.599***	−0.207***
	(0.0887)	(0.0965)	(0.0263)
Observations	3,042	2,816	2,789
R-squared	0.458	0.416	0.267
Controls	YES	YES	YES
Year	YES	YES	YES
Area	YES	YES	YES

to the regression results, the above two aspects may co-occur, resulting in no significant effect of foreign direct investment on the emission of the three types of pollutants.

Fixed investment (*fai*) significantly reduced industrial sulfur dioxide and industrial wastewater emissions, indicating that the higher government expenditure on fixed assets during the study period and the emphasis on investment in the construction of technology-based and developmental assets reduced environmental pressure to a certain extent and had a dampening effect on pollutant emissions.

Expenditure on science and technology (*ssp*) only had a significant reduction effect on industrial sulfur dioxide emissions, which may be because government expenditure on science and technology did not provide sufficient support for green innovation or energy conservation and emission reduction, resulting in no significant reduction effect of pollutant emissions from science and technology expenditure.

The disincentive effect of education expenditure (esp) on pollutant emissions shows that the higher the government's focus on education, the less polluting the area is. Scientific research in education helps companies improve resource efficiency, significantly reducing pollutant emissions.

The level of economic development (*pcgdp*) has a significant impact on industrial wastewater (*lnsw*) and industrial sulfur dioxide (*lnso*) emissions significantly, probably because the transformation of enterprises has not yet been fully completed. There are still many traditional industries whose technologies contribute to a larger output and environmental pollution.

Population density (*pod*) is only significant for industrial soot (*lnsm*) emissions. It has a significant suppressive effect, suggesting that an increase in population density generates positive externalities, bringing about technological development and labor force spillover effects, facilitating the optimal industrial transformation of government enterprises and contributing to a reduction in pollutant emissions.

4.2 Analysis of Intermediary Effects

The regression results above simply show a significant inhibitory effect of Internet development on the emission of environmental pollutants, and the impact of its specific mechanism needs further analysis. Models (2)-(3) are the mediating effect models in this paper, and this paper uses a stepwise test to verify the existence of the mediating effect. Table 4 reports the regression results of the first step of the mediating effect test. The coefficient of Internet development in model (1) and model (2) is significantly evidenced at the 1% level, indicating that Internet development increases the number and quality of green patent applications and enhances green innovation in cities. The Internet development coefficient in model (3) is significantly positive at the 1% level, indicating that Internet development has promoted industrial structure optimization.

Panel A in Table 5 reports the impact of industrial structure advancement on various environmental pollutants. The coefficients of industrial structure advancement in models (2) and model (3) are significantly negative at the 1% level. The coefficients of the cross-product terms of the Bootstrap test are quite negative, indicating that Internet development reduces pollutant emissions in cities by optimizing industrial structure, which is consistent with the analysis in Hypothesis 2 (Table 6).

However, in Panel B, the indirect effect coefficients in the bootstrap tests for the number and quality of green innovations in models (1), (2), and (3) are significantly positive. In contrast, the direct effect coefficients are significantly negative, suggesting a masking effect of green innovations on the emission reduction effect affecting Internet development [38]. The reason is the inverted U-shaped relationship between green innovation and environmental pollution as a whole, the fact that green innovation has not yet reached a high level of suppression of environmental pollution. The possible existence of certain negative externalities and delays in the use of green innovation leads to the masking effect, which is consistent with the analysis in Hypothesis 3.

4.3 Robustness Tests

The following robustness tests are used to ensure the reliability of the empirical findings.

4.3.1 Replacement of Core Explanatory Variables

The Digital Inclusive Finance compiled by the Digital Finance Research Center of Peking University index reflects the level of development of digital finance in each city. The text takes inclusive digital finance as the core. It uses five digital economy development-related indicators using the index compilation method of hierarchical analysis to compile the digital economy index (lnde). In this paper, the core explanatory variable Internet development level index (Id) is replaced by this digital economy index (lnde). It reduces the data to panel data from 2011–2019 to verify the robustness of the empirical results. The regression results of the fixed effects model are shown in Table 7, where it can be obtained that the coefficients of the digital economy index (lnde) coefficients are all significantly negative, and the inhibitory effect on pollution abatement is also roughly the same as the baseline regression results, indicating that the previous regression results are robust.

Table 4. Mediating variables and environmental pollution

	(1)	(2)	(3)
VARIABLES	lnsm	lnso	lnsw
Panel A	Advanced industrial structure and environmental pollution		
Lnhsi	−0.623***	−1.148***	−0.588***
	(0.0573)	(0.0501)	(0.0387)
Id	−0.0777***	−0.483***	−0.177***
	(0.0250)	(0.0220)	(0.0174)
Constant	10.66***	12.90***	10.44***
	(0.197)	(0.172)	(0.133)
Bootstrap	0.357	0.900	0.512
Indirect	−0.051***	−0.036***	−0.033***
	(z = −5.94)	(z=−2.74)	(z = −5.21)
Direct	−0.155***	−0.091***	−0.106*
	(z=−4.03)	(z=−3.00)	(z = −6.98)
Observations	2,604	2,598	2,604
R-squared	0.679	0.774	0.854
R-squared	0.667	0.756	0.853
Panel B	Green innovation quality and environmental pollution		
lnpgi	−0.0908*	−0.240***	−0.140***
	(0.0185)	(0.0175)	(0.0124)
Id	−0.283***	−0.621***	−0.228***
	(0.0254)	(0.0239)	(0.0174)
Constant	10.59***	13.81***	10.99***
	(0.223)	(0.209)	(0.148)
Bootstrap	0.265	0.320	0.508
Indirect	0.100***	0.072***	0.111***
	(z=7.06)	(z=5.98)	(z=6.26)
Observations	2,608	2,604	2,612
R-squared	0.676	0.741	0.852
Panel C	Number of green innovations and environmental pollution		
lnqgi	−0.0580***	−0.304***	−0.202***
	(0.0167)	(0.0151)	(0.0113)
Id	−0.216***	−0.506***	−0.144***

(*continued*)

Table 4. (*continued*)

	(1)	(2)	(3)
VARIABLES	lnsm	lnso	lnsw
	(0.0261)	(0.0236)	(0.0180)
Constant	10.83***	14.28***	11.42***
	(0.221)	(0.198)	(0.148)
Bootstrap	0.211	0.472	1.101
Indirect	0.081***	0.050***	0.097***
	(z=6.03)	(z=5.53)	(z=6.62)
Direct	−0.229***	−0.176***	−0.128***
	(z = −6.67)	(z = −5.84)	(z=−4.22)
Observations	2,823	2,817	2,822
Controls	YES	YES	YES
City	YES	YES	YES

Table 5. Robustness analysis of the impact of Internet development on environmental pollution

	(1)	(2)	(3)
VARIABLES	lnsm	lnso	lnsw
lnde	−0.359***	−0.353***	−0.364***
	(0.0650)	(0.0576)	(0.0436)
Constant	10.05***	9.991***	9.152***
	(0.159)	(0.142)	(0.341)
Observations	1,558	1,571	1,576
R-squared	0.153	0.238	0.917
Controls	YES	YES	YES
Year	YES	YES	YES
Area	YES	YES	YES

4.3.2 Endogeneity Test

Between provinces, there is a risk that some important variables that do not change over time, such as the province level, may be omitted, resulting in biased and inconsistent estimation results. The article uses the provincial fixed effect to solve the above problems. Table 8 shows that the regression results for the Internet development level index (Id) are all significantly negative at the 1% level. The sign does not change significantly, indicating that the basic findings of this paper are robust.

Table 6. Impact of fixed provinces on environmental pollution

	(1)	(2)	(3)
VARIABLES	lnsm	lnso	lnsw
Id	−0.266***	−0.808***	−0.354***
	(0.0201)	(0.0194)	(0.0145)
Constant	10.71***	8.764***	8.101***
	(0.220)	(0.268)	(0.155)
N	2,847	2,842	2,845
R-squared	0.663	0.715	0.834
Controls	YES	YES	YES
Year	YES	YES	YES
Prov	YES	YES	YES

4.4 Spatial Heterogeneity Test

As the level of economic development of each region in China is at different stages, whether it is the Level of Internet development or environmental pollution, there are significant differences in regional distribution. Chinese cities are divided into eastern, central, and western, where the eastern part is near the sea and has a higher degree of openness and more rapid economic development, followed by the central region, and the western region is more backward than the eastern and central. There is a particular need to discuss the sample of cities in the three areas, and this paper uses the formula (1) to conduct a heterogeneity analysis. Table 8 shows the results of the heterogeneity analysis. Columns (1) to (3) in the table report the Internet development index (Id) coefficients.

Firstly, regardless of the region, the Internet development index (Id) coefficient has a significantly negative coefficient, indicating that the Level of Internet development is 1% level substantially reduces the emission of environmental pollutants in different regions. Among them, the emission reduction effect of central cities is greater than that of eastern and western cities. On the one hand, it may be since the proportion of traditional industries in central cities is higher than that in eastern and western cities, and urban environmental pollutant emissions and urban output value mainly rely on traditional high-polluting industries. With the development of the level of the Internet in recent years, the construction of Internet infrastructure among cities has been improved, and the degree of networking has gradually increased, thus accelerating the integration of the Internet with traditional industries, promoting industrial transformation and optimising resource allocation. The inhibiting effect of central cities on the emission of environmental pollutants is also significantly higher than that of eastern cities with a higher level of Internet development and a more reasonable industrial structure, and western cities with a lower level of Internet development and a poorer industrial structure. On the other hand, the inhibiting effect of the level of Internet development on the emission of environmental pollutants may be in an "S" shape, i.e. the inhibiting effect on the emission of environmental pollutants first gradually strengthens as the level of Internet

Table 7. Heterogeneity test of the Level of Internet development affecting environmental pollution

	(1)	(2)	(3)
VARIABLES	lnsm	lnso	lnsw
East			
Id	−0.189***	−0.751***	−0.281***
	(0.0266)	(0.0267)	(0.0182)
Constant	10.20***	12.28***	10.01***
	(0.198)	(0.197)	(0.129)
Observations	1,144	1,138	1,132
R-squared	0.695	0.695	0.851
Central			
Id	−0.495***	−1.045***	−0.501***
	(0.0430)	(0.0395)	(0.0307)
Constant	11.05***	8.235***	8.254***
	(0.268)	(0.247)	(0.177)
Observations	1,010	1,013	1,019
R-squared	0.585	0.681	0.748
Western			
Id	−0.203***	−0.693***	−0.343***
	(0.0393)	(0.0385)	(0.0303)
Constant	10.24***	11.76***	5.208***
	(0.272)	(0.242)	(0.211)
Observations	693	691	694
R-squared	0.709	0.783	0.811
Controls	YES	YES	YES
Year	YES	YES	YES
Area	YES	YES	YES

increases and then gradually decreases after the level of Internet development reaches a certain level.

Secondly, compared with cities in central and western China, eastern cities have a large population, a developed economy, early and rapid Internet development, a high degree of the Internet and traditional industries networking, and a reasonable industrial structure. Transportation between cities is convenient, and communication is frequent. The existence of city clusters, such as the Pearl River Delta, Shandong Peninsula, Yangtze

River Delta, and Beijing-Tianjin-Hebei, is conducive to sharing knowledge and information between cities and makes it easy to bring into play the knowledge spillover effect of the Internet.

Finally, in the western region, the level of urban Internet development is low, and the construction of urban Internet infrastructure is backward. Due to geographical constraints and inconvenient transportation, inter-city communication is low, and the transfer of knowledge and information between cities is hindered. It is therefore not conducive to the spatial spillover effect of the Internet on environmental pollution emissions.

5 Conclusions

This paper employs hierarchical analysis to measure the Level of Internet development in Chinese cities from 2009–2019 in a multidimensional manner. Based on panel data from 295 Chinese cities from 2009–2019, the impact of the level of Internet development on environmental pollution and its underlying mechanisms are empirically tested in a multidimensional manner using fixed-effects models, mediating effects models, regional heterogeneity analysis, and the main findings indicate that.

Firstly, Internet development significantly reduces the emission of environmental pollutants. After robustness tests using methods such as replacing core explanatory variables and endogeneity tests, the conclusion still holds, in terms of regional heterogeneity, that the emission reduction effect of Internet development is more remarkable in central regional cities than in eastern and western cities. Then, Internet development helps to improve industrial structure optimization and green innovation enhancement, reducing environmental pollution emissions through the industrial structure optimization effect. However, there is a particular masking effect of green innovation on the emission reduction effect of Internet development. The above conclusions show that the development of the Internet is conducive to improving the quality of the urban environment. The Internet has an apparent spatial spillover effect.

Secondly, as the Internet has apparent spatial spillover effects, it should also take complete account of the geographical areas of cities, emphasize coordinated urban development, establish various economic city clusters, guide and disseminate the information and resources of developed cities, and form the learning and exchange effects of information technology. The government continues to vigorously promote the advancement of technological innovation in cities, allowing internet development to actively play a role in environmental emissions reduction through the green innovation capacity effect and strengthening the promotion of green innovation in production processes. At the same time, the government focuses on the internet and economic development of remote cities in the west, adopting dynamic and differentiated policy measures for cities in different regions. For weak cities in the west, the government has increased its policies and established a suitable funding and financing system to help companies have sufficient incentive to gain technological development and progress. The government should also play a role in fiscal taxation, increase Internet infrastructure construction and do an excellent job of joint regional development.

Finally, industries use internet technology to continuously innovate and use the internet and other relevant platforms for technology exchange and cooperation. The spillover effect of industrial knowledge should also be given full play to achieve the goal of coordinated regional emission reduction ultimately.

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