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An Empirical Study on The Impact of Digital Economy on Industrial Pollution Emissions

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Abstract: In order to explore the impact of digital economy on industrial pollution emissions, based on the data of 288 cities at or above the prefecture level from 2011 to 2019, this paper takes a set of composite variables composed of industrial waste gas emissions, industrial wastewater emissions and industrial solid waste emissions as explained variables, and the development level of digital economy as explained variables. A series of control variables were added to establish a benchmark regression model to empirically test the impact of digital economy on industrial pollution emissions. The results show that: (1) digital economy can significantly inhibit the emission of pollutants; (2) There are regional differences in the effect of digital economy on pollutant emission reduction. The effect of pollution reduction is strongest in central region, middle in eastern region, and weakest in western region. In order to better protect the environment, to achieve energy saving and emission reduction. This paper proposes that the construction of digital infrastructure should be accelerated; We will raise the level of human capital and strengthen inter-regional exchanges and cooperation.

Keywords: Digital economy; Industrial pollution; Spatial heterogeneity.

1. Introduction

The advent of the digital economy era has not only changed the daily life of the masses, but also had a profound impact on all walks of life. The digital economy is constantly creating new economic growth points in the process of combining with the real economy to help the development of our economy. At the same time, China's economy is in an important node of high-speed growth to high-quality development, and environmental problems are particularly serious. The concept of "green water Jinshan is Jinshan Silver Mountain" vividly portrays the relationship between economic development and environmental protection. Then digital economy as one of the driving factors of China's economic growth, can it have an impact on environmental pollution? Can the development of digital economy promote economic growth and environmental protection at the same time?

Therefore, it is of far-reaching significance to study the impact of digital economy on industrial pollution emissions and better play the positive impact of digital economy on pollution reduction. In this context, this paper selects the panel data of 288 cities at the prefecture level and above from 2011 to 2019 to study the impact of digital economy on industrial pollution emissions, in order to provide references for the formulation of relevant policies.

2. Literature Review

Digital economy was first produced in western developed countries, so the study of digital economy was first started by western scholars. Foreign research on digital economy starts from the definition of digital economy, and then gradually extends to the measurement of digital economy and the impact of digital economy on other aspects. After the digital economy enters our country, Chinese scholars also start from the definition of digital economy, and then study the measurement of digital economy and the impact of digital economy on other industries. However, at present, the domestic calculation of the digital economy has not yet formed a unified accounting system.

China's economy has made great achievements since reform and opening up. With the help of the growth of industrial economy, the economy as a whole is growing steadily. However, with the expansion of China's industrial economy and the rapid economic growth, it has caused a waste of resources, environmental pollution and ecological damage, and paid a heavy price. Therefore, many scholars turn their attention to environmental pollution and environmental protection. Academics have explored the impact of many factors on environmental pollution.These studies have also laid a solid foundation for the research of this paper.

The digital economy has had a profound impact on all aspects of social production activities. However, due to the late development of the digital economy, few scholars directly discuss the connection between the digital economy and industrial pollution. This paper reviews the research results of digital economy on environmental pollution and finds that the existing research results can be mainly divided into three categories.

A group of scholars believe that the development of digital economy can reduce environmental pollution. Li Guanghao and Zhou Xiaoliang (2021) show that the development of digital economy can significantly reduce the emission of major environmental pollutants SO2, and this "pollution control effect" has an obvious "accumulation" feature [1]. Wang Lingfei and Chen Xiaohui (2021) conducted an empirical study based on the panel data of 31 provinces and municipalities in China from 2009 to 2018, and believed that the level of digital infrastructure construction would affect industrial waste gas emissions, thereby effectively improving environmental quality [2].

On the contrary, some scholars believe that the development of digital economy will aggravate air pollution. Li Leiming and Jia Jiangtao (2011) showed that Internet use would accelerate power consumption, but the degree of power consumption of Internet use in different provinces was different [3]. At the same time, many scholars based on foreign data found that the use of the Internet will aggravate the consumption of electricity. The last group of scholars believe that the impact of digital economy on air pollution is non-linear. In their study, Jin Fei and Xu Changle (2022) found that digital economy has a significant inverted "U-shaped" effect on carbon emissions, which is firstly promoted and then suppressed [4]. Wang Lanying et al. (2011) pointed out that the information industry has both positive and negative effects on sustainable development, but they did not prove this effect from an empirical perspective [5].

Scholars at home and abroad have made rich achievements in digital economy and environmental pollution respectively, which provides theoretical support for this paper. However, the existing research results rarely study the impact of digital economy on pollution emissions, and few scholars use empirical methods for analysis and research, so it is difficult to quantify the impact of digital economy on industrial pollution emissions. For the digital economy, the academic community has not yet formed a unified and authoritative accounting standards. Therefore, based on the existing research results, this paper uses the econometric model to explore the impact of digital economy on industrial pollution emissions.

The marginal contribution of this paper is: (1) This paper uses a set of coincidence variables to characterize industrial pollution, including: industrial waste gas emissions, industrial wastewater emissions and industrial solid waste emissions. Composite variables enable a more comprehensive characterization of industrial pollutants and better exploration of the effects of the digital economy on different pollutants. (2) Based on baseline regression, this paper explores the spatial heterogeneity of the digital economy on industrial pollution emissions. Consistent with baseline regression, this paper also explores the impact of digital economy on different pollutants in different regions in the part of heterogeneity analysis, in order to provide better policy recommendations.

3. Research Design

3.1 Model construction

This paper builds the following basic model to analyze the direct transmission mechanism of industrial pollution emissions affected by digital economy:

$$Y_{it} = \beta_0 + \beta_1 \mathrm{DEI}_{it} + \beta_2 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

Where i represents the city and t represents the year. Yit is a group of "three wastes" complex explained variables composed of industrial sulfur dioxide emissions (lnso2), industrial wastewater emissions (lnwater) and industrial smoke dust emissions (lnsomke). DEIit is the development level of digital economy of city i in t period. Xit is a set of vectors representing a set of control variables; And represent the regional fixed effect and the time fixed effect respectively, and are random disturbance terms. The parameter that this paper focuses on is that the coefficient measures the impact of digital economy on industrial pollution emissions. If it is significantly positive, it indicates that the development of digital economy has significantly inhibited industrial pollution emissions.

3.2 Explanation of main variables

Core Explanatory Variable: At present, there are few literatures on the specific measurement of the development level of digital economy in academic circles, and more are measured on the development level of digital economy at the provincial level. This paper draws on the digital economy evaluation index system constructed by Zhao Tao et al. (2020) (index system is shown in Table 1), and calculates the digital economy development level of prefecture-level cities through principal component analysis [6]. The index system measures the level of digital economy development (DEI) from the two aspects of Internet development and digital financial inclusion.

Table 1. Digital economy development level index system

Primary index	Secondary index	Specific index	Index attribute
Development level of digital economy（DEI）	Internet penetration	Internet users per 100 people	+
	Number of Internet-related employees	Percentage of employees in computer services and software	+
	Internet-related output	Total telecommunications services per capita	+
	Number of mobile Internet users	Number of mobile phone users per 100 people	+
	Inclusive development of digital finance	China Digital Financial Inclusion Index	+

Explained variable: Industrial exhaust emissions (lnso2) : Industrial sulfur dioxide emissions are measured logarithmically. Industrial wastewater Discharge (lnwater) : Industrial wastewater discharge is measured logarithmically. Industrial smoke emissions (lnsmoke): Industrial smoke emissions are measured logarithmically. The explained variables in this paper are a set of complex variables composed of industrial waste gas discharge, industrial waste water discharge and industrial solid waste discharge.

Control variable：Economic development level (lnrgdp), measured by logarithm of regional GDP per capita; The level of openness to the outside world is measured by the ratio of the total amount of foreign investment actually utilized plus one to the GDP; Population density (dens), measured by logarithmic ratio of total population to administrative area at the end of the year. Government Investment in Research and Development (lnrd), measured as the logarithm of fiscal expenditure on science and technology.

3.3 Data source

Based on sample availability, data from 288 cities at the prefecture level and above from 2011 to 2019 were selected for research. The digital financial inclusion index of the core explanatory variable comes from the Peking University Digital Financial Inclusion Index of the second Digital Financial research group of Peking University, and the other four secondary indicators come from the China City Statistical Yearbook. The "three wastes" index in the explained variables came from China City Statistical Yearbook and statistical bulletins of various provinces and cities, and some missing data were filled in by linear interpolation method.

3.4 Descriptive statistics

This paper conducted a study on 288 cities at the prefecture level and above in China from 2011 to 2019, and formed 2,592 balanced panel observations. Table 2 shows the descriptive statistical results of the main variables in this paper. As can be seen from Table 2, the mean value of the digital economic Development index (DEI) is 0.64, the minimum value is 0.6, and the maximum value is 1, indicating that the development level of China's digital economy is high. The mean values of industrial sulfur dioxide emissions (lnso2), industrial wastewater emissions (lnwater) and industrial smoke emissions (lnsmoke) were 10.028, 8.167 and 9.692, respectively, indicating that China's industrial pollution emissions were at a relatively high level, among which industrial sulfur dioxide emissions were the highest. For control variables, the mean values of economic development level (lnrgdp) and science and technology input (lnrd) are 10.689 and 10.367, respectively, indicating that China has a good level of economic development and attaches great importance to science and technology input. The standard deviation of population density (Dens) is 3.442, indicating that there are significant differences in population density among prefecture-level cities, which may be caused by the significant differences in population distribution between eastern and western cities due to differences in topography, climate, development level, etc.

Table 2. Descriptive statistics of variables

Variable	Obs	Means	Std. Dev	Min	Max
lnso2	2592	10.028	1.212	0.693	13.183
lnwater	2592	8.167	1.119	1.946	11.477
lnsmoke	2592	9.692	1.182	2.398	15.458
Dei	2592	0.64	0.04	0.6	1
lnrgdp	2592	10.689	0.577	8.773	13.056
openness	2592	0.017	0.018	0	0.198
lnrd	2592	10.367	1.377	6.624	15.529
dens	2592	4.359	3.442	0.051	27.591

4. Results of empirical analysis

4.1 Analysis of baseline regression results

Table 3. Analysis of baseline regression results

Variable	(1) lnso2	(2) lnwater	(3) lnsmoke
dei	-22.464*** (2.204)	-9.664*** (1.178)	-13.001*** (2.054)
lnrgdp	-1.342*** (0.13)	-0.688*** (0.084)	-0.842*** (0.111)
openness	4.733** (2.271)	1.47 (1.32)	1.724 (1.657)
lnrd	-0.121** (0.058)	-0.046 (0.033)	-0.037 (0.046)
dens	-0.263*** (0.054)	-0.018 (0.047)	-0.083** (0.036)
Cons	41.069*** (1.492)	22.233*** (0.917)	27.729*** (1.396)
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	2592	2592	2592
R2	0.427	0.262	0.197

Note: Robustness standard errors are reported in parentheses in the table, ***, **, and * indicate that the regression results passed the significance test at 1%, 5%, and 10% confidence levels, respectively, as in the table below.

The regression model of digital economy on industrial pollutant emissions is constructed, and the regression results are shown in Table 3. In model (1), model (2) and model (3), the estimated coefficients of the Digital economy index (DEI), the core explanatory variable, are all significantly negative at the level of 1%, and the digital economy significantly inhibits the emission of three types of industrial pollutants. Among them, sulfur dioxide emissions are the most affected by the digital economy, followed by soot emissions, and industrial wastewater emissions are the least affected.

As for the control variables, the regression coefficients of all regional economic development levels (lnrgdp) are significantly negative at the level of 1%, indicating that the higher the level of regional economic development in China, the more conducive to reducing industrial pollution emissions. China has gradually got rid of the traditional extensive economic growth model of high pollution and high emissions, residents' awareness of environmental protection and enterprises' awareness of emission reduction are enhanced, and economic development is more and more sustainable. openness promotes SO2 emission at the significance level of 1%, while the regression coefficients for wastewater emission and soot emission are positive but not significant. However, this also verifies the hypothesis of "pollutant refuge", the developed countries transfer high energy consumption and high pollution industries to our country, which aggravates the pollution level of our country; Government investment in Research and Development (lnrd) suppressed SO2 emissions at a significant level of 5%. Although the impact of government R&D input on wastewater discharge and smoke discharge is negative, it is not significant. The possible reason is that government R&D input has not been transformed into R&D output, or R&D input has been transformed into R&D output but R&D output has not been effectively promoted, resulting in high R&D input but failed to produce the expected effect. Population density (dens) also inhibits the emission of the three types of pollutants, but the significance is different. Population density (dens) inhibits sulfur dioxide emissions at a significant level of 1% and soot emissions at a significant level of 5%, while population density has a negative but not significant effect on industrial wastewater emissions. Although the influence of control variables on various pollutants is different, the level of economic development (lnrgdp), government investment in research and development (lnrd) and population density (dens) can inhibit sulfur dioxide emissions at 1% significance level, while the level of openness can promote sulfur dioxide emissions at 1% significance level.

4.2 Heterogeneity analysis

Table 4. Heterogeneity analysis results

Variable	Eastern region			Central region			Western region		
	lnso2	lnwater	lnsmoke	lnso2	lnwater	lnsmoke	lnso2	lnwater	lnsmoke
dei2	-22.334***	-8.622***	-14.326***	-30.749***	-15.664***	-17.301***	-14.848***	-5.509***	-7.789**
	(3.81)	(1.487)	(2.515)	(2.93)	(2.208)	(4.68)	(2.776)	(1.675)	(3.024)
lnrgdp	-1.23***	-0.489***	-0.518***	-1.428***	-0.756***	-1.166***	-1.295***	-0.749***	-0.838***
	(0.182)	(0.108)	(0.125)	(0.276)	(0.151)	(0.26)	(0.175)	(0.162)	(0.171)
openness	7.128**	3.914**	3.528*	2.016	-2.092	0.966	-2.576	2.888	-3.334
	(2.951)	(1.553)	(2.042)	(2.561)	(1.992)	(2.036)	(6.266)	(6.663)	(6.175)
lnrd	-0.015	0.029	0.018	-0.191**	-0.102*	-0.049	-0.151*	-0.069	-0.038
	(0.097)	(0.051)	(0.067)	(0.094)	(0.052)	(0.089)	(0.08)	(0.07)	(0.079)
dens	-0.338***	-0.072***	-0.128***	-0.01	0.105	0.006	-0.252	0.247	-0.273
	(0.063)	(0.023)	(0.04)	(0.144)	(0.122)	(0.126)	(0.71)	(0.327)	(0.493)
Cons	40.034***	19.642***	25.221***	46.466***	26.615***	33.535***	35.06***	18.768***	24.205***
	(2.616)	(1.327)	(1.978)	(2.483)	(1.52)	(2.998)	(2.739)	(2.262)	(2.591)
City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1035	1035	1035	981	981	981	576	576	576
R^2	0.421	0.229	0.21	0.468	0.364	0.232	0.439	0.242	0.176

Due to the differences in the level of economic development and industrial structure in different regions, the development level of digital economy and environmental pollution problems in different regions are different. Based on the above reasons, this paper classifies 12 provinces (municipalities) of Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi and Hainan into the eastern region by referring to the division basis of the basic database of Beijing's macroeconomic and social development. Nine provinces (autonomous regions) of Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan were divided into the central region, and 10 provinces (municipalities/autonomous regions) of Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Ningxia, Qinghai and Xinjiang were divided into the western region. According to the results of the above regional division, this paper adds control variables, and analyzes the heterogeneity by controlling the fixed effects of city and time.

According to the heterogeneity analysis results, the digital economy significantly inhibited the emission of three types of pollutants in the eastern, central and western regions. The pollution reduction effect in the central region is the strongest, the eastern region is the middle, and the western region is the weakest. China's eastern and central regions have developed the digital economy earlier. Compared with the central region, the eastern region has a good economic foundation, concentrated superior resources to develop the digital industry, and a higher level of digital economy development. However, the effect of pollution reduction in the central region is stronger than that in the eastern region. The possible reason is that the eastern region has realized industrial transformation and upgrading, and there are fewer polluting industries, while the central region has more high-pollution and high-energy consumption industries. Therefore, the digital economy in the central region can better play the role of pollution reduction. Compared with the central and eastern regions, the western region has developed the digital economy late, the construction of digital infrastructure is insufficient, digital technology and traditional industries have not been well integrated, and the dividends of the digital economy cannot be fully released. Therefore, the effect of digital economy on pollution reduction in the western region is poor.

5. Conclusion and Suggestion

5.1 Conclusion

In contemporary China, the development of digital economy is of great significance. The integration of digital economy and traditional industries can not only create new economic growth points, but also promote the high-quality development of China's economy in different degrees. In the process of high-quality economic development in China, pollution prevention and environmental management are two important problems. Protecting the ecological environment and improving environmental quality is the only way to achieve high-quality development.

Based on the panel data of the digital economy development level and industrial pollution of 288 cities at or above the prefecture level from 2011 to 2019, this paper constructs a two-way fixed effect model to empirically test the impact of the digital economy development level on industrial pollution emissions. In addition, on the basis of the baseline regression results, this paper further explores the geographical differences in the effects of digital economy on industrial pollution, and draws the following conclusions:

1) The digital economy has significantly inhibited the emission of three types of industrial pollutants. Among them, sulfur dioxide emissions are the most affected by the digital economy, followed by soot emissions, and industrial wastewater emissions are the least affected.

2) Digital economy can significantly inhibit the emission of pollutants, and there are regional differences in the effect of digital economy on pollutant emission reduction. The digital economy has significantly curbed the emission of three types of pollutants in the eastern, central and western regions. The pollution reduction effect in the central region is the strongest, the eastern region is the middle, and the western region is the weakest.

5.2 Suggestion

This study shows that the development of digital economy can effectively inhibit the emission of pollutants, thus contributing to energy conservation and emission reduction and improving environmental quality. In order to better exert the emission reduction effect of the digital economy, this paper puts forward the following policy recommendations:

1) Accelerate the construction of digital infrastructure

Digital infrastructure is an important guarantee for the development of digital economy. However, there is an obvious regional imbalance in the development of China's digital economy. The digital infrastructure construction in the western region is weaker than that in the eastern region, and the digital infrastructure construction in the rural area is also weaker than that in the urban area. The eastern region, with its early development of digital economy and relatively complete digital infrastructure, should make use of its own advantages, step up digital technology innovation, and actively promote the development of the central and western regions. The western region should firmly grasp its own advantages of low cost and resource endowment, and constantly increase infrastructure construction to lay a solid foundation for industrial digital transformation. In addition, while accelerating the construction of their own digital infrastructure, urban areas should also strengthen the radiation of rural areas. Multi-azimuth development, improve our digital infrastructure construction level.

2) Improve the level of human capital

Reducing pollutant emissions is not only an inevitable requirement for high-quality development, but also an important way to improve people's happiness in life. However, the use of digital economy to achieve pollution reduction faces two major difficulties, one is the lack of digital infrastructure construction, and the other is the low level of human capital.

Therefore, we should increase the investment in the level of human capital. First of all, strengthen the top-level design, and actively implement the strategy of strengthening the country through talent. For digital economy talents, through government subsidies, financial grants and other forms to attract them to participate in energy conservation, emission reduction and environmental protection; For existing talents, we actively provide learning and communication platforms, and constantly enhance their ability to learn and apply new technologies. Secondly, colleges and universities should give full play to the role of cultivating compound talents. As the cradle of talent cultivation, colleges and universities should break the discipline barriers, actively promote interdisciplinary integration, and cultivate compound talents in short supply in our country. Finally, enterprises should invest more in human capital in the process of digital transformation. Enterprises should not only pay attention to the introduction of talents, but also pay attention to the learning of existing employees of enterprises, fundamentally safeguard and improve the quality of talents, and expand the compound talent team of enterprises.

3) Strengthening inter-regional cooperation and exchanges

Industrial pollution control can never be viewed in isolation, and all regions or cities should strengthen cooperation to jointly control environmental pollution. First, joint governance will help build an efficient and win-win regional governance system and avoid beggar-thy-neighbor problems. Second, co-governance helps to promote technology exchange, share experience and technology, and save the investment of capital and other resources. Cities with higher levels of economic development and environmental governance will drive cities with lower levels of economic development and environmental governance to achieve common progress.

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