The Impact of Digital Economy Development on Environmental Pollution in the Yangtze River Delta Region

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***Abstract*—With the advancement of the global digitization wave, the Yangtze River Delta region, as a significant engine of China's economic development, has continued to expand its digital economy, making increasingly remarkable contributions to economic growth. However, this process is also accompanied by potential risks of environmental pollution. Therefore, this paper takes the Yangtze River Delta region as the research scope, analyzing the impact of digital economy development on environmental pollution, aiming to provide theoretical support for the simultaneous development of the region's digital economy and improvement of environmental pollution.**

***Keywords*—digital economy, environmental pollution**

I. Introduction

The digital economy, an emerging economic form, stands as one of the most vibrant sectors in China today and is widely regarded as a crucial pivot for transforming China's traditional and new growth drivers. According to the "Research Report on the Development of China's Digital Economy (2023)," China's digital economy has further achieved reasonable quantitative growth. In 2022, the scale of China's digital economy reached 50.2 trillion yuan, representing a nominal year-on-year growth of 10.3%, marking the 11th consecutive year that it has significantly outpaced the nominal GDP growth rate over the same period. The digital economy now accounts for 41.5% of GDP, a proportion equivalent to that of the secondary industry in the national economy. Leveraging continually upgraded network infrastructure and intelligent devices such as smartphones, the digital economy accelerates the integration of digital technologies and elements into deeper levels and broader sectors, fostering the transformation of the economic landscape from an industrial economy to a smart economy, thereby ushering in a paradigm shift in overall economic operations. Amidst increasingly severe ecological and environmental challenges, the digital economy emerges as an "accelerator" and "stabilizer" for China's economic growth under the new normal. China has also elevated the development of the digital economy to a national strategic level, with significant deployments made in the 20th National Congress of the Communist Party of China's report on "accelerating the development of the digital economy" and "speeding up the construction of a digital China." However, the question this paper endeavors to explore is whether the digital economy can indeed serve as a "new growth driver" for economic development, alleviating market distortions, empowering industrial structural upgrades, enhancing economic quality and efficiency, and realizing green development. Thus, this paper focuses on examining the impact of digital economy development on environmental pollution in cities within the Yangtze River Delta region.

II. Literature Review

A. The Impact of Digital Economy Development on Environmental Pollution

With the booming rise of the digital economy, it has inevitably accelerated the rapid progress and widespread application of numerous modern information and communication technologies. Furthermore, emerging business models fueled by big data, the Internet, and other cutting-edge technologies have driven the development of the digital economy and gradually demonstrated an effective restraint on environmental pollution. Li and Zhou (2021) argue that the development of the digital economy can effectively alleviate environmental pollution issues, primarily through stimulating technological innovation among enterprises, promoting the transition of industrial production methods towards intensification, and facilitating the shift of residents' lifestyles towards online platforms. Hu *et al.* (2022) contend that while the digital economy improves local ecological environment quality, its spillover effects on neighboring regions are insignificant. Instead, the digital economy can synergistically enhance local ecological environment quality when combined with the health industry. Based on the empirical findings by Deng and Zhang (2022) that the development of the digital economy significantly reduces the emission of urban environmental pollutants and exerts a negative spatial spillover effect on the environmental pollutants in surrounding cities, this paper proposes the following hypothesis:

H1: The development of the digital economy is conducive to restraining the level of environmental pollution in the Yangtze River Delta region.

B. The Mechanism of Digital Economy Development's Effect on Environmental Pollution

On the one hand, Guo (2020) argues that public supervision over environmental issues can translate into a preference for green products, making them more competitive in the commodity market, and digital technology precisely provides effective support for the design and development of green products by enterprises. On the other hand, Ma (2024) *et al.* contend that as public environmental awareness increases, enterprises are more inclined to leverage digital means to apply data collection, storage, analysis, and sharing technologies to green innovation activities in order to cultivate long-term competitive advantages and enhance green innovation capabilities. When enterprises face heightened public environmental concerns, they are more likely to pursue development goals such as energy conservation, emission reduction, low-carbon

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circularity, and clean production through green innovation, thereby improving environmental quality. Furthermore, Wu (2022) *et al.* suggest that with the involvement of public environmental concerns, government environmental governance investment behaviors are influenced, such as increasing investments in urban environmental infrastructure construction projects and consolidating fiscal expenditures on energy conservation and environmental protection. NEU (2022) *et al.* maintain that the digital economy also provides the public with more comprehensive channels for environmental supervision and feedback, enabling them to quickly access pollution information in cities and provide timely feedback through online government platforms and online media. Under the dual pressure of the government and the public, the digital economy strengthens corporate constraints on polluting behaviors. Based on the above analysis, this paper proposes the second hypothesis:

H2: Public environmental supervision plays a mediating role in the impact of digital economy development on environmental pollution.

III. Materials and Methods

A. Sample Selection and Data Sources

Given the rapid development of the digital economy in recent years and the relatively late commencement of statistical data for related industries, the research timeframe for this paper is set from 2011 to 2022. Data used in the digital economy index system are sourced from the "China City Statistical Yearbook," provincial and municipal statistical yearbooks, as well as the National Bureau of Statistics. The Digital Inclusive Finance Index is derived from the "Digital Inclusive Finance Index System and Index Compilation" published by the Institute of Digital Finance at Peking University (Guo *et al.*, 2020). The environmental pollution data employed in this paper is PM2.5 concentration data, which originates as raster data from the Atmospheric Composition Analysis Group (A.C.A.G). Using ArcGIS software, information is extracted from the raster layers, converting nc-formatted raster data into Excel data. Subsequently, zonal statistics are applied to match the data with administrative divisions, calculating urban haze data based on Global/Regional Estimates (V5.GL.02).

B. Selection of Research Variables

1) Explained variable

Environmental pollution level (POLLU): This paper adopts PM2.5 concentration data from the Atmospheric Composition Analysis Group at Washington University in St. Louis (formerly the Atmospheric Composition Analysis Group at Dalhousie University, Canada) as an indicator to measure urban haze.

2) Explanatory variables

Digital Economy (DE): Drawing on the research by Zhao *et al.* (2020), an index system for measuring the development level of the digital economy is constructed from five dimensions: internet penetration rate, internet-related employment status, internet output, mobile internet penetration rate, and the Digital Inclusive Finance Index.

3) Mediating variable

Public Environmental Supervision (PES): Following the research by Guo (2024), the Baidu Index, which measures the frequency of internet users searching for "environmental pollution" using Baidu search engine, is used as a proxy for public environmental supervision.

4) Control variables

Drawing on the studies by Sun (2024) and Zhu (2023), the following indicators are selected as control variables:

Per capita GDP (LNPGDP): Measured as the ratio of regional GDP to the total population at the end of the year. Industrialization level (STR): Represented by the ratio of industrial added value to urban GDP. Consumption activity (CON): Characterized by the proportion of total retail sales of consumer goods to city GDP. Foreign dependence (FDI): Measured by the actual amount of foreign direct investment to indicate a city's dependence on foreign capital. Technological Innovation Level (INN): Assessed by the number of green patent applications in the current year. Infrastructure level (ROAD): Measured by per capita road area.

C. Research Model

To test the aforementioned research hypotheses, the following basic model is first constructed for the direct transmission mechanism:

$$POLLU_{it} = \alpha_0 + \alpha_1 DE_{it} + \alpha_k CV_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

wherein, "i" and "t" represent cities and years, respectively; "α" is the constant term; "μ" represents city fixed effects; "δ" represents time fixed effects; "ε" is the random disturbance term; the explained variable "POLLU" denotes the level of environmental pollution; the core explanatory variable "DE" represents the development level of the digital economy; and "CV" denotes the set of control variables that influence environmental pollution.

Previous theoretical mechanism analyses indicate that the development of the digital economy can affect environmental pollution through public environmental supervision. As existing studies have already corroborated the energy-saving and emission-reduction effects of public environmental supervision (Yu *et al.*, 2024; Liu *et al.*, 2024), drawing on the approach of Yu and Duan (2022), this paper focuses on whether the digital economy influences the mechanism variables, which in turn affect the level of environmental pollution. Based on this, the following mechanism testing model is constructed:

$$PES_{it} = \alpha_0 + \alpha_1 DE_{it} + \alpha_k CV_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

In this model, the explained variable represents public environmental supervision, while the core explanatory variable, the set of control variables, and other parts of the model have the same meanings as in the basic regression model.

IV. Result and Discussion

A. Descriptive Statistics

The descriptive statistics of the variables are shown in Table 1.

Table 1. Descriptive statistics

Variable	Obs	Mean	Std.Dev.	Min	Medn	Max
POLLU	492	41.491	11.646	18.891	41.876	64.532
DE	492	−0.00049	0.779	−1.249	−0.077	1.996
LNPGDP	492	11.086	0.598	9.462	11.152	12.101
STR	492	0.387	0.079	0.209	0.389	0.585
CON	492	0.398	0.090	0.221	0.389	0.647
FDI	492	0.027	0.019	0.002	0.022	0.087
INN	492	6.418	1.403	2.565	6.328	9.876
ROAD	492	23.481	6.847	11.480	23.802	44.401
PES	492	8.955	0.966	5.835	8.958	10.862

B. Benchmark Regression Results

Table 2(1) reports the impact of digital economy development on urban environmental pollution in the Yangtze River Delta region. The results show that the development of the digital economy has an inhibitory effect on the level of environmental pollution, with a coefficient of −3.739, which is significant at the 1% level. Therefore, Hypothesis 1 is confirmed, i.e., the development of the digital economy is conducive to improving environmental pollution. Analysis of the control variables reveals that per capita GDP contributes to environmental pollution and is significant at the 1% level, indicating that the urban economic development level in the Yangtze River Delta region is still on the left side of the inflection point of the Environmental Kuznets Curve. The increase in per capita income has not yet had a positive impact on environmental pollution control. Instead, the growth of the regional economy has led to an expansion in the demand for resources and industrial products, thereby aggravating environmental pollution. This further suggests that green development in the Yangtze River Delta region has not been fully realized. The level of industrialization (STR) also contributes to environmental pollution, indicating that high-pollution and high-energy-consuming industries in the Yangtze River Delta region have exacerbated pollutant emissions and led to a deterioration in ecological environmental quality. However, this effect is not significant, failing to pass the significance test. Foreign Direct Investment dependence (FDI) is negative at the 1% significance level, which aligns with the "Pollution Halo Hypothesis," suggesting that foreign direct investment does not lead to the deterioration of local ecological environments but instead facilitates the management of environmental issues. On the one hand, local governments benefit from technological spillovers brought by foreign-invested enterprises during the process of attracting foreign investment, learning and absorbing relatively advanced production technologies from foreign-invested enterprises, thereby improving the production efficiency and resource utilization efficiency of local enterprises, and reducing pollutant emissions. Consumer activity (CON) significantly inhibits the level of environmental pollution in the Yangtze River Delta region at the 1% level. Technological innovation (INN) is negative at the 5% significance level, with a value of −0.875, indicating that urban technological innovation activities in the Yangtze River Delta region are driving economic development towards a green and sustainable direction, thereby effectively inhibiting environmental pollution and reducing it.

Table 2. Benchmark regression and robustness test results

Variables	(1)	(2)	(3)	(4)
	Y0	Y1	Y2	Y3
DE	−3.739***	−38.38***	−3.094***	−3.723***
	(0.728)	(5.499)	(0.918)	(0.729)
LNPGDP	3.021***	−10.03***	2.562*	2.974***
	(0.949)	(1.611)	(1.324)	(0.948)
STR	4.122	31.68***	−0.603	4.063
	(3.762)	(7.699)	(5.512)	(3.765)
CON	−10.66***	12.87**	−8.883*	−10.74***
	(3.008)	(6.131)	(4.900)	(3.009)
FDI	−29.11**	−50.09*	−35.48**	−28.96**
	(12.81)	(27.23)	(17.97)	(12.82)
INN	−0.875**	0.848	−0.801	−0.804*
	(0.442)	(0.577)	(0.543)	(0.442)
ROAD	−0.101**	−0.333***	−0.125*	−0.100**
	(0.0434)	(0.0907)	(0.0707)	(0.0435)
City	YES	YES	YES	YES
Year	YES	YES	YES	YES
_cons	22.63**	149.3***	29.76**	22.84**
	(9.745)	(16.12)	(13.69)	(9.751)
N	492	492	369	492
R^2	0.923	0.632	0.838	0.923

Standard errors in parentheses
* p < 0.1, ** p < 0.05, *** p < 0.01

Different scholars have varying interpretations of the definition of environmental pollution status, and there are differences in the current status of digital economy and environmental pollution based on different measurement methods. To ensure the robustness of the empirical results, the study conducted robustness tests. Firstly, the explanatory variables were replaced. The study adopted the entropy method to measure the level of digital economy development. As shown in Table 2(2), the regression results indicate that the coefficient of digital economy development level is significantly negative at the 1% level, with a value of −38.38, confirming the robustness of the results. Secondly, the study interval was changed. After excluding the years impacted by the COVID-19 pandemic, as shown in Table 2(3), the impact of digital economy development level on environmental pollution remains significantly negative at the 1% significance level. Thirdly, the data was winsorized, with outliers beyond the 1% to 99% range replaced by the variable values at the 1% and 99% percentiles. As shown in Table 2(4), analyzing the regression results reveals that the coefficient of digital economy development level's impact on environmental pollution remains significantly negative after winsorization, indicating that the development of the digital economy does indeed contribute to improving environmental pollution and verifying the robustness of the previous conclusions.

C. Test of Transmission Mechanism

Based on the analysis of the benchmark regression model and related robustness tests discussed earlier, it can be inferred that the level of digital economy development in the Yangtze River Delta region can inhibit and reduce environmental pollution. Chapter above has theoretically analyzed the internal mechanism of how digital economy development reduces environmental pollution and proposed corresponding research hypotheses. This paper argues that digital economy development can reduce environmental

pollution through public environmental supervision, but this hypothesis still needs to be verified through empirical analysis.

Therefore, referring to the common practices of mechanism testing in existing literature, this paper uses the mediation effect model constructed earlier to test the possible mechanism between digital economy development and environmental pollution. To ensure the accuracy of the mediation effect test and avoid endogeneity in the model, this paper draws on the approach of Jiang (2022) for causal analysis of mediation effects. Specifically, only the second step of the three-step test method is used to examine the mediation effect, focusing on the influence of the level of digital economy development on environmental pollution. The results are shown in Table 3.

It can be observed from Table 3 that the coefficient of the level of digital economy development affecting public environmental supervision is positive and significant at the 1% level, with a value of 0.2567. This indicates that for every 1% increase in the level of digital economy development, public environmental supervision will increase by 0.2567%. Therefore, digital economy development can inhibit environmental pollution by enhancing public environmental supervision. Thus, research H2 is verified.

Table 3. Results of mediation effect test

VARIABLES	(1)	(2)
	POLLU	PES
DE	−3.739***	0.2567***
	(0.728)	(3.4200)
LNPGDP	3.021***	0.7757***
	(0.949)	(7.9393)
STR	4.122	0.2712
	(3.762)	(0.6992)
CON	−10.66***	0.4285
	(3.008)	(1.3821)
FDI	−29.11**	−4.4612***
	(12.81)	(−3.3767)
INN	−0.875**	0.0132
	(0.442)	(0.2900)
ROAD	−0.101**	−0.0235***
	(0.0434)	(−5.2485)
City	YES	YES
Year	YES	YES
_cons	22.63**	1.2038
	(9.745)	(1.1984)
N	492	492
R^2	0.923	0.3434

Standard errors in parentheses
* p < 0.1, ** p < 0.05, *** p < 0.01

V. Conclusion

Based on the panel data of 41 cities in the Yangtze River Delta region from 2011 to 2022, this paper analyzes the impact of digital economy development on environmental pollution in the region. The study proceeds as follows: firstly, a benchmark regression analysis is conducted to examine the effect of digital economy on environmental quality; secondly, endogeneity and robustness tests are performed; and finally, a mediation mechanism test (public environmental supervision) is conducted. The key findings are: The digital economy has an inhibitory effect on environmental pollution, and this conclusion remains valid after endogeneity and robustness tests. Public environmental supervision plays a mediating role in the mechanism of how digital economy development affects environmental pollution. Based on these findings, the following policy recommendations are proposed:

A. Strengthen the Emission Reduction Role of the Digital Economy

The digital economy, with data and technology at its core, has a significant inhibitory effect on environmental pollution, providing an opportunity to improve environmental quality. Therefore, efforts should be made to vigorously develop the digital economy. Firstly, actively promote the construction of digital technology infrastructure, accelerating the deployment of new digital infrastructure that supports digital technologies such as 5G base stations, cloud computing platforms, and IPV6 addresses. This includes upgrading gigabit fiber optic networks and building artificial intelligence public computing centers. Secondly, addressing the difficulties in monitoring and quantifying environmental pollution in the region, the government should establish an environmental governance platform based on digital visualization technology. This platform can provide real-time pollution data recording through gridded monitoring in different zones and blocks, enabling precise monitoring of environmental pollution in target areas across all time periods. Additionally, an environmental monitoring database should be created to ensure proper data collection, usage, and tracking. This not only secures data for future use and analysis but also solidifies the technical support for leveraging the digital economy's positive impact on environmental pollution reduction. Lastly, strengthen top-level design to provide macro-level guidance for the development of the digital economy in environmental pollution control.

B. Emphasize Public Satisfaction with the Environment

Utilize intelligent methods such as big data to promote environmental information disclosure and optimize channels for public participation in environmental governance. By converting increased public environmental concern into greater public environmental engagement, the non-mandatory supervision and restraint of enterprises and local governments can be enhanced.

Conflict of Interest

The author declares no conflict of interest.

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