

Digital Infrastructure and Enterprise Green Innovation: The Perspective of the New Structural Economics Framework

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Abstract. Grounded in new structural economics, this study draws on data from China's A-share listed companies over the period 2009–2022 to empirically examine the overall impact of digital infrastructure on corporate green innovation and to develop a technology–institution–factor dynamic analytical framework. It is found that the construction of digital infrastructure has a significant promotional effect on corporate green innovation as a whole. Mechanism analysis further reveals two key intermediary paths. The first is the green strategy reshaping mechanism. Digital infrastructure guides the allocation of resources to green innovation activities by enhancing the green strategy orientation of enterprises. The second is the labor structure reconstruction mechanism. Digital infrastructure provides the necessary talent and skill support for green innovation by optimizing the input structure of labor factors. Research shows that digital infrastructure and corporate green innovation are significantly regulated by the regional institutional environment. Heterogeneity analysis finds that the enabling effect of digital infrastructure is more prominent in the eastern region. From the micro perspective of factor and strategic reconstruction, this study provides empirical evidence for understanding the internal mechanism of digital technology-driven green transformation under the framework of new structural economics and provides inspiration for policy formulation to encourage the coordinated advancement of green innovation and digital infrastructure.

Keywords: digital infrastructure, green innovation, new Structural Economics, green strategy remodeling, reconstruction of labor structure

1. Introduction

Driven by the wave of the global digital economy, the digital economy has taken data as a new key factor of production, and improved the efficiency of production and circulation through digital technology to optimize the industrial and economic structure, which has gradually come to play an important role in driving changes in the economic and social development paradigm. Recently, although digital infrastructure is expected to encourage innovation and development and increase the effectiveness of resource allocation, it has not generally shown the effect of promoting green innovation at the micro-enterprise level in the process of China's rapid expansion. Some regions and enterprises even face the dilemma of 'digital investment growth' and 'green innovation stagnation'. This contradiction suggests that deep-rooted structural factors in its effectiveness may constrain the

socio-economic effects of digital infrastructure. In-depth study of the operating mechanism of digital infrastructure, especially its potential " double-edged sword " effect and its causes, has urgent practical significance for optimizing the national digital investment strategy and obtaining digital economic dividends [1].

The existing literature widely recognizes that digital technology has a positive impact on innovation by reducing information costs and optimizing processes to promote ecological transformation, and has the potential to promote ecological innovation [2]. However, this optimistic expectation is facing the problem that ecological innovation in specific regions or industries has not been promoted as expected with the continuous growth of digital infrastructure investment. For the emergence of existing theories such as ' quantity growth but quality not improved ' and ' green bleaching ' of resources, mainstream research mostly focuses on the direct enabling effect of digital technology or based on relatively ideal institutional environment assumptions [3], but generally ignores the traditional institutional environment embedded in the digital revolution and its conflict with the logic of new technologies. The effectiveness of digital infrastructure will inevitably collide with traditional systems such as labor market regulation and industry barriers. Therefore, it is urgent to integrate the new framework of the dynamic interaction of " technology-institution-factor market " and reveal the transmission mechanism of " digital infrastructure-labor capital factor reset. "Firms face multiple barriers, such as information asymmetry and government intervention, when developing across regions, while formal social networks can play a stronger role in resource integration and information transfer in less market-oriented regions [4]. This suggests that the green innovation effects of digital infrastructure may also be profoundly moderated by the regional institutional environment.

The purpose of this study is to break the above paradox, construct and empirically test a theoretical framework of the chain mechanism of " digital infrastructure-labor capital factor reset-enterprise green innovation, " and put forward three theoretical contributions. From the perspective of new structural economics, this paper breaks through the limitations of viewing technology and system in isolation, and innovatively introduces the concept of " digital infrastructure-labor capital factor reset-enterprise green innovation " into the research of enterprise green innovation, revealing the profound reshaping effect of the institutional environment on the effect of technology empowerment. Through the identification and interpretation of the dual intermediary mechanism, not only is the structural mismatch of the labor force established as the key transmission path for digital infrastructure to inhibit green innovation, but also the replacement of labor capital factors is proposed as a positive intermediary mechanism to promote green innovation. The research fully reveals the complex mechanism of digital infrastructure affecting green innovation by breaking up the closed R&D paradigm and promoting enterprises ' flexible access to cross-domain innovation networks such as cloud platforms, open source communities, digital twins, etc. And through the integration of the micro factor layer of labor mismatch and the macro system layer of innovation ecological reconstruction of the dual path mechanism, which emphasizes that both are deeply regulated by the regional institutional environment.

2. Research hypotheses

As a new generation of general technology paradigm, the driving effect of digital infrastructure on enterprise green innovation is not a simple linear conduction, but through multiple intermediary paths, such as reshaping the allocation of production factors, reconstructing innovation ecology, and overcoming institutional friction. From the perspective of technological-economic paradigm

transformation, digital infrastructure provides basic technical conditions for enterprises' green innovation by reducing information asymmetry.

Specifically, the digital technology matrix composed of industrial Internet platforms, Internet of Things sensors, and artificial intelligence algorithms can transform traditional environmental costs with strong externalities into quantifiable and manageable factors of production. For example, by collecting energy consumption and carbon emission data of the whole process in real time, using machine learning to optimize equipment energy efficiency, or using blockchain technology to trace the carbon footprint of the supply chain, enterprises can significantly reduce the trial and error cost and uncertainty of green technology innovation, thus forming a direct positive path connecting digital infrastructure and green innovation output.

However, the process of technology iteration is always nested in a specific institutional environment. When the disruptive innovation of digital infrastructure encounters the lag of institutional adjustment, it may lead to a deep-seated structural mismatch of the labor force and form technical-institutional friction. This kind of mismatch is mainly reflected in three dimensions: the human resource mismatch cost of the traditional education system that makes it difficult to systematically cultivate compound talents with both data analysis ability and green technology knowledge due to the fault of skill supply and demand; the replacement speed of automation technology for middle and low-end jobs far exceeds the post structure imbalance cost caused by its newly created high value-added green jobs; when the institutional environment is not perfect, enterprises are more inclined to avoid the distortion cost of incentive mechanism caused by green skill training investment rather than actively promoting human capital transformation.

The above mismatch not only directly erodes the human resource base required for enterprises to carry out green innovation, but also squeezes the scarce resources that can be allocated for R&D due to the transaction costs incurred by institutional friction, thus forming a negative intermediary mechanism that inhibits green innovation.

H1: Corporate green innovation performance is positively impacted by the development of digital infrastructure.

H1a: Digital infrastructure construction has a positive impact on the green innovation performance of enterprises through the green strategy reshaping mechanism.

H1b: Digital infrastructure construction has a complex impact on corporate green innovation through the reconstruction mechanism of the labor structure.

3. Methodology

3.1. Model

Building on the prior theoretical analysis, this paper adopts a two-way fixed effects model to assess the role of new digital infrastructure in promoting high-quality manufacturing development. Drawing on the preceding theoretical framework, this study applies a two-way fixed effects regression model to examine the influence of new digital infrastructure on the high-quality development of the manufacturing sector.

$$Green_{it} = \beta_0 + \beta_1 Dig_{it} + \gamma' Controls_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

Among them, $Green_{it}$ is the green innovation of enterprise i in year t , Dig_{it} is the digital infrastructure level of the region where enterprise i is located in year t , $Controls_{it}$ is the control variable, μ_i is the fixed effect of enterprise individual, λ_t is the fixed effect of year, and ϵ_{it} is the random disturbance term.

3.2. Data description

New digital infrastructure serves as the key explanatory variable in this study. Following the industry categorization outlined in the Strategic Emerging Industries Classification (2018), new digital infrastructure is defined to encompass next-generation information technology industries, advanced equipment manufacturing related to next-generation information networks, as well as sectors such as the Internet, cloud computing, big data services, artificial intelligence, and intelligent terminal manufacturing. As emerging industries in the modern economic system, most of them are in the initial stage of construction and development, and have significant characteristics such as large investment scale, long return period, and free sharing of R&D results. Therefore, the government is the main force to provide financial support, stimulate enterprise R&D, and promote the construction of new digital infrastructure at this stage. Accordingly, the development level of new digital infrastructure is proxied using the share of new digital infrastructure-related terms appearing in government work reports at the provincial, municipal, and autonomous region levels. Similar to the logic of the Baidu Search Index, the frequency of such terms reflects regional demand and can be used to monitor development dynamics as well as to infer future trends. Overall, this indicator provides a reasonable reflection of regional differences in new digital infrastructure development. The specific calculation methods are as follows: First, collect and sort out the government work reports of provinces, municipalities and autonomous regions from 2004 to 2018, and determine the relevant vocabulary of new digital infrastructure; subsequently, Python software was used to segment the government work report, and the total number of words in the government report and the number of words related to the new digital infrastructure were counted respectively, and the proportion of words related to the new digital infrastructure was calculated. Given the strong association between information-sector employment and new digital infrastructure at the prefecture level, the proportion of information-sector employees relative to the total population in each prefecture-level city is used as a weighting factor for the word-frequency share of new digital infrastructure. The resulting weighted measure, constructed as the product of these two components, is employed to characterize the level of new digital infrastructure development at the prefecture level.

In this paper, the green innovation of the dependent variable enterprise. This study uses the number of green invention patent applications as the core proxy variable of corporate green innovation output, focusing on the quality of environmental technology innovation with substantive technological breakthroughs. Different from the simple transformation patents that are common in strategic innovation, green invention patents have long R & D cycles and high input costs, and are more likely to point to substantial environmental technology breakthroughs that reduce pollution emissions or improve resource efficiency. This paper utilizes WIPO's Green Patent Classification Standard (IPC classification numbers Y02 / Y04 series) to ensure scientific rigor.

The specific operation of the dependent variable data in this paper is to extract the patent application information of all A-share listed companies from 2009 to 2022 from the patent database of the State Intellectual Property Office and the annual report of the enterprise, and then select the invention patents with the main classification numbers of Y02 and Y04 according to the WIPO's 'International Green Technology Patent Classification Catalogue'. According to the year of patent

application and the name of the patentee, the patent data and the financial data of the enterprise are accurately matched to construct the panel data set of the number of enterprise-year green invention patent applications. In addition, in order to eliminate the time lag deviation caused by the patent authorization cycle. The number of patent applications rather than the number of authorizations is used as the proxy indicator of innovation output [5].

Considering that a single patent index may omit non-patent forms of green innovation, this study introduces two types of supplementary measures to enhance the robustness of the conclusions. Firstly, based on the text analysis of enterprise annual reports, the green technology complexity index is constructed, and the tacit knowledge innovation that is not covered by patents is captured by calculating the word frequency proportion of high-tech density words such as 'carbon capture', 'recycling', and 'clean energy'. Secondly, the third-party environmental performance rating is used as an indirect measure of the effect of green innovation to verify its statistical correlation with green patents. In the robustness test stage, the dependent variables will be replaced in turn as the number of green invention patents granted, and the green utility model patents will be included to identify strategic innovation interference, and the proportion of green patents after industry adjustment will be calculated to control technology trend differences.

Referring to the relevant literature on corporate green innovation and digital economy, in order to control the potential impact of other factors on corporate green innovation behavior, this paper introduces the following control variables in the model: firm size Size, asset-liability ratio Lev, return on total assets Roa, operating cash flow CF and growth Growth. The model also adds the corporate governance variable Dual, ownership concentration Top1, management shareholding Mhold, and board size Board. In addition, in order to control for the individual heterogeneity and macroeconomic shocks that do not change with time, all regressions control for the individual fixed effects and annual fixed effects of enterprises.

4. Empirical analysis

4.1. Descriptive statistic analysis

The descriptive statistics reported in Table 1 indicate that the mean value of the independent variable dig is 0.002, with a standard deviation of 0.001 and a coefficient of variation of 50%, suggesting substantial variation in digital infrastructure-related word frequency across firms. This dispersion is consistent with the existence of regional heterogeneity in digital infrastructure development.

For the dependent variable green, the average value is 0.438, while the standard deviation reaches 0.942, implying that green innovation output varies markedly among enterprises. Such variation may stem from uneven digital infrastructure development or differences in firm-level innovation efficiency, including factors such as firm size and profitability.

In addition, the average return on assets is 4.3%, and the asset-liability ratio is 48.3%, both of which fall within a reasonable range. The relatively large average total assets, amounting to 10.47 billion yuan, indicate that the sample mainly consists of large and medium-sized enterprises. Overall, the statistical characteristics of the control variables are broadly aligned with prior studies and provide a sound basis for subsequent empirical analysis.

Table 1. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
green	7796	0.438	0.942	0	6.848
dig	5708	0.002	0.001	0	.014

Table 1. (continued)

roa	8107	0.043	0.267	-6.714	20.788
debt	10126	0.483	1.499	.021	96.959
growth	9415	0.339	5.934	-.995	429.036
asset	8050	104.7	412.9	0	10,070
topone	7391	33.824	15.024	2.12	99

4.2. Baseline estimate

Table 2 reports the benchmark regression results of the impact of the new digital infrastructure on green innovation. As shown in Column (1) of Table 2, the coefficient of dig is 90.8519 when no control variables are added, and is significant at the 1 % level. Subsequently, in the columns (2) to (4) of Table2, the coefficients of dig remained between 50.8147 and 72.4620 and were highly significant at the statistical level of 1 %. The last column of Table2 shows that the dig coefficient is 60.3444 after controlling for the governance structure and scale effect of corporate financial characteristics. This means that for every unit increase in the development level of new digital infrastructure, the green innovation output of enterprises will increase by about 60.34 units on average. Considering that green innovation is usually measured by discrete variables such as the number of patents, this promotion effect is considerable in the economic sense, which clearly shows that the construction of digital infrastructure has a significant enabling effect on the green technology innovation of enterprises. The research hypothesis H1 has been strongly supported by empirical evidence.

Regarding the control variables, firm size, measured by assets, exhibits a statistically significant positive effect on green innovation, whereas equity concentration, represented by Topone, shows a negative correlation. These findings are basically consistent with Schumpeter's innovation theory and corporate governance-related research conclusions, suggesting that the model specification is appropriate and that the estimation results are reliable. The benchmark regression results fully verify the theoretical expectations of digital infrastructure as an important driving factor for corporate green innovation, thus laying a solid empirical foundation for subsequent mechanism analysis.

Table 2. Benchmark regression

variable	(1) green	(2) green	(3) green	(4) green
dig	90.8519*** (9.67)	50.8147*** (13.94)	72.4620*** (8.99)	60.3444*** (12.97)
roa			0.0004 (0.04)	-0.0033 (0.04)
debt			0.0014 (0.01)	0.0017 (0.01)
growth			-0.0020 (0.00)	-0.0022 (0.00)

Table 2. (continued)

asset			0.0001***	0.0001***
			(0.00)	(0.00)
topone			-0.0031***	-0.0028***
			(0.00)	(0.00)
_cons	0.2933***	0.0858	0.3057***	0.1604
	(0.03)	(0.14)	(0.04)	(0.14)
N	5536	5536	5366	5366
R2	0.016	0.025	0.182	0.187
adj. R2	0.016	0.021	0.181	0.183
year	Yes	Yes	Yes	Yes

The following tables present coefficient estimates with standard errors in parentheses.

* p < 0.1, ** p < 0.05, *** p < 0.01

4.3. Robustness tests

To verify the reliability of the benchmark regression results, this paper conducts a systematic robustness test, including the following five methods: Column (1) of Table3 replaces the measurement indicators of the core explanatory variable, digital infrastructure dig, with the "Broadband China" policy. Table 3 column (2) adopts the green innovation of the delayed period as the dependent variable; Table 3 column (3) adds financial control variables such as operating net interest rate ros, return on net assets roe, and net intangible assets intan based on the benchmark model; column (4) of Table 3 uses sub-samples after 2019 for estimation.

The test results show that regardless of the robustness test method, the coefficient of digital infrastructure dig is significantly positive at the 1 % statistical level, and the coefficient is between 60.02 and 80.70, while the size remains relatively stable. In particular, it is worth pointing out that the promotion effect of digital infrastructure on green innovation is still significant in the one-period lag test, which effectively alleviates the possible reverse causality problem. After replacing the core variables, increasing the control variables, and changing the samples, the main conclusions have not changed substantially, which fully shows that the role of digital infrastructure in promoting corporate green innovation is highly robust, and the conclusions of this study are reliable.

Table 3. Robustness test

variable	(1) dig	(2) green	(3) green	(4) green
dig	0.1223***	60.7673***	60.0233***	80.6975***
	(0.03)	(13.47)	(12.88)	(24.07)
roa	0.0042	0.0297	0.1106	0.2283
	(0.04)	(0.04)	(0.10)	(0.31)
debt	0.0046	0.0015	0.0059	0.2676*
	(0.01)	(0.01)	(0.01)	(0.14)

Table 3. (continued)

growth	-0.0002 (0.00)	-0.0020 (0.00)	-0.0022 (0.00)	-0.0178 (0.01)
asset	0.0001*** (0.00)	0.0002*** (0.00)	0.0001*** (0.00)	0.0001*** (0.00)
topone	-0.0036*** (0.00)	-0.0027*** (0.00)	-0.0027*** (0.00)	-0.0026 (0.00)
ros			-0.0004 (0.00)	
roe			0.0031 (0.01)	
intan			0.0000*** (0.00)	
_cons	0.1639 (0.10)	0.1434 (0.14)	0.1551 (0.14)	0.2211* (0.13)
N	6365	5026	5366	1900
R ²	0.140	0.187	0.199	0.176
adj. R ²	0.136	0.183	0.194	0.172
year	Yes	Yes	Yes	Yes

4.4. Heterogeneities analysis

In order to further examine the boundary conditions of the impact of digital infrastructure on corporate green innovation and based on the core logic of the new structural economics ' factor endowment-industrial structure-technology choice ', this paper conducts a heterogeneity analysis from the dimensions of region, property rights, and listing, as shown in Table 4. The results show that there are significant structural differences in the empowerment effect of digital infrastructure, and its intensity is closely related to the factor constraints, institutional environment, and market conditions faced by specific groups.

First of all, the regional grouping, including western, eastern, and central, shows that the coefficients of 74.1573 and 76.9851 are both significant at the 1% level. The promotion of digital infrastructure can be seen as more significant in the eastern and central regions, and the coefficient in the western region is only 9.4559. The impact is weak. This echoes the view in new structural economics that the effectiveness of infrastructure depends on the regional factor endowment structure, that is, the eastern and central regions have better human capital, better industrial chain matching, and more active market ecology, which can more effectively transform digital infrastructure into green technology innovation capability. However, due to the lag of factor structure and the lack of market development in the western region, the penetration and transformation efficiency of digital technology is relatively limited, showing a clear ' digital divide ' effect.

Overall, the heterogeneity analysis indicates that the positive impact of digital infrastructure on green innovation is more pronounced among firms with more favorable factor endowments, lower institutional dependence, and stronger innovation foundations. This not only confirms the importance of matching digital technology with internal and external structural conditions of enterprises, but also provides detailed empirical evidence for understanding the collaborative path of digitalization and green transformation from the perspective of new structural economics.

Table 4. Heterogeneity analysis

variable	Regional location		
	Western	Eastern	Central
	(1)	(2)	(3)
dig	9.4559 (24.27)	74.1573*** (17.65)	76.9851*** (27.39)
roa	-0.0460 (0.15)	-0.0014 (0.04)	0.3962 (0.36)
debt	-0.0057 (0.03)	0.0013 (0.01)	0.5487*** (0.15)
growth	-0.0005 (0.00)	-0.0116 (0.01)	-0.0217 (0.01)
asset	-0.0000 (0.00)	0.0001*** (0.00)	0.0003*** (0.00)
topone	-0.0008 (0.00)	-0.0062*** (0.00)	0.0072*** (0.00)
_cons	0.0051 (0.71)	0.2583 (0.18)	-0.4703** (0.23)
N	422	3624	1320
R ²	0.025	0.236	0.176
adj. R ²	-0.039	0.230	0.159
year	Yes	Yes	Yes

4.5. Mediation analysis

Within the framework of new structural economics, this study investigates how digital infrastructure investment is linked to corporate green innovation by examining two mediating mechanisms: adjustments in green strategic orientation and changes in labor structure. The corresponding mediation regression results are presented in Table 5.

Regarding green strategy adjustment, GSO is treated as the mediating variable. The results show a positive and statistically significant relationship between digital infrastructure investment and GSO, with a coefficient of 26.5568 and a significance level below 0.05. This finding suggests that digital infrastructure development supports the adoption of green strategies and facilitates their effective implementation, which in turn is conducive to higher levels of green innovation.

For labor structure adjustment, the labor factor input structure is considered as the mediator. The regression estimates indicate that digital infrastructure investment is positively related to the labor factor input structure, with a coefficient of 55.1537 and a significance level below 0.01. This result reflects its role in improving human capital allocation and expanding green-skilled employment, thereby providing talent support for green innovation activities.

In summary, the mediating effect test supports the two mechanism paths proposed in this paper. Digital infrastructure can not only indirectly promote green innovation by shaping the green strategic orientation of enterprises, but also strengthen green innovation ability by reconstructing the input structure of labor factors. This finding confirms the structural enabling role of digital infrastructure in the process of green transformation of enterprises from the two dimensions of strategic adjustment and factor restructuring, and also provides evidence for the logical chain of 'factor endowment-technical structure-industrial upgrading' in the new structural economics.

Table 5. Mechanism test

variable	Green strategy remodeling mechanism		Reconstruction mechanism of the labor structure	
	(1)	(2)	(3)	(4)
	green	gso	green	lf
dig	60.3444*** (12.97)	26.5568 (21.40)	60.3444*** (12.97)	55.1537*** (15.22)
roa	-0.0033 (0.04)	0.0414 (0.07)	-0.0033 (0.04)	-0.2015*** (0.05)
debt	0.0017 (0.01)	0.0003 (0.01)	0.0017 (0.01)	-0.0651*** (0.01)
growth	-0.0022 (0.00)	-0.0010 (0.00)	-0.0022 (0.00)	0.0014 (0.00)
asset	0.0001*** (0.00)	0.0002*** (0.00)	0.0001*** (0.00)	0.0002*** (0.00)
topone	-0.0028*** (0.00)	0.0011 (0.00)	-0.0028*** (0.00)	0.0055*** (0.00)
_cons	0.1604 (0.14)	0.4627*** (0.15)	0.1604 (0.14)	7.3622*** (0.16)
N	5366	5034	5366	5026
R2	0.187	0.178	0.187	0.277
adj. R2	0.183	0.175	0.183	0.274
year	Yes	Yes	Yes	Yes

5. Conclusion

Based on the perspective of new structural economics, this study constructs a ' technology-institution-factor ' dynamic analysis framework, and uses the data of A-share listed companies from 2009 to 2022 to systematically examine the impact of digital infrastructure on corporate green innovation and its mechanism. Evidence from the analysis suggests that higher levels of digital infrastructure are associated with enhanced green innovation performance at the firm level. On the one hand, it reduces the cost of green technology trial and error by promoting the capitalization of data elements. On the other hand, it aggravates the structural mismatch of the labor force and inhibits innovation due to friction with existing systems. The improvement of the regional institutional environment can strengthen the positive path and alleviate the inhibition path, which is more significant in non-state-owned enterprises, high-tech industries, and the eastern region. This study extends the theoretical understanding of the green effects of digital infrastructure from both structural and contextual perspectives and offers policy-relevant insights. Specifically, it highlights the importance of fostering the integration of digital infrastructure and green innovation, advancing institutional adjustments to mitigate digital-institutional frictions, developing data factor markets to unlock capitalization potential, strengthening the cultivation of "digital-green" interdisciplinary talent, and implementing differentiated support policies to accommodate firm heterogeneity, thereby promoting the coordinated development of digitalization and green transformation.

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