

Original Paper

The Impact of Digital Infrastructure on Enterprise Green
Innovation—A Quasi-Natural Experiment Based on the
Broadband China Strategy

Tingfei Che¹

¹ Gansu University of Political Science and Law, School of Economics, Lanzhou, Gansu, China

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Abstract

Under the background of the deep integration of the “dual-carbon” strategy and the digital economy, digital infrastructure has become a key support for driving enterprise green innovation. This paper uses the “Broadband China” pilot policy as a quasi-natural experiment, and based on data from A-share listed companies in Shanghai and Shenzhen from 2007 to 2024, uses a multi-period difference-in-differences model to empirically examine the impact, transmission mechanism, and heterogeneity characteristics of digital infrastructure construction on enterprise green innovation. The study finds that the “Broadband China” policy significantly improves the level of enterprise green innovation; benchmark regression shows that the policy shock increases enterprise green innovation by an average of 7.4%; endogeneity treatment and multiple robustness tests verify the reliability of the conclusions. Mechanism analysis shows that digital infrastructure empowers green innovation through a dual path of promoting enterprise digital transformation and driving regional digital finance development. Heterogeneity analysis shows that this promoting effect is more significant in manufacturing, state-owned enterprises, and growth-stage enterprises. This paper provides causal identification evidence for the integration of digital infrastructure and green innovation, enriches the theoretical connotation of the digital economy driving low-carbon transformation, and provides empirical support for accurately promoting digital infrastructure and enterprise green development.

Keywords

Broadband China, Enterprise Green Innovation, Difference-in-Difference Model

1. Introduction

Green innovation is the core path for enterprises to achieve low-carbon transformation, enhance

long-term competitiveness and sustainable development capabilities. It is also the micro-foundation for promoting the transformation of my country's economic development mode, overcoming resource and environmental constraints, and implementing the "dual-carbon" strategic goal. Currently, global green competition is fierce, and resource and environmental pressures are significant. Enterprises should no longer passively choose compliance, but rather proactively develop technological advantages and expand their market space to achieve high-quality development (Xie, 2022). Green innovation can promote cleaner production processes, more efficient energy use, and lower-carbon product supply. While reducing pollution emissions and improving resource efficiency, it creates new value growth points for enterprises, serving as a key support for enterprises to balance economic, environmental, and social benefits (Yang, 2026). The National 15th Five-Year Plan clearly places green and low-carbon transformation and the deep empowerment of the real economy by digital technology in a prominent strategic position, proposing to strengthen the leading role of enterprises in innovation, guide enterprises to increase investment in green technology research and development, promote innovation in green products, green processes, and green management, and build a green innovation system centered on enterprises. The plan also emphasizes accelerating the construction of digital infrastructure, focusing on 5G, big data centers, industrial internet, and computing networks, promoting the deep integration of digital technology with green and low-carbon industries, driving green development with digitalization, and leading digitalization with green development, providing modern infrastructure support and a technologically empowering environment for enterprise green innovation. This series of deployments points the way for digital infrastructure to empower enterprise green innovation and provides important policy basis and practical background for this study.

As the concept of green development continues to deepen, the strategic value of enterprise green innovation is becoming increasingly important. However, multiple obstacles still exist in its practical implementation. On the one hand, enterprises generally face the dilemma of high R&D costs, long R&D cycles, and significant innovation risks in carrying out green innovation, resulting in significant issues of funding constraints and return mismatch (Li & Zheng, 2016). On the other hand, information asymmetry exists in the field of green technology, and the channels for knowledge spillover transmission are not smooth enough, further reducing the overall efficiency of multi-entity collaborative green innovation (Gu et al., 2018). Furthermore, traditional production and management models are highly rigid, resulting in low efficiency in the transformation of green technologies from R&D to practical application (Li & Xiao, 2020). Meanwhile, small and medium-sized private enterprises (SMEs) suffer from insufficient resource reserves and weak comprehensive capabilities, further exacerbating their lack of both motivation and capacity in green innovation (Feng, 2020).

Digital infrastructure construction can effectively address various practical challenges faced by enterprises in green innovation, providing an important path for overcoming development bottlenecks. As the fundamental hardware support for the development of the digital economy, digital infrastructure can break through the spatial and temporal constraints of traditional development models, promoting

the efficient flow and rational allocation of core innovation elements such as data, technology, and knowledge, thereby reducing the information acquisition costs and market transaction costs for enterprises in the process of carrying out green innovation (Meng & Zhu, 2025). This type of infrastructure can help enterprises complete the digital upgrade of the entire chain of R&D, production, and operation, thereby improving the R&D level and efficiency of practical results transformation of green technologies (Huang et al., 2019). It can also provide an operational foundation for application scenarios such as digital financial services, intelligent environmental supervision, and industrial chain collaborative development, alleviating external financing pressure on enterprises while strengthening the incentive role of green innovation and improving the precision of regional environmental governance (Tang et al., 2020). Relying on deep technological penetration, cross-entity network linkage, and massive data empowerment, digital infrastructure can help enterprises promote green innovation practices from a holistic perspective, cultivating new momentum for regional green, low-carbon, and sustainable development (Meng, Zhu, Huang et al., 2025).

This paper uses the “Broadband China” pilot policy as a quasi-natural experiment. Based on data from A-share listed companies in Shanghai and Shenzhen from 2007 to 2024, it uses a multi-period difference-in-differences model to empirically examine the impact of digital infrastructure construction on enterprise green innovation. Based on benchmark regression, it uses instrumental variable methods, propensity score matching, and Heckman two-stage methods to alleviate endogeneity issues, and conducts a series of robustness tests, including parallel trend tests, placebo tests, and substitution variables. This paper further reveals the inherent transmission mechanism through two paths: enterprise digital transformation and regional digital finance development. It also conducts heterogeneity analysis from dimensions such as industry, ownership structure, and enterprise lifecycle to comprehensively identify the effects, mechanisms, and differences in how digital infrastructure empowers enterprise green innovation.

The marginal innovations and contributions of this paper are mainly reflected in three aspects: First, it identifies causal relationships using the exogenous policy shock of “Broadband China,” effectively mitigating endogeneity issues such as two-way causality and omitted variables, providing more reliable causal evidence for digital infrastructure and enterprise green innovation. Second, it reveals a dual-mediation transmission mechanism through enterprise digital transformation and regional digital finance development, connecting the logical chain of “digital infrastructure—micro-transformation—financial empowerment—green innovation,” deepening the theoretical understanding of how the digital economy drives green development. Third, it conducts heterogeneity tests from multiple dimensions including industry, ownership, and lifecycle to identify the differences in policy effects, providing empirical support for precise policy implementation and categorized promotion of the integration of digital infrastructure and green innovation, enriching micro-level empirical research in the field of digital economy and green development.

2. Literature Review and Research Hypotheses

(I) Theoretical and Effect Research on Digital Infrastructure Digital infrastructure is a crucial cornerstone for the development of the digital economy. Existing research mainly focuses on its definition, economic effects, green effects, and transmission pathways, constructing research systems from different levels. The academic community has largely reached a consensus on the connotation of digital infrastructure, namely, it is centered on digital technology, uses data as a production factor, and uses networks as a carrier, encompassing three major categories: information infrastructure, integrated infrastructure, and innovative infrastructure (Ma et al.; Sheng et al., 2019). Information infrastructure forms the core layer, including 5G base stations, big data centers, fiber optic broadband, and the industrial internet; integrated infrastructure relies on digital technology to transform traditional infrastructure; and innovative infrastructure supports the research and development and breakthroughs in digital technology. Early studies often used policy dummy variables such as the “Broadband China” pilot program and smart city pilot programs as proxy indicators (Lü, 2024). Later studies gradually constructed a comprehensive indicator system covering dimensions such as infrastructure investment, technology penetration rate, computing power scale, and network coverage (Donaubauer et al., 2016; Wu et al., 2021). Existing measurement methods still suffer from the problem of limited dimensions, making it difficult to distinguish the differentiated impacts of different types of digital infrastructure (Lin et al., 2023).

Digital infrastructure can significantly promote high-quality urban development and industrial upgrading. Ma Qian et al., based on a progressive difference-in-differences model, confirmed that digital infrastructure improves urban development quality through knowledge flow mechanisms, exhibiting a positive spatial spillover effect, which is more pronounced in urban clusters such as the Yangtze River Delta and the Pearl River Delta. Wu H, using panel data from Chinese prefecture-level cities, found that digital infrastructure construction drives industrial upgrading through technological innovation and specialization agglomeration effects, with stronger effects in eastern regions and cities with larger economies. Donaubaauer et al. constructed a global infrastructure index, finding that digital infrastructure construction can enhance national trade openness, providing international evidence from a macro perspective. At the enterprise level, digital infrastructure promotes low-carbon transformation by enhancing organizational innovation capabilities, strengthening senior management’s environmental awareness, and increasing green finance support (Dong et al., 2023). At the same time, it optimizes corporate ESG performance by increasing government environmental attention, enhancing enterprises’ willingness to fulfill their responsibilities, and improving information transparency.

(II) Research on Driving Factors of Enterprise Green and Low-Carbon Development Enterprise green and low-carbon development, centered on green innovation, low-carbon production, and emission reduction, is a sustainable development model that balances economic, environmental, and social benefits. Existing research has systematically analyzed its core connotations, influencing factors, and mechanisms of action. The core of enterprise green and low-carbon development is green innovation,

mainly encompassing green products, processes, and management innovation. Related studies often use indicators such as green patent applications and authorizations, green total factor productivity, and carbon emissions as proxy variables (Qiao et al., 2024). Some studies also measure differences in innovation quality by distinguishing between green invention patents and utility model patents, but existing research still has certain shortcomings, such as neglecting non-patented green innovation and emphasizing quantity over quality (Liu et al., 2023).

Regarding core influencing factors, environmental regulation is an important external policy tool, mainly divided into market-based regulation and command-based regulation. Qi Shaozhou et al., based on the SO₂ emissions trading pilot program, found that market-based regulation can internalize environmental costs through price signals, stimulating green innovation in enterprises, with a more significant incentive effect on non-state-owned enterprises. Li Qingyuan et al. found that cost-driven regulations such as pollution discharge fees can promote green innovation, while environmental subsidies tend to create a crowding-out effect, weakening enterprises' motivation for independent innovation. The digital economy and digital transformation can directly drive enterprises' green innovation levels; enterprises with higher levels of digitalization produce richer green innovation outputs. Qiao et al. found that enterprise digital transformation empowers green innovation by optimizing internal management and enhancing technology absorption capabilities. Digital finance, relying on big data and blockchain technology, reduces information asymmetry, alleviates corporate financing constraints, and increases R&D investment to support green innovation. Liu et al. believe that these effects are more pronounced in economically underdeveloped regions and highly polluting industries. The digital economy optimizes the financial structure and improves credit availability, with the core being to provide financial security for green and low-carbon development by alleviating financing constraints. Furthermore, heterogeneous characteristics such as enterprise ownership, industry attributes, and technological level also have a significant impact. State-owned enterprises, technology-intensive enterprises, and enterprises in regions with higher environmental regulatory intensity show more significant improvements in green innovation. Enterprises in heavily polluting industries are also more sensitive to environmental regulations and digital empowerment.

(III) The Mechanism of Digital Infrastructure's Role in Enterprise Green Innovation Digital infrastructure, relying on technological penetration, network coverage, and computing power support, lowers the technological threshold for enterprises' low-carbon production and green innovation, thereby improving the efficiency of enterprise green innovation. Dong Yuanxiang et al. found that digital infrastructure significantly promotes enterprises' carbon reduction transformation; Lü Dan believes that digital infrastructure construction can enhance enterprises' green innovation capabilities and ESG levels. From a municipal perspective, digital infrastructure promotes the agglomeration of green technology innovation, further radiating and driving enterprises' green and low-carbon behaviors (Song et al., 2022); from an enterprise perspective, digital infrastructure supports digital transformation, promoting the decarbonization of production processes and the greening of R&D processes (Qiao et al.,

2024). Based on the mechanism verification conclusions of this paper, the transmission path of digital infrastructure to enterprise green innovation can be summarized into two core paths: the digital transformation intermediary mechanism and the digital finance transmission mechanism, further refining the existing transmission mechanism research: The popularization and improvement of digital infrastructure will penetrate into enterprise R&D innovation, production operation, low-carbon management, and other aspects, promoting enterprise digital transformation and thus driving the improvement of green innovation levels. Lin Yu'en and Wen Xuezhou pointed out that digital infrastructure has a positive driving effect on enterprise green innovation, with digital transformation playing a key intermediary role in this process. Digital infrastructure construction accelerates enterprise digital transformation, optimizes resource allocation, reduces innovation costs, and improves the efficiency of green patent commercialization, ultimately driving a steady improvement in enterprises' green innovation capabilities. This path validates that digital infrastructure achieves incremental breakthroughs in green innovation by transforming enterprise micro-operational models and empowering technology absorption and R&D collaboration (Qiao et al., 2024).

Digital finance is a product of the deep integration of finance and digital technology. The digital finance system is highly compatible with underlying digital infrastructure technologies, enabling it to overcome spatial and temporal constraints through data fusion, facilitating the cross-entity flow and sharing of green knowledge, and amplifying the empowering effect of digital technology on enterprises' green innovation process (Xiao et al., 2024). Yu Huan et al. proposed that regions with high digital finance endowments will more strongly amplify the promoting effect of digital infrastructure on enterprises' green innovation compared to regions with lower levels of digital finance development. Digital infrastructure, as the underlying support for the development of digital finance, can significantly improve the level of regional digital finance development. This, in turn, provides financial security for enterprises' green innovation by alleviating financing constraints and increasing investment in green R&D (Liu et al.; Jiang et al., 2022). This chain-like transmission path has been effectively verified empirically.

Simultaneously, the construction of digital infrastructure can greatly break down geographical limitations, promote the flow of innovative elements such as knowledge, technology, and data, and enhance enterprises' technology absorption capacity and R&D efficiency. Wu et al. pointed out that digital infrastructure construction provides support for green and low-carbon technology R&D through technological innovation effects; Lin Peng et al. confirmed that digital infrastructure construction optimizes the allocation of industrial production factors and improves the efficiency of green industrial development. Digital infrastructure construction can effectively improve the accuracy and intelligence of environmental supervision, strengthen the enforcement of environmental regulations, and force enterprises to undergo green and low-carbon transformation. Dong Yuanxiang et al. found that strict environmental supervision amplifies the carbon reduction effect of digital infrastructure construction; Li Qingyuan et al. pointed out that market-based regulation and digital technology collaboration can

more effectively stimulate green innovation.

Based on the above analysis, this paper proposes the following:

Hypothesis 1: The digital infrastructure construction brought about by the “Broadband China” policy can significantly improve the green innovation level of enterprises, and the two are positively correlated.

Hypothesis 2: Digital infrastructure improves the green innovation level of enterprises by promoting their digital transformation.

Hypothesis 3: Digital infrastructure improves the green innovation level of enterprises by promoting regional digital finance development.

3. Institutional Background and Research Design

(I) Institutional Background

Under the dual strategic guidance of global digital transformation and China’s green and low-carbon economic development, digital infrastructure has become a core support for driving industrial upgrading and empowering green innovation. From an international perspective, major economies such as the United States, the European Union, and Japan have all incorporated high-speed broadband networks into their national strategic layouts, promoting the deep integration of digital infrastructure and green technology innovation through top-level design, attempting to gain a first-mover advantage in global low-carbon competition and the digital economy wave. Digital infrastructure is not only a physical carrier of information transmission, but also a key channel for the flow of innovative elements, the spillover of technological knowledge, and green R&D collaboration. Its construction level directly determines a country’s green innovation efficiency and the speed of industrial low-carbon transformation. Against this backdrop, the State Council officially issued the “Broadband China” strategy and implementation plan in 2013, explicitly defining broadband networks as a national strategic public infrastructure for the first time. This marked a new stage in my country’s broadband development, characterized by strategic guidance and systematic advancement. Since the “Broadband China” policy was proposed in 2013, the country has adopted a deployment model of “pilot projects first, phased advancement, and gradual expansion.” The Ministry of Industry and Information Technology and the National Development and Reform Commission jointly organized the review, and announced the list of “Broadband China” demonstration cities (city clusters) in three batches in 2014, 2015, and 2016, with 39 cities established in each batch. Ultimately, a pilot network covering 117 demonstration cities (city clusters) nationwide was formed, constructing a gradual advancement pattern of “demonstration at key points, online linkage, and overall coverage.” The pilot selection process strictly followed the procedures of “city application - provincial pre-review - expert review”, comprehensively considering the regional economic foundation, network construction conditions, demonstration and promotion value and regional balance. It covered developed cities in the east, central and western central cities, old industrial bases in the northeast and cities in ethnic minority areas, taking

into account both representativeness and exogenous factors, which provided good conditions for this paper to carry out quasi-natural experiments.

(2) Model setting

In order to explore the impact of digital infrastructure construction on corporate green innovation, this article introduces a quasi-natural experiment of the “Broadband China” pilot policy and uses the Difference-In-Difference (DID) model to conduct causal analysis. The specific model is constructed as follows:

$$\text{LnGreen_Invict} = \alpha_0 + \alpha_1 \text{policy}_{it} + \sum \theta \text{Control}_{ict} + \mu_i + \gamma_c + \lambda_t + \varepsilon_{ict} \quad (1)$$

Among them, i , c , and t represent the individual enterprise, the city and year where the enterprise is located respectively; the explained variable LnGreen_Invict measures the number of green applications of enterprises; the core explanatory variable policy_{it} is a policy impact dummy variable. If the city where enterprise i is located is affected by the “Broadband China” policy in year t , it is assigned a value of 1, otherwise it is 0; Control_{ict} is a series of control variables; μ_i is an enterprise fixed effect, which controls differences at the enterprise level; γ_c is a city fixed effect, which absorbs differences at the city level; λ_t is a year fixed effect, which excludes the impact of time changes; ε_{ict} is a random disturbance term.

(3) Variable definition

1. Explained variable: number of invention green patent applications (LnGreen_Inv)

The core of green innovation is to achieve win-win economic and environmental benefits through technological breakthroughs. As the patent category with the highest technological content and the strongest degree of innovation, invention patents can accurately depict the company’s substantive green innovation capabilities and effectively eliminate interference from strategic innovation. Li Wenjing and Zheng Manni stated in “Economy” Research” pointed out that the number of invention patent applications is a reliable indicator to measure the core innovation capabilities of enterprises. Wang Hongjian et al. (2021)’s research in “Economic Research” further verified that the number of green invention patent applications and authorizations can accurately reflect the true R&D strength of enterprises in the field of environmental protection technology, and its reliability is better than indirect indicators. The core explained variable, the enterprise’s green innovation level, is measured by the number of green invention patent applications (LnGreen_Inv). The number of enterprise’s green invention patents is added by 1 to take the natural logarithm.

2. Core explanatory variable: Broadband China policy (policy)

The core explanatory variable is the broadband China policy impact dummy variable, and a double difference (DID) identification index is constructed based on the policy’s gradual advancement characteristics. The list of “Broadband China” pilot cities published by the Ministry of Industry and Information Technology and the National Development and Reform Commission in three batches from 2014 to 2016 is based on whether the city where the company is registered is included in the pilot and the time of pilot implementation: if the city where the company is located is determined to be a pilot

city in the observation year, the policy value is 1 for that year and subsequent years; if the city where the company is located is not included in the pilot, or the observation year is earlier than the year when the pilot was approved, the policy value is 0. This variable is set through a quasi-natural experiment, which can effectively explore the net effect of digital infrastructure improvements brought about by the Broadband China policy on corporate green innovation, and the exogenous characteristics of the policy pilot can alleviate endogeneity problems and provide reliable support for the identification of causal relationships.

3. Control variables

In view of the large differences in the characteristics of different enterprises, with reference to existing research, the selected control variables include: asset-liability ratio (Lev), expressed as total liabilities divided by total assets; net profit margin on total assets (ROA), measured by the ratio of net profit to average total assets; net asset income ROE (ROE), expressed as net profit divided by average net assets; total asset turnover (ATO), measured as the ratio of operating income to average total assets; cash flow ratio (Cashflow), expressed as the ratio of net cash flow from operating activities to total assets; fixed assets accounted for (FI XED), used to measure the characteristics of an enterprise's asset structure. The calculation formula is the ratio of net fixed assets to total assets; the operating income growth rate (Growth), which reflects the company's growth momentum and market expansion speed; the shareholding ratio of the top five shareholders (Top5), used to measure the concentration of corporate governance and ownership structure characteristics; Tobin Q value (TobinQ), used to measure the market value and investment opportunities of a company, using the ratio of market value to replacement cost; List Age (ListAge), using the natural logarithm of the company's listing years, reflects the company's maturity and system standardization level.

4. Data sources and descriptive statistics

In order to explore the impact of Broadband China's policy on corporate green innovation, this article uses China's Shanghai and Shenzhen A-share listed companies from 2007 to 2024 as the initial research sample, and systematically screens and standardizes the original data. The specific process is as follows: ① Eliminate ST, *ST and PT companies during the sample period. Abnormally operating companies may lead to large differences between green innovation behavior and normal operating companies, thereby interfering with the validity of the empirical results; ② Observation samples with missing data on important indicators such as core explanatory variables, explained variables, and control variables are eliminated to ensure the integrity of sample information; ③ In order to avoid the biased influence of extreme values on the estimation results, all continuous variables are winsorized at the upper and lower 1% quantiles to effectively alleviate the interference caused by outliers. Taking into account the authority and reliability of the data, the data sources of this article are: ① Corporate green patent data (including the number of green patent applications and authorizations) mainly come from the CN/RDS database, which provides data support for accurate measurement of green innovation levels; ② Company-level control variable data are all from the Guotai'an Database (CSMAR).

After the above screening and processing, this article finally obtained 47,256 observations from 4,722 Shanghai and Shenzhen A-share listed companies, forming a balanced panel data structure. The descriptive statistical results of each main variable are shown in the table below.

Table 1. Descriptive Statistics

Variable	variable symbol	Observations	mean	standard deviation	minimum value	maximum value
Corporate Green Innovation	LnGreen Inv	47,256	0.609	1.027	0	7.197
Broadband China Policy	Policy	47,256	0.540	0.498	0	1
Asset-liability ratio	Lev	47,256	0.419	0.209	0.0274	0.935
Net profit margin on total assets	ROA	47,256	0.0387	0.0672	-0.375	0.255
return on net assets	ROE	47,256	0.0577	0.142	-1.005	0.462
total asset turnover ratio	ATO	47,256	0.638	0.442	0.0537	3.106
cash flow ratio	Cashflow	47,256	0.046	0.0696	-0.226	0.283
Proportion of fixed assets	FIXED	47,256	0.203	0.158	0.00160	0.769
operating income growth rate	Growth	47,256	0.147	0.386	-0.654	3.808
Shareholding ratio of top five shareholders	Top5	47,256	0.533	0.157	0.171	0.892
Tobin's Q value	TobinQ	47,256	2.005	1.298	0.789	16.65
Years on the market	ListAge	47,256	2.043	0.947	0	3.466

4. Empirical Analysis

(1) Baseline regression results

The following table shows the baseline regression results of the impact of digital infrastructure policies on corporate green innovation. Among them, columns (1) and (2) are the benchmark regression results. The results show that the estimated coefficient of the core explanatory variable policy is always significantly positive. After adding control variables, the estimated coefficient of digital infrastructure policy is 0.074 and is significant at the 1% level; the regression coefficient shows that compared with companies that are not affected by the policy, the implementation of digital infrastructure policies can significantly improve the level of green innovation output of companies. The average level of green innovation of companies affected by the policy increases by 7.4%. Column (3) is the regression result of further adopting a multi-dimensional and high-dimensional fixed effects model and absorbing multi-level fixed effects of year, city, and individual enterprise. After replacing the fixed effects setting, the coefficient size and significance of the core explanatory variables remain stable, and the benchmark regression results have good robustness. The benchmark model only controls individual, year, and

city-level fixed effects and cannot effectively capture time-varying regional policies at the province-year level that do not change with enterprises. Therefore, this paper further introduces province-time high-dimensional fixed effects to absorb all unobservable confounding factors that change with years at the province-level. The regression results are shown in column (4) of Table 2. After strictly controlling regional temporal variability, digital infrastructure still significantly promotes corporate green innovation, and the benchmark conclusion is robust and credible.

Table 2. Baseline Regression Results

Variable	(1)	(2)	(3)	(4)
	No control variables included	Include control variables	Multidimensional fixed effects	High-dimensional fixed effects
	LnGreen_Inv	LnGreen_Inv	LnGreen_Inv	LnGreen_Inv
Policy	0.073** (0.030)	0.074** (0.029)	0.074** (0.029)	0.076* (0.039)
Lev		0.336*** (0.054)	0.336*** (0.054)	0.340*** (0.054)
ROA		0.081 (0.160)	0.081 (0.160)	0.040 (0.160)
ROE		0.239*** (0.070)	0.239*** (0.070)	0.256*** (0.070)
ATO		-0.050* (0.030)	-0.050 (0.030)	-0.043 (0.030)
Cashflow		-0.063 (0.057)	-0.063 (0.057)	-0.070 (0.057)
FIXED		0.023 (0.077)	0.023 (0.077)	0.041 (0.077)
Growth		-0.012 (0.009)	-0.012 (0.009)	-0.012 (0.009)
Top5		0.294*** (0.092)	0.294*** (0.093)	0.319*** (0.093)
TobinQ		-0.026*** (0.004)	-0.026*** (0.004)	-0.024*** (0.004)
ListAge		-0.003 (0.017)	-0.003 (0.017)	-0.015 (0.018)
Constant term	0.569***	0.345***	0.345***	0.344***

	(0.016)	(0.076)	(0.076)	(0.078)
Time fixed effects	YES	YES	YES	YES
City fixed effects	NO	NO	YES	YES
Individual fixed effects	NO	NO	YES	YES
Time—province fixed effects	YES	YES	NO	YES
Observations	47,256	47,256	47,256	47,256
R2	0.697	0.700	0.700	0.706

Note. ***, **, and * indicate significance at the 1%, 5%, and 10% levels respectively, the same below.

(2) Endogeneity test

1. Instrumental variable method. Limited by objective factors such as urban endowment differences and non-random policy pilots, cities with higher levels of green innovation and better resource bases are more likely to be selected for the Broadband China pilot list. At the same time, improved digital infrastructure will continue to empower enterprises to innovate and upgrade green technologies. It can be seen that there is a typical two-way causal relationship between the impact of Broadband China policies and corporate green innovation. In order to ensure the accuracy of the research conclusions, this study refers to the research methods of Wang Qiao (2021) and Nunn and Puga (n.d.), using urban terrain relief as the exogenous instrumental variable of the interaction term of broadband China policy. On the one hand, urban terrain undulation is a natural endowment of geography, which directly determines the cost and difficulty of digital infrastructure construction. It is highly related to the probability of local broadband China pilot approval and the intensity of digital infrastructure construction, and strictly meets the instrumental variable correlation constraints. On the other hand, terrain undulation is an innate exogenous geographical condition and cannot directly affect corporate green innovation behavior. Therefore, this instrumental variable satisfies the two core assumptions of correlation and exclusivity at the same time.

Column (1) of Table 4 reports the first-stage regression results: there is a significant negative correlation between instrumental variables and Broadband China policy variables; the Kleibergen-Paap rk LM statistic is significant at the 1% level, rejecting the null hypothesis of insufficient identification of instrumental variables; the Kleibergen-Paap rk Wald F statistic is much greater than the critical value (16.38) at the 10% level of the Stock-Yogo test, effectively eliminating the problem of weak instrumental variables. Column (2) of Table 3 reports the second-stage regression estimation results: after mitigating endogenous problems such as bidirectional causality and omitted variables, digital infrastructure construction still has a significant positive effect on corporate green innovation, proving the robustness of the baseline regression.

2. Propensity score matching. Considering that there may be a self-selection bias between Broadband

China policy and corporate green innovation, this study uses the PSM-DID method to test the endogeneity of the policy impact effect. In the sample matching process, 1:1 nearest neighbor replacement matching is used to perform PSM matching. The matching test results are shown in column (3) of Table 3. The regression coefficients of Policy are all significantly positive, indicating that after controlling for endogeneity issues such as sample selection bias, digital infrastructure construction still has a significant role in promoting corporate green innovation, providing support for the robustness of the research conclusions.

3. Heckman two-stage test. In order to alleviate the problem of endogenous selection bias in the model, this paper uses the Heckman two-stage method for estimation. In the first stage, a probit selection equation is constructed to estimate the probability of enterprises carrying out green innovation activities, and the inverse Mills ratio (IMR) is calculated accordingly; in the second stage, the inverse Mills ratio is incorporated into the two-way fixed effect DID benchmark regression model to correct the sample selectivity bias. The regression results are shown in column (4) of Table 3. The inverse Mills ratio coefficient is significant, proving that there is an obvious self-selection problem in the sample; after controlling for selection bias, the core explanatory variables and significance have not changed substantially, and the conclusions of this benchmark study are still robust and reliable.

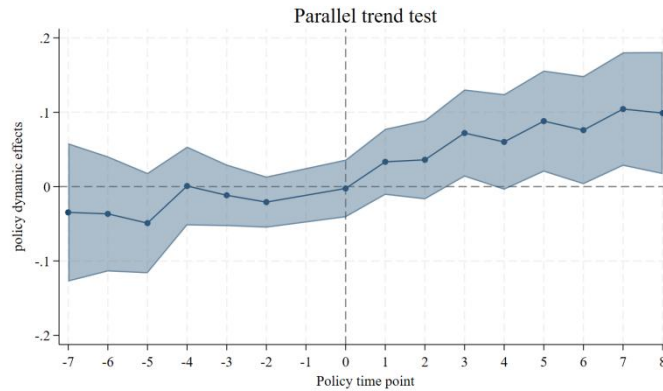
Table 3. Endogeneity Test

Variable	(1)	(2)	(3)	(4)
	First stage	Second stage	PSM-DID	Heckman
	Policy	LnGreen_Inv	LnGreen_Inv	LnGreen_Inv
IV	-0.075*** (0.010)			
Kleibergen-Paap rk LM	82.842***			
Kleibergen-Paap rk Wald F	54.700***			
Policy		0.538** (0.235)	0.060* (0.037)	0.915*** (0.089)
Lev	-0.002 (0.027)	0.872*** (0.069)	0.334*** (0.069)	3.651*** (0.317)
ROA	-.0389*** (0.110)	-0.029 (0.261)	-0.253 (0.237)	0.034 (0.157)
ROE	0.092** (0.044)	0.822*** (0.122)	0.335*** (0.102)	3.461*** (0.304)
ATO	-0.017* (0.008)	-0.049* (0.024)	-0.061 (0.031)	-0.215*** (0.078)

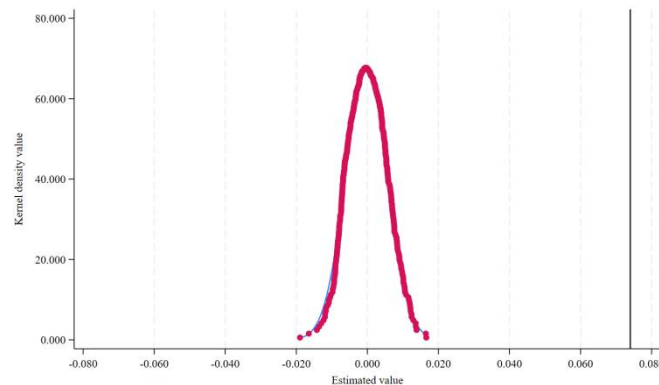
	(0.010)	(0.030)	(0.039)	(0.035)
Cashflow	0.017	0.157	0.084	-0.248***
	(0.042)	(0.110)	(0.090)	(0.059)
FIXED	-.300***	-0.112	0.000	-0.805***
	(0.032)	(0.113)	(0.095)	(0.109)
Growth	0.001	-0.019	-0.005	0.080***
	(0.005)	(0.014)	(0.015)	(0.012)
Top5	0.094**	0.293***	0.388***	-0.082
	(0.033)	(0.112)	(0.125)	(0.097)
TobinQ	0.010**	-0.066***	-0.033***	-0.368***
	(0.003)	(0.007)	(0.007)	(0.032)
ListAge	0.002	0.106***	0.004	0.312***
	(0.006)	(0.015)	(0.024)	(0.031)
IMR				5.683***
				(0.533)
Constant term			0.289***	-7.217***
			(0.104)	(0.710)
Time fixed effects	YES	YES	YES	YES
City fixed effects	NO	NO	YES	YES
Individual fixed effects	NO	NO	YES	YES
Observations	47128	47128	19,588	47,256
R2	0.033	0.048	0.657	0.670

(3) Robustness test

1. Parallel trend test. In order to ensure the validity of the benchmark regression results, the regression analysis in this article needs to meet the parallel trend condition. This article refers to Beck et al. [30] and uses the event study method to conduct parallel trend testing. It tests the parallel trend hypothesis by setting dummy variables before and after the “Broadband China” policy takes effect and deleting the period before the policy is implemented. As shown in the figure, before the policy was implemented, the dummy variable coefficients in each period were not significantly different from 0, and the treatment group and the control group met the premise assumption of parallel trends; after the policy came into effect, the treatment effect continued to increase from zero and was significant in the long term, indicating that the “Broadband China” policy has a continuously amplified positive long-term impact on corporate green innovation. This shows that the two groups of samples before the implementation of the policy basically meet the parallel trend assumption.



2. Placebo test. Drawing on the classic research paradigm of Li et al., this paper constructs a false policy impact through 500 repeated random samplings and conducts a counterfactual placebo test. It can be seen from the estimated coefficient kernel density distribution results that the regression coefficients of the false policy interaction term under random allocation are highly concentrated near the 0 value, and the overall distribution obeys the standard normal distribution characteristics. This verifies that the model in this article does not have endogeneity problems such as missing key variables and sample selection bias, and the core causal conclusion of the benchmark regression has good robustness.



3. Replace the explained variable. In the benchmark regression, the explained variable is the natural logarithm of the number of corporate green invention patent applications plus 1. This indicator focuses on reflecting the willingness and innovation activity of corporate green innovation R&D. In the robustness test, it is replaced by the natural logarithm of the number of corporate green invention patent authorizations plus 1. Patent authorization requires substantive review by the Intellectual Property Office, which can better characterize the high-quality and substantive green innovation output level of the company. The regression results are shown in column (1) of Table 4. After replacing the explained variable, the policy coefficient of the core explanatory variable is 0.049, which is significantly positive at the 5% statistical level. Therefore, the baseline regression results are still robust after the dependent variable is replaced.

4. Exclude samples from municipalities directly under the Central Government. The four major

municipalities are significantly different from ordinary prefecture-level cities in many aspects such as policy pilot layout and economic development level. Their special administrative levels may interfere with the causal identification results of benchmark regression and cause estimation errors. This article re-estimates the regression after excluding the samples of enterprises within the municipality area. The regression results are shown in column (2) of Table 4. After excluding the samples of the municipality, the coefficient of the core explanatory variable policy is significantly positive, which verifies the robustness of the benchmark regression results.

5. Eliminate extreme values. In order to avoid the interference of abnormal extreme values on the benchmark conclusion, this paper performs a two-sided 5% winsorization process (Winsorize) on all continuous variables and re-carries the benchmark model regression. The regression results are shown in column (3) of Table 4. The core explanatory variable policy regression coefficient is 0.066, which is significantly positive at the 1% statistical level. The results show that the positive effect of digital infrastructure pilot policies on promoting corporate green innovation is not driven by extreme outliers in the sample, and the benchmark regression results are still robust.

6. Eliminate the impact of the epidemic. The COVID-19 outbreak in 2019 has had a comprehensive exogenous impact on corporate production, operations, R&D and innovation activities, which will interfere with corporate green innovation output and may cause omitted variable bias in benchmark regression results. The regression results are shown in column (4) of Table 4. The baseline regression results are still robust after excluding the samples affected by the epidemic.

7. Eliminate interference from other relevant policies at the same time. In addition to the “Broadband China” policy, my country’s digital infrastructure-related pilots include national-level big data comprehensive pilot zones and low-carbon city construction policy pilots. Both types of policies will affect corporate green innovation behaviors. In order to clarify the net effects of core policies and avoid confusion between different pilot policies and interference with baseline estimates, this article simultaneously incorporates two types of national pilot policies into the regression model and separately identifies the independent effects of the dual policies. The regression results are shown in columns (5) and (6) of Table 4. After incorporating the big data comprehensive pilot area variable, the core explanatory variable policy coefficient is 0.068, which is significantly positive. After further incorporating the low-carbon city pilot variable, the core explanatory variable policy coefficient is 0.069, which is significantly positive. The results show that the baseline regression results remain robust after excluding other policy interferences.

Table 4. Robustness Check

Variable	(1)	(2)	(3)	(4)	(5)	(6)	
	Replace the explained variable	Remove municipalities	Eliminate extreme values	Exclude the impact of the epidemic	theBig data comprehensive pilot area variable	Low carbon urban policy	carbon

Time fixed effects	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES	YES	YES
Observations	47,256	36,947	47,256	26,363	47,256	47,256
R2	0.643	0.671	0.663	0.698	0.700	0.700

(4) Heterogeneity analysis

1. Industry heterogeneity. As China's high-quality economic development advances in depth, the manufacturing industry, as the core position of green innovation and digital transformation, assumes key functions in green process upgrading, low-carbon technology research and development, and pollution reduction transformation, and the space for integration with digital infrastructure is broader. In order to identify the differential impact of digital infrastructure in different industries, the sample was divided into two groups, manufacturing and non-manufacturing, to perform group regression. The regression results are shown in columns (1) (2) of Table 5. Compared with non-manufacturing industries, the broadband China policy has a more significant promotion effect on green innovation of manufacturing enterprises. The manufacturing industry has stronger demand for green innovation, greater space for process transformation, greater reliance on digital control and data-driven emission reduction, and prominent demand for industrial chain collaboration. Digital infrastructure can effectively reduce collaboration costs and improve green R&D efficiency. The non-manufacturing industry is dominated by service activities, the demand for green innovation is weak, and the marginal driving role of digital infrastructure is relatively limited.

2. Heterogeneity of property rights. Enterprises with different property rights have obvious differences in resource allocation, policy responses, and innovation goals. The effect of digital infrastructure on enterprise green innovation may be asymmetric. In order to test this difference, according to the attributes of the actual controller of the enterprise, the sample is divided into state-owned enterprises and non-state-owned enterprises for separate regression. The regression results are shown in columns (3) (4) of Table 5. The positive impact of the "Broadband China" policy on corporate green innovation is more prominent among state-owned enterprises. Although non-state-owned enterprises have a positive effect, the intensity of the effect is relatively weak. The possible reasons are: state-owned enterprises bear important responsibilities for green transformation and policy implementation, and respond more promptly and implement the "Broadband China" policy more promptly; non-state-owned enterprises face stronger market competition and financing constraints, and their short-term transformation efficiency is relatively low.

3. Life cycle heterogeneity. There are significant differences in the innovation motivation, resource

constraints and strategic orientation of enterprises at different life cycle stages, and the green innovation effect of digital infrastructure may change with the development stage. According to the corporate life cycle theory, the sample is divided into three groups: growth period, maturity period and decline period for group regression. The regression results are shown in columns (5) (6) (7) of Table 5. The “Broadband China” policy’s promotion of corporate green innovation is only significant in the growth stage, and the effect is not obvious in the maturity and decline stages. The possible reasons are: Enterprises in the growth stage have high enthusiasm for R&D and have great demand for digital technology and green processes. Digital infrastructure construction can help them reduce information barriers and ease financial pressure; companies in the mature stage and those in the decline stage have relatively fixed technologies and models, weak innovation motivation, and more capital investment is used to maintain daily operations.

Table 5. Heterogeneity Test

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Manufacturing	Non-manufactur	State-owned	Non-state-owne	Growth period	Mature stage	Recession
		ing	enterprises	d enterprises			period
	LnGreen_Inv	LnGreen_Inv	LnGreen_Inv	LnGreen_Inv	LnGreen_Inv	LnGreen_Inv	LnGreen_Inv
Policy	0.086** (0.037)	0.067 (0.046)	0.095** (0.048)	0.063* (0.035)	0.085** (0.035)	0.073 (0.056)	0.049 (0.053)
Lev	0.438*** (0.068)	0.107 (0.084)	0.406*** (0.110)	0.279*** (0.058)	0.345*** (0.068)	0.324*** (0.123)	0.270*** (0.078)
ROA	0.243 (0.212)	-0.267 (0.240)	0.568 (0.373)	-0.157 (0.189)	0.143 (0.237)	-0.261 (0.494)	0.116 (0.229)
ROE	0.165* (0.095)	0.346*** (0.101)	-0.003 (0.136)	0.331*** (0.091)	0.161 (0.109)	0.282 (0.179)	0.139 (0.094)
ATO	-0.102** (0.045)	0.015 (0.037)	-0.010 (0.051)	-0.059 (0.039)	-0.037 (0.038)	-0.074 (0.060)	-0.053 (0.045)
Cashflow	0.029 (0.072)	-0.260*** (0.085)	-0.119 (0.101)	-0.015 (0.069)	-0.171 (0.106)	-0.102 (0.237)	-0.013 (0.110)
FIXED	0.035 (0.089)	-0.151 (0.118)	-0.094 (0.135)	0.111 (0.085)	0.056 (0.087)	0.127 (0.203)	-0.202 (0.137)
Growth	-0.013 (0.015)	-0.001 (0.010)	-0.012 (0.015)	-0.005 (0.012)	-0.034*** (0.013)	0.016 (0.028)	-0.022 (0.016)
Top5	0.382*** (0.121)	0.140 (0.136)	0.464** (0.185)	-0.071 (0.107)	0.304*** (0.110)	0.044 (0.175)	0.263* (0.147)
TobinQ	-0.026***	-0.026***	-0.035***	-0.020***	-0.016***	-0.051**	-0.020***

	(0.006)	(0.007)	(0.011)	(0.005)	(0.006)	(0.021)	(0.007)
ListAge	-0.040*	0.081***	0.117**	0.033*	-0.044**	0.016	0.014
	(0.020)	(0.031)	(0.047)	(0.019)	(0.021)	(0.039)	(0.044)
Constant	0.364***	0.328***	0.045	0.392***	0.430***	0.418***	0.301**
term							
	(0.093)	(0.123)	(0.182)	(0.084)	(0.091)	(0.153)	(0.149)
Time	YES	YES	YES	YES	YES	YES	YES
fixed							
effects							
City fixed	YES	YES	YES	YES	YES	YES	YES
effects							
Individual	YES	YES	YES	YES	YES	YES	YES
fixed							
effects							
Observations	30,223	16,896	16,461	27,631	31,667	4,730	8,309
R2	0.714	0.716	0.745	0.666	0.730	0.740	0.739

(5) Mechanism analysis

1. The degree of digital transformation of enterprises. Referring to Wen Zhonglin's step-by-step test method for intermediary effects, the intermediary effect analysis was carried out. The popularization and improvement of digital infrastructure has penetrated into corporate R&D innovation, production operations, low-carbon management and other aspects, and has a certain positive effect on corporate green innovation models (Lin Yuen; Wen Wenzhou). This section uses the degree of digital transformation of enterprises as an intermediary variable to carry out mechanism testing. The regression results are shown in columns (1) and (2) of Table 6: The impact of broadband China policy significantly and positively promotes the digital transformation of enterprises, and at the same time, the improvement of the level of digital transformation can promote corporate green innovation. It shows that digital transformation plays a partial intermediary role in the process of digital infrastructure empowering corporate green innovation. Digital infrastructure construction drives the steady improvement of corporate green innovation levels by accelerating corporate digital transformation, optimizing factor allocation, reducing corporate innovation costs, and improving the efficiency of green patent achievement conversion. The specific model settings are as follows:

$$DIGI_text\ ict = \beta_0 + \beta_1\ policy\ it + \sum \theta\ Control\ ict + \mu\ i + \gamma\ c + \lambda\ t + \varepsilon\ ict \quad (2)$$

$$LnGreen_Inv\ ict = \beta_0 + \beta_1\ policy\ it + \beta_2\ DIGI_text\ ict + \sum \theta\ Control\ ict + \mu\ i + \gamma\ c + \lambda\ t + \varepsilon\ ict \quad (3)$$

2. Regional digital finance development level. Digital finance is the product of the deep integration of finance and digital technology. The digital financial system is highly compatible with the underlying

digital infrastructure technology. It can rely on data fusion to break through time and space constraints, facilitate the cross-subject flow and sharing of green knowledge, and amplify the enabling effect of digital technology on the green innovation process of enterprises (Xiao Renqiao, etc.). Compared with areas with low levels of digital finance development, areas with high digital financial endowment should be able to better amplify the role of digital infrastructure in promoting corporate green innovation (Yu Huan et al.). Therefore, this article incorporates digital financial development into the intermediary effect testing framework to explore its chain transmission effect. The regression results are shown in columns (3) and (4) of Table 6: Digital infrastructure construction has significantly improved the level of regional digital financial development, and digital financial development has a significant positive impact on corporate green innovation. This intermediary transmission path is established.

Table 6. Mechanism Test

variable	digital transformation		Digital financial development	
	(1)	(2)	(3)	(4)
	DIGI_text	LnGreen_Inv	Score	LnGreen_Inv
Policy	0.003*** (0.001)	0.056* (0.029)	0.010*** (0.002)	0.080*** (0.029)
DIGI_text		5.125*** (0.569)		
Score				-0.053 (0.052)
Lev	0.003* (0.001)	0.325*** (0.054)	-0.001 (0.004)	0.329*** (0.056)
ROA	-0.023*** (0.004)	0.211 (0.159)	-0.019 (0.016)	0.085 (0.178)
ROE	0.009*** (0.002)	0.192*** (0.070)	0.009 (0.007)	0.218*** (0.080)
ATO	-0.000 (0.001)	-0.050* (0.030)	-0.001 (0.002)	-0.052* (0.031)
Cashflow	0.000 (0.001)	-0.054 (0.057)	-0.004 (0.006)	-0.049 (0.059)
FIXED	-0.008*** (0.002)	0.062 (0.077)	-0.002 (0.005)	0.037 (0.078)
Growth	0.000	-0.013	-0.001	-0.005

	(0.000)	(0.009)	(0.001)	(0.009)
Top5	-0.010***	0.342***	-0.006	0.270***
	(0.003)	(0.092)	(0.006)	(0.095)
TobinQ	-0.001***	-0.023***	0.001*	-0.027***
	(0.000)	(0.004)	(0.000)	(0.005)
ListAge	0.004***	-0.021	-0.001	0.000
	(0.000)	(0.017)	(0.001)	(0.018)
constant term	0.014***	0.275***	0.309***	0.358***
	(0.002)	(0.076)	(0.005)	(0.081)
Time fixed effects	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Observations	46,135	46,135	42,415	42,415
R2	0.809	0.702	0.750	0.703

5. Conclusions and Suggestions

This article uses the “Broadband China” pilot policy as a quasi-natural experiment, based on the data of China’s Shanghai and Shenzhen A-share listed companies from 2007 to 2024, and uses a multi-period double-difference model to conduct empirical testing. The results show that digital infrastructure construction can significantly improve the level of corporate green innovation. The average level of corporate green innovation increased by 7.4% under policy impact, and this conclusion is still reliable after a series of endogeneity treatments and robustness tests. Digital infrastructure mainly empowers corporate green innovation through the two core paths of promoting corporate digital transformation and promoting regional digital financial development, gradually forming a complete transmission chain of “digital infrastructure - micro-transformation - financial empowerment - green innovation”; at the same time, this promotion effect shows significant heterogeneity, which is more prominent in manufacturing, state-owned enterprises and growth-stage enterprises. This research conclusion provides solid micro-causal evidence and empirical support for promoting the deep integration of digital economy and green and low-carbon transformation during the “15th Five-Year Plan” period. Based on the above empirical research results, this article proposes the following policy implications.

The first is to lay out digital infrastructure in advance to lay a solid foundation for corporate green innovation. The country must closely focus on the deployment requirements of the “15th Five-Year Plan”, appropriately advance the construction of green and inclusive digital infrastructure such as 5G, computing networks, and industrial Internet, coordinate the construction of the East-West Computing Project and the national integrated computing network, and shift more resources to manufacturing clusters and areas where growth-stage enterprises are concentrated, so as to solidly build the hardware and technology foundation required for corporate green innovation.

The second is to open up the dual transmission mechanism and give full play to the actual effect of digital empowerment. Focusing on the two core transmission mechanisms of enterprise digital transformation and digital financial development, efforts should be made to build a public service platform for digital transformation, continuously improve the regional digital financial system, effectively reduce the cost and financing pressure of enterprises to carry out green innovation, make the channels for digital infrastructure to empower enterprises' green innovation smoother, and continue to amplify the long-term empowering effect of relevant policies.

The third is to implement accurately classified policies and fully unleash the dividends brought by heterogeneous policies. Combined with the heterogeneous characteristics discovered by empirical research, a precise classification policy approach will be adopted, focusing on strengthening digital empowerment and policy support for manufacturing, state-owned enterprises, and growth-stage enterprises. At the same time, targeted completion of the digital shortcomings of non-state-owned enterprises, non-manufacturing enterprises, and enterprises in mature and declining stages will enable all types of enterprises to achieve balanced development and improve efficiency of green innovation.

The fourth is to strengthen the main role of enterprises and guide them to proactively seize the opportunities of digital transformation. Enterprises themselves must actively connect with the policy dividends brought by the development of digital infrastructure, accelerate the digitalization and green transformation of the entire process of R&D, production, and operations, increase investment in green technology research and development, actively use digital finance to broaden financing channels, transform the external advantages brought by digital infrastructure into the core competitiveness of their own green innovation, and effectively shoulder the responsibility of enterprises as innovation entities.

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