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The Impact of E-Commerce on Urban Green Innovation Development:
Evidence From Chinese Cities

Bingbing Wang, Shanghai University of Political Science and Law, China
Liang Zhang, Jilin University, China*
Dingqing Wang, Jilin University, China
https://orcid.org/0000-0001-5687-0126
Guoliang Jiang, Jilin University, China

ABSTRACT

Green innovation development is essential to achieve "carbon neutrality and carbon peaking" and drive sustainable urban growth, which greatly influences the global green economy. This paper probes into the influence of e-commerce on urban green innovation and its mechanism using a multi-period double difference model. The authors examine the heterogeneous impact of e-commerce on urban green innovation under various urban characteristics. The study reveals that e-commerce development enhances urban entrepreneurial vitality, promotes investment agglomeration, and fosters favorable social conditions and sufficient financial guarantees for green innovation development. E-commerce development's promotion effect shows a "U-shaped" trend as the extent of urban green innovation increases. Additionally, the impact of e-commerce development on urban green innovation is highly dependent on its resource endowments. Therefore, we should focus on the empowering effect of e-commerce development on green innovation to provide new growth opportunities for the green economy.

KEYWORDS

Carbon Neutrality, Carbon Peaking, China, Development Economics, E-Commerce, Green Economy, Green Innovation, Sustainable Development

INTRODUCTION

There are prominent alterations in the way people live and consume along with the growth of information and communication technology. E-commerce, as a commercial transaction activity on the open network, is a major driving force behind these changes (Mitchell, 2001). By changing the traditional business model, e-commerce has accelerated the flow of information and knowledge sharing and helped enterprises establish new connections and create new values. This has led to the

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intelligent upgrading of enterprise products, enhanced environmental responsibility, and accelerated the process of green product innovation, thereby advancing green innovation (Cho et al., 2021; Liang et al., 2004; McCarthy, 1999). Moreover, e-commerce has become integrated into various fields of the economy, leading to the development of new business models and becoming an engine to promote the green economy. This has given rise to a series of new models that help boost the development of the green economy (Zhu et al., 2021).

Green innovation is essential for promoting high-quality economic growth, as well as achieving the objective of "carbon neutrality and carbon peaking," which contribute to long-term sustainable economic development (Du & Li, 2019). On the one hand, as society moves toward "carbon neutrality and carbon peaking," it must cut back on the use of fossil fuels, instead using more green energy sources such as solar energy and water. Green technology occupies an important position in developing and using clean energy. Green technology innovation directly impacts the use of clean energy, which affects carbon emissions and is related to achieving "carbon neutrality and carbon peaking." On the other hand, the aim of "carbon neutrality and carbon peaking" raises the bar for environmental responsibility and carbon emissions of enterprises, leading to higher expectations for the green and environmental protection level of their products. The enterprise's green innovation ability will determine the greenness of their products and their environmental impact (Wang et al., 2021). Therefore, enhancing the green innovation level is also the key to enhancing the greening and environmental protection of enterprise products.

In the current context of e-commerce integration with traditional industries, it is crucial to leverage e-commerce's empowering effect on green innovation in cities. E-commerce facilitates enterprises' access to local market information, reducing information asymmetry in traditional transactions and lowering external and internal transaction costs. This integration accelerates enterprises' green innovation activities, driving green and high-quality urban development. To promote urban e-commerce development, the Chinese government established the first e-commerce demonstration city in Shenzhen in 2009, and then selected 53 other cities in 2011, 2014, and 2017. These cities established e-commerce demonstration bases to popularize and apply e-commerce to impact green innovation in cities. Examining the influence of e-commerce development on urban green innovation is critical, including its mechanism of action and how this impact may differ depending on cities' conditions, such as resource endowment and location distribution. Addressing these questions will clarify the effect of e-commerce development on green innovation, providing new ideas and pathways to accomplish "carbon neutrality and carbon peaking," which has both theoretical and practical significance.

This manuscript takes the construction of China's e-commerce demonstration cities as a quasi-natural experiment to explore the impact of e-commerce development on urban green innovation. The main contributions are as follows: on the one hand, current research on urban green technology innovation mainly focuses on transaction costs, green development, and financial services. Although some studies have focused on the green development effect of e-commerce development, no literature has included e-commerce as a key influencing variable for green innovation in the research. For the first time, the authors have included the development of e-commerce in the category of influencing factors for urban green technology innovation, constructed a theoretical framework to analyze the urban green innovation effect generated by e-commerce development, and elaborated on its internal mechanism. Finally, they conducted empirical testing to expand the current research boundaries. On the other hand, this research validates the entrepreneurial vitality enhancement effect and investment agglomeration acceleration effect brought by the development of e-commerce for urban green innovation, deepens the research on the economic effects of e-commerce development, and further tests the differential impact of e-commerce development on green innovation in different cities, based on different resource conditions, location distribution, and other factors. The authors aim to develop e-commerce in different regions with different conditions. Improving green innovation capabilities provides theoretical support.

LITERATURE REVIEW

With the digital economy driving green development, e-commerce has garnered significant attention in academic research. Previous literature has primarily focused on three aspects of e-commerce: its direct and indirect effects, as well as its applications.

The first is to study the direct effects brought by e-commerce. First, it compresses the time and cost of information transmission, improves information transmission efficiency, reduces the office cost of enterprises, and improves the efficiency of enterprise marketing (Heil & Prieger, 2010). Second, the establishment of e-commerce platforms builds a bridge for communication between enterprises and consumers, promotes information exchange between sellers and buyers of goods, helps enterprises obtain timely feedback from consumers, and reduces the information search cost of enterprises (Li et al., 2008). For enterprises, with the reduction of their information search costs, their willingness and ability to develop and innovate green technologies will be continuously enhanced, which is conducive to motivating them to improve their green innovation and R&D level (Paunov & Rollo, 2016). Third, it can accelerate information and knowledge sharing, help enterprises establish a wider connection, spawn new services, and create new values. For example, online Internet platforms, such as Amazon, eBay and Alibaba, have replaced traditional intermediaries and can provide not only supply and demand matching information but also value-added services such as fund supervision, logistics tracking, credit guarantees, and financial lending through digital technology tools and corporate credit (Pauli et al., 2021).

The second objective is to probe the indirect effects of e-commerce. Existing studies indicate that e-commerce has both facilitated new technology applications and enabled knowledge and information dissemination, overcoming time and space constraints. This has also accelerated the accumulation of knowledge required for innovation (Shih, 2012). Moreover, e-commerce development has contributed to improving knowledge mobility and accessibility while reducing the cost of knowledge acquisition. It has enabled businesses and individuals to swiftly gain new knowledge and skills, thereby promoting the accumulation of regional human capital and fostering a favorable innovation atmosphere (Globerman et al., 2001).

The third is to examine the applications within specific areas of e-commerce. In terms of digital platforms, e-commerce assists Small and medium-sized enterprises (SMEs) in participating directly in national trade by building digital intermediary platforms that provide fast search and matching services for manufacturers and consumers, providing services including online payment, imports and exports, logistics, marketing, insurance, and consumer protection (Ridley-Duff & Bull, 2021). In terms of agricultural development, e-commerce models are further innovated, especially the customer to customer (C2C) model, Taobao villages, live webcasting, and other various forms of business models, which have greatly facilitated the participation of individual business owners and producers of agricultural products in the market circulation in a wider market scope (Qi et al., 2019). In poverty reduction, some scholars point out that e-commerce can effectively reduce poverty by stimulating social innovation (Cui et al., 2017).

In addition, some studies have discussed the relationship between e-commerce and green development. For example, some studies have analyzed the influence of the development of e-commerce on farmers' green consciousness and found that participation in e-commerce has significantly improved farmers' overall green production consciousness (Wang et al, 2022). Some scholars also believe that e-commerce is of great significance to green sustainable development. Without the successful implementation and sustainable growth of e-commerce, the realization of green sustainable development goals will be greatly challenged (Mustafa et al, 2022). In addition, some studies also show that the development of e-commerce will encourage rural families engaged in the management of non-wood forest products to adopt green production behavior, which can improve soil quality, reduce mudslides and soil erosion in mountainous areas, and is conducive to the sustainable development of the region (Li et al, 2021). The rapid development of e-commerce in today's era has

had a great impact on the world supply chain system, and it will have a certain impact on the ecological environment. The development of e-commerce has promoted the improvement of the green supply chain and laid the foundation for the world's green sustainable development (Abukhader & Jonson, 2004). Therefore, according to the research conclusions of existing scholars, the popularization and development of e-commerce will not only affect the production and operation behavior of farmers at the micro level, but also affect the development of the world green supply chain and green finance at the macro level, which has opened up a new road for world green development.

Despite some literature exploring the relevance of e-commerce development to enterprise green development, which suggests that e-commerce can promote the greening process of enterprise products, reduce pollution, and enhance environmental responsibility (Zhao et al., 2021), there is a dearth of studies examining the influence and path of its development on green technology innovation in cities. Given the rapid popularity of e-commerce and its potential as a new drive for economic development, exploring e-commerce's influence on green innovation and analyzing its intrinsic path can have both theoretical significance and practical value. By doing so, cities can unlock the potential for green innovation driven by e-commerce and transform its economic growth momentum.

THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

Background and Main Initiatives for the Establishment of Chinese E-Commerce Model Cities

To enhance e-commerce penetration, the Chinese central government launched a pilot, e-commerce demonstration city in Shenzhen in 2009. The initiative aimed to address contradictions and problems in e-commerce development and establish a comprehensive support system in the city. In subsequent years (2011, 2014, and 2017), the policy pilot category was expanded to over 50 cities to further promote the construction of e-commerce demonstration cities (Pan & Zhou, 2022).

The core purpose of national e-commerce demonstration cities is to accelerate the popularization and application of e-commerce, increase the proportion of the service industry, optimize the industrial structure, and enhance the radiation of e-commerce on the economy, which will have a significant impact on regional green development. On the one hand, an important purpose of the Chinese government in building a national e-commerce demonstration city is to reduce the consumption of material resources and energy, reduce environmental pollution, and develop a green economy. Therefore, developing a green economy and enhancing urban green innovation capabilities are important links in the construction of China's national e-commerce demonstration cities. On the other hand, the Chinese government has clearly stated in the document on building a national e-commerce demonstration city that it is necessary to improve the development environment of e-commerce, expand the e-commerce service industry, and effectively support strategic emerging industries such as energy conservation, environmental protection, and high-end manufacturing. This will also provide new support for the development of the green economy, which is conducive to the implementation of urban green innovation activities and the improvement of green innovation efficiency.

Therefore, the pilot cities will receive more support in terms of funds, policies, and electronic information infrastructure construction, which can rapidly enhance e-commerce popularity and have external impacts on urban green innovation with stable continuity. Taking these pilot cities as a quasi-natural experiment is feasible in theory.

Theoretical Analysis of the Green Innovation Driving Effect of E-Commerce

Constructing e-commerce demonstration cities in China will increase the penetration rate of e-commerce, inject new momentum into urban economic growth, and give full play to its radiation drive on economic and social development through policy support and financial guarantees. E-commerce

has been shown to significantly reduce the cost of information circulation and improve its efficiency (Solaymani et al., 2012), promoting the deep integration of digital and real economies and ultimately improving the green technology innovation of enterprises (Xie et al., 2019).

In 1943, Professor Joseph A. Schumpeter, an Austrian-trained economist, economic historian, author, and well-known business theorist developed a theory of innovation. Schumpeter's innovation theory highlights the importance of information transfer in the process of reorganizing production methods, materials, and organization. E-commerce development enhances the efficiency of information circulation and builds a communication bridge between producers and consumers, facilitating rapid access to production information and reducing transaction costs of information collection and acquisition (Coase, 1937; Sweezy, 1943). The reduction in transaction costs helps to ease financing constraints and enhance the capital flow space of producers, allowing them to invest more in green R&D and accelerating the green innovation process. Urban green innovation is closely related to that of enterprises (Audretsch & Link, 2018), and urban e-commerce can provide urban enterprises with more funds for green R&D, thus improving the level of green innovation. Therefore, the authors propose the following hypothesis:

Hypothesis 1: E-commerce development can enhance the level of cities' green innovation.

Analysis of the Mediating Mechanism of the Green Innovation Driving Effect of E-Commerce

E-commerce promotes the flow of knowledge, information, and technology, which stimulates the enthusiasm of workers' entrepreneurship and improves entrepreneurship in cities. At the same time, e-commerce is closely related to investment growth, and it also represents urban investment agglomeration, which injects vitality into the growth of urban investment, and the extent of entrepreneurship and investment agglomeration in cities will both have an impact on cities' green innovation. As a consequence, the authors discuss the indirect influence mechanism from the two perspectives of entrepreneurial activity and investment agglomeration.

Mechanism of the Entrepreneurship-Driven Innovation Effect

The innovation strategy school believes that innovation is a subconscious or a spontaneous behavior, which is a concentrated expression of entrepreneurship. The popularity of e-commerce enables entrepreneurs to understand consumer preferences in a more timely and in-depth manner, reducing the organizational costs and information acquisition costs of entrepreneurs who are the brains of the enterprise. The operation of e-commerce is also gradually blurring the boundaries of enterprises, making various forms of business existence and contract structures possible, and greatly reducing the cost of entrepreneurship (Humphreys et al., 2006; Kaefer & Bendoly, 2004; Liang et al., 2004). E-commerce platforms make enterprises establish direct contact with suppliers and customers, reduce the mediating circulation links of production factors and products, break the time and space restrictions of factor flow, reduce business operation and transaction costs, and improve market enterprise competitiveness (Arvanitis & Loukis, 2009). Therefore, e-commerce reduces entrepreneurial cost on the one hand and increases the breadth and depth of the entrepreneurial concept on the other, which helps to stimulate urban entrepreneurial vitality and enhance the entrepreneurship level. Urban entrepreneurship will raise the competitive pressure of enterprise products, force entrepreneurs to carry out product innovation, prompt enterprises to adapt to consumer demand, and force them to develop toward green and branding (Tian et al., 2022). Green innovation is the necessary condition of high-quality enterprises and the prerequisite for green development. Urban entrepreneurial vitality prompts enterprises to implement green innovation, promoting urban green innovation.

Investment Agglomeration Effect Driving Mechanism

E-commerce is widely adopted due to the dual effects of diminishing the marginal cost of information networks and increasing the marginal returns of technological rewards. This leads to a concentration of investment factors in regions with high information transfer efficiency, promoting the agglomeration effect and spillover of knowledge and technology, which in turn lowers the cost of factor reorganization and encourages green innovation in cities. Additionally, e-commerce enhances information flow between regions, improves the regional market environment, and attracts foreign capital. It also stimulates market demand, increases potential consumers, and provides a consumption foundation for urban investment and entrepreneurship. Therefore, e-commerce accelerates investment agglomeration in cities, providing financial guarantees and introducing urban innovation talent, which plays a vital part in pushing forward green innovation. As such, the authors propose the following hypotheses:

Hypothesis 2.1: E-commerce development increases urban entrepreneurial activity, leading to a higher level of urban green innovation.

Hypothesis 2.2: E-commerce development promotes urban investment clustering, resulting in a higher level of urban green innovation.

Heterogeneous Discussion of the Green Innovation-Driven Effects of E-Commerce

E-commerce needs to rely on a city's economic and social foundation, and different resource endowments of the city itself are likely to have a differential effect on the influence of e-commerce development.

First, cities' location distribution can make a difference in urban green R&D and innovation, with cities in eastern China having locational advantages due to their earlier introduction of international talents and technologies, better transportation infrastructure, and stronger policy support. Conversely, cities in central and western China may lag behind in green innovation due to factors such as an insufficient talent pool and weaker economic development (Yang et al., 2022a, 2022b). E-commerce development can leverage the rich innovation resources of cities in eastern China and is likely to produce a greater promotion effect on improving the green innovation level. Second, urban science and education resources are important for green technology innovation, and e-commerce development can further achieve the majorization of innovation resource allocation in cities with more advantageous scientific and educational resources, contributing to green innovation (Glaeser et al., 1992; Zhou & Luo, 2018). Third, different administrative levels of cities tend to bring out a large division in green innovation resources. Compared with ordinary prefecture-level cities, cities such as provincial capitals have richer scientific and educational resources, better infrastructure, more convenient transportation services, and attract high-quality talent and high-tech industries (Yang et al., 2022a, 2022b). E-commerce development may help to stimulate green innovation vitality, improving the urban green innovation level in these central cities. Fourth, the Bohai Rim, the Pearl River Delta, and the Yangtze River Delta economic circles are the gathering places of advanced technologies and industries in China, the frontier of the new-generation information technology industry, rich in human resources and capital, and the "three growth poles" of China's innovation-driven development. Therefore, cities located in China's three major economic centers are in more developed innovation networks, and innovation factors such as talent and capital are more convenient to flow, so the promotion effect of e-commerce on improving green innovation level in cities located in the three major economic centers may be stronger. As a consequence, the authors propose the following hypothesis.

Hypothesis 3: E-commerce promotes the extent of green innovation more strongly in eastern Chinese cities, cities with richer scientific and educational resources, cities with higher administrative hierarchies, and cities located in China's three economic spheres.

STUDY DESIGN

Model Setting

Drawing on Bertrand et al. (2004), the authors explore the impact of e-commerce development on green innovation using Chinese e-commerce demonstration cities as a quasi-natural experiment. This study employs a multi-period double difference approach to control for regional differences and eliminates differences between pilot cities before and after they are selected with more reliable findings, as shown in Equation (1):

$$g-inno_{it} = \alpha_0 + \alpha_1 ele-com\_city_{it} + \sum \alpha_j X_{jit} + u_i + v_t + \varepsilon_{it} \quad (1)$$

where *i* is an individual city and *t* is the year. *g-inno* denotes green innovation, which is this paper's core explanatory variable, measured by the number of urban green invention patents per 10,000 people. *ele-com_city* denotes a dummy variable of China's e-commerce demonstration-type city pilot policy, that is, the year in which the city is selected and the year after is recorded as 1; otherwise, it is 0. *X* is the set of control variables, including foreign direct investment, city human capital level, and other key variables affecting city green innovation. v_t denotes time fixed effects, u_i denotes city individual fixed effects, and ε is a random error term.

To verify Hypothesis 2.1 and Hypothesis 2.2, which examine the mechanism of the effect of e-commerce on green innovation, the authors constructed the regression models shown in Equation (2) and Equation (3). Together with Equation (1), they combine into a complete mediating effect model for empirical testing:

$$M_{it} = \beta_0 + \beta_1 ele-com\_city_{it} + \sum \beta_j X_{jit} + u_i + v_t + \varepsilon_{it} \quad (2)$$

$$g-inno_{it} = \gamma_0 + \gamma_1 ele-com\_city_{it} + \gamma_2 M_{it} + \sum \gamma_j X_{jit} + u_i + v_t + \varepsilon_{it} \quad (3)$$

In Equations (2) and (3), *M* denotes the mediating variables, namely, urban entrepreneurial activity and investment agglomeration. If α_1 is significant, it implies that e-commerce greatly influences urban green innovation. β_1 and γ_2 are significant, which indicates that e-commerce development influences green innovation by increasing entrepreneurial activity and promoting investment factor agglomeration.

To test Hypothesis 3, this paper further constructs Equation (4) to examine the heterogeneous impact of e-commerce development due to differences in cities from the aspects of location characteristics, scientific and educational resources, administrative hierarchy, and whether they are located in economic circles:

$$g-inno_{it} = \lambda_0 + \lambda_1 ele-com\_city_{it} + \lambda_2 Z + \sum \lambda_j X_{jit} + v_t + u_i + \varepsilon_{it} \quad (4)$$

Among them, *Z* is the moderating variable, which are the interaction terms of city location distribution, city science and education resource level, city administrative level, and economic circle with policy dummy variables, respectively. Their coefficients reflect various effects of e-commerce development on urban green innovation under various city characteristics, respectively.

Variable Selection

Dependent Variable

Urban green innovation (*g-inno*) is represented by the number of urban green patents per 10,000 people. Patents are the direct output of innovation activities, and this paper uses this measure to analyze the level of city green innovation. Other commonly used alternative indicators are also considered in subsequent robustness tests.

Explanatory Variable

This paper's core explanatory variable is the China e-commerce demonstration city dummy variable (*ele-com_city*), which takes a value of 1 if the city is rated in the year and after; and 0 otherwise, thereby reducing the need for constant checks.

Control Variables

The authors selected several control variables that impact green innovation in cities. These variables included foreign direct investment (*fdi*), human capital (*hum*), financial development (*fin*), economic agglomeration (*agglo*), urban economic and social development level (*develop*), and government innovation support (*support*).

Mediating Variables

To measure the level of entrepreneurial activity in a city, the authors used the specific gravity of private and self-employed workers in the total population (*entre*). Additionally, they measured the concentration of investment factors in a city by calculating the ratio of investment in fixed assets to the city's area (*invest*).

Moderating Variables

The moderating variables are interaction terms of the dummy variables of city location distribution (*location*), city science and education resources (*resource*), city administrative level (*administrative*), city economic circle (*circle*) group and the dummy variable of e-commerce model city. The specific settings are as follows:

- **City Location Dummy Variables:** Cities in the eastern region are recorded as 1, and central and western cities are recorded as 0.
- **City Science and Education Resource Dummy Variables:** Cities with 211 universities are recorded as 1; otherwise, they are recorded as 0. This is because 211 universities are a group of higher education institutions and key disciplines that the central and local governments of China attach great importance to and cultivate. They not only have a superior teaching environment and faculty compared to other universities, but are also important training bases for Chinese higher talent. It is reasonable to use them as the basis for dividing urban science and education resources.
- **City Administrative Level Dummy Variables:** Sub-provincial cities, provincial capitals, and municipalities directly under the central government are recorded as 1, and other prefecture-level cities are recorded as 0.
- **Economic Circle Moderating Variables:** Cities situated in the Yangtze River Delta, Pearl River Delta, and Bohai Sea Economic Circle are recorded as 1, and other cities are recorded as 0.

Data Source

This study analyzes a panel dataset of 285 prefecture-level cities in China from 2003 to 2018. Data on e-commerce demonstration cities were collected from multiple official sources, including the Development and Reform Commission of China, the Ministry of Commerce, the People's Bank of China, the General

Administration of Taxation, and the General Administration for Industry and Commerce, as well as some provincial and municipal government websites. City-level data was obtained from various statistical yearbooks, including the China City Statistical Yearbook, the China City Construction Statistical Yearbook, and some provincial and municipal yearbooks. To ensure the credibility of the findings, the authors replaced outliers and log-transformed some of the data to address issues of multicollinearity and the influence of magnitude. Table 1 presents the variable definitions and descriptive statistics.

EMPIRICAL ANALYSIS

Parallel Trend Test

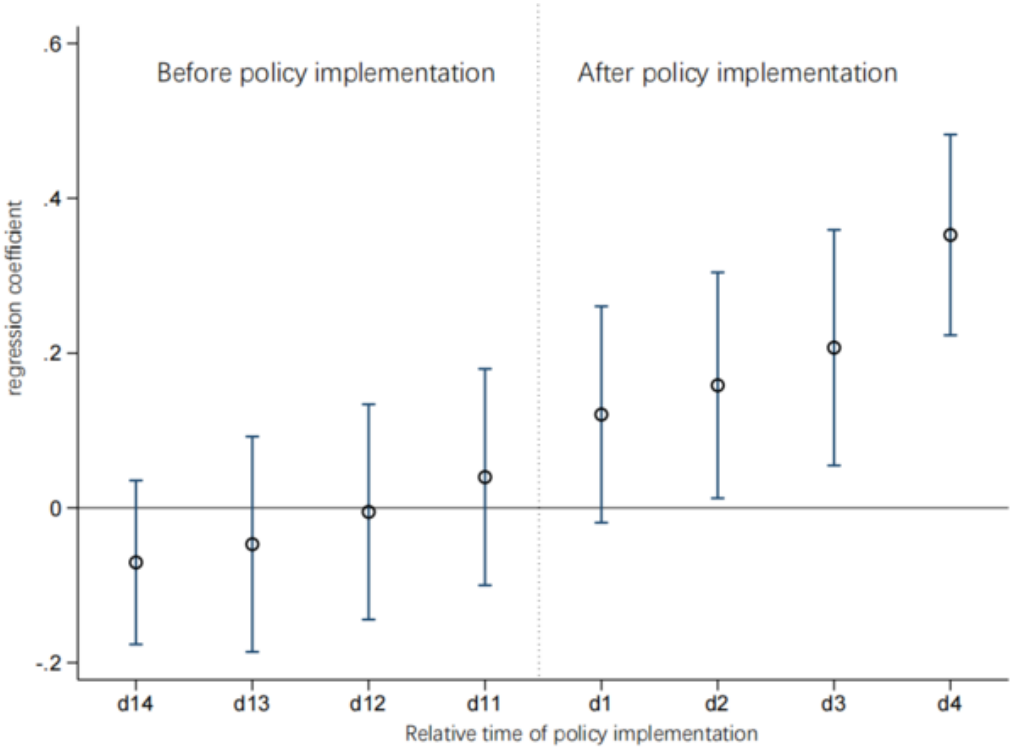
Before utilizing the difference in differences or double difference (DID) method, a parallel trend test needed to be performed to ensure that the experimental group and control group had similar trends of change before policy implementation. This is a prerequisite for using the DID method. To ensure that the parallel trend assumption is met, this paper divides the policy implementation period into four periods before and after implementation and uses the policy implementation period as the critical point. The significance of regression coefficients in each period is tested to determine whether a parallel trend is present. Figure 1 displays the specific results of these tests.

Before policy implementation, the coefficients of *ele-com_city* were not significant, indicating no significant difference between the two groups. This satisfies the parallel trend hypothesis. However, in the current and post-policy implementation periods, the significance level and absolute value of *ele-com_city*'s coefficients gradually increased. This suggests that e-commerce development enhances urban green innovation and that the promotion effect increases over time.

Table 1. Descriptive statistics of variables

Variable Category	Variable Name	Sample Size	Average Value	Maximum	Minimum	Median
Explanatory Variables	E-commerce city (*ele-com_city*)	4560	0.0814	0	1	0
Explained Variables	Green Innovation Level (*g-inno*)	4560	0.3442	0	2.7785	0.8734
Mediating Variables	*Entrepreneurial* activity (*entre*).	4560	0.1092	0.0003	0.2126	0.0744
	Investment clustering (*invest*)	4560	0.3999	0.0021	0.8621	0.2532
Control Variables	foreign direct investment (*fdi*)	4560	0.0297	0	0.7826	0.0181
	Human capital level (*hum*)	4560	0.0157	0	0.1311	0.0074
	Level of financial development (*fin*)	4560	2.0252	0.2472	16.7426	1.7481
	Level of economic agglomeration (*agglo*)	4560	0.0426	0.0005	0.2648	0.0352
	Level of economic and social development of the city (*develop*)	4560	3.6655	0.0099	46.7749	2.7709
	Government Innovation Support (*support*)	4560	0.0021	0.0002	0.0633	0.0013
Moderating Variables	Urban location regulation (*location*)	4560	0.0419	0	1	0
	Regulation of science and education resources (*resource*)	4560	0.0500	0	1	0
	City administrative level regulation (*administrative*)	4560	0.0471	0	1	0
	Urban economic circle regulation (*circle*)	4560	0.0351	0	1	0

Figure 1. Parallel trend test



Baseline Regression Analysis

Table 2 displays the regression results of Equation (1) to test Hypothesis 1 regarding the impact of e-commerce development on urban green innovation. The results of model (1) indicate that the policy dummy variable coefficient is positive and significant at the 1% level. This suggests that e-commerce development significantly affects green innovation. However, it is vital to take the potential impact of time and individual differences in cities into account in these findings. To address potential issues related to time factors and individual differences in cities, this paper uses several models. Model (2) controls individual fixed effects on top of model (1), while model (3) controls time fixed effects on top of model (2). Model (4) employs a panel interaction fixed effects model to estimate regression, which includes the interaction effects of individual and time. This approach helps eliminate the differences in the effects of common factors on different individuals. In model (1)-model (4), the coefficients of the policy dummy variables for e-commerce demonstration cities are all positive at the 1% significance level, showing that e-commerce development significantly contributes to green innovation in cities, and Hypothesis 1 is confirmed.

Robustness Tests

First, one potential issue with using the double difference model test is the possible sample selectivity bias due to the non-random selection of e-commerce demonstration cities. Factors such as economy and city size may have influenced the selection, making it non-random. This can lead to a biased estimation of the policy effect. For this reason, the authors introduced the propensity score matching-double difference method, which can better address the problem of potential sample selection bias. This method can better address the problem of sample selection bias and provide more robust results.

Table 2. Baseline regression result

	(1)	(2)	(3)	(4)
	g-inno	*g-inno*	*g-inno*	*g-inno*
ele-com_city	0.6123***	0.2383***	0.1353***	0.0841*
	(0.0791)	(0.0658)	(0.0429)	(0.0469)
fdi	2.0838***	0.0556	0.6921**	0.3563
	(0.4969)	(0.4391)	(0.2851)	(0.2320)
hum	11.5118***	17.3479***	0.6422	0.1414***
	(1.0958)	(1.9923)	(1.3120)	(1.3016)
fin	0.2699***	0.3351***	0.0263*	0.0253**
	(0.0197)	(0.0200)	(0.0152)	(0.0116)
agglo	16.3166***	13.0735***	5.0621**	0.9970
	(0.5888)	(3.5027)	(2.2546)	(2.5965)
develop	0.2713***	0.3517***	0.0068	0.0189***
	(0.0071)	(0.0076)	(0.0067)	(0.0064)
support	115.1491***	104.9963***	43.2489***	15.0715***
	(6.5910)	(5.438582)	(3.7537)	(3.0482)
Time fixed effects	No	No	Yes	Yes
Individual fixed effects	No	Yes	Yes	Yes
Interaction fixed effects	No	No	No	Yes
R^2	0.6455	0.6082	0.8424	
Constant	-2.3860***	-2.1557***	-3.4029***	5.0618***
	(0.0502)	(0.1507)	(0.1022)	(0.1212)
Observations	4560	4560	4560	4560

Note: *, **, *** denote 10%, 5%, and 1% significance levels, respectively, and standard errors are in parentheses.

To implement the propensity score matching-double difference method, we refer to the research method of Heckman et al. (1997). The paper selects foreign direct investment (*fdi*), human capital (*hum*), financial development (*fin*), economic agglomeration (*agglo*), urban economic and social development level (*develop*), and government innovation support (*support*) as matching variables. The probability of a city being rated is calculated using these variables, and the nearest neighbor matching method is used to match samples. After matching, the final sample size was 4451. Using the matched samples, this paper further estimates Equation (1) and presents the results in model (1) of Table 3. The regression coefficient of e-commerce demonstration cities in model (1) is still significantly positive at the 1% level, indicating that e-commerce development can greatly improve green innovation in cities. This result demonstrates the strong robustness of the conclusion.

Second, the authors conducted a regression analysis by replacing the explanatory variables with the number of cities' green utility model patents per 10,000 people. The results are shown in model (2). Model (2) demonstrates that the coefficients of the policy dummy variables are still significantly positive even after changing the measurement of the explanatory variables. This result suggests that e-commerce development can enhance and foster green innovation vitality in cities.

Third, since the four municipalities directly under the central government of Beijing, Shanghai, Tianjin, and Chongqing are ahead of other cities in terms of human capital, R&D funding, and

policy support, their urban green innovation capability is stronger than that of other cities. Therefore, excluding the above four cities from the sample can eliminate the influence caused by extreme values on the findings of this paper. As shown in Regression (3), the regression coefficient of ele-com_city is still significantly positive, which is the same as the previous conclusion.

Fourth, in the process of e-commerce demonstration cities, other policies will be implemented to influence urban green innovation, which will produce certain policy superposition effects and affect conclusions. For this reason, the authors control policies that affect urban green innovation with reference to relevant studies, including the national high-tech zone policy (Hainmuellar, 2012), the smart city policy (Cao et al., 2019), the innovation city policy (Jiang et al., 2023), and the intellectual property demonstration city policy (Falk & Peng, 2018). In particular, to ensure the robustness of their findings, the authors included five policy dummy variables in equation (1) using the same methodology as for the explanatory variables in this paper. These variables were set to 1 in the year and after policy implementation; and 0 otherwise. The results of Model (4) demonstrate that the regression coefficient for e-commerce model cities remains positive and significant at the 1% level even after controlling for these five policies. Thus, the authors can confidently conclude that their previous findings are robust.

Fifth, because this policy may be influenced by factors such as the city's own economic scale and technological development level, the setting may not be random and prone to endogeneity problems.

To solve the potential endogeneity issue, the authors employed a panel instrumental variable method in this study. Following the method proposed by Nunn and Qian (2014), the authors constructed the interaction term of the city topographic undulation degree and the time trend term as instrumental variables for e-commerce demonstration city construction in the regression analysis. The reason for choosing topographic relief as a tool variable is that the construction of e-commerce cities is closely related to the construction level of local information infrastructure. The cost of information infrastructure construction is greatly influenced by urban topography. The greater the topographic relief, the greater the cost of network infrastructure construction. At the same time, terrain fluctuation will also affect the popularization and application of e-commerce. Therefore, terrain undulation satisfies the correlation hypothesis of tool variable setting. However, urban green innovation depends more on R&D investment, human capital, science, and technology, and is less directly affected by terrain fluctuation, which also meets exogenous conditions. Therefore, it is reasonable to choose topographic relief as a tool variable. The results of Model (5) demonstrate that the regression coefficient for *ele-com_city* remains significantly positive, indicating that the potential endogeneity issue did not interfere with the accuracy of the authors' conclusions. Thus, they can confidently conclude that their findings are accurate and reliable.

To further test the robustness of this research's conclusions and avoid the error of regression results that may be caused by only using the least square method, the authors changed the estimation methods and used the generalized maximum likelihood estimation method, the minimum residual ruler estimation method, and the moment estimation method for the regression test, respectively. The results are shown in Table 4. From the regression in Table 4, it can be seen that after changing the regression methods, the regression coefficients of *ele-com_city* are all positive at the 1% significance level, which once again shows the development of e-commerce.

Sixth, to eliminate the influence of missing variables on the study, the authors randomly generated policy pilot areas for an indirect placebo test, randomly generated pilot cities, repeated 500 regression simulations according to the benchmark model, counted the coefficients of the regression results, and drew the false estimates of the regression coefficients and the nuclear density distribution map, as shown in Figure 2. The estimated value of the false coefficient conforms to the normal distribution with a median value of 0. At the same time, the nuclear density diagram shows that the p value of most estimated values is greater than 0.1, which is in line with the expectation of the placebo test, indicating that the research results of this paper are less affected by the estimation bias caused by the

Table 3. Robustness checks 1

	(1)	(2)	(3)	(4)	(5)
	PSM-DID Test	**Substitution of Explanatory Variables**	**Moderating Sample**	**Excluding Other Policy Interference**	**Tool Variables**
	G-Inno	*G-Inno*	*G-Inno*	*G-Inno*	*G-Inno*
ele-com_city	0.167***	0.0836***	0.1403***	0.1606***	23.5260***
	(0.0314)	(0.0097)	(0.0447)	(0.0472)	(3.2248)
Control variables	Yes	Yes	Yes	Yes	Yes
Other Policies				Yes	
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes
R^2	0.6450	0.7214	0.8443	0.8425	0.3823
Constant	287.6***	-1.4106***	-3.1408	-3.4079***	9.8436***
	(10.44)	(0.0111)	(0.0505)	(0.1036)	(1.8519)
Observations	4451	4560	4496	4560	4560

Table 4. Robustness test 2

	Generalized Maximum Likelihood Estimation Method	**Minimum Residual Rule Estimation Method**	**Moment Estimation Method**
	G-Inno	*G-Inno*	*G-Inno*
ele-com_city	0.3693***	0.4383***	0.4293***
	0.1148)	0.1068)	0.1042)
Control variables	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes
Observations	4560	4560	4560

interference of non-observed random factors and the problem of missing variables, and the research conclusion has strong credibility.

Quantile Regression

To examine the marginal effect of e-commerce development on urban green innovation at different extents of green innovation, this paper further introduces a quantile regression model for testing. In this paper, nine quartiles of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% are selected, and the results are presented in Table 5.

This paper utilizes a quantile regression model to assess the influence of e-commerce on green innovation in cities with varying degrees of green innovation. The study analyzes nine quartiles (10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90%) and presents the findings in Table 5. It illustrates that the regression coefficients of e-commerce demonstration cities display a U-shaped trend in relation to green innovation, with a decrease followed by an increase. This implies that e-commerce development's influence on green innovation in cities weakens before ultimately strengthening. The absolute values and significance levels of the coefficients support this conclusion. In addition, this

Figure 2. Placebo test

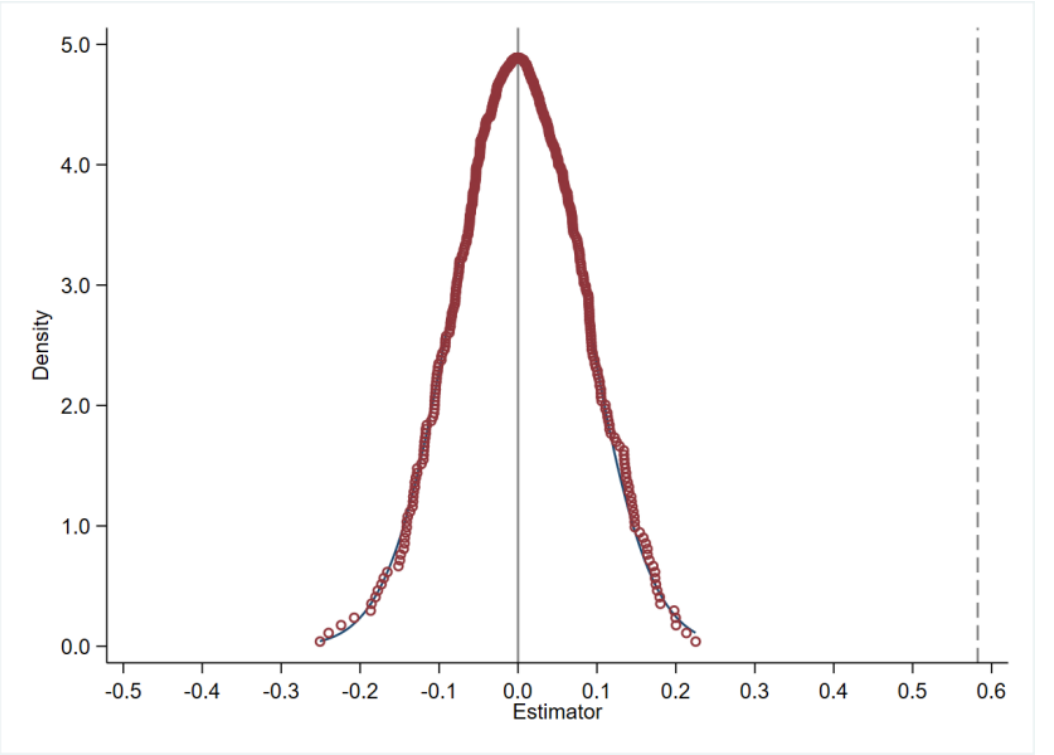


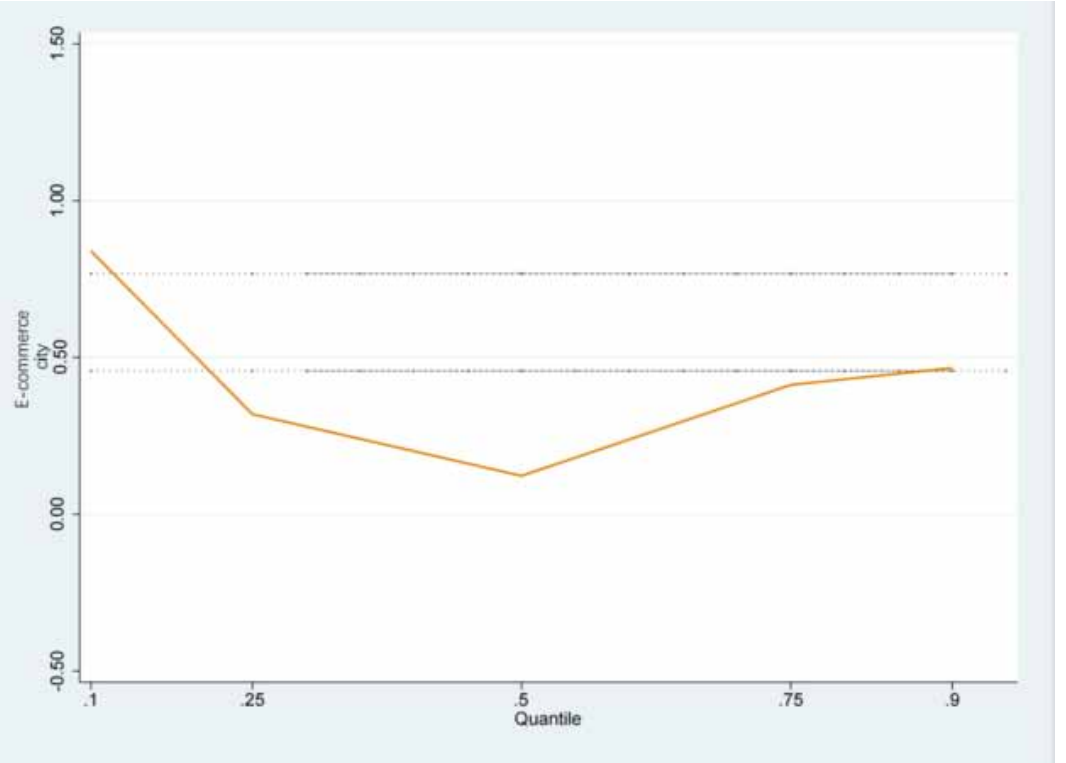
Table 5. The quantile regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Subsites	10%	20%	30%	40%	50%	60%	70%	80%	90%
ele-com_city	0.8361***	0.4672***	0.4672***	0.1447	0.1596	0.2576***	0.3714***	0.3501***	0.4399***
	(0.1548)	(0.1293)	(0.1293)	(0.1490)	(0.1513)	(0.1042)	(0.0957)	(0.0888)	(0.1409)
constant	1.2312***	1.3929***	1.3929***	1.8903***	2.0540***	2.2716***	2.5236***	2.7812***	3.2642***
	(0.1170)	(0.1019)	(0.1019)	(0.0692)	(0.0699)	(0.0790)	(0.0707)	(0.0772)	(0.0983)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	F =4.69, P[q10=q20=q30=q40=q50=q60=q70=q80=q90]=0.0000								
Observations	4560	4560	4560	4560	4560	4560	4560	4560	4560
R^2	0.2929	0.3388	0.3735	0.4024	0.4263	0.4461	0.4644	0.4798	0.4920

paper also tested whether the coefficients of e-commerce demonstration cities were statistically significantly different in different quartiles, and the results showed that $F = 56.86$, $p = 0.000$, rejecting the hypothesis of equal coefficients in nine quartiles.

To better illustrate the dynamic impact of e-commerce development on green innovation in cities with varying green innovation extents, this study presents a graphical representation of the regression coefficients for all sub-locations. The plot is depicted in Figure 3.

Figure 3. Quantile regression plot



Analysis of Mediating Mechanism

As previously mentioned, the mechanism by which e-commerce development enhances green innovation may involve two hypotheses. The first hypothesis suggests that the development of urban e-commerce drives entrepreneurial activity, which subsequently improves green innovation (Hypothesis 2.1). The second hypothesis proposes that e-commerce development promotes investment factor agglomeration in cities, leading to increased financial support for green innovation (Hypothesis 2.2). This paper conducts further tests on the two mechanisms described above, as presented in Table 6. Models (1) and (2) represent the outcomes of the mediation mechanism of urban entrepreneurial activity. The regression coefficient of *ele-com_city* in Model (1) is significantly positive, indicating that e-commerce development can enhance urban entrepreneurial dynamics and stimulate urban entrepreneurial activities.

The regression coefficients of entrepreneurial activity in Model (2) are significantly positive, indicating that urban entrepreneurial activity has a significant positive relationship with urban green innovation capacity, and the increase in urban entrepreneurial activity effectively promotes the enhancement of urban green innovation capacity. Combining the regression results of model (1) and model (2), the authors can conclude that the development of e-commerce significantly stimulates the city's entrepreneurial vitality, which in turn leads to the improvement of the city's green innovation level, and the further Sobel test also verifies the existence of the mediating effect of entrepreneurial activity, and Hypothesis 2.1 is verified. Model (3) and model (4) are the regression results of urban investment agglomeration mediation.

Regression coefficients for entrepreneurial activity in Model (2) are significantly positive, indicating a positive and significant relationship between urban entrepreneurial activity and urban

green innovation capacity. This implies that an increase in urban entrepreneurial activity effectively promotes the enhancement of green innovation capacity. By combining the outcomes from Model (1) and Model (2), the authors can conclude that e-commerce development greatly stimulates urban entrepreneurial vitality, which subsequently leads to elevated green innovation levels. Furthermore, the Sobel test confirmed a mediating effect of entrepreneurial activity, thus verifying Hypothesis 2.1. Models (3) and (4) represent the regression outcomes of urban investment agglomeration mediation.

Heterogeneity Analysis

To verify the heterogeneous effects of e-commerce on green innovation due to different conditions, such as cities' own endowment and location distribution, this paper further regresses equation (4), and the outcomes are presented in Table 7. Model (1) to Model (4) are heterogeneity results of city location distribution, science and education resources, city administrative level, and whether the city is located in an economic circle, respectively.

The coefficients of the regulating variables of city location in model (1) are significantly positive, indicating that the promotion effect of e-commerce development on the level of green innovation in eastern cities is stronger than that in central and western cities. In model (3), the regression coefficient of the regulating variable of the administrative level of cities is significantly positive, implying that e-commerce development produces a stronger influence on accelerating green innovation in cities with higher administrative levels, such as provincial capitals, than in other cities in China. In model (4), the regression coefficient of the regulating variable of economic circles is significantly positive, meaning that e-commerce development has a stronger influence on accelerating green innovation in cities in China's three economic circles than in other cities.

In Model (1), the coefficients of the regulating variables of city location are significantly positive, indicating that the impact of e-commerce development on urban green innovation is stronger in eastern China than in central and western China. In Model (3), the regression coefficient of the regulating variable of the administrative level of cities is significantly positive, suggesting that e-commerce development has a greater effect on promoting green innovation in cities with higher administrative levels, such as provincial capitals, sub-provincial cities, and municipalities directly under the central government, than in other cities across China.

Table 6. The mediating effects test

	(1)	(2)	(3)	(4)
	entre	*g-inno*	*invest*	*g-inno*
ele-com_city	0.0441***	0.6035***	0.2063***	0.1013***
	(0.0060)	(0.0809)	(0.0066)	(0.0255)
invest				3.4771***
				(0.2070)
entre		0.1993**		
		(0.0999)		
Control variables	Control	Control	Control	Control
Sobel test	0.0088*(0.0048)		0.7173*** (0.0603)	
R^2	0.4632	0.6448	0.5771	0.7049
Constant	-0.0365***	2.3646***	-0.0232***	2.3625***
	(0.0038)	(0.0515)	(0.0039)	(0.0509)
Observations	4560	4560	4560	4560

In Model (4), the regression coefficient of the regulating variable of economic circles is significantly positive, illustrating that e-commerce has a stronger influence on accelerating green innovation in cities located in China's three economic circles than in other cities. Based on the results presented in Table 7, Hypothesis 3 is supported.

The coefficients of the moderating variables in Model (1) to Model (4) are significantly positive, indicating that e-commerce development's effect on the green innovation level in cities varies depending on the cities' own endowment and location distribution. Specifically, the promotion effect of e-commerce development on the green innovation level is stronger in cities located in the eastern region of China, cities with higher administrative levels such as provincial capitals and so on, and cities in China's three major economic centers.

CONCLUSION AND POLICY IMPLICATIONS

Green innovation is a critical driver of the sustainable urban economy and social development, as well as a key factor in achieving "carbon neutrality and carbon peaking." The Chinese e-commerce demonstration city policy is designed to promote the use of e-commerce in strategic emerging industries such as energy conservation and environmental protection, high-end manufacturing, and industrial structure upgrading while also reducing environmental pollution. This policy occupies a crucial position in advancing green innovation in cities. This study employs a variety of models, including multi-period double difference, mediating effect, moderating effect, and quantile

Table 7. Heterogeneity analysis results

	(1)	(2)	(3)	(4)
	City Location	**Science and Education Resources**	**City Rating**	**Economic Circle**
	g-inno	*g-inno*	*g-inno*	*g-inno*
ele-com_city	0.0468***	0.1168**	0.0941**	0.1296*
	(0.0152)	(0.0588)	(0.0468)	(0.0713)
Zone regulation	0.1767**			
	(0.0756)			
Reconciliation of scientific and educational resources		0.2251***		
		(0.0764)		
City level moderating			0.3021***	
			(0.0755)	
Economic Circle Reconciliation				0.1075***
				(0.0082)
Control variables	Control	Control	Control	Control
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes
R^2	0.8426	0.8427	0.8430	0.8424
Constant	-3.3742***	-3.3626***	-3.3440***	-3.4023***
	(0.1028)	(0.1030)	(0.1030)	(0.1024)
Observations	4560	4560	4560	4560

regression, to probe into e-commerce development's effect on the urban green innovation level. The authors' analysis identifies the pathways and factors that influence this relationship. Their findings reveal that e-commerce development significantly improves the urban green innovation level, and this effect is more pronounced as the level of green innovation increases. In addition, e-commerce development can stimulate entrepreneurial activity and investment concentration in cities, leading to higher levels of green innovation. The impact of e-commerce development on the promotion of green innovation level in cities is influenced by factors such as location, scientific and educational resources, administrative level, and economic circles. Specifically, the effect of e-commerce development on promoting green innovation is stronger in cities located in eastern China, cities with rich scientific and educational resources, cities with higher administrative levels, and cities located in economic circles.

Green technology innovation is at the core of promoting cities' green development, reducing carbon emissions, and reducing environmental pollution. This paper highlights the importance of e-commerce in promoting green innovation in cities, providing practical guidance for policymakers. E-commerce plays a key part in stimulating urban entrepreneurial activity and creating favorable conditions for green innovation. Therefore, countries around the world should make efforts to promote the popularization and application of e-commerce, learn from relevant initiatives of China's "e-commerce demonstration cities," introduce relevant policies that are suitable for e-commerce development in cities, accelerate network infrastructure construction improvement, promote organic combination of e-commerce with manufacturing, agriculture, and service industries, and accelerate industrial structure upgrading. In the meantime, society should pay attention to e-commerce applications in strategic emerging industries such as environmentally friendly industries and high-end manufacturing to provide new growth opportunities for the green economy. Recognizing that the impact of e-commerce development on green innovation can vary depending on a city's resource endowments, which is of vital importance. Therefore, to maximize the empowering effect, development strategies should be tailored to the specific economic and social characteristics of each city.

In the era of the digital economy, giving full play to the newly founded advantages of the digital economy and realizing economic digital transformation are important means to embark on the journey of green and sustainable development. As an important part of the digital economy, e-commerce is of great value to further accelerate the popularization and application of e-commerce and release its green development effect. Our research confirms that the development of e-commerce can have an important promoting effect on urban green technology innovation, accelerate the process of urban green innovation, and help realize the goal of regional green development. Therefore, countries worldwide should attach importance to the development of e-commerce and strive to provide resource support for its development. On the one hand, developing countries can follow China's initiative to build a national e-commerce demonstration city, introduce policies to adapt to the development of e-commerce, establish a national e-commerce demonstration center, and create a growth pole of e-commerce, as such initiatives will further radiate to the development of e-commerce in other regions. On the other hand, while developing e-commerce and building e-commerce platforms, developed countries should focus on the radiation effect of e-commerce on energy conservation, environmental protection, new energy, and other industries, take advantage of e-commerce, accelerate the popularization and application of clean energy, improve the green innovation ability of enterprises, and accelerate the transformation of urban green development. In addition, countries should also fully realize the effect of enhancing the entrepreneurial vitality and accelerating the investment agglomeration that are created by the development of e-commerce, release the green vitality of cities, provide sufficient financial and human capital support for urban green technological innovation, and help

realize the goal of green sustainable development. Finally, we should also realize that the impact of e-commerce development on green innovation might vary with the resource endowment of cities, as resource endowment is very important. Therefore, to maximize the promotion effect of e-commerce on urban green innovation, the development strategy should be suitable for the specific economic and social characteristics of each city.

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