

How e-commerce development affects urban carbon emissions: Evidence from China

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Abstract. Under the dual constraints of ensuring economic growth and achieving the "dual carbon" goals, the impact of e-commerce development on urban carbon emissions has become a new frontier in this era. This study utilizes urban panel data from 2008 to 2021 to systematically investigate the specific effects and mechanisms of e-commerce on carbon emissions from both theoretical and empirical perspectives. The research reveals that pilot policies such as the construction of national e-commerce demonstration cities significantly reduce carbon emissions, a conclusion that holds true even after a series of robustness tests. Further exploration indicates that promoting green innovation and enhancing energy efficiency are vital mechanisms through which pilot policies of national e-commerce demonstration city construction drive carbon emission reductions. Regions in the eastern and southern parts of the country, along the Yangtze River Economic Belt, non-resource-based cities, and peripheral cities are better positioned to leverage the digital economy dividend to advance carbon emissions reduction. This study contributes to a deeper understanding of carbon reduction and the social impacts of e-commerce development.

Keywords: E-commerce; Carbon emissions; Green innovation; Energy efficiency.

1. Introduction

Since the reform and opening up, with the continuous development of China's economy and society and the improvement of urban economic vitality, the scale of urban economy has been expanding, the development of heavy industry has been rapid, and the consumption of fossil energy, such as coal, has been increasing, which puts a great pressure on China's and the world's carbon emission reduction and low-carbon economic growth (Fischer et al., 2021; Jin et al., 2022). Controlling greenhouse gas (GHG) emissions is not only a serious problem for China, but also a fundamental issue for the well-being of all human beings and the sustainable development of the global economy and society. For this reason, General Secretary also pointed out in the report of the 20th Party Congress that "we should actively and steadily promote carbon peaking and carbon neutrality, based on China's energy resource endowment, establish the new before abolish the old, and implement carbon peaking actions in a planned and step-by-step manner". Previous studies have shown that rapid urbanization due to population growth and economic development has led to increasing environmental problems (Aldousari et al., 2022). Expanding urban areas, in turn, can cause an increase in carbon emissions (Rahaman et al., 2022), leading to various negative impacts such as air degradation and severe economic losses (Zhang et al., 2024).

In 2023, the scale of China's digital economy exceeded 55 trillion yuan, accounting for nearly 50% of the GDP. The digital economy has become an important engine driving China's economic growth. E-commerce, as an early representative of the digital economy, has developed into China's most innovative and dynamic sector, with the country being the world's largest online retail market for 11 consecutive years. The National Development and Reform Commission once stated that one of the significances of creating e-commerce demonstration cities is to "reduce the consumption of physical resources and energy, decrease environmental pollution, and promote a green economy." Intuitively, the shift from offline activities to online bring about by e-commerce is bound to have some impact on carbon emissions. However, during the processes of product transactions, logistics, and delivery services, e-commerce also generates direct or indirect resource and energy consumption through transportation emissions, freight packaging, and other activities, which negatively impacts the climate

and environment (Xue et al., 2019). Currently, with the ongoing implementation of the "dual carbon" goals, various industries face significant pressure to reduce emissions. The key issue is to understand whether the development of e-commerce can positively affect urban carbon emissions, whether it can become a new driving force for low-carbon development, and what its underlying mechanisms are in influencing urban carbon emissions.

Existing research has extensively discussed the relationship between urban e-commerce and carbon emissions. Biao et al. (2023) argued that the construction of national e-commerce demonstration cities could reduce urban carbon emission levels by promoting industrial structure upgrades, alleviating mismatches in labor and capital factors, driving green technological innovation in cities, fostering economic agglomeration effects, and lowering transaction costs (Liu Naiquan et al., 2021). Xu and Jiang (2023) believed that urban e-commerce significantly reduces carbon emissions and improves carbon efficiency. However, some studies have presented different views. Cheba et al. (2021), using empirical data from European cities, showed that the increase in online shopping drives the expansion of the logistics industry, leading to higher energy consumption in the transportation sector. Additionally, it increases the consumption of packaging materials, electricity, and other resources (Pålsson et al., 2017), all of which have negative impacts on reducing carbon emissions. Other research has found that e-commerce promotes the improvement of urban green total factor productivity (Cao et al., 2021) and enhances corporate environmental performance (Zhang and Zhang, 2023). Based on this, the author seeks to explore whether e-commerce can be an effective driving force for reducing carbon emissions under the concept of green development. If the answer is yes, what are the underlying mechanisms at play? Do the effects vary across different times and places?

The marginal contributions of this paper are as follows: First, it incorporates e-commerce and urban carbon emissions into a unified analytical framework, attempting to explore the environmental spillover effects of e-commerce from the perspective of national e-commerce demonstration city construction policies, expanding the scope of existing literature on e-commerce. Second, this paper investigates the transmission mechanisms of how e-commerce can reduce urban carbon emissions by promoting green innovation and reducing energy consumption, providing a potential pathway for e-commerce to drive carbon reduction and achieve green urban development.

2. Literature review and hypothesis development

2.1. Test of hypothesis 1: Relationship between NECDC and CO₂

Entering the 21st century, with the rapid development of the global internet industry, e-commerce has become a new engine for economic growth in major developed countries. The construction of e-commerce demonstration cities in China has also gradually expanded its scope in line with market development and policy advancements. Unlike traditional business models, e-commerce, as an emerging business model, promotes the rational allocation of resources and products through innovation in traditional supply chains and industrial chains, achieving energy conservation and emission reduction.

E-commerce is equipped with digital technology and a reliable credit regulatory system, providing a public service information platform for small and micro enterprises (Chen and Peng, 2022). From the supply perspective, on one hand, e-commerce advocates low-carbon production, circulation, and sales of products through digital technology, fully unleashing the dividends of data and information. It gradually forms efficient and energy-saving supply chains, industrial chains, and consumption chains, reducing the marginal carbon emissions of each product unit (Zhang and Zhang, 2023). On the other hand, the new e-commerce model promotes the green development of logistics companies. Under the "dual carbon" goals, e-commerce enterprises are encouraged to accelerate the green operation process through innovative logistics mobilization and warehousing management models. The development of e-commerce is conducive to building resource-saving and environmentally friendly logistics companies and will also encourage multi-party cooperation with recycling

companies (Wang et al., 2020), thereby improving the responsibility system for qualified packaging product suppliers in logistics companies.

From the demand perspective, it promotes the connection between enterprises, governments, and consumers, expands product sales channels, and creates healthy market competition. The expansion of urban e-commerce, driven by digital technology and business model innovation, supports high-tech industries and integrates e-commerce systems into the production, sales, and after-sales processes of traditional enterprises. This expansion increases consumer access to product information, reduces information asymmetry and consumer search costs (Ye et al., 2023), and promotes the transformation of the economic development model. Therefore, it enhances product diversity, optimizes resource allocation, and improves market efficiency. In addition, as residents' awareness of ecological and environmental protection increases, the green consumption rate will further rise, accelerating the shift of life and production toward a "green model" (Xu et al., 2024). Accordingly, this paper proposes the following hypothesis:

Research Hypothesis 1: The national e-commerce demonstration city construction policy will reduce urban carbon emissions.

2.2. Test of hypothesis 2: NECDC, GRP and CO₂

The construction of national e-commerce demonstration cities can promote urban innovation. First, the construction of these cities uses digital technology as a core driving force and is an important initiative for building a strong digital economy. It can lead to industrial structure transformation, export technology upgrading, increased e-commerce sales, and human capital accumulation effects (He and Wang, 2024). Second, the construction of national e-commerce demonstration cities enhances urban entrepreneurial activity through two channels: expanding the supply of entrepreneurial resources and stimulating market demand potential (Zhang and Lü, 2024), injecting fresh energy into urban green innovation. Third, the development of urban e-commerce promotes the clustering of productive service industries by increasing industrial coordination in the region and reducing transaction costs for manufacturing and domestic private enterprises. Relying on the agglomeration effect, it improves the level and quality of urban innovation. The production clustering effect can also intensify market competition, pushing companies to gain a competitive edge through green innovation, further promoting urban green innovation (Zeng et al., 2021).

Green innovation can effectively reduce carbon emissions. First, Jin et al. (2022) argue that the construction of e-commerce demonstration cities can drive green technological innovation in micro-enterprises, thereby promoting green, high-quality development. Green technological innovation, empowered by digitalization, can accelerate the development of solar, wind, and renewable energy, effectively promoting the growth of the new energy sector. This shift supports the transformation of the energy consumption structure towards green, low-carbon, and clean energy, directly reducing carbon emissions (Guo et al., 2022). Second, green technological innovation also improves corporate production methods, enhances energy efficiency, and supports the transition of industrial structures toward low-carbon and green industries, reducing corporate energy consumption (Guo and Wang, 2022). It is the essential path to achieving the "dual carbon" goals. Accordingly, this paper proposes the following hypothesis:

Research Hypothesis 2: The national e-commerce demonstration city construction policy will promote green innovation or the advancement of industrial structures in pilot areas, thereby reducing carbon emissions.

2.3. Test of hypothesis 3: NECDC, ENERGY and CO₂

The national e-commerce demonstration city construction policy will promote improved energy efficiency in pilot areas. First, logistics and transportation in e-commerce are major sources of energy consumption. By using biodegradable or recyclable packaging materials and optimizing logistics routes and transportation methods, resource waste can be reduced, and energy efficiency can be improved (Zhao et al., 2023). Second, e-commerce has also fostered the emergence and growth of

new service industries, which not only optimize human capital and continuously update physical capital but also promote the construction of a modern, digitalized, and green industrial system (Li et al., 2024). In the process of industrial integration and the emergence of new industries, specific high-efficiency sectors such as high-tech and strategic emerging industries gradually expand, thus improving the energy efficiency of the entire production sector. Third, the integration of e-commerce in rural areas has completely transformed the economic and social development models, greatly changing farmers' perspectives, ideas, and habits. This shift encourages farmers to gradually transition from traditional biomass energy to modern clean alternative energy for household use (Cao et al., 2024).

Improving energy efficiency can effectively reduce urban carbon emissions. First, enhancing energy efficiency directly reduces energy consumption, thereby lowering carbon emissions associated with energy production. According to a United Nations report, most global greenhouse gas emissions come from the burning of fossil fuels, including those used for electricity generation and heating. By increasing energy efficiency, reliance on fossil fuels can be reduced, which in turn decreases urban carbon emissions (Hong et al., 2022). Second, improving energy efficiency is often accompanied by increased use of renewable energy. Renewable energy sources, such as solar, wind, and hydropower, offer clean and sustainable energy solutions (Justice et al., 2024). The International Renewable Energy Agency (IRENA) estimates that by 2050, 90% of the world's electricity could and should come from renewable energy. This suggests that by improving energy efficiency and transitioning to renewable energy, cities can significantly reduce their carbon emissions. Accordingly, this paper proposes the following hypothesis:

Research Hypothesis 3: The national e-commerce demonstration city construction policy will promote improved energy efficiency in pilot areas, thereby reducing carbon emissions.

3. Research design

3.1. Sample selection

3.1.1. Dependent variable

A substantial body of research has demonstrated a positive correlation between nighttime light intensity and carbon dioxide emissions (Zhu et al., 2019). This study estimates urban carbon emissions based on nighttime light data by constructing a panel data model (Chen et al., 2023; Zhang et al., 2022; Zhang et al., 2021). Specifically, the estimation of urban carbon emissions proceeds as follows: firstly, carbon emissions for 30 provinces and municipalities in inland China (excluding Tibet) from 2008 to 2021 are calculated using the method outlined in the IPCC report for carbon emissions accounting from energy consumption. Subsequently, an equation is developed to relate nighttime light intensity to provincial carbon emissions, estimating the coefficient between the two. Finally, the total nighttime light values at the urban level are combined with the estimated coefficients to derive carbon emissions for 282 cities from 2008 to 2021.

3.1.2. Key independent variable

The construction of national e-commerce demonstration cities is the central explanatory variable in the article. The study generates time dummy variables based on the specific implementation time of different demonstration city constructions (defined as 1 for the year of policy implementation and onwards, and 0 otherwise) and policy dummy variables based on specific pilot cities (defined as 1 for demonstration cities and 0 otherwise). Interaction terms of these dummy variables are used as the core explanatory variables.

3.1.3. Mechanism variables

Building upon existing scholarly research (Sun and Zhang, 2022), this study matched the green patent application numbers at the city level by aligning the green patent classification list and international classification codes released by the World Intellectual Property Organization (WIPO)

in 2010 with the classification numbers of patent data from the Chinese National Intellectual Property Administration. This was done to increase the count of green patent applications to the city level. This count serves as a proxy variable for green innovation, denoted as "grp". In the empirical testing process, this variable was incremented by 1 and then natural logarithm was taken. A higher value of this transformed variable indicates a higher level of green innovation in the city.

Drawing on previous research (Wang et al., 2023; Wang, 2023), this study employs million tons standard coal to measure energy efficiency, denoted as "energy". The conversion coefficients used are as follows: natural gas conversion coefficient = 13.3 tce/10,000m³, liquefied petroleum gas conversion coefficient = 1.7143 tce/t, and electricity conversion coefficient = 1.229 tce/ (10,000 kW·h).

3.2. Methodology

The construction of national e-commerce demonstration cities is an exogenous shock variable, and the pilot cities are randomly selective and will vary according to the implementation of policies, so the construction of demonstration cities can be regarded as a quasi-natural experiment. A total of 68 prefecture-level cities were planned as model cities in three batches in 2011, 2014 and 2017. In order to verify the policy effect of national e-commerce demonstration city construction on urban carbon emission, this paper takes the national e-commerce demonstration city construction as a quasi-natural experiment, and constructs a double-difference model as follows.

$$CO2_{it} = \alpha_0 + \alpha_1 treated_i \cdot time_t + \alpha_2 Z_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

In Eq. (1), $CO2_{it}$ represents the energy intensity of city i at time t . The variable "*treated-time*" serves as the core explanatory variable, indicating whether a city has implemented the construction of a national e-commerce demonstration city. If city " i " implements the construction of a national e-commerce demonstration city in year " t ," the value is 1; otherwise, it is 0. Moreover, this study introduces control variables represented by Z_{it} . Specifically: the level of economic development (gdp) is measured by the logarithm of per capita GDP in the city. Population density (pnd) is measured by the ratio of total population at the end of the year to the area of the region. Foreign investment openness (fdi) is measured by the ratio of FDI in the city to GDP. The degree of financial development (fin) is measured by the ratio of the amount of loans from financial institutions to GDP. The completeness of infrastructure (Trans) is represented by the ratio of road mileage to the total area of the region. Here, μ_i captures city-level fixed effects, δ_t represents time-level fixed effects, and ε_{it} represents the random disturbance term.

Further, this paper utilizes PSM-DID estimation for robustness testing, firstly, we use kernel matching method to find the control group which is closest to the characteristics of the experimental group to be matched, and then we use the propensity score-matched experimental and control groups to perform DID regression. The model is constructed as follows.

$$CO2_{it}^{psm} = \alpha_0 + \alpha_1 treated_i \cdot time_t + \alpha_2 Z_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

The meaning of the symbols in Eq. (2) is consistent with the baseline regression.

3.3. Data

The data for this study were sourced from the "China City Statistical Yearbook," "China Rural Statistical Yearbook," Wind database. Interpolation was used to fill in missing values in some instances. The descriptive statistical results of the data are presented in Table 1.

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
<i>did</i>	3948	0.137	0.344	0.000	1.000
<i>CO2</i>	3948	3.477	0.139	2.958	4.059
<i>gdp</i>	3948	10.609	0.640	8.189	12.456

<i>pnd</i>	3948	1.733	0.184	0.463	2.080
<i>end</i>	3948	-0.172	0.520	-2.584	2.266
<i>fdi</i>	3948	-6.584	1.413	-15.115	-3.499
<i>urban</i>	3948	-1.326	0.664	-3.961	0.889
<i>trans</i>	3948	-0.087	0.601	-3.045	0.966
<i>grp</i>	3948	4.398	1.788	0.000	9.666
<i>energy</i>	3947	4.401	1.268	0.089	8.311

4. Results and discussion

4.1. Baseline model

Table 2 reports the baseline regression results of the impact of the national e-commerce demonstration city construction policy on urban carbon emissions. Each column in Table 2 presents the regression results based on different control variables in equation (1). The regression results show that, after controlling for all variables, the national e-commerce demonstration city construction policy significantly reduces total urban carbon emissions at the 1% level, with the pilot policy reducing urban carbon emissions by 1.5%, thus confirming Hypothesis 1. For instance, mainstream e-commerce companies like Alibaba and Tencent have set environmental goals covering the entire value chain, clearly outlining corporate emission reduction pathways. They achieve this by transforming traditional business models to optimize product production and allocation, thereby reducing carbon emissions (Wang et al., 2023).

It is worth noting that the estimated coefficient for the control variable measuring foreign capital openness remains significantly positive at the 1% confidence level across all models. Theoretically, foreign investment can result in two opposing effects: the "pollution haven hypothesis" and the "pollution halo hypothesis." This study confirms the existence of the "pollution haven hypothesis," where multinational enterprises recognize their competitive disadvantage when competing with firms in countries or regions with stricter environmental regulations (Kiviyiro and Arminen, 2014; Yan and Qi, 2017). As a result, foreign investors transfer high-pollution, high-energy consumption industries to China through direct investment.

Table 2. Baseline Regression Results.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>did</i>	-0.012*** (0.003)	-0.010*** (0.003)	-0.010*** (0.003)	-0.010*** (0.003)	-0.009*** (0.003)	-0.009*** (0.003)
<i>gdp</i>		0.045*** (0.005)	0.045*** (0.005)	0.044*** (0.005)	0.054*** (0.005)	0.054*** (0.006)
<i>pnd</i>			0.022 (0.093)	0.030 (0.096)	0.037 (0.098)	0.036 (0.096)
<i>fdi</i>				0.003*** (0.001)	0.003*** (0.001)	0.003*** (0.001)
<i>fin</i>					0.020*** (0.003)	0.020*** (0.004)
<i>trans</i>						0.001 (0.018)
<i>_cons</i>	3.479*** (0.000)	2.996*** (0.055)	2.960*** (0.167)	2.982*** (0.169)	2.865*** (0.174)	2.866*** (0.172)
<i>City FE</i>	Y	Y	Y	Y	Y	Y
<i>Time FE</i>	Y	Y	Y	Y	Y	Y
<i>N</i>	3948	3948	3948	3948	3948	3948
<i>adj. R²</i>	0.965	0.968	0.968	0.968	0.969	0.969

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% confidence levels, respectively. Robust standard errors are reported in parentheses. The same applies to the following tables.

4.2. Robustness test results

4.2.1. Parallel trend test

The parallel trend assumption is a crucial prerequisite for the DID model. It requires that, prior to the implementation of the national e-commerce demonstration city pilot policy, the carbon emission levels in both pilot and non-pilot cities exhibit a consistent trend. Following previous studies (Zhou and Yu, 2021), this paper conducts a parallel trend test. The specific steps are as follows: first, we set a series of time dummy variables, where the value is 1 for the given year and 0 for other years. Additionally, we generate city dummy variables, with a value of 1 for cities that are pilot cities for the national e-commerce demonstration city construction, and 0 otherwise. Next, we construct interaction terms between the time dummy variables and the city dummy variables.

Figure 1 reports the analysis results. From the results, all regression coefficients before 2013 are insignificant, indicating that prior to the implementation of the national e-commerce demonstration city pilot policy, the treatment group and the control group exhibited a consistent trend with no significant differences. This suggests that the parallel trend assumption is satisfied.

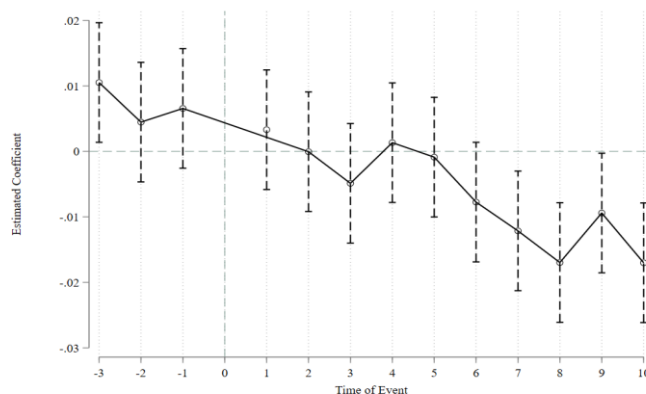


Figure 1. Parallel trend test.

4.2.2. Propensity Score Matching-Difference in Difference (PSM-DID)

The pilot policy for the "National E-commerce Demonstration City Construction" is organized by local governments, with the list of demonstration cities being announced after a review by higher authorities. This selection process may introduce sample self-selection bias. To address the selection bias in the policy implementation process, the PSM-DID method is used for robustness testing (Zhang et al., 2022).

First, kernel matching is employed to match the treatment group and the control group year by year, removing unmatched samples. Then, the matched samples are used to perform a regression based on equation (1). As shown in column (1) of Table 3, after re-matching the control group samples, the "National E-commerce Demonstration City Construction" pilot policy still significantly reduces total urban carbon emissions at the 1% level.

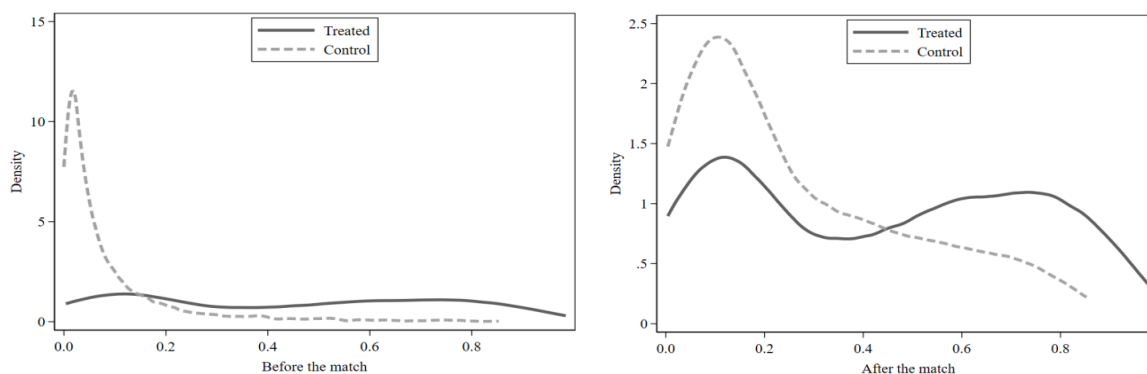


Figure 2. Probability Distribution Density Function of Propensity Scores.

4.2.3. Replace variables

This paper follows the research of Zhao et al. (2024) and adopts a continuous dynamic distribution method based on the random kernel density function to analyze the carbon emission intensity of Chinese cities. The total carbon emissions for each city are calculated by summing emissions from transportation and buildings, industrial production processes, agriculture, forestry, land-use changes, and waste treatment activities, denoted as CO22. The results in column (2) of Table 3 indicate that, even after changing the method of measuring carbon emissions, the "National E-commerce Demonstration City Construction" pilot policy still significantly reduces carbon emissions, promoting the achievement of carbon neutrality, and further enhancing the credibility of the conclusions.

4.2.4. Using interactive fixed effects

In addition, due to the influence of historical and geographical factors, the impact across different regions may exhibit systematic trends over time. Therefore, this paper incorporates province and time interaction fixed effects by adding Pro*Year in equation (1). As shown in the results of column (3) in Table 3, after accounting for different fixed effects, the implementation of the "National E-commerce Demonstration City Construction" pilot policy still significantly reduces urban carbon emissions and promotes the achievement of carbon neutrality.

4.2.5. Exclude interfering policies

Excluding the impact of other policies: During the study period, other policies may have influenced carbon emissions. Previous research has confirmed the impact of the "Broadband China" strategy on carbon emissions (Guo et al., 2023). To control for the influence of other policies on urban carbon emissions, and considering that the "Broadband China" strategy was implemented in phases, policy dummy variables related to the "Broadband China" strategy were included as control variables in the baseline regression. As shown in column (4) of Table 3, the results indicate that the regression coefficients of the "National E-commerce Demonstration City Construction" pilot policy are significantly negative, while the coefficient of the "Broadband China" strategy is negative but not significant, suggesting the robustness of the baseline regression results.

Table 3. The robustness test.

	(1) PSM-DID	(2) Replace variables	(3) Interactive fixed effects	(4) Exclude interfering policies
<i>newdid</i>	-0.009*** (0.003)			
<i>did</i>		-0.022** (0.011)	-0.009*** (0.003)	-0.009*** (0.003)
<i>did_Broadband</i>				-0.000 (0.002)
<i>gdp</i>	0.054*** (0.006)	0.199*** (0.021)	0.044*** (0.006)	0.054*** (0.006)
<i>pnd</i>	0.036 (0.096)	0.118 (0.374)	-0.010 (0.053)	0.036 (0.096)
<i>fdi</i>	0.003*** (0.001)	0.009*** (0.003)	0.002* (0.001)	0.003*** (0.001)
<i>fin</i>	0.020*** (0.004)	0.070*** (0.014)	0.015*** (0.003)	0.020*** (0.004)
<i>trans</i>	0.001 (0.018)	-0.010 (0.067)	0.024** (0.011)	0.001 (0.018)
<i>_cons</i>	2.866*** (0.172)	1.809*** (0.667)	3.046*** (0.116)	2.866*** (0.172)
<i>City FE</i>	Y	Y	Y	Y
<i>Year FE</i>	Y	Y	Y	Y
<i>Pro*Year FE</i>	N	N	Y	N
<i>N</i>	3948	3948	3878	3948
<i>adj. R²</i>	0.969	0.962	0.975	0.969

4.2.6. Placebo test

Different cities have many distinct characteristics. Although the impact of these characteristics on carbon emissions has been controlled for through city fixed effects and control variables in previous analyses, some characteristics may have varying effects over time, which could influence the identification assumptions. These effects cannot be controlled by the model used in this paper. To obtain a more reliable causal identification effect, this paper follows existing research (Wang et al., 2022) and uses a permutation test method by randomly selecting the policy intervention group for validation. Figure 3 reports the significance and distribution of estimated coefficients after 1,000 random samples. The solid black line in the figure represents the kernel density curve of the estimated coefficients from the randomly selected policy intervention group for the "National E-commerce Demonstration City Construction" pilot policy, while the dashed line represents the estimated coefficients for the actual policy intervention group of the "Broadband China" strategy. From Figure 3, it can be seen that the distribution of estimated coefficients after random sampling is centered on zero and follows a normal distribution, which aligns with the expectations of a placebo test. This result indirectly confirms that the impact of the "National E-commerce Demonstration City Construction" pilot policy on reducing carbon emissions is not due to other unobservable factors, further reinforcing the robustness of the conclusions in this paper.

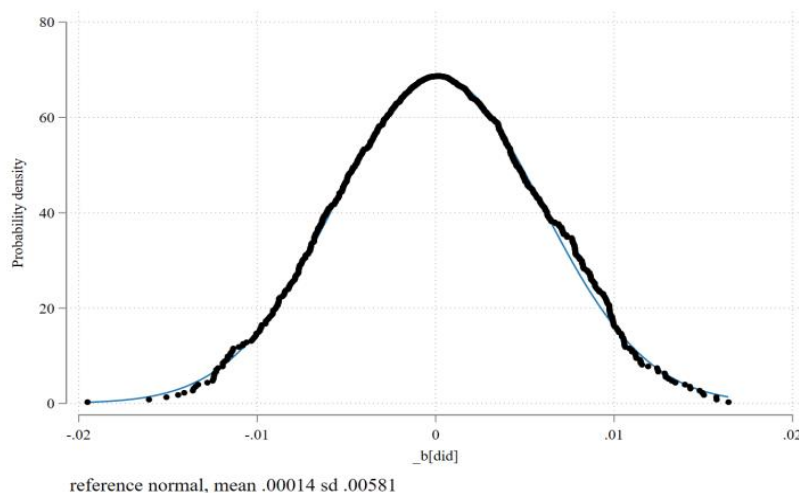


Figure 3. Placebo test.

5. Further discussion

5.1. Mechanism analysis

In traditional stepwise methods, analyzing mediation effects can lead to reduced statistical power and estimation bias. Jiang (2022) suggests that instead of relying on the traditional stepwise regression method, one can theoretically propose intuitive mediation variables that impact the dependent variable, and then examine the effects of the independent variable on the dependent variable and the independent variable on the mediation variable. This approach avoids the need to formally distinguish if there are unexplained direct effects beyond the indirect effects. Following this approach, this paper refers to existing research and, after performing regression analysis on the "National E-commerce Demonstration City Construction" pilot policy and carbon emissions, only conducts regression analysis on the pilot policy and the mediation variables. The impact of mediation variables on carbon emissions is validated through theoretical literature.

Column (1) of Table 4 shows that the "National E-commerce Demonstration City Construction" pilot policy can promote green innovation in enterprises. Specifically, this policy fosters the improvement of green innovation levels through knowledge and technology spillovers and cross-regional collaboration. Green innovation, characterized by low cost, low energy consumption, low

pollution, and low emissions, balances environmental protection with green development, thus significantly promoting the reduction of carbon emissions.

Column (2) of Table 4 indicates that the "National E-commerce Demonstration City Construction" pilot policy can enhance energy use efficiency. Generally, the promotion of e-commerce is accompanied by the widespread application of information technologies such as cloud computing and big data analytics. These technologies help optimize resource allocation and improve energy use efficiency. For example, data analysis can optimize logistics routes, reducing unnecessary transportation and energy waste (Cao et al., 2021). Improving energy use efficiency means achieving the same service or product with less energy consumption during production and consumption processes. This is typically accomplished through the adoption of advanced technologies, improvement of process flows, optimization of energy management, and changes in consumer behavior. Since the burning of fossil fuels is a major source of global carbon emissions, reducing energy consumption directly leads to decreased use of fossil fuels and increased use of renewable (clean) energy, thereby reducing greenhouse gas emissions (Hong et al., 2022).

Table 4. Mechanism analysis.

	(1) <i>grp</i>	(3) <i>energy</i>
<i>did</i>	0.852*** (0.127)	0.362*** (0.077)
<i>gdp</i>	1.118*** (0.108)	1.214*** (0.081)
<i>pnd</i>	1.554* (0.876)	2.305*** (0.461)
<i>fdi</i>	0.008 (0.045)	-0.061* (0.033)
<i>fin</i>	0.883*** (0.114)	0.441*** (0.086)
<i>trans</i>	0.119 (0.241)	-0.153 (0.162)
<i>_cons</i>	-10.072*** (1.929)	-12.881*** (1.203)
<i>City FE</i>	Yes	Yes
<i>Time FE</i>	Yes	Yes
<i>N</i>	3878	3878
<i>adj. R²</i>	0.791	0.719

5.2. Heterogeneity analysis

Previous research has confirmed the overall positive impact of the National E-commerce Demonstration City Construction on reducing urban carbon emissions. However, it has not verified whether the impact of e-commerce development on carbon emissions varies among cities with different locational characteristics. This paper will further examine the heterogeneous effects of the National E-commerce Demonstration City Construction on carbon emissions from two dimensions: geographical location and city characteristics.

5.2.1. Heterogeneity for geographical location

Columns (1) to (3) of Table 4 indicate that the impact of the National E-commerce Demonstration City Construction on carbon emissions is more significant in the eastern region. This is because, geographically, the eastern region has higher market openness, more frequent technological exchanges and trade activities, and e-commerce typically first enters and clusters in the eastern region (Bieao et al., 2023). Additionally, the eastern region has a higher concentration of renowned universities and research institutions, providing more research talent and greater innovation vitality. As a result, the eastern region is more capable of embracing e-commerce.

China's vast territory and the significant geographical span between the north and south mean that differences in natural resource endowments, economic structures, and development paths can lead to varying responses to e-commerce demonstration city construction and carbon emissions. Therefore, this paper divides the entire sample into northern and southern cities for separate regression analyses, with the results shown in columns (5) and (6) of Table 5. Compared to northern cities, the correlation between e-commerce development and carbon reduction is stronger and more significant in southern cities, indicating that the National E-commerce Demonstration City Construction has a greater carbon reduction effect in southern cities. This could be because the southern region has a more diversified industrial structure, with rapid development in high-tech industries such as electronic information and internet technology (Chen et al., 2023). Consequently, southern cities have more opportunities and incentives to adopt low-carbon technologies and business models to achieve carbon reduction goals. In contrast, northern regions have a higher proportion of traditional industries, with slower transformation and upgrading, which may result in a weaker acceptance and promotion of e-commerce.

The Yangtze River Economic Belt, as a major strategic development region in China, has achieved significant economic development results due to its enormous development potential and distinct geographic advantages. It has become a key area for leading high-quality development and advancing green transformation. Based on this, the paper divides the entire city sample into Yangtze River Economic Belt cities and non-Yangtze River Economic Belt cities, with the regression results shown in columns (7) and (8) of Table 5. The coefficient for Yangtze River Economic Belt cities is significantly negative at the 1% level, indicating that the carbon reduction effect is notably better than in non-Yangtze River Economic Belt cities. This is because, overall, cities along the Yangtze River Economic Belt have a solid technological foundation. Technological advantages further facilitate the introduction of e-commerce, giving the Yangtze River Economic Belt region stronger capabilities, potential, and acceptance for e-commerce (Zhu Yeliang, 2023). At the same time, pollution issues in the Yangtze River Economic Belt cannot be ignored. The "Ecological and Environmental Protection Plan for the Yangtze River Economic Belt" indicates that the total pollution emissions in the Yangtze River Economic Belt are large and intense, with chemical oxygen demand, ammonia nitrogen, sulfur dioxide, and other emissions per unit area being 1.5 to 2.0 times the national average level. Thus, there is significant potential for emission reduction in the Yangtze River Economic Belt region.

Table 5. Heterogeneity test-geographical location.

	(1) east	(2) centre	(3) west	(4) northeast	(5) north	(6) south	(7) CJ=1	(8) CJ=0
<i>did</i>	-0.011*** (0.004)	-0.007* (0.004)	-0.010* (0.005)	-0.009 (0.009)	-0.006 (0.006)	-0.013*** (0.003)	-0.016*** (0.004)	-0.006 (0.004)
<i>gdp</i>	0.036*** (0.008)	0.051*** (0.009)	0.040*** (0.010)	0.012 (0.013)	0.049*** (0.009)	0.046*** (0.007)	0.032*** (0.007)	0.051*** (0.007)
<i>pnd</i>	-0.003 (0.148)	-0.002 (0.095)	0.112 (0.127)	-0.040 (0.029)	0.058 (0.115)	-0.012 (0.085)	0.023 (0.077)	0.037 (0.111)
<i>fdi</i>	-0.001 (0.002)	0.005** (0.002)	0.005*** (0.001)	-0.003** (0.001)	0.001 (0.001)	0.006*** (0.001)	0.010*** (0.002)	-0.000 (0.001)
<i>fin</i>	0.002 (0.004)	0.016*** (0.004)	0.021*** (0.005)	0.010 (0.007)	0.022*** (0.005)	0.015*** (0.004)	0.022*** (0.005)	0.019*** (0.005)
<i>trans</i>	0.035*** (0.009)	0.027** (0.011)	0.075*** (0.019)	-0.099*** (0.008)	-0.035 (0.025)	0.043*** (0.009)	0.054*** (0.012)	-0.018 (0.022)
<i>_cons</i>	3.193*** (0.306)	2.941*** (0.184)	2.873*** (0.252)	3.325*** (0.135)	2.863*** (0.221)	3.051*** (0.170)	3.128*** (0.169)	2.886*** (0.208)
<i>City FE</i>	Y	Y	Y	Y	Y	Y	Y	Y
<i>Year FE</i>	Y	Y	Y	Y	Y	Y	Y	Y
<i>N</i>	1204	1106	1162	476	1806	2142	1484	2464
<i>adj. R²</i>	0.984	0.963	0.961	0.947	0.961	0.979	0.981	0.962

5.2.2. Heterogeneity of city characteristics

Typically, resource-based cities have a relatively singular economic growth point, heavily reliant on resource endowments, which affects the effectiveness of the national e-commerce demonstration city policy in promoting low-carbon economic transformation. To explore whether the resource endowment of resource-based cities influences urban innovation, this paper classifies the sample cities into resource-based and non-resource-based cities based on the "National Sustainable Development Plan for Resource-Based Cities (2013–2020)" issued by the State Council in 2013, assigning a value of 1 to resource-based cities and 0 to non-resource-based cities. The regression results in columns (1) and (2) of Table 6 show that the coefficient for non-resource-based cities is significantly negative at the 1% level. This confirms that the carbon reduction effect of the national e-commerce demonstration city policy is weaker in resource-based cities compared to non-resource-based cities. This phenomenon is likely due to the fact that the economic development model of resource-based cities has long been dependent on resource-intensive industries (Deng and Wu, 2024). This leads to a singular industrial structure and strong path dependency in economic growth. Additionally, the limitations in technological level affect resource utilization efficiency, potentially resulting in higher carbon emissions and limited reduction potential in the short term (Guo and Liang, 2022).

To further consider the heterogeneous impact of urban characteristics, this paper constructs a city-level dummy variable, assigning a value of 1 to the four municipalities directly under the central government and 15 sub-provincial cities: Shenyang, Changchun, Harbin, Nanjing, Wuhan, Guangzhou, Jinan, Hangzhou, Chengdu, Shenzhen, Xiamen, Ningbo, Qingdao, Dalian, and Xi'an, and a value of 0 to other cities. The results in column (4) of Table 6 show that cities with lower levels and smaller scales have significantly negative coefficients. This indicates that the national e-commerce demonstration city policy has a more pronounced effect on carbon reduction in smaller cities. The possible reasons for this phenomenon are as follows: On the one hand, compared to large cities, smaller cities generally have a more singular industrial structure, and the costs and resistance to transformation are relatively lower. On the other hand, smaller cities have fewer management levels, making it easier to decompose and implement policy goals. Therefore, under the promotion of the national e-commerce demonstration city policy, smaller cities can more quickly optimize and upgrade their industrial structures, thus reducing carbon emissions.

Table 6. Heterogeneity test-urban characteristics.

	(1) resource=1	(2) resource=0	(3) city_level=1	(4) city_level=0
<i>did</i>	-0.012 (0.008)	-0.011*** (0.003)	-0.001 (0.006)	-0.005** (0.002)
<i>pnd</i>	0.058*** (0.008)	0.043*** (0.006)	0.035*** (0.007)	0.054*** (0.003)
<i>fdi</i>	-0.022 (0.073)	0.088 (0.109)	-0.030 (0.300)	0.042 (0.037)
<i>fin</i>	0.004*** (0.001)	0.002 (0.001)	-0.008** (0.004)	0.003*** (0.001)
<i>trans</i>	0.026*** (0.005)	0.013*** (0.004)	0.006 (0.011)	0.021*** (0.002)
<i>energy</i>	-0.057*** (0.020)	0.054*** (0.012)	0.011 (0.010)	-0.006 (0.005)
<i>_cons</i>	2.886*** (0.155)	2.906*** (0.206)	3.317*** (0.602)	2.840*** (0.068)
<i>City FE</i>	Y	Y	Y	Y
<i>Year FE</i>	Y	Y	Y	Y
<i>N</i>	1582	2366	266	3682
<i>adj. R²</i>	0.951	0.977	0.994	0.959

6. Conclusion

Under the "Dual Carbon" strategy, this paper, based on the flourishing development of e-commerce, delves into the effects and mechanisms of carbon reduction. Utilizing city panel data from China from 2008 to 2021, the paper rigorously tests the effect of the national e-commerce demonstration city policy on reducing carbon emissions and its underlying mechanisms. The main conclusions are as follows:

The national e-commerce demonstration city policy significantly reduces carbon emission levels and serves as a crucial driving force for achieving high-quality development in China.

Mechanism analysis indicates that the policy impacts carbon emissions through two key channels: promoting green innovation and reducing energy consumption.

Heterogeneity analysis reveals that the negative impact of the policy on carbon emissions is more pronounced in the eastern region, southern region, Yangtze River Economic Belt, non-resource-based cities, and smaller cities.

Based on the above research conclusions, this paper proposes the following policy recommendations to further promote the development of e-commerce and the continuous reduction of carbon emissions under the "dual carbon" strategy:

First, deepen green innovation and encourage technological upgrading and application. On the one hand, implement the top-level design of the national e-commerce demonstration city pilot policy, strengthen policy support or establish special funding subsidies, and promote e-commerce enterprises to accelerate breakthroughs and application of green technologies through independent research and development and collaborative innovation. On the other hand, establish innovation incentive mechanisms to create policy synergy, guide more enterprises and research institutions to participate in green technology development, and make green innovation an intrinsic driving force for the development of e-commerce.

Second, accelerate the construction of information infrastructure to provide technical support for the further development of e-commerce. On the one hand, in areas with better information infrastructure construction, such as non-resource-based cities, eastern cities, and the Yangtze River Economic Belt, continue to vigorously implement the national e-commerce demonstration city promotion work, further improve urban informatization, and enhance its role in driving the development of e-commerce in surrounding cities. On the other hand, in areas with relatively backward information infrastructure construction, such as resource-based cities, central and western regions, and some northern areas, greatly strengthen the construction of information network infrastructure, form technical support for the development of e-commerce, and develop clear e-commerce development goals based on local characteristics, promoting a development model that integrates technology-driven production and production-driven construction.

Third, strengthen regional coordinated development and promote the replication and promotion of carbon reduction experiences. Actively promote the practices and experiences of eastern, southern regions, and the Yangtze River Economic Belt, and help lagging regions adopt green e-commerce development models. By establishing regional cooperation platforms, facilitate technology exchange and cooperation between advanced regions in the east and south and central, western, and northern regions, and promote the diffusion of advanced green technologies and management models nationwide. At the same time, considering the differences in local economies and resource endowments, develop e-commerce according to local conditions and formulate carbon reduction policies that match local characteristics, encourage local governments and enterprises to explore and practice in green logistics, energy structure adjustment, technological innovation, and other areas, and form regional synergy to support the achievement of national carbon reduction goals.

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