How Does Internet Development Affect Green Technology Innovation in China?

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ABSTRACT

With the advent of the information age, the internet is a new tool for “mass entrepreneurship and innovation initiative” and contributes to the emergence of new products, new technologies, and new business formats. However, the question of how internet development affects green technological innovation has not been well answered. This article measures the comprehensive Internet development level of 264 prefecture-level cities from 2003 to 2018 in China and then conducts empirical research. The results show that internet development can increase high-quality and low-quality green technological innovation. This conclusion remains robust after endogeneity testing. Secondly, internet development can not only directly promote green technology innovation, but also indirectly play a positive role through financial development and industrial structure upgrading. Thirdly, the positive effect of internet development on green technology innovations presents significant nonlinear characteristics of increasing marginal effect. It indicates that Metcalfe’s law is valid in this paper.

KEYWORDS

China, Green Technology Innovation, Influencing Mechanism Analysis, Internet Development, Panel Threshold Model

INTRODUCTION

In recent years, climate change mainly caused by greenhouse gas emissions, widely affects the natural ecosystem and human living environment. As the world’s largest CO₂ emitter (Liu et al., 2015), China’s carbon reduction efforts are crucial to promoting global climate governance. The goal of a 2030 carbon peak and 2060 carbon neutrality is a major strategic decision made by the Chinese government. Under the constraints of carbon neutrality by 2060, it is necessary for China’s economy to realize the green and low-carbon transformation. However, the tradeoff between economic growth and CO₂ emission reduction is key to realizing carbon neutrality. Green technology innovation is a long-term mechanism to achieve carbon emission reduction and economic growth (Xu et al., 2021). Many scholars have paid keen attention to the role of green innovation in China (Du & Li, 2019; Shen et al., 2021; Lin & Ma, 2022a). With China’s economy entering structural transformation, the economic growth model of high pollution and high emission is no longer reasonable. Green innovation has become an important tool to promote economic growth and carbon reduction, which are expected to effectively improve sustainable economic development (Yu et al., 2021).
Since the beginning of the 21st century, information technologies such as the Internet, big data, and cloud computing have been integrated into people’s daily life. Informatization has driven a new round of technological revolution and industrial transformation (Lin et al., 2021). It has a profound impact on human production and lifestyle. For example, in response to COVID-19, digital solutions, tools, and services based on the Internet and big data effectively helped minimize the spread of the pandemic in China. The “Statistical Report on China’s Internet Development Status” (2020) pointed out that China is the world’s largest netizen country, as the scale of e-commerce transactions ranks first globally. As an important macroeconomic factor, the Internet has also become an important driving force for technological innovation in China (Han et al., 2019). Arthur (2007) believed that the wide application of the Internet promoted the dissemination and diffusion of knowledge and information among the public, thus promoting technological innovation. Audretsch et al. (2015) found that broadband infrastructure played a significant role in improving innovation activities.

Integrating the internet into all areas of the economy and society has had a significant impact on the macro economy and micro individuals. From the perspective of the macro-economy, the existing literature mostly focuses on discussing the impact of the Internet on economic activities, including economic growth (Yin et al., 2019), technological innovation (Arthur, 2007; Audretsch et al., 2015), labor market (Shao et al., 2021) and import and export trade (Meijers, 2014). However, little literature have discussed the internal correlation between Internet development and green technology innovations. Thus, it is difficult to judge the influencing mechanism of the effect of Internet development on green technology innovation. Therefore, the authors intend to include Internet development as a key macro factor in the analysis framework of green technology innovation. This paper discusses the following important research issues from theoretical analysis and empirical tests. Does Internet development significantly increase green technology innovation in Chinese cities? And if it does, what are the influencing mechanisms? Furthermore, different cities have different economic scales, innovation environments, and resource endowments. Is the impact of Internet development on green innovation significantly different in different cities? Under the background of carbon neutrality, the empirical results will provide a theoretical and empirical basis for Chinese cities to improve green innovation through the Internet, which will help to coordinate the development of informatization with the economic green and low-carbon transition.

The existing literature ignores the characteristics of informatization, digitization, and networking in green innovation activities in the information age. The question on how the Internet affects green technological innovation has not been well answered. This paper makes three main contributions to the literature. Firstly, this paper takes the Internet development as an important macro factor and incorporates it into the analysis framework of green technological innovation. This provides a new perspective for understanding how to improve urban green innovation and enrich the literature in related fields. Secondly, regarding research data, the authors use the principal global component analysis method to measure the Internet comprehensive development level index of 264 prefecture-level cities in China. What’s more, the researchers empirically study the impact of internet development on urban green technology innovation and its internal influence mechanism from the perspective of direct effect, indirect effect, heterogeneity effect and non-linear effect. Third, based on the empirical results, targeted policy suggestions are put forward for Chinese cities to improve the level of green innovation and promote the transformation of urban development mode to green and low-carbon.

The rest of this paper is organized as follows. Section 2 is the literature review and theoretical mechanism. The econometric model and variable selection are explained in Section 3. The empirical research results and analysis are represented in Section 4. Section 5 concludes this paper and proposes policy suggestions.
LITERATURE REVIEW AND THEORETICAL MECHANISM

After reviewing the existing literature, this paper summarizes four theoretical mechanisms of the impact of Internet development on green technology innovation. Information dissemination and knowledge spillover, public environmental attention, financial development, and industrial structure upgrading are included.

INTERNET DEVELOPMENT, INFORMATION DISSEMINATION AND KNOWLEDGE SPILLOVER

The Internet can promote information dissemination and knowledge spillover (Arthur, 2007) and effectively alleviate the “information asymmetry” problem in daily life. The Internet can break through the limitation of geographical location and greatly expand the spread and popularity of knowledge, thus reducing the cost of knowledge collection and acquisition (Harris, 1998). Activities such as information generation, communication and sharing can significantly promote technological progress, including environmentally friendly green technologies (Czernich et al., 2011; Keller, 2002). On the one hand, through the Internet platform, enterprises can obtain information about related technological innovations (Laursen & Salter, 2006), which helps reduce the research and development cycle of their independent innovation. On the other hand, with Internet’s rapid development, market information transparency has increased continuously. Hence, information exchanges between companies and investors, consumers, and scientific research institutions have become very frequent, thereby reducing the uncertainty of corporate innovation activities (Collis, 1992; Milliken et al., 1987). The communication between enterprises and consumers is particularly important for innovations (Lin et al., 2022). The full communication between them helps enterprises collect creative information, clarify market needs and adjust the direction of research and development in a targeted manner, which effectively avoids “the no market after the commercialization of green technologies” situation when the application of technologies is outdated.

INTERNET DEVELOPMENT, PUBLIC ENVIRONMENTAL ATTENTION, AND GREEN TECHNOLOGY INNOVATION

The Internet can promote green innovation by raising public awareness of environmental issues. Generally speaking, the profit-seeking behavior of capital and technology path dependence leads to an insufficient supply of green technologies (Hötte, 2020). Relying on the free market alone cannot effectively push technology toward a green direction (Ren et al., 2021). Public supervision and government intervention are particularly important to encourage enterprises to choose green technology (Klemetsen et al., 2018). With the rapid development of the Internet, the cost of public access to environmental information is getting lower and lower, as the access to environmental information is getting timelier. This collective environmental concern stimulates the scale of green investment and encourage enterprises, especially high-polluting enterprises, to adopt green technologies (Liao & Shi, 2018). Through the Internet platform, the public also gradually understand the harm of environmental pollution. The increasing demand for environmental quality and clean air increase people’s willingness to pay for green products and technologies (Sun et al., 2017). People’s willingness to pay can also be reflected by their investment behavior in the stock market (Lei & Shcherbakova, 2015). Comparing the stock market performance after 161 serious environmental and non-environmental accidents reported by The New York Times, it is found that major environmental accidents will change the investment behavior of the American people in the capital market. Investors will lower their investment in companies that report negative environmental events (Carpentier & Suret, 2015). Increasing public concern about environmental pollution can reduce investment in polluting enterprises, encouraging companies to increase investment in green products and green
innovative activities (Arranz et al., 2019). At the same time, the public is increasingly concerned about environmental pollution, leading to their active participation in the supervision and treatment of environmental pollution (Leng et al., 2022). With the development of instant messaging tools such as Weibo and WeChat, the public can express their views promptly and participate in environmental supervision and governance more conveniently (Zheng et al., 2012). Public demands can force the government and relevant departments to issue relevant laws, regulations, and environmental policies. Government policy intervention forms a significant driving force for green technology innovation (Acemoglu et al., 2012).

INTERNET DEVELOPMENT, FINANCE DEVELOPMENT, AND GREEN TECHNOLOGY INNOVATION

The green innovation activities of enterprises need long-term capital investment (Yu et al., 2021). Green innovation activities of enterprises often fall into the dilemma of financing constraints due to the long investment cycle, earnings uncertainty, and the externality of environmental protection (Lin & Ma, 2022a). These constraints inhibit the green innovation activities of companies (Aghion et al., 2012). Traditional financial institutions represented by banks rely on establishing institutional outlets, which are unwilling to lend to green innovation projects with high risk and low return (Zhang et al., 2015). Internet finance integrates mobile Internet, cloud computing, big data, and other information technologies with financial services. Internet finance has broken through the traditional mode of simple offline audit of financial institutions, as financial services are no longer limited by geographical location (Feng et al., 2022). At the same time, Internet finance can effectively reduce the information asymmetry between capital supply and demand and the transaction cost of financial services (Ozili, 2018). In addition, Internet finance does not require physical assets as collateral, which guarantees the continuous financing of small and micro enterprises, especially small-scale technology enterprises. Thus, it may bring a new solution to the problem of financing constraints of green technological innovation (Cao et al., 2021).

INTERNET DEVELOPMENT, INDUSTRIAL UPGRADE, AND GREEN TECHNOLOGY INNOVATION

The effect of the Internet on industrial structure mainly comes from two aspects: industrial digitization and digital industrialization. Firstly, information technology is deeply integrated with traditional industries, which promotes the transformation of traditional industries to digitalization and realizes the transformation and upgrading of traditional manufacturing industries into intelligent manufacturing (Ying et al., 2021). Secondly, the Internet can accelerate the formation and emergence of new models, products and business forms (Laouris & Laouri, 2008). With the help of Internet, new forms of digital industries such as e-commerce, online office and education are booming in China (Lin, 2019). Digital industries, such as smart logistics and transportation, have great potential for energy conservation and emission reduction (Zhao et al., 2022). Compared with the industrial structure with high pollution and low resource utilization, the relatively clean industrial structure promotes green technology innovation (Jin & Li, 2013). Finally, the Internet can optimize the allocation of the elements of innovation to technology-intensive industries, which improves green technology innovation. As a result, the Internet can indirectly improve green innovation through industrial structure upgrading (Wang & Xu, 2021). To sum up, the four influencing mechanism is represented in Figure 1.
Existing literature mainly explores the influencing factors of green technology innovation from government subsidies, environmental regulation, and economic development. From a new perspective, Internet development is incorporated into the analysis framework of green technological innovation. Meanwhile, the authors summarize four influencing mechanisms of Internet development on green technology innovation. This paper provides a new understanding of improving green technology innovation in China and enriches the literature in related fields. The theoretical analysis provides policy enlightenment for the Chinese government to formulate targeted policy suggestions.

ECONOMETRIC MODEL AND VARIABLE SELECTION

Model Specification

This paper constructs the following regression model to study the impact of Internet development on green technology innovations.

\[
Y_{it} = \alpha_0 + \beta_1 INT_{it} + X_i \gamma + u_i + \lambda_t + \varepsilon_{it} \tag{1}
\]

Where \( Y \) denotes the explained variable. Subscript \( i \) represents the city, and subscript \( t \) denotes the year. \( INT \) represents the Internet comprehensive development index. \( \beta_1 \) measures the impact of Internet development on green technology innovations. \( X \) denotes a vector of control variables. \( \lambda_t \) is the time fixed effect, and \( u_i \) is the city fixed effect of city \( i \). \( \varepsilon_{it} \) is the random error.

The above model reflects the direct impact of the Internet development on green technology innovations. To further study the potential indirect influencing channels of Internet on green technology innovations, this paper introduces mediating variable (MED) to construct the following mediating effect model:
Innovation resources in different regions are similar, but innovation outputs and efficiency are greatly different (Tödtling & Kaufmann, 1999). Innovation resources are not the only reason for regional innovation output differences. Metcalfe’s law states that the value of a network is proportional to the square of the number of connected users. This paper adopts the panel threshold model to test whether Metcalfe’s law is valid in urban green innovation activities in China (Hansen, 1999). The model is constructed as follows:

\[
Y_{it} = \alpha_0 + \beta_1 INT_{it} + \beta_2 MED_{it} + X_{it}' \gamma + u_i + \varepsilon_{it} \quad (4)
\]

Where \( T \) is the threshold variable, and \( \tau \) is the threshold to be estimated. The other variables are defined similarly as equation (1). In Eq (4), the authors consider the single-threshold model, which can be extended to a multi-threshold model according to sample data.

**VARIABLE SELECTION**

**Dependent Variable**

The explained variable is green technology innovation and green technology progress direction. Following Xu et al. (2021) and Lin and Ma (2022a), the number of green patent applications indicate green innovation. Compared with the number of patents granted, the number of patent applications can timely represent the technological innovation achievements of a city in the current year, because patents can only be granted within 1 to 3 years after application (Hall & Harhoff, 2012). The number of patents granted is often subject to some external factors. Patents include invention patents, utility model patents and design patents (Amore & Bennedsen, 2016). Green invention patents (\textit{Green_Inv}) can represent high-quality technological innovation, while green utility model patents (\textit{Green_Uti}) can represent low-quality green technology innovation (Tang et al., 2021). Furthermore, to eliminate city size’s influence on the number of patent applications, the authors adopt the number of green patent applications per thousand people to measure green technological innovation. As a proxy variable for green technology progress direction (\textit{Green_Dir}), this paper adopts the ratio of green patents to all patents. Higher proportions of green patents indicates that the region is more inclined to green technological innovation. The “IPC Green Inventory” can be adopted to identify green patents in China.

**CORE EXPLANATORY VARIABLE**

Internet development is the core explanatory variable. There are two main methods to evaluate the development level of the Internet. One is the single index method. The Internet penetration rate, the proportion of mobile terminals, broadband users, and other indicators are used to measure Internet development. The other is the comprehensive index method. The authors consider that a single indicator cannot comprehensively measure Internet development. There is no doubt that Internet development should also include Internet infrastructures, such as the number of domain names, the number of IP addresses, the length of long-distance optical cables, and Internet application indicators, such as the average number of websites owned by a company. However, the researchers can only get
these quantitative data at the provincial-level data, and it is not easy to obtain them at the city level in China. The method of Huang et al. (2019) is adopted by existing research (Wang et al., 2021; Zhao et al., 2020), which is relatively reasonable. Therefore, this paper adopts the method of Huang et al. (2019) to measure Internet development in Chinese cities. According Huang et al. (2019), the authors construct the Internet development indicator system covering four dimensions: Internet penetration rate, Internet-related employees, Internet-related output, and mobile Internet users. The authors use the number of broadband users per hundred people as the proxy of Internet penetration rate. The authors utilize the proportion of computer service and software employees in the total number of employees as the indicator of Internet-related employees. Internet-related outputs are measured by telecom business per capita. The authors measure mobile Internet users using the number of mobile phone users per hundred people. The authors first standardized the four indicators, and then used the global principal component method to construct the comprehensive index of the Internet development level.

CONTROL VARIABLES

There are many influencing factors of urban green technological innovation. To control for the influence of other factors, several important control variables are introduced into the model (1). First, due to the “free rider” phenomenon, enterprises lack incentives to push green innovation activities. The government’s financial support is beneficial to stimulate the innovative vitality of enterprises (Chi et al., 2021). The government fiscal support (GOV) is measured by the proportion of fiscal expenditure on education and science to total fiscal expenditure. Second, human capital is a prerequisite for technological progress (Yang et al., 2015). Following Lin and Ma (2022a), the authors utilize high school students as the indicator of human capital (HC). Third, the investment structure of a city may significantly affect the local green development (Du et al., 2021). Cities with high investment in fixed assets and real estate may inhibit local green economic growth. The authors utilize the ratio of fixed asset investment to GDP as the proxy for the fixed asset investment (INV) level. Fourth, two opposing viewpoints can explain the impact of foreign direct investment on green technology innovations, namely the “pollution haven” and “pollution halo” hypothesis. The pollution haven hypothesis supposes that FDI results in transferring pollution-intensive industries to the host country. However, the pollution halo hypothesis means that advanced environmentally friendly technologies and industries may be introduced to the host country via FDI. Foreign direct investment (FDI) is represented by the ratio of real foreign investment to GDP. Fifth, economically developed cities have a better urban innovation environment and can invest more capital in green industries and technologies. The level of economic development is chosen as one control variable. The authors follow Lin and Ma (2022b) to use real GDP per capita (PGDP) as the city’s economic size proxy. Finally, proper environmental regulation by the government aid in improving green technology innovation in Chinese cities (Chen et al., 2022). Following Jia et al. (2021), the comprehensive utilization rate of industrial solid wastes is used to measure environmental regulation.

MEDIATING VARIABLE

Section 2 has summarized four influencing mechanisms. Information dissemination and knowledge spillover, public environmental attention, financial development, and industrial structure upgrading are included. However, due to the availability of Chinese city-level data, this paper selects industrial structure upgrading and financial development as intermediary variables to study the indirect effects of the Internet on green innovation. Industrial structural upgrade (STR) is represented by the ratio of the output value of the tertiary industry to secondary industry, and financial development (FIN) is represented by the ratio of the balance of deposits and loans of financial institutions to GDP at the end of the year.
DATA SOURCES AND STATISTICAL DESCRIPTION

After 2002, the classification standard of the national economy industry changed greatly, adding information transmission, computer service and software industry. After deleting cities with serious missing values, the research sample of this paper is panel data of 264 prefecture-level cities in China from 2003 to 2018. The raw data for this paper comes from the CEIC database, China City Statistical Yearbook, and the Chinese Research Data Services (CNRDS) Platform. Table 1 shows the variable definition and descriptive statistics.

| Variable symbol | Definition                                                                 | Obs  | Mean      | SD          | Min   | Max          |
|-----------------|----------------------------------------------------------------------------|------|-----------|-------------|-------|--------------|
| Green_Inv       | High-quality green technology innovation                                    | 4224 | 0.0371    | 0.1160      | 0     | 2.3787       |
| Green_Uti       | Low-quality green technology innovation                                     | 4224 | 0.0369    | 0.1012      | 0     | 2.0869       |
| Green_Dir       | Green technological progress direction                                       | 4224 | 0.0972    | 0.0427      | 0     | 0.6667       |
| INT             | Internet comprehensive development index                                     | 4224 | 0         | 1.2326      | -1.4043 | 13.6380      |
| L.INT           | The first-order lagged term of Internet development                          | 3960 | -0.0511   | 1.2028      | -1.4043 | 13.6380      |
| Gov             | Government fiscal support                                                    | 4224 | 0.1974    | 0.0463      | 0.0158 | 0.4974       |
| HC              | Human capital                                                               | 4224 | 5.3201    | 0.6604      | 3.4012 | 7.5602       |
| Inv             | Fixed-asset investment                                                       | 4224 | 0.6587    | 0.2912      | 0.0830 | 2.3124       |
| FDI             | Foreign direct investment                                                    | 4224 | 0.0205    | 0.0223      | 0     | 0.3758       |
| PGDP            | Economic development level                                                  | 4224 | 9.9721    | 0.7575      | 7.7792 | 11.9451      |
| ER              | Environmental regulation                                                     | 4224 | 0.7907    | 0.2272      | 0.0024 | 1.0000       |
| STR             | Industrial structural upgrade                                               | 4224 | 0.8972    | 0.4500      | 0.1286 | 5.0222       |
| FIN             | Financial development                                                       | 4224 | 2.1120    | 1.0031      | 0.5879 | 12.2386      |

RESULTS AND DISCUSSION

Baseline Regression Result

According to the setting of the model (1), the direct effect of Internet development on green innovation is studied. The estimated results of the benchmark model are shown in Table 2. The explained variables in columns (1) and (2) are the high-quality and low-quality green innovation respectively. The explained variable in column (3) is the ratio of green patents to total patents, which can represent the direction of technological progress (Dong & Wang, 2021). The estimated coefficients of Internet development (INT) are significantly positive at 10% (See columns (1) and (2)), which means that Internet development can significantly increase high-quality and low-quality green innovation. When the Internet comprehensive development index increases by one unit, per thousand people green invention patents increases by 0.0452 and per thousand people green utility model patents increase...
by 0.0283. Our results are consistent with Tang et al. (2021), who found that telecommunications infrastructure contributes to increasing green innovation of Chinese enterprises. The estimated coefficient of INT is positive but not statistically significant (See column (3)), indicating that Internet development has not significantly pushed the direction of urban technological progress towards a green direction. The main reason is that Internet development can not only promote the number of green technological innovations, but also improve other types of technological innovation. The overall direction of technological progress is not significantly toward a green direction.

The coefficients of government fiscal support are significantly positive, representing that the government’s investment in education and science contributes to green innovation. The estimated results of foreign direct investment are significantly negative at 10%, which indicates that the “pollution haven” hypothesis is valid in this paper. FDI will inhibit the increase of green innovation in Chinese cities. The coefficient of fixed asset investment is significantly negative at the level of 1%, meaning that urban fixed-asset investment will hinder the development of green innovation. As expected, cities with better human capital are conducive to green innovation activities. However, economic development and environmental regulation do not increase green technology innovation.

Table 2. Estimated results of baseline regression

|          | (1)         | (2)          | (3)          |
|----------|-------------|--------------|--------------|
| Green_Inv| 0.0452**    | 0.0283*      | 0.0006       |
|          | (0.0208)    | (0.0168)     | (0.0013)     |
| GOV      | 0.5529***   | 0.4029***    | -0.0005      |
|          | (0.1266)    | (0.0966)     | (0.0246)     |
| FDI      | -0.3068     | -0.4667**    | -0.0600      |
|          | (0.2014)    | (0.1914)     | (0.0583)     |
| HC       | 0.0471      | 0.0562*      | 0.0120**     |
|          | (0.0306)    | (0.0291)     | (0.0055)     |
| INV      | -0.0336**   | -0.0327**    | -0.0040      |
|          | (0.0139)    | (0.0129)     | (0.0044)     |
| PGDP     | -0.1063**   | -0.1035***   | -0.0105      |
|          | (0.0419)    | (0.0327)     | (0.0082)     |
| ER       | -0.0230     | -0.0223      | 0.0079       |
|          | (0.0176)    | (0.0145)     | (0.0071)     |
| Constant | 0.6703**    | 0.6188***    | 0.1024       |
|          | (0.3239)    | (0.2201)     | (0.0857)     |
| Year     | Yes         | Yes          | Yes          |
| City     | Yes         | Yes          | Yes          |
| N        | 4224        | 4224         | 4224         |
| R²       | 0.3831      | 0.3902       | 0.0908       |

Note: * p < 0.10, ** p < 0.05, *** p < 0.01; Cluster robust standard errors in parentheses.
ENDOGENEITY DISCUSSION

Endogeneity is a common problem in econometric models, which leads to biased parameter estimation. Omitted variables and reverse causality may cause the endogeneity problem. On the one hand, Internet development provides an internal driving force for green technology innovation. Green technologies may also become the technological foundation for the development of the Internet. The two reinforce each other. On the other hand, there are many driving factors affecting green innovation. Some potential variables have been controlled in this paper. However, due to the limitation of data availability at the city level, it is difficult to control all the significant factors influencing green technology innovation. Our model may have the problem of omitted variables.

The endogeneity problem will be tackled from two aspects to solving the estimation deviation. Firstly, the first-order lag term of INT is taken as a core independent variable. The reason is that \( L.INT \) would not be impacted by the current green innovation, which helps to alleviate the endogeneity problems caused by reverse causality. Many scholars have utilized this method to solve endogeneity problem (Lin & Ma, 2022a; Yan et al., 2020). The estimated results are shown in Table 3. Secondly, the authors adopt the instrumental variable (IV) method to address the endogeneity problem. A good instrumental variable should satisfy both correlation and externality. On the one hand, \( L.INT \) is used as an instrumental variable, and the two-stage least square method is adopted to estimate the model (1). The Internet development needs the support of information infrastructure. The first-order lag term of Internet development may significantly affect the current Internet development, which satisfies the correlation condition. Table 4 represents the estimation results. On the other hand, according to Huang et al. (2019) and Zhao et al. (2020), the number of landline telephones in 1984 is utilized as an instrumental variable of INT. From the development history of the Internet in China, the Internet started from dial-up Internet access. The areas where the penetration rate of landline telephones was relatively high in the past are very likely to be the regions where the Internet development level is now relatively high. From this aspect, the number of landline telephones in 1984 is selected as an instrumental variable to satisfy the correlation requirement. With the decline of usage frequency, the effect of traditional communication tools such as landline telephones on current green innovation is gradually weakened, which meets the exogenous condition. Following Nunn and Qian (2014), the cities’ number of landline telephones per 10,000 people in 1984 and the Chinese number of Internet users in the previous year constitute an interaction term, which is utilized as the IV for Internet development in that year. The estimated results are represented in Table 5. The value of the Wald F statistic is 20.730, indicating that the instrumental variable is not a weak instrumental variable. The authors summarize the empirical results in Tables 3, 4 and 5. The coefficient sign and statistical significance of the core explanatory variable are consistent with that in Table 2. Internet development can significantly improve high-quality and low-quality green technological innovations, but it cannot obviously push technological progress toward a green direction. The empirical results are robust.

Table 3. Estimation results of the first-order lag term

|         | (1)          | (2)          | (3)          |
|---------|--------------|--------------|--------------|
| Green_Inv | Green_Uti    | Green_Dir    |
| \( L.INT \) | 0.0471**     | 0.0302*      | 0.0007       |
|          | (0.0205)     | (0.0158)     | (0.0013)     |
| \( GOV \) | 0.5638***    | 0.4045***    | 0.0157       |
|          | (0.1304)     | (0.0975)     | (0.0243)     |
| \( FDI \) | -0.3636*     | -0.5893***   | -0.0506      |
|          | (0.2147)     | (0.1961)     | (0.0579)     |

Table 3 continued on next page
Table 3 continued

|               | (1)       | (2)       | (3)       |
|---------------|-----------|-----------|-----------|
| \( HC \)      | 0.0506*   | 0.0585**  | 0.0134**  |
|               | (0.0281)  | (0.0276)  | (0.0055)  |
| \( INV \)     | -0.0293** | -0.0266** | -0.0057   |
|               | (0.0127)  | (0.0116)  | (0.0046)  |
| \( PGDP \)    | -0.1073** | -0.1057***| -0.0146*  |
|               | (0.0426)  | (0.0340)  | (0.0086)  |
| \( ER \)      | -0.0227   | -0.0219   | 0.0068    |
|               | (0.0182)  | (0.0148)  | (0.0067)  |
| Constant      | 0.6758**  | 0.6430*** | 0.1378    |
|               | (0.3404)  | (0.2417)  | (0.0926)  |
| Year          | Yes       | Yes       | Yes       |
| City          | Yes       | Yes       | Yes       |
| \( N \)       | 3960      | 3960      | 3960      |
| \( R^2 \)     | 0.3742    | 0.3815    | 0.0716    |

Note: * p < 0.10, ** p < 0.05, *** p < 0.01; Cluster robust standard errors in parentheses.

Table 4. Estimation results of two-stage least square method (2SLS)

|               | (1)       | (2)       | (3)       |
|---------------|-----------|-----------|-----------|
| \( Green_{Inv} \) | 0.0755*** | 0.0484*** | 0.0011    |
|               | (0.0174)  | (0.0143)  | (0.0017)  |
| \( GOV \)     | 0.5081*** | 0.3687*** | 0.0149    |
|               | (0.0921)  | (0.0755)  | (0.0215)  |
| \( FDI \)     | -0.3140***| -0.5575***| -0.0499   |
|               | (0.1064)  | (0.1040)  | (0.0454)  |
| \( HC \)      | 0.0520*** | 0.0595*** | 0.0134*** |
|               | (0.0128)  | (0.0122)  | (0.0050)  |
| \( INV \)     | -0.0252***| -0.0240***| -0.0056   |
|               | (0.0065)  | (0.0056)  | (0.0045)  |
| \( PGDP \)    | -0.0828***| -0.0900***| -0.0143*  |
|               | (0.0233)  | (0.0198)  | (0.0077)  |
| \( ER \)      | -0.0215** | -0.0211** | 0.0069    |
|               | (0.0103)  | (0.0087)  | (0.0054)  |
| Year          | Yes       | Yes       | Yes       |

Table 4 continued on next page
HeTerogeneity ANALySIS

In 2012, China put forward the concept of “Internet +” for the first time, which has significantly impacted China’s economic and social development. Since the Internet has become a new tool for mass entrepreneurship and innovation in China and a new engine for improving the quality and efficiency of the Chinese economy. Studying the heterogeneous effect of the Internet in different periods is necessary. The dummy variable $D$ which represents the year after 2012 is set up. The estimated results of $INT \times D$ is significantly positive, as the estimated coefficients of $INT$ is negative (See Table 5).

Table 4 continued

|                | (1)        | (2)        | (3)        |
|----------------|------------|------------|------------|
| City           | Yes        | Yes        | Yes        |
| Kleibergen-Paap rk Wald F statistic | 226.945    | 226.945    | 226.945    |
| Stock-Yogo weak ID test critical values | 16.38 (10%) | 16.38 (10%) | 16.38 (10%) |
| $N$            | 3960       | 3960       | 3960       |

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Cluster robust standard errors in parentheses.

Table 5. Estimation results of two-stage least square method (2SLS)

|                | (1)        | (2)        | (3)        |
|----------------|------------|------------|------------|
| $INT$          | 0.4247***  | 0.2748***  | -0.0123    |
|                | (0.1069)   | (0.0820)   | (0.0087)   |
| $GOV$          | -0.0979    | -0.0538    | 0.0303     |
|                | (0.2195)   | (0.1581)   | (0.0267)   |
| $FDI$          | 0.3096     | -0.0498    | -0.1236*** |
|                | (0.3011)   | (0.2298)   | (0.0440)   |
| $HC$           | 0.0743**   | 0.0691***  | 0.0036     |
|                | (0.0359)   | (0.0266)   | (0.0047)   |
| $INV$          | 0.0863**   | 0.0467     | -0.0037    |
|                | (0.0386)   | (0.0288)   | (0.0052)   |
| $PGDP$         | 0.2396***  | 0.1224*    | -0.0302*** |
|                | (0.0896)   | (0.0666)   | (0.0113)   |
| $ER$           | -0.0231    | -0.0192    | 0.0058     |
|                | (0.0260)   | (0.0181)   | (0.0059)   |
| $Year$         | Yes        | Yes        | Yes        |
| $City$         | Yes        | Yes        | Yes        |
| Kleibergen-Paap rk Wald F statistic | 20.730     | 20.730     | 20.730     |
| Stock-Yogo weak ID test critical values | 16.38 (10%) | 16.38 (10%) | 16.38 (10%) |
| $N$            | 3376       | 3376       | 3376       |

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Cluster robust standard errors in parentheses.

HETEROGENEITY ANALYSIS

In 2012, China put forward the concept of “Internet +” for the first time, which has significantly impacted China’s economic and social development. Since the Internet has become a new tool for mass entrepreneurship and innovation in China and a new engine for improving the quality and efficiency of the Chinese economy. Studying the heterogeneous effect of the Internet in different periods is necessary. The dummy variable $D$ which represents the year after 2012 is set up. The estimated results of $INT \times D$ is significantly positive, as the estimated coefficients of $INT$ is negative (See Table 5).
indicating that Internet development could not promote green innovation before 2012. After the implementation of the “Internet +” strategy, Internet development can significantly increase green technology and promote technological progress towards a green direction. The reasons are that China’s economy has entered a new normal after 2012, transforming from high-speed to high-quality growth. The Chinese government attaches great importance to green and low-carbon economic transformation.

At the same time, the authors intend to study the regional heterogeneity effect of INT on green innovation. Dummy variable \( C \) represents that the cities are in the central region, and Dummy variable \( W \) represents that the cities are in the western region. The coefficients of \( INT \times C \) and \( INT \times W \) are significantly negative, and the coefficients of \( INT \) are significantly positive at the level of 5% (See columns (4) and (5) in Table 6). The marginal impact of the Internet on high-quality green innovation is 0.0589 in eastern cities, 0.0251 in central cities, and 0.0197 in western cities, which is significantly positive in all three regions. The results mean that the positive effect of \( INT \) on green innovation is most substantial in eastern cities, followed by central cities, and weakest in western cities. Wang et al. (2021) also found that Internet development has regional heterogeneity effects on green economic development in Chinese cities. The possible reason is that compared with the cities in the central and western regions, eastern cities have better Internet development, higher economic development, and a better innovation environment. At the same time, the eastern city’s local government attaches more importance to green economic growth. The conditions of the central cities are better than those of western cities. Hence, the positive effect of \( INT \) is strongest in eastern cities, followed by central cities, and lowest in western cities.

Table 6. Heterogeneity analysis

|       | (1)  | (2)  | (3)  | (4)  | (5)  | (6)  |
|-------|------|------|------|------|------|------|
| Green_Inv | -0.0091 | -0.0197* | -0.0008 | 0.0589** | 0.0416** | 0.0011 |
|       | (0.0120) | (0.0110) | (0.0015) | (0.0264) | (0.0211) | (0.0014) |
| INT \times D | 0.0740*** | 0.0655*** | 0.0020** |
|       | (0.0069) | (0.0057) | (0.0009) |
| INT \times C | -0.0338* | -0.0346*** | -0.0054* |
|       | (0.0177) | (0.0117) | (0.0030) |
| INT \times W | -0.0392** | -0.0363*** | 0.0013 |
|       | (0.0188) | (0.0132) | (0.0023) |
| GOV   | 0.4616*** | 0.3220*** | -0.0029 | 0.5270*** | 0.3770*** | -0.0034 |
|       | (0.0912) | (0.0552) | (0.0247) | (0.1331) | (0.1003) | (0.0246) |
| FDI   | -0.1196 | -0.3009* | -0.0551 | -0.1038 | -0.2658 | -0.0421 |
|       | (0.1768) | (0.1650) | (0.0589) | (0.2255) | (0.1909) | (0.0622) |
| HC    | 0.0125 | 0.0255* | 0.0111** | 0.0475 | 0.0561* | 0.0110** |
|       | (0.0151) | (0.0135) | (0.0055) | (0.0305) | (0.0287) | (0.0055) |
| INV   | -0.0025 | -0.0051 | -0.0031 | -0.0278* | -0.0267* | -0.0031 |
|       | (0.0079) | (0.0073) | (0.0043) | (0.0146) | (0.0137) | (0.0043) |
| PGDP  | -0.0455** | -0.0496*** | -0.0089 | -0.0898** | -0.0884** | -0.0117 |
|       | (0.0230) | (0.0167) | (0.0082) | (0.0437) | (0.0355) | (0.0081) |
| ER    | -0.0125 | -0.0131 | 0.0082 | -0.0217 | -0.0214 | 0.0074 |

Table 6 continued on next page
INFLUENCE MECHANISM ANALYSIS

The above empirical results have confirmed that Internet development contributes to increasing urban high-quality and low-quality green technological innovation. Furthermore, the authors intend to explore how Internet development affects green innovation in Chinese cities. In section 2, the authors have summarized four influencing mechanisms. There are information dissemination and knowledge spillover, public environmental attention, financial development and industrial structure upgrading. However, due to the availability of urban data in China, it is difficult to measure information dissemination and public environmental attention with quantitative data. Therefore, the two mechanisms have not been empirically studied in this paper. This paper can only use quantitative data to empirically study two influencing mechanisms of financial development and industrial structure upgrading.

Industrial structure upgrading and financial development are taken as two mediating variables to study the influencing mechanism of Internet development on green innovation. The estimated results of Eq. (2) and (3) are shown in Table 7. First, the coefficient of $INT$ on industrial structure upgrading is significantly positive, representing that the Internet development promotes industrial structure upgrading. Since the Internet can be integrated with traditional industries and contribute to the emergence of new forms of business (Laouris & Laouri, 2008), it results in the industrial upgrading of the overall economy. As can be seen from columns (2) and (3), the coefficients of $STR$ and $INT$ are significantly positive at the 5% level, meaning that Internet development indirectly plays a significant role in high-quality and low-quality green technological innovation through the upgrading of industrial structure. Second, the estimated results of $INT$ are significantly positive (See column (4) in Table 6), suggesting that Internet development contributes to improving financial development. Financial development is also an important intermediary channel for the influence of the Internet on green technology innovation (See columns (5) and (6)). The Internet helps promote the development of Internet finance. Internet finance helps ease the financing constraints of enterprises’ green innovation activities. It can bring a new solution to the financing constraint of green technological innovation. The above empirical results represent that Internet development can not only directly promote green technological innovation but also positively impact on urban green innovation through industrial structure upgrading and financial development.

Table 6 continued

|     | (1)      | (2)      | (3)      | (4)      | (5)      | (6)      |
|-----|----------|----------|----------|----------|----------|----------|
| Constant | 0.2623   | 0.2576*  | 0.0915   | 0.5033   | 0.4682** | 0.1168   |
| Year  | (0.2161) | (0.1472) | (0.0859) | (0.3119) | (0.2260) | (0.0855) |
| City  | Yes      | Yes      | Yes      | Yes      | Yes      | Yes      |
| N     | 4224     | 4224     | 4224     | 4224     | 4224     | 4224     |
| $R^2$ | 0.5927   | 0.6046   | 0.0916   | 0.3980   | 0.4083   | 0.0924   |

Note: * p < 0.10, ** p < 0.05, *** p < 0.01; Cluster robust standard errors in parentheses.
NoNLIN eAR effeCT ANALySIS

Metcalfe's law states that the value of a network is proportional to the square of the number of connected users. This section will further explore how the Internet affects green innovation in cities under the different level of Internet development. The panel threshold model is adopted to estimate the non-linear moderating effects. The Internet development is taken as the threshold variable. Table 8 show the estimation results. When the development level of the Internet is low, the Internet development inhibits both high-quality and low-quality green innovation. With the improvement of Internet development level, the positive effect of the Internet gradually appears and shows the nonlinear character of the increasing marginal effect. The above empirical results mean that Metcalfe's law is valid in urban green innovation activities in China. The reason is that large-scale information infrastructure needs to be built in the early stage of Internet development, which inevitably squeezes out investment in urban innovation resources. With the improvement of information infrastructure, the dividend of the Internet is gradually released, which promotes the quantity and quality of green innovation.

Table 7. Analysis of influencing mechanism

|       | (1)       | (2)       | (3)       | (4)       | (5)       | (6)       |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|
|       | STR       | Green_Inv | Green_Uti | FIN       | Green_Inv | Green_Uti |
| INT   | 0.1431*** | 0.0531*** | 0.0378**  | 0.1836*** | 0.0579*** | 0.0409*** |
|       | (0.0231)  | (0.0184)  | (0.0151)  | (0.0322)  | (0.0194)  | (0.0151)  |
| STR   | 0.0578**  | 0.0473*** |           |           |           |           |
|       | (0.0226)  | (0.0171)  |           |           |           |           |
| FIN   |           |           |           | 0.0187*   | 0.0198**  |           |
|       |           |           |           | (0.0104)  | (0.0096)  |           |
| Constant | 0.7980   | -0.6363   | -0.7616*  | -0.6884   | -0.5772   | -0.7102*  |
|       | (0.4940)  | (0.4331)  | (0.3930)  | (0.8001)  | (0.4209)  | (0.3791)  |
| Control variables | Yes       | Yes       | Yes       | Yes       | Yes       | Yes       |
| City  | Yes       | Yes       | Yes       | Yes       | Yes       | Yes       |
| N     | 4224      | 4224      | 4224      | 4224      | 4224      | 4224      |
| R²    | 0.1747    | 0.3376    | 0.3293    | 0.2740    | 0.3251    | 0.3232    |

Note: * p < 0.10, ** p < 0.05, *** p < 0.01; Cluster robust standard errors in parentheses.
Conclusion and Policy Implications

Conclusion

In the information age, Internet development contributes to the emergence of new products, business forms, and technologies. To study the effect of Internet development on green technology innovation and its internal influencing mechanism, the authors use the panel data covering Chinese 264 prefecture-level cities from 2003 to 2018. Based on the construction of the Internet comprehensive development level index of prefecture-level cities in China, the impact of Internet development on green technological innovation is studied from direct, indirect, heterogeneous, and non-linear effect. This paper summarizes the following conclusions.

First, Internet development can increase high-quality and low-quality green technological innovation. The Internet has become an important driving force for green innovation in China. The result is still robust after variant endogeneity tests. Second, the results of heterogeneity analysis showed that Internet development could not increase green technology innovation before 2012. After implementing the “Internet +” strategy, Internet development significantly increased the green technology innovation and pushed technological progress toward the green direction. At the same time, compared with central and western cities, the positive effect of Internet development on green innovation is more obvious in eastern cities. Third, Internet development can not only directly promote high-quality and low-quality green technological innovation but also positively impact urban green innovation through industrial structure upgrading and financial development. Fourth, the positive effect of Internet development shows the nonlinear character of increasing marginal effect. Hence, Metcalfe’s law is valid in urban green innovation activities in China.

Policy Implications

In terms of China’s actual situation, although the level of green technology innovation has achieved certain improvement, there are still practical problems such as low innovation quality and unbalanced regional development. The Internet, as the important driving force to promote “mass entrepreneurship and innovation”, undoubtedly provides a good recipe for solving the abovementioned problems. In view of the above conclusions, the authors propose some policy suggestions. Firstly, the Chinese government should continue to increase the construction of broadband infrastructure, promote the
intensity and scale of Internet investment, and improve the Internet penetration rate. Enterprises should continue enriching and innovating the content of Internet application services and improve the quality of Internet services. It is significant to expand investment in the widespread application of new information technologies such as 5G and the Internet of Things. Secondly, it is important to implement a dynamic and differentiated Internet development strategy. The positive effect of the Internet on green technology innovation in central and western cities needs to be enhanced, which indicates that regional differentiation of Internet development strategy should be adopted. It is necessary to make the Internet become the technical support to alleviate regional development imbalance. Thirdly, the urban innovation environment is an important guarantee for green innovation activities, and it is very important to continuously optimize the urban innovation environment relying on information technology. For example, relying on the Internet builds an information-sharing platform and accelerates the dissemination of knowledge so that innovation subjects can quickly acquire and absorb relevant knowledge at a lower cost. The government can encourage the integration of the Internet with traditional financial services. Relying on Internet finance can ease the financing constraints of enterprises and expand the capital sources to execute green innovation activities.

CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

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