SCIREA Journal of Economics
ISSN: 2995-3863
http://www.scirea.org/journal/Economics
November 21, 2023
Volume 8, Issue 5, October 2023
https://doi.org/10.54647/economics790424

# Information infrastructure , market-oriented environmental regulation and high-quality green innovation of enterprises

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## Abstract

We take China A-share listed companies from 2006 to 2020 as samples to empirically test the mechanism that information infrastructure and market-based environmental regulation affect high-quality green innovation of enterprises.We find that the information infrastructure significantly promotes high-quality green innovation of enterprises, and market-oriented environmental regulation positively moderates the relationship between them; The mechanism test shows that the increase of R&D funds and personnel in enterprises under market-oriented environmental regulation will stimulate high-quality green innovation; The heterogeneity test shows that the information infrastructure is more effective for the high-quality green innovation of enterprises in the eastern and central regions; Further analyses shows that the level of executive salary incentive and risk-taking can enhance high-quality green innovation of enterprises, and the complementary role of command-oriented environmental regulation to market-oriented environmental regulation is not statistically significant. Our findings provide theoretical basis for China to improve information infrastructure and market environment

regulation to promote high-quality green innovation of enterprises.

**Keywords:** Information infrastructure; Green innovation; Market-oriented environmental regulation; Resource allocation

## 1. Introduction

In the process of continuous transformation of economic growth momentum in China, exploring a new concept oriented to green development is the focus of economic and social attention. One of the problems in realizing green development is how to coordinate economic benefits and environmental values[1].The effective way to solve the problem of green development is green innovation (Kemp, 2002), the report of the 19th National Congress of the Communist Party of China clearly put forward to build a market-oriented green innovation system, which is the core task of the country to promote green development and ecological civilization construction. In practice, enterprises' green innovation is faced with the dilemma of "great quantity and lame quality". Some enterprises tend to pursue strategic, imitative and fraudulent activities in pursuit of profits. In the short term, the number of green patents may increase rapidly, so as to obtain government funds and tax incentives. There are fewer truly high-quality green innovation activities, and enterprises are more willing to carry out low-quality innovation that can produce performance in a short period of time, rather than high-quality green innovation with great difficulty and risk. As we all know, high-quality green innovation has obvious positive externalities. Under the current imperfect technical knowledge protection and pricing mechanism of environmental compensation, enterprises may not be able to enjoy all the due benefits and cost compensation brought by green technology when they invest in R&D. The mismatch between R&D expenditure and benefits has become a dilemma for enterprises to face in green innovation. So, how to encourage enterprises to carry out high-quality green innovation?

At present, one of the key measures to realize the continuous transformation of economic growth momentum in China is the new infrastructure. The Fifth Plenary Session of the 19th

[1] Neoclassical economics believes that environmental protection will increase private production cost and reduce the competitiveness of enterprises, thus offsetting the positive effects brought by environmental protection to society. However, Porter Hypothesis(Porter and Linde, 1995) holds that proper environmental regulation can encourage enterprises to carry out more innovative activities, and these innovations will improve the productivity of enterprises, thus offsetting the cost brought by environmental protection and enhancing the profitability of enterprises in the market.

Central Committee of China pointed out to promote the construction of new infrastructure[2] and accelerate the development of digital China. The information infrastructure based on information technology is in the primary position[3] in the new infrastructure, which plays a fundamental supporting role for the current digital transformation of China and the transformation of economic growth momentum. New technology is the power source for the conversion of old and new momentum, and information infrastructure means that new technology has replaced old technology as an important social and technical phenomenon and institutional phenomenon. Building the operating foundation and framework of social operating system contains new value logic, conventions and norms, which brings legitimacy pressure[4] to enterprises (Broekhuizen, 2021) and affects enterprise behavior (Meyer et al., 2011; Hartley and Sawaya, 2019), encouraging enterprises to engage in technological innovation activities to avoid being eliminated in market competition.

In addition, the information infrastructure promotes the industrial upgrading and transformation, and the economy growth type changed from the extension to the connotation, no longer at the expense of the environment. In particular, new technologies, new formats and new energy are natural in environmental protection responsibilities, and the information infrastructure contains environmental protection responsibilities. Its additional market value logic and norms further encourage enterprises to engage in green innovation activities. As an institutional environment for green innovation of enterprises, whether and how can the information infrastructure encourage high-quality green innovation behavior of enterprises? Related research has not been carried out so far.

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[2] In 2018, the Central Economic Work Conference clearly proposed for the first time to accelerate the construction of new infrastructure such as 5G network, artificial intelligence, industrial Internet and Internet of Things. The 2019 Government Work Report further proposed to strengthen the construction of a new generation of information infrastructure. On April 20, 2020, the National Development and Reform Commission of China defined the concept and scope of new infrastructure, and considered that "new infrastructure" is an infrastructure system that is guided by new development concepts, driven by technological innovation, based on information networks, and meets the needs of high-quality development, providing services such as digital transformation, intelligent upgrading and integrated innovation.

[3] The new infrastructure mainly includes three aspects: information infrastructure, integration infrastructure and innovation infrastructure. Specifically, information infrastructure mainly refers to the infrastructure based on the evolution of a new generation of information technology, including communication network infrastructure represented by 5G, Internet of Things, industrial Internet and satellite Internet, new technology infrastructure represented by artificial intelligence, cloud computing and blockchain, and computing infrastructure represented by data centers and intelligent computing centers. Integration infrastructure mainly refers to the deep application of Internet, big data, artificial intelligence and other technologies to support the transformation and upgrading of traditional infrastructure, and then form a integration infrastructure, such as intelligent transportation infrastructure and smart energy infrastructure. Innovation infrastructure mainly refers to the public infrastructure that supports scientific research, technology development and product development, such as major scientific and technological infrastructure, science and education infrastructure, industrial technology innovation infrastructure and so on.

[4] According to the new institutionalism of organizational sociology, legitimacy is the degree to which an organization's actions are accepted and recognized by various internal and external stakeholders, and the degree to which it is consistent with universally existing norms, rules and beliefs. When organizations obey the institutional pressure and follow the social norms of organizational structure and process, they can gain higher legitimacy.

The prior literature on the economic consequences of information infrastructure mainly focuses on the influence of the level of regional informatization infrastructure on economic growth (Ward and Zheng, 2012; Xu, 2010; Pan and Han, 2018; Zhang, 2015). In recent years, the studies on the economic consequences of information infrastructure has gradually shifted from the macro level to the meso level, and studies have begun to pay attention to the connection of information infrastructure and industrial innovation efficiency (Sun and Xu, 2018). However, there is a lack of research on the micro-level economic consequences of information infrastructure. Only Li Kunwang et al. (2015) study the impact of regional information infrastructure level on the export performance of China enterprises. The studies on the impact of information infrastructure on micro-enterprises is in its infancy, especially the studies on the impact of information infrastructure on the quality of green innovation of enterprises has not been carried out, which is an important theoretical and practical problem that needs to be solved urgently. Under the background of high-quality economic development in China, the study on whether and how to promote the green innovation of enterprises by information infrastructure needs to be carried out, especially what market incentives need to be designed to effectively promote the information infrastructure to promote the high-quality green innovation of enterprises?

Environmental regulation measures change the environmental cost and profitability of enterprises and affect the investment in green technology R&D. Environmental regulation involves market-oriented and command-oriented, and market-oriented environmental regulation mainly adopts trading behaviors such as carbon emission rights and environmental rights, which can effectively stimulate innovation (Blackman et al., 2018), command-oriented environmental regulation mainly adopts administrative means such as environmental law enforcement, energy control and government subsidies(Wang and Qi, 2016), usually as a complement or alternative to market-oriented environmental regulation. What role do market-oriented environmental regulation and command-oriented environmental regulation play in the information infrastructure and high-quality green innovation of enterprises? These problems are the key problems that must be solved to promote the green development of enterprises by information infrastructure.

Our studies make the following contributions. First, the microeconomic consequences of the information infrastructure are studied for the first time. From the prior literature, there is a lack of research on the micro-level economic consequences of the information infrastructure. We study the influence mechanism of information infrastructure on high-quality green innovation of micro-enterprises for the first time, providing marginal evidence for studying the micro-level economic consequences of the information infrastructure, helping the current Chinese government to promote the information infrastructure, and also providing a reference path for enterprises to achieve high-quality green innovation.

Second, Our study complement the influencing factors of high-quality green innovation. Most of the prior literature analyze the internal mechanism of the quality of green innovation from environmental regulation (Tao et al., 2021), green credit policy (Wang and Wang., 2021) and industrial agglomeration (Yang et al., 2020), etc., which rarely involves high-quality green innovation, and also fails to consider government behavior and market regulation means in a unified framework. We complement and explore high-quality green innovation, further effectively combine the government-oriented information infrastructure with market-oriented environmental regulation, and study the mechanism of the two for enterprise green innovation, enriching the previous research results.

## 2. Theoretical framework and hypotheses

The decision-making basis of enterprise element input is that the input elements can get due income and cost compensation. However, under the condition of distorted element market, imperfect technical knowledge protection and pricing mechanism of environmental compensation, enterprises may not enjoy all the due benefits and reasonable cost compensation brought by green technology when investing in element resources for R&D. Therefore, executives tend to allocate less resources in high-quality green innovation activities.In recent years, some enterprises tend to have more low-quality innovation activities such as utility models and industrial designs, which are strategic and imitative[5] (Lin and Long, 2019). High-quality green innovation has relatively unpredictable revenue prospects and high R&D difficulties, and its short-term performance is not obvious. In particular, the uncertainty of the R&D process may increase business risks, so enterprises usually reduce the investment in high-quality green innovation. What's more, rationally weakening the investment in high-quality green innovation is relatively hidden, and it is often difficult to attract the attention of the capital market. However, the negative impact of high-quality green

[5] Low-quality green innovation has the advantages of short cycle, quick return and high visibility. R&D investment and market return are easy to attract investors' attention. Maintaining or increasing low-quality green innovation appropriately is a way for the company to convey its stable and positive venture capital situation, which is easy to convey good signals to the market.

innovation will be amplified in the capital market[6], enterprises have insufficient motivation for high-quality green innovation.

2.1. Information infrastructure and high-quality green innovation of enterprises

First, the information infrastructure is conducive to improving the income distribution mechanism of cooperative R&D among enterprises. High-quality technological innovation often adopts cooperative R&D strategy (Cai and Li, 2018). Enterprises will tend to carry out high-quality innovation in order to improve their position in R&D cooperation and enjoy as much income as possible. On the one hand, traditional infrastructure, such as transportation infrastructure, weakens the restriction of geographical boundary of element market and reduces the transaction cost of innovation element resources. The expansion of element market is also helpful for enterprises to cooperate in R&D of elements, and enterprises inclines to high-quality innovation have more opportunities to match the most advantageous innovation resources in the market and participate in benefit distribution; On the other hand, new infrastructure such as information infrastructure can reduce the cost of knowledge search and accelerate the dissemination and exchange of data and information knowledge (Almeida and Kogut, 1999). Information technology weakens information asymmetry and strengthens information transmission and cooperation among enterprises (Hendriks, 1999; Kaufmann et al., 2003), the convenience of technological knowledge diffusion brings more shared benefits, and the greater the contribution, the higher the benefits.

Second, the information infrastructure is conducive to the market-oriented compensation mechanism for green technology transactions. The partial failure of the market compensation mechanism of green innovation is one of the main reasons for the slow development of green technology in China. The information infrastructure will reduce transaction costs, increase the frequency of technology transactions, promote the gradual improvement of local technology trading platforms, and enhance the convenience and fairness of technology transactions between the supply and demand sides. The market gradually recognizes and forms the compensation of green technology pricing and innovation investment, which can alleviate the failure of market compensation mechanism of green innovation cost to a certain extent. The increase of green technology transaction frequency can form a fair unit price of technical knowledge and transaction cost, ease the resource constraints of R&D funds and personnel allocation between enterprises and within enterprises, and form green innovation incentives.

[6] If the slightly unsatisfactory signal in the R&D process is transmitted to the capital market, it may cause panic and increase the risk of operation and stock price collapse. There is a greater probability that the risks of high-quality green innovation outweigh the benefits.

Specifically, on the one hand, the increase in the frequency of green technology transactions has given birth to the pricing and identification of environmental protection and energy-saving technologies, and the cost of green technology R&D expenditure has been reasonably compensated. Element suppliers can get reasonable or even excessive compensation from the final technology transfer profits, and the accumulation of this function will change the behavior decision of element suppliers in the allocation of elements, guide the rational allocation of innovative resources among enterprises, and encourage enterprises to invest in green innovation; On the other hand, the increase of green technology transaction frequency means that the relationship between supply and demand has gradually changed, the transaction price of green technology knowledge and innovative resources has decreased, and the general innovation cost in the market has decreased. The difference of green technology price conveys the signals that mismatch of external cost and benefits of innovation, and the original innovation cost of green innovation deviates from the general equilibrium level. The Non-equilibrium state causes enterprises to optimize internal resources and improve the mismatch of innovation elements within enterprises.

Third, the information infrastructure is conducive to the signal transmission mechanism of high-quality green innovation. Non-financial information such as enterprise innovation information plays an increasingly important role in stock pricing in the capital market. High-quality green innovation activities can transmit a signal of strong innovation ability to the capital market, while low-quality green innovation is not easy to transmit a authentic signal. Authentic and credible signals help investors to accurately judge the quality of green innovation in stock pricing. The packaging of low-quality green innovation into high-quality technological achievements increases the cost of signal transmission. More importantly, with the rapid development of information technology, the possibility of false positive signals being discovered is increasing, which in turn improves investors' avoidance psychology. Therefore, the information infrastructure shortens the geographical distance and reduces the information asymmetry, which is conducive to the signal transmission of high-quality green innovation, and enterprises are more willing to carry out high-quality green innovation. Based on the above analyses , we propose the following hypothesis .

**Hypotheses 1.** Information infrastructure significantly promotes high-quality green innovation of enterprises.

4.2. Information infrastructure, market-oriented environmental regulation and high-quality green innovation of enterprises.

The information infrastructure led by the government is conducive to improving the income distribution mechanism of cooperative R&D, creating the market-oriented compensation mechanism of green technology transactions, restricting low-quality green innovation, and forming new social business rules and value networks. However, the spillover effect of public knowledge induced by the information infrastructure and the defects of green compensation mechanism often reinforce each other, and it is difficult for the government-led information infrastructure to meet the increasing investment demand for high-quality green innovation. Market-oriented environmental regulation guides the optimal allocation of innovation element resources and provides more flexible and effective innovation incentives (Jaffe et al., 1995; Blackman et al., 2018). The optimal allocation of innovation element resources is the decisive factor for enterprises to realize high-quality green innovation. Market-oriented environmental regulation guides the innovation element resources between enterprises and within enterprises to flow to high-quality green innovation activities.

First, under the moderating effect of market-oriented environmental regulation, the information infrastructure produces the effect of innovative resource allocation among enterprises, and the innovation element resources are optimally allocated among enterprises. The information infrastructure forms a perfect infrastructure construction, breaking the time and space constraint of innovation resources exchange, which can attract R&D funds and personnel to flow from imperfect areas to areas with good infrastructure environment. The cost of enterprise technology exchange and learning is reduced, and the success rate of cooperative R&D is improved. Under the regulation of market-oriented environmental regulation, the optimal allocation of innovation element resources among enterprises is further promoted. On the one hand, the cost of environmental compliance guides the flow of innovation resources and motivate the willingness of high-quality innovation. Under the market-oriented environmental regulation, enterprises can obtain competitive advantage in the market by reducing the cost of environmental compliance, and guide innovation elements such as R&D funds and personnel to flow among enterprises under the attraction of the competitive position, optimize the structure of innovation elements among enterprises, and realize Pareto optimality in the quantity, quality and efficiency of innovation elements; On the other hand, under the market-oriented environmental regulation, we will further improve the efficiency of resource utilization and encourage high-quality innovation. Market-oriented environmental regulation create pressure on R&D systems. The collection of sewage charges and trading of sewage will promote the flow of innovative elements such as knowledge and capital to enterprises with high utilization efficiency of innovative resources.

Second, under the moderating effect of market-oriented environmental regulation, the information infrastructure will produce the effect of internal allocation of innovative resources, and actively optimize the allocation of R&D funds and personnel within enterprises. Market-oriented environmental regulation guide enterprises to innovate high-quality green technologies to reduce environmental compliance cost and increase growth opportunities (Segal et al., 2015). For enterprises that originally has relative industrial and technological advantages, they need to maintain a leading position. Enterprises need to increase R&D funds and optimize personnel allocation to obtain higher innovation performance. Other enterprises also need to increase internal R&D funds and personnel investment to improve the weak position. On the one hand, under the moderating effect of market-oriented environmental regulation, the information infrastructure makes it easy to realize the high profits brought by high-quality green innovation, and guides market funds to flow into high-quality green innovation enterprises, providing financial support for high-quality green innovation and project landing. The information infrastructure can produce the effect of technology diffusion and information transmission, enhance the attractiveness of the location of manufacturers in the region, attract the inflow of innovation capital, which is helpful to increase the investment in high-quality green innovation and reduce the cost of environmental violation; On the other hand, under the regulation of market-oriented environmental regulation, the information infrastructure can produce the effect of absorbing human resources, and motivate enterprises to increase investment in green R&D personnel. As is all known, the development of infrastructure contributes to the accumulation of human capital. The convenience of transportation and information exchange will not only bring about the continuous inflow of capital, but also bring about the rational flow and allocation of human resources. It will guide the flow of human resources elements to green technologies and new industries with good future development prospects. It will accumulate high-quality technical personnel for enterprises' green innovation and thus motivate enterprises to carry out high-quality green innovation. Based on the analyses above , we propose the following hypotheses:

**Hypotheses 2.** The stronger the market-oriented environmental regulation, the more obvious the role of the information infrastructure in promoting green innovation of enterprises.

**Hypotheses 2.a** The stronger the market-oriented environmental regulation, the more obvious the effect of stimulating R&D funds investment by the information infrastructure, and increase the high-quality green innovation of enterprises.

**Hypotheses 2.b** The stronger the market-oriented environmental regulation, the more obvious the effect of stimulating R&D personnel investment by the information infrastructure, and increase the high-quality green innovation of enterprises.

## 3. Research design

3.1. Regression specification

3.1.1. Baseline regression model

We estimate the following baseline regression model:

$$gti_{it}=\alpha_0+\alpha_1 infra_t+\alpha_2 fee_t+\sum control+\sum year+\sum industry+\varepsilon_{it} \quad (1)$$

Here, $gti_{it}$ represents the high-quality green innovation level of enterprise at time t. $Infra_t$ indicates the development level of information infrastructure in a certain area at time t. $Fee_t$ represents the degree of market-oriented environmental regulation at time t of a certain area, which is measured by the sewage fee income of each province. Control is a set of control variables, year and industry represent year fixed effects and industry fixed effects, respectively, and $\varepsilon_{it}$ is the error term.

3.1.2. Moderating effect

Further, we add the interactive terms of information infrastructure and market-oriented environmental regulation to model (1), and model (2) is obtained.

$$gti_{it}=\beta_0+\beta_1 infra_t+\beta_2 fee_t+\beta_3 infra\_fee_t+\sum control+\sum year+\sum industry+\varepsilon_{it} \quad (2)$$

We focus on the interaction between the information infrastructure and market-oriented environmental regulation. If $\beta_3$ is significantly positive, the market-oriented environmental regulation has a significant positive moderating effect.

3.1.3. Mechanism test

The above theoretical analyses point out that the increase in investment in innovation resources and the level of corporate risk-taking under the market-oriented environmental regulation will affect the incentive effect of the information infrastructure on green innovation. On the basis of model (1), we introduce the interaction term between information infrastructure and mechanism variables, and the interaction term between information infrastructure, market-oriented environmental regulation and mechanism variables, investigate the mechanism of information infrastructure affecting enterprise green innovation under the moderating effect of market-oriented environmental regulation, in order to verifie H2a and H2b. Therefore, We construct the following model (3):

$$gti_{it}=\delta_0+\delta_1 infra\_fee\_mech_{t+}\delta_2 infra\_mech_t+\sum control+\sum year+\sum industry+\varepsilon_{it} \quad (3)$$

$Mech_t$ is the mechanism variable of the enterprise at time t, including R&D funds investment (rd) and R&D personnel investment (human).

3.1.4. Heterogeneity test

The above moderating effect model mainly investigates the impact of the information infrastructure on high-quality green technological innovation of enterprises under the moderating effect of market-oriented environmental regulation, and discusses its significance. However, the moderating effect model does not study the influence of different levels of information infrastructure on enterprises in different regions, nor does it consider the regional differences of market-oriented environmental regulation. We follow the Feng et al. (2023) and divide the sample into eastern, central and western regions according to the classification of the National Bureau of Statistics, testing the significance and symbols of the interaction coefficient under different samples to further verify the conclusions of model (2). This approach can largely mitigate the endogenous problems caused by regional differences that make enterprises selective for high-quality green technology innovation.

3.2. Sample selection and data sources

In our study, China A-share listed companies from 2006 to 2020 are selected as samples, and screened according to the following criteria: Eliminate samples with missing relevant data; Eliminate ST and *ST companies; Eliminate financial industry companies; Eliminate samples with abnormal value.

The related data of the information infrastructure come from CNNIC, China Statistical Yearbook and the Report of the Ministry of Industry and Information Technology. we collect the data of 30 provinces except Tibet, Hongkong, Macao and Taiwan Province. The data of provincial sewage fee income comes from China Environmental Yearbook. The data green patents come from the Green Patent Research Database (GPRD). Other data are calculated through CSMAR database. The missing data is complemented by the data of the following year. Finally, 10781 companies-annual samples were obtained. All continuous variables have been winsorized at both the lower and upper 1% quantiles.

### 3.3. Variable definitions

#### 3.3.1. Dependent variables

Enterprise high-quality green innovation (gti). Based on the practice of Kim J et al (2021), we use the cited times of authorized green patents to measure the high-quality green innovation of enterprise.The more cited times, the greater the application value, the more likely it is to promote the progress of social green technology and the higher the quality. Specifically, we take the natural logarithm of one plus the total cited times of authorized green patents at time t, and the number of self-citations is excluded. There are three reasons for this. First, There may be unqualified patents in the applied green patents, so the number of authorized green patents is more scientific; Second, the higher the quality of green patents, the more likely they are to be cited, so the cited times of green patents can well reflect the quality of enterprise green innovation; Third, among the cited green patents, there are some patents cited by enterprises themselves, so eliminating them can more truly reflect the quality of green innovation of enterprises. Considering that some authorized green patents have never been cited during the sample period, this paper excludes the companies whose the cited times of authorized green patents during the sample period has been zero, further enhancing the credibility of the conclusions .

Enterprise low-quality green innovation (ugp). Based on Long and Wang (2015), the authorized green utility model patents[7] of enterprise at time t are taken as proxy variables, and the companies with zero utility model patents in the sample period are excluded.

The quantity of enterprise green innovation (tgp). The quantity of enterprise green innovation is measured by the total number of authorized green patents of enterprises. Similarly, companies with zero number of authorized green patents during the sample period are excluded.

#### 3.3.2. Independent variables

Information infrastructure (infra). On the basis of the prior literature[8], considering data availability and timeliness, we measure the information infrastructure from four dimensions:

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[7] Judging from the difficulty of manipulation, non-invention patents are more likely to become the main object of patent management. Invention patents are more stringent in terms of examination conditions, examination procedures, examination period, protection period and maintenance cost. Compared with invention patents, non-invention patents (e.g., utility models and industrial designs) are easier to manipulate (e.g., loose application conditions, simple examination procedures, short examination period), which provides greater convenience for enterprises to implement patent management.

[8] In 1996, the National Bureau of Statistics of China issued the informatization level index (II) to evaluate the informatization development level of various regions in China. At present, the academic indicators to measure infrastructure mainly include telephone service price (Röller and Waverman, 2001), the number of telephone lines per 100 households (Datta et al, 2004), Broadband permeability(Han and Zhu, 2014), fixed broadband speed (Koutrompisp, 2019) and so on.

construction, platform, application and development of information infrastructure. The construction level includes broadband access ratio, broadband access households per capita, highway density and railway density. The platform level includes digital inclusive finance index, the natural logarithm of domain names, the natural logarithm of netizens and the natural logarithm of websites. The application level includes road freight volume per capita, railway freight volume per capita, mobile phone penetration rate, information transmission, employment in information transmission, computer services and software industry. The development level includes the natural logarithm of software revenue, the natural logarithm of telecommunication traffic, the natural logarithm of e-commerce sales and the natural logarithm of new products revenue of industrial enterprises above designated size. After the standardization of indicators, principal component analysis is used to measure the information infrastructure.

The eigenvalue of correlation matrix in Table 1 shows that there is a strong positive correlation between the original indicators, and the principal component analysis is feasible. The eigenvalues of the first four principal components are all greater than one, and the cumulative contribution is 83.73% (greater than 80%). Therefore, we select the first four principal components as the standard for calculating the index of information infrastructure. The greater the value, the higher the development level of information infrastructure in the region.

**Table 1** Dimension description of information infrastructure and eigenvalue of matrix.

| Aspect | Variables | Eigenvalue | Difference | Proporition | Cumulaitive |
|---|---|---|---|---|---|
| Construction | Broadband access ratio (per 100 people) | 8.4653 | 6.0695 | 0.5291 | 0.5291 |
| | Broadband access households per capita (households) | 2.3958 | 0.8874 | 0.1497 | 0.6788 |
| | Highway density (km/km$^2$) | 1.5083 | 0.4808 | 0.0943 | 0.7731 |
| | Railway density (km/km$^2$) | 1.0275 | 0.3715 | 0.0642 | 0.8373 |
| Platform | Digital inclusive finance index | 0.6561 | 0.1675 | 0.0410 | 0.8783 |
| | the nature logarithm of domain names | 0.4886 | 0.1288 | 0.0305 | 0.9088 |
| | the natural logarithm of netizens | 0.3597 | 0.1208 | 0.0225 | 0.9313 |

| | | | | | |
|---|---|---|---|---|---|
| | the natural logarithm of websites | 0.2389 | 0.0326 | 0.0149 | 0.9463 |
| | Road freight volume per capita (ton/person) | 0.2063 | 0.0413 | 0.0129 | 0.9591 |
| | Railway freight volume per capita(ton/person) | 0.1650 | 0.0103 | 0.0103 | 0.9695 |
| Application | Mobile phone penetration rate (per 100 person) | 0.1547 | 0.0595 | 0.0097 | 0.9791 |
| | Employment in information transmission, computer service and software industry (%) | 0.0952 | 0.0130 | 0.0060 | 0.9851 |
| | the natural logarithm of software revenue | 0.0823 | 0.0100 | 0.0051 | 0.9902 |
| | the natural logarithm of total telecom services | 0.0723 | 0.0192 | 0.0045 | 0.9947 |
| Development | the natural logarithm of telecommunication traffic | 0.0532 | 0.0221 | 0.0033 | 0.9981 |
| | the natural logarithm of new products revenue of industrial enterprises above designated size | 0.0310 | | 0.0019 | 1.0000 |

Note: The data in the table comes from the author's calculation and arrangement.

Market-oriented environmental regulation (fee). Market-oriented environmental regulation usually adopts means such as sewage charges and sewage transactions. In recent years, China has advocated more market-oriented environmental regulation and guided market players to protect the environment by collecting sewage fee. Following prior studies, we measure the market-oriented environmental regulation by the sewage fee income of each province.

The interaction between the information infrastructure and market-oriented environmental regulation (infra_fee). Firstly, the data of information infrastructure and market-oriented environmental regulation are centralized respectively, and then multiply them to eliminate the influence of multicollinearity. It´s a key variable to measure the moderating effect of market-oriented environmental regulation, if the estimated coefficient is significantly positive, meaning that market-oriented environmental regulation plays a significant positive moderating role.

### 3.3.3. Control variabless

We control the micro-characteristic that affect the green innovation of enterprises, and considering that the level of regional economic development, urbanization rate and energy conservation and environmental protection expenditure affect the technological progress and environmental protection of enterprises respectively, we also add these three macro-control variables. See Table 2 for variable definitions.

**Table 2** Variable definitions.

| Variables | Definition |
|---|---|
| gti | Enterprise high-quality green innovation, defined as the cited times of authorized green patents at time t |
| ugp | Enterprise low-quality green innovation, defined as the cited times of authorized green utility model patents |
| tgp | The quantity of enterprise green innovation, defined as the total number of authorized green patents |
| infra | information infrastructure. Principal component analysis of regional data |
| fee | Market-oriented environmental regulation, defined as the provincial sewage fee income |
| cash | Cash holdings, defined as the balance of cash and cash equivalents at the end of the period/total assets |
| ppe | Fixed assets ratio, defined as the net fixed assets/total assets |
| roa | Net profit/total assets |
| debt | Total liabilities/total assets |
| ind | Independent directors percentage |
| growth | (Current operating income-previous operating income)/previous operating income |
| duality | An indicator variable that equals one if the chairman concurrently serves as CEO, and zero otherwise |
| urb | Urbanization rate |
| energy | Regional fiscal expenditure on energy conservation and environmental protection |
| gdp | Regional GDP |
| year | Year fixed effect, the sample period is 2006-2020. |
| industry | Industry fixed effect, industry code classification of CSRC 2012 |

# 4. Empirical analysis

4.1. Descriptive statistics

Table 3 provides summary statistics for the variables used in our empirical analyses. The mean value of enterprise's green innovation quantity is 0.593, and the standard deviation is 0.884. There are differences in the total number of enterprises' green patents. The mean value of high-quality green innovation of enterprises is 1.367, and the standard deviation is 1.235. The cited times of enterprise green patents are quite different. The mean value of low-quality green innovation of enterprises is 0.510, and the standard deviation is 0.802, which shows that there are some differences in the number of green utility models among sample enterprises. The maximum value of the information infrastructure is 4.483, the minimum value is -1.971, and the standard deviation is 1.559. Thedevelopment level of information infrastructure varies greatly in different regions. The standard deviation of market-oriented environmental regulation is 0.871, which shows that the level of market-oriented environmental regulation in different provinces is different.

**Table 3** Descriptive statistics.

| Variables | N | min | max | mean | p50 | sd |
|---|---|---|---|---|---|---|
| gti | 10781 | 0.000 | 5.323 | 1.367 | 1.099 | 1.235 |
| ugp | 15225 | 0.000 | 3.466 | 0.510 | 0.000 | 0.802 |
| tgp | 17386 | 0.000 | 3.932 | 0.593 | 0.000 | 0.884 |
| infra | 10781 | -1.971 | 4.483 | 2.173 | 2.352 | 1.559 |
| fee | 10781 | 8.040 | 12.790 | 11.020 | 11.050 | 0.871 |
| cash | 10781 | 0.011 | 0.580 | 0.148 | 0.120 | 0.109 |
| ppe | 10781 | 0.004 | 0.695 | 0.220 | 0.183 | 0.160 |
| debt | 10781 | 7.210 | 93.710 | 45.620 | 45.640 | 19.700 |
| growth | 10781 | -0.493 | 2.028 | 0.163 | 0.111 | 0.344 |
| roa | 10781 | -25.250 | 18.720 | 3.531 | 3.513 | 6.000 |
| duality | 10781 | 0.000 | 1.000 | 0.253 | 0.000 | 0.435 |
| ind | 10781 | 0.333 | 0.571 | 0.374 | 0.353 | 0.054 |
| energy | 10781 | 0.251 | 7.474 | 2.347 | 2.093 | 1.550 |
| urb | 10781 | 38.700 | 89.300 | 66.890 | 67.490 | 12.970 |

| | | | | | | |
|---|---|---|---|---|---|---|
| gdp | 10781 | 0.483 | 11.080 | 4.640 | 3.711 | 2.882 |

4.2. Baseline regression

The variance inflating factor (VIF) test has been carried out, and the VIF of each variable in the model is less than 5, the average VIFis 2, indicating that there is no serious multicollinearity.

We use Ordinary Least Squares (OLS) regression in our main analyses. Table 4 reports our main results. Column (1) shows that the information infrastructure is significantly positive at the statistical level of 1%, suggesting that the information infrastructure has significantly promoted the high-quality green innovation level of enterprises, and H1 has been proved. Column (2) shows that the interaction coefficient between the information infrastructure and market-oriented environmental regulation is significantly positive at the statistical level of 1%, indicating that market-oriented environmental regulation positively moderates the relationship between the information infrastructure and high-quality green innovation of enterprises. The stronger the market-oriented environmental regulation is, the more obvious the role of information infrastructure in promoting high-quality green innovation of enterprises, and H2 will also be proved.

It is worth noting that the results in columns (3)-(6) show that the information infrastructure has also increased the total number of green patents and the number of green utility model patents to a certain extent, but market-oriented environmental regulation has not produced a significant positive moderating effect. It shows that the information infrastructure will increase the total amount of green innovation, and also play an incentive role for low-quality green innovation. However, market-oriented environmental regulation does not further stimulate the total amount of green innovation and low-quality green innovation of enterprises, that is, market-oriented environmental regulation only has obvious incentive effect on high-quality green innovation.

**Table 4** Baseline regression results.

| Variables | （1）<br>gti | （2）<br>gti | （3）<br>ugp | （4）<br>ugp | （5）<br>tgp | （6）<br>tgp |
|---|---|---|---|---|---|---|
| infra_fee | | $0.032^{***}$ | | $-0.009^{*}$ | | -0.003 |
| | | (3.491) | | (-1.857) | | (-0.605) |

| | | | | | | |
|---|---|---|---|---|---|---|
| infra | 0.171*** | 0.204*** | 0.099*** | 0.087*** | 0.104*** | 0.100*** |
| | (8.391) | (8.701) | (8.267) | (6.124) | (8.654) | (6.983) |
| fee | -0.015 | -0.012 | -0.010 | -0.011 | -0.007 | -0.008 |
| | (-0.889) | (-0.720) | (-1.011) | (-1.139) | (-0.746) | (-0.777) |
| cash | 0.424*** | 0.427*** | 0.183*** | 0.182*** | 0.199*** | 0.199*** |
| | (3.699) | (3.730) | (3.130) | (3.107) | (3.440) | (3.431) |
| ppe | -0.565*** | -0.569*** | -0.005 | -0.006 | -0.084 | -0.084 |
| | (-6.214) | (-6.264) | (-0.098) | (-0.122) | (-1.614) | (-1.620) |
| debt | 0.013*** | 0.014*** | 0.008*** | 0.008*** | 0.009*** | 0.009*** |
| | (19.043) | (19.153) | (20.230) | (20.199) | (22.172) | (22.161) |
| growth | -0.104*** | -0.106*** | -0.097*** | -0.097*** | -0.120*** | -0.120*** |
| | (-3.237) | (-3.291) | (-5.458) | (-5.449) | (-6.564) | (-6.555) |
| roa | 0.021*** | 0.021*** | 0.013*** | 0.013*** | 0.014*** | 0.014*** |
| | (10.558) | (10.669) | (11.197) | (11.163) | (12.031) | (12.014) |
| duality | -0.076*** | -0.077*** | 0.015 | 0.015 | 0.002 | 0.002 |
| | (-3.039) | (-3.073) | (1.032) | (1.015) | (0.137) | (0.132) |
| ind | 0.967*** | 0.970*** | 0.611*** | 0.610*** | 0.450*** | 0.450*** |
| | (4.401) | (4.424) | (4.822) | (4.813) | (3.513) | (3.508) |
| energy | 0.078*** | 0.081*** | 0.031*** | 0.030*** | 0.038*** | 0.038*** |
| | (6.515) | (6.701) | (4.168) | (3.985) | (4.993) | (4.914) |
| urb | -0.003** | -0.005*** | -0.006*** | -0.006*** | -0.006*** | -0.006*** |
| | (-2.076) | (-3.020) | (-6.751) | (-5.837) | (-6.095) | (-5.595) |
| gdp | -0.054*** | -0.063*** | -0.017*** | -0.013** | -0.019*** | -0.018*** |
| | (-6.412) | (-6.941) | (-3.201) | (-2.201) | (-3.552) | (-2.950) |
| _cons | -0.061 | -0.003 | -0.371*** | -0.388*** | -0.308** | -0.312** |
| | (-0.204) | (-0.010) | (-2.642) | (-2.786) | (-2.152) | (-2.196) |
| industry | Yes | Yes | Yes | Yes | Yes | Yes |
| year | Yes | Yes | Yes | Yes | Yes | Yes |

| | | | | | | |
|---|---|---|---|---|---|---|
| N | 10781 | 10781 | 15225 | 15225 | 17386 | 17386 |
| Adj $R^2$ | 0.212 | 0.213 | 0.174 | 0.174 | 0.190 | 0.190 |

Note: Test statistics based on robust standard errors are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5%, 10% levels, respectively.

### 4.3. Mechanism test

Columns (1)-(3) of Table 5 show that the interaction coefficient among the information infrastructure, market-oriented environmental regulation and R&D funds investment is significantly positive at the statistical level of 1%, indicating that the R&D funds investment is the mechanism to encourage enterprises to carry out high-quality green innovation. Columns (4)-(6) of Table 5 show that the interaction coefficient among the information infrastructure, market-oriented environmental regulation and R&D personnel investment is positive and statistically significant, suggesting that the R&D personnel investment is also the mechanism to inspire enterprises to carry out high-quality green innovation. At the same time, R&D funds and personnel investment will also increase the low-quality green innovation and the total amount of green innovation.

**Table 5** Mechanism test results.

| Variables | （1） | （2） | （3） | （4） | （5） | （6） |
|---|---|---|---|---|---|---|
| | gti | ugp | tgp | gti | ugp | tgp |
| infra_fee_rd | 0.022*** | 0.008*** | 0.014*** | | | |
| | (3.925) | (2.990) | (5.041) | | | |
| infra_rd | 0.029*** | 0.004 | 0.012*** | | | |
| | (4.897) | (1.379) | (3.799) | | | |
| infra_fee_human | | | | 0.054*** | 0.017*** | 0.029*** |
| | | | | (5.127) | (2.663) | (4.490) |
| infra_human | | | | 0.128*** | 0.048*** | 0.066*** |
| | | | | (12.980) | (7.927) | (10.641) |
| _cons | -0.816** | -1.015*** | -0.989*** | -0.815** | -0.920*** | -0.895*** |
| | (-2.267) | (-11.437) | (-10.489) | (-2.387) | (-5.721) | (-5.635) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| industry | Yes | Yes | Yes | Yes | Yes | Yes |

| | | | | | | |
|---|---|---|---|---|---|---|
| year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 9917 | 13178 | 15025 | 7106 | 8232 | 9401 |
| Adj $R^2$ | 0.209 | 0.160 | 0.177 | 0.240 | 0.160 | 0.178 |

Note: Test statistics based on robust standard errors are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5%, 10% levels, respectively.

### 4.4. Heterogeneity analysis

The heterogeneity test results show that the information infrastructure has significantly promoted the high-quality green innovation of enterprises in the eastern and central regions, while it has not had a statistically significant impact on enterprises in the western region. Market-oriented environmental regulation has a positive and statistically significant moderating effect on high-quality green innovation of enterprises in the eastern and central regions. At the same time, the information infrastructure also induces the low-quality green innovation activities of enterprises in the eastern, central and western regions and increases the total amount of green innovation to a certain extent. But the moderating effect of market-oriented environmental regulation is not statistically significant, indicating that market-oriented environmental regulation only significantly stimulates high-quality green innovation, but does not increase low-quality green innovation.

The inconsistency of the information infrastructure level and the difference of environmental regulation form the factors endowment conditions and comparative advantages of each region, which can screen the green technological innovation. In practice, there are different stages of green technology development in different regions, which will further affect the direction of green technology innovation. For example, the western region is more dependent on resources and often chooses non-green technology innovation, while the eastern region with mature service industry and high-tech industry will prefer to choose high-quality green technology innovation, and the central region is in between.

## 5. Robustness test

### 5.1. Key variables lag by one period

Considering that the development of information infrastructure is path-dependent, and the level of previous infrastructure also has an impact on the current high-quality green innovation, to address this concern, we lag the independent variables and control variables by one period. Table 6 shows that the estimated coefficient of the one lag period has improved to a certain extent, and it is statistically significant. After the endogenous problems are alleviated, the information infrastructure has a stronger driving effect. The interaction coefficient between the information infrastructure and market-oriented environmental regulation is also statistically significant, indicating that the green innovation driving effect of the information infrastructure is robust.

**Table 6** Key variables lag by one period.

| Variables | （1） | （2） | （3） | （4） | （5） | （6） |
|---|---|---|---|---|---|---|
| | gti | gti | ugp | ugp | tgp | tgp |
| L.infra_fee | | 0.028*** | | -0.015** | | -0.009 |
| | | (2.638) | | (-2.559) | | (-1.564) |
| L.infra | 0.177*** | 0.209*** | 0.111*** | 0.092*** | 0.119*** | 0.107*** |
| | (7.368) | (7.417) | (8.412) | (5.705) | (8.937) | (6.608) |
| L.fee | -0.042** | -0.033 | -0.014 | -0.020* | -0.012 | -0.015 |
| | (-2.141) | (-1.644) | (-1.293) | (-1.738) | (-1.053) | (-1.301) |
| _cons | 0.272 | 0.252 | -0.317** | -0.306* | -0.255 | -0.245 |
| | (0.783) | (0.732) | (-2.021) | (-1.945) | (-1.599) | (-1.526) |
| L.Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| industry | Yes | Yes | Yes | Yes | Yes | Yes |
| year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 8881 | 8881 | 13146 | 13146 | 15015 | 15015 |
| Adj $R^2$ | 0.230 | 0.231 | 0.173 | 0.174 | 0.189 | 0.189 |

Note: Test statistics based on robust standard errors are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5%, 10% levels, respectively.

## 5.2. Instrumental variable

Furthermore, the Terrain relief and the development of rural information infrastructure[9] are adopted as instrumental variables for the information infrastructure, and the two-stage least

[9] The principal component analysis is carried out by using seven indicators, such as the kilometers of rural delivery lines, the population coverage rate of rural radio programs, the number of rural broadband access households, the proportion of rural cable radio and television households to the total number of households, the number of village clinics set up by township hospitals, the expenditure of local finance on urban and rural social affairs, and the proportion of villages with clinics to the number of administrative villages..

square method is used for regression. Terrain relief affects the cost, quality and operation efficiency of information infrastructure, which has correlation; Terrain relief usually does not directly affect the green innovation of enterprises, so it is exogenous. At the same time, the infrastructure between rural and urban areas is relevant; Moreover, the development of rural information infrastructure will not have a direct impact on the green innovation of enterprises.

DWH results show that the model may has endogenous problems. The first-stage regression results show that the estimated coefficient of instrumental variables is positive at the statistical level of 1%, suggesting that instrumental variables have correlation. Cragg-Donald Wald test shows that there is no weak instrumental variable problem. The *p*-value of Sargan statistic and Basmann statistic based on over-identification hypothesis is 0.191 and 0.193, respectively, which rejects the unrecognized original hypothesis, that is, the selected instrumental variables pass the exogenous test. Table 7 reports the results, columns (1) and (2) show that the estimated coefficient of the information infrastructure is positive and statistically significant, and the interaction coefficient is significantly positive too. The conclusion of baseline regression results has not been changed.

**Table 7** Instrumental variable regression results.

| Variables | （1）<br>gti | （2）<br>gti | （3）<br>ugp | （4）<br>ugp | （5）<br>tgp | （6）<br>tgp |
|---|---|---|---|---|---|---|
| infra_fee | | $0.149^{***}$ | | $0.035^{*}$ | | $0.055^{***}$ |
| | | (4.281) | | (1.805) | | (2.800) |
| infra | $0.347^{***}$ | $0.819^{***}$ | $0.229^{***}$ | $0.328^{***}$ | $0.256^{***}$ | $0.423^{***}$ |
| | (3.537) | (4.657) | (5.088) | (3.192) | (5.454) | (4.004) |
| fee | -0.023 | -0.025 | -0.015 | -0.012 | -0.015 | -0.012 |
| | (-1.373) | (-1.482) | (-1.595) | (-1.232) | (-1.598) | (-1.253) |
| _cons | 0.862 | $2.787^{***}$ | 0.250 | 0.577 | 0.457 | $1.029^{**}$ |
| | (1.438) | (3.243) | (0.937) | (1.308) | (1.625) | (2.213) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| industry | Yes | Yes | Yes | Yes | Yes | Yes |
| year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 10781 | 10781 | 15225 | 15225 | 17386 | 17386 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Adj $R^2$ | 0.207 | 0.166 | 0.167 | 0.157 | 0.183 | 0.165 |

Note: Test statistics based on robust standard errors are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5%, 10% levels, respectively.

## 5.3. Change the independent variable

Referring to the practice of Sun and Xu[10] (2018), we use the weighted average method to calculate the information infrastructure index (infra2). The calculation of information infrastructure indicators is shown in model (4), n=1, $W_1$=25%, and m=16. The results in Table 8 show that the Interactive item coefficient is significant at 1%, indicating that market-oriented environmental regulation significantly moderates the information infrastructure and high-quality green innovation of enterprises, consistent with the main results.

$$\mathrm{infra2} = \sum_{i=1}^{n} \mathrm{W_i} \left( \sum_{j=1}^{n} \frac{1}{m} \mathrm{P_{it}} \right) \qquad (4)$$

**Table 8** Change the independent variable.

| Variables | (1) gti | (2) gti | (3) ugp | (4) ugp | (5) tgp | (6) tgp |
|---|---|---|---|---|---|---|
| infra2_fee | | 0.013** | | -0.009*** | | -0.006** |
| | | (2.366) | | (-3.528) | | (-2.391) |
| infra2 | 0.070*** | 0.083*** | 0.023** | 0.013 | 0.015 | 0.008 |
| | (3.459) | (3.931) | (1.964) | (1.036) | (1.276) | (0.662) |
| fee | -0.006 | -0.002 | -0.006 | -0.013 | -0.002 | -0.007 |
| | (-0.377) | (-0.101) | (-0.575) | (-1.260) | (-0.186) | (-0.655) |
| _cons | -0.877*** | -0.911*** | -0.829*** | -0.739*** | -0.823*** | -0.766*** |
| | (-3.129) | (-3.242) | (-6.447) | (-5.441) | (-6.369) | (-5.650) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| industry | Yes | Yes | Yes | Yes | Yes | Yes |
| year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 10781 | 10781 | 15225 | 15225 | 17386 | 17386 |

[10] Sun and Xu (2018) weighted three indicators, namely, telephone ownership, TV ownership and computer ownership, to calculate the new infrastructure index value.

| Adj $R^2$ | 0.208 | 0.209 | 0.171 | 0.171 | 0.186 | 0.187 |
|---|---|---|---|---|---|---|

Note: Test statistics based on robust standard errors are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5%, 10% levels, respectively.

### 5.4. Change the sample period

Since the 18th National Congress of the CPC in 2012, the state has attached great importance to the information infrastructure, and successively issued a series of major strategies and measures such as network power, broadband China, artificial intelligence and "new infrastructure". To enrich the analysis, we further set the sample period from 2012 to 2020. The results in columns (1) and (2) of Table 9 show that the estimated coefficient of the information infrastructure is still positive and statistically significant, suggesting that the baseline regression results are robust.

**Table 9** Change the sample period.

| Variables | （1）<br>gti | （2）<br>gti | （3）<br>ugp | （4）<br>ugp | （5）<br>tgp | （6）<br>tgp |
|---|---|---|---|---|---|---|
| infra_fee | | 0.028*** | | -0.003 | | 0.003 |
| | | (2.613) | | (-0.356) | | (0.460) |
| infra | 0.173*** | 0.200*** | 0.098*** | 0.095*** | 0.107*** | 0.110*** |
| | (8.041) | (8.006) | (6.993) | (5.789) | (7.537) | (6.584) |
| fee | 0.005 | -0.001 | -0.015 | -0.014 | -0.006 | -0.008 |
| | (0.251) | (-0.060) | (-1.226) | (-1.118) | (-0.523) | (-0.645) |
| _cons | 0.157 | 0.275 | -0.249 | -0.269 | -0.202 | -0.180 |
| | (0.530) | (0.929) | (-1.494) | (-1.560) | (-1.199) | (-1.045) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| industry | Yes | Yes | Yes | Yes | Yes | Yes |
| year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 9608 | 96080 | 11649 | 11649 | 13288 | 13288 |
| Adj $R^2$ | 0.212 | 0.213 | 0.161 | 0.161 | 0.172 | 0.172 |

Note: Test statistics based on robust standard errors are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5%, 10% levels, respectively.

## 6. Further analyses

## 6.1. Internal incentives effect of enterprises on high-quality green innovation

High-quality green innovation requires the construction of new business rules and value networks under the concept of green development, which not only needs the role of external institutional environment, but also needs the internal adaptive incentive structure of enterprises (Bergek et al., 2008; Markard et al., 2016). Therefore, high-quality green innovation may also be influenced by internal incentive factors such as executive salary and risk-taking level. On the basis of model (1), we introduce the interactive items of information infrastructure and internal incentive factors, as well as the interactive items of information infrastructure, market-oriented environmental regulation and internal incentive factors, so as to investigate the role of executive salary and risk-taking level in the information infrastructure and high-quality green innovation of enterprises.

Executive salary. Enterprise green innovation not only depends on external factors such as the information infrastructure and environmental regulation, but also is affected by internal corporate governance factors. Green innovation is risky and long-term. Executives´ opportunism and shortsightedness will make it only care about the short-term interests of the company rather than the long-term performance of the company, which hinders the enterprise's green innovation. The salary contract can motivate and restrain the behavior of executive. It affects the initiative of the green innovation in the process of the enterprise's decision-making, and is the internal driving force for enterprises to actively implement green innovation. Executive salary (salary) is the natural logarithm of the salary of the top three executives (Wand and Zhang, 2012). Results are shown in column (1) of Table 10, the interaction coefficient among the information infrastructure, market-oriented environmental regulation and executive salary is positive and statistical significant, suggesting that the incentive of executive salary has enhanced the driving effect of information infrastructure on enterprise green innovation.

Risk-taking level. The level of enterprise risk-taking reflects the willingness of venture capital such as R&D, we bring the risk-taking level into the research framework. Altman Z_Score is adopted as the risk-taking level of the enterprise, and the greater the value, the higher the risk-taking level. From the column (3) of Table 10, it can be seen that the interaction among the information infrastructure, market-oriented environmental regulation and enterprise risk-taking level is positive and statistical significant, indicating that the improvement of enterprise risk-taking ability will enhance the green innovation effect of the information infrastructure.

**Table 10** Internal incentives.

| Variables | (1) gti | (2) ugp | (3) tgp | (4) gti | (5) ugp | (6) tgp |
|---|---|---|---|---|---|---|
| infra_fee_salary | 0.045*** | 0.015*** | 0.018*** | | | |
| | (4.850) | (3.502) | (4.176) | | | |
| infra_salary | 0.048*** | 0.009* | 0.018*** | | | |
| | (6.641) | (1.755) | (3.604) | | | |
| infra_fee_Z_Score | | | | 0.005*** | -0.002*** | -0.001*** |
| | | | | (2.994) | (-4.411) | (-3.153) |
| infra_Z_Score | | | | -0.006*** | -0.002*** | -0.002*** |
| | | | | (-5.937) | (-4.296) | (-5.085) |
| _cons | -1.170*** | -0.929*** | -0.908*** | -1.198*** | -0.933*** | -0.909*** |
| | (-5.573) | (-13.084) | (-12.122) | (-5.829) | (-13.494) | (-12.464) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| industry | Yes | Yes | Yes | Yes | Yes | Yes |
| year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 10753 | 15186 | 17343 | 10427 | 15040 | 17171 |
| Adj $R^2$ | 0.211 | 0.171 | 0.187 | 0.215 | 0.172 | 0.189 |

Note: Test statistics based on robust standard errors are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5%, 10% levels, respectively.

## 6.2. Complement effect of command-oriented environmental regulation on market-oriented environmental regulation

In practice, when the market-oriented environmental regulation is not perfect or the cost is too high, the command-oriented environmental regulation will act as a substitute and complement to encourage enterprises to make high-quality green innovation. In recent years, some studies suggest that command-oriented environmental regulation promote enterprise innovation, while others argue that command-oriented environmental regulation and innovation have a significant negative correlation (Jaffe,1997). There is a great controversy in the related research, mainly due to the lack of analysis of the role of command-oriented environmental regulation from the perspective of the interaction between command-oriented environmental regulation and market-oriented environmental regulation, which is not in line with realistic logic.

The environmental regulation composite index (eri) is adopted as the proxy variable of command-oriented environmental regulation. The environmental regulation composite index is calculated from industrial wastewater discharge, industrial $SO_2$ discharge and industrial smoke and dust emission. Standardizing the above data and get the weight of each pollutant, we get the environmental regulation composite index by multiplying the weight and standardization. Column (1) of Table 11 shows that command-oriented environmental regulation have a negative and statistical significant impact on green innovation of enterprises. The interaction coefficient is positive but not statistical significant[11], which shows that the complementary effect of command-oriented environmental regulation on market-oriented environmental regulation is not obvious.

**Table 11** Command-oriented environmental regulation.

| Variables | （1）<br>gti | （2）<br>ugp | （3）<br>tgp |
|---|---|---|---|
| infra_fee_eri | 0.016 | 0.001 | 0.002 |
| | (1.210) | (0.083) | (0.306) |
| infra | 0.170*** | 0.098*** | 0.105*** |
| | (8.297) | (8.150) | (8.616) |
| fee | 0.013 | -0.010 | -0.003 |
| | (0.616) | (-0.843) | (-0.266) |
| eri | -0.116*** | 0.001 | -0.016 |
| | (-3.291) | (0.075) | (-0.814) |
| _cons | -0.180 | -0.367** | -0.325** |
| | (-0.548) | (-2.366) | (-2.045) |
| Controls | Yes | Yes | Yes |
| industry | Yes | Yes | Yes |
| year | Yes | Yes | Yes |

[11] A positive coefficient of interaction among the information infrastructure, market-oriented environmental regulation and command-oriented environmental regulation indicates a complementary relationship, while a negative coefficient indicates a substitution relationship.

| | | | |
|---|---|---|---|
| N | 10781 | 15225 | 17386 |
| Adj $R^2$ | 0.213 | 0.174 | 0.189 |

Note: Test statistics based on robust standard errors are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5%, 10% levels, respectively.

## 7. Conclusions and policy suggestions

### 7.1. Conclusions

Our findings show that the information infrastructure significantly promotes high-quality green innovation of enterprises, and market-oriented environmental regulation positively moderates the relationship between them. We strengthen our inferences by conducting a battery of robustness tests that rule out alternative explanations. The mechanism test shows that the increase of R&D funds and personnel in enterprises under market-oriented environmental regulation will stimulate high-quality green innovation. The heterogeneity test shows that the information infrastructure has significantly promoted the high-quality green innovation of enterprises in the eastern and central regions, but it has not had a significant impact on the high-quality green innovation of enterprises in the western region. Market-oriented environmental regulation has a positive and statistically significant moderating effect on high-quality green innovation of enterprises in the eastern and central regions. Further analyses shows that the improvement of executive salary incentive and enterprise risk-taking level will enhance the incentive effect on high-quality green innovation of enterprises. Command-oriented environmental regulation can inhibit high-quality green innovation, and it is not statistically or economically significant to complement market-oriented environmental regulation.

### 7.2. Policy suggestions

First of all, moderately maintain the reasonable advancement of traditional infrastructure and new infrastructure, and continue to promote the upgrading of information infrastructure. Moderate foresight can make enterprises have isomorphic effect and produce adaptive incentive structure for high-quality green technological innovation. With the development of green technology, the new infrastructure temporarily idle will not only be out of date and eliminated, but also correctly guide and accelerate the upgrading of green technology.

Second, based on market-oriented environmental regulation, increase the investment of high-quality green innovation of enterprises. Use market incentives to guide innovative resources to flow into enterprises with emission reduction capacity and encourage enterprises to increase investment in green innovation. Further explore various means and intensity of market-oriented environmental regulation, consider adopting command-oriented environmental regulation within a reasonable range in the short term to prevent the distortion of factor market, and gradually use market-oriented environmental regulation to reverse the mismatch of factors among industries, so as to provide new impetus for high-quality green innovation of enterprises.

Then, promote information infrastructure and environmental regulation markets according to local conditions, and effectively promote high-quality green innovation cooperation among regions. In view of the factor endowment conditions and comparative advantages of the eastern, central and western regions, there are differences in the incentive effect of green technology. The eastern and central regions should actively play the demonstration and leading role of high-quality green innovation, drive the western region with heavy resource dependence to realize momentum conversion as soon as possible, and enhance the effect of high-quality green innovation in value creation.

In addition, improve the risk-taking level of enterprises and explore the risk-sharing mechanism of green technology R&D. In recent years, China has further strengthened the construction of information infrastructure, and enterprises should seize the opportunity to obtain economic benefits and competitive advantages through high-quality green technology innovation. Explore R&D programs that accord with the market position and resource conditions of enterprises, actively set up independent R&D institutions, improve their R&D level through risk-sharing cooperative R&D mechanism, and enhance their ability to integrate various innovative resources.

Last but not least, stimulate the innovation awareness of company executives and improve the implementation of green innovation. Executives´ opportunism restricts the decision-making and behavior of green innovation, and executives´ behavior directly affects the initiative of green innovation in enterprises. A reasonable executive salary incentive system should be formulated, combining executive recruit, performance appraisal, rewards and punishments, salary with green innovation performance, so as to reduce executives´ opportunism and promote the green innovation motivation of enterprises.

## References

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