The impact of environmental investments on green innovation: An integration of factors that increase or decrease uncertainty[1]

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Accepted for publication in Business Strategy and the Environment

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Abstract: How institutional factors that increase or reduce uncertainty can impact the effect of environmental investments (EIs) on green innovation (GI) deserves more investigation. In this study, we first examine the direct impact of EIs on GI. We further consider political uncertainty as a factor that increases uncertainty and marketization degree and environmental regulations as another two factors that reduce uncertainty, and examine the effects of these factors on EI and GI. Using key environmental cities in China covering the period 2003 to 2016 as the research sample, empirical results indicate that EIs can have a positive effect on GI and two different types of GI (green invention and green utility). In addition, political uncertainty can weaken the positive effect of EIs on GI. Furthermore, the association between EIs and GI varies with the intensity of environmental regulations, but does not vary with the degree of marketization. The positive effect of EIs on GI is more pronounced in cities with a higher intensity of environmental regulations. Overall, political uncertainty that increases uncertainty can weaken the positive effect of EIs on GI, whereas environmental regulations that decrease uncertainty can strengthen the promotion effect of EIs on GI.
Keywords: environmental investments; green innovation; political uncertainty; marketization degree; environmental regulations

1. Introduction

How to effectively coordinate the development of the economy and the protection of the environment has become a severe challenge worldwide. Under the double pressures of promoting economic development and protecting the environment, traditional technological innovation has been gradually replaced with green innovation (GI), and GI has become a new focus of research (Roper & Tapinos, 2016; Tariq, Badir, Tariq, & Bhutta, 2017). GI can be characterized as innovation that "allows for new ways of addressing current and future environmental problems and decreasing energy and resource consumption, while promoting sustainable economic activity" (OECD, 2012). Seeing from the nature of GI, it is characterized

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[1]Abbreviations: EIs, environmental investments; GI, green innovation; GIP, green invention patents; GUP, green utility patents; PU, political uncertainty; MD, marketization degree; ERs, environmental regulations; R&D, research and development; RBV, resource-based view; VRIN, valuable, rare, imperfectly imitable and nonsubstitutable; PSM, propensity score matching

by "double externalities". It can not only release the spillover effects of technological innovation, but also produce positive externalities in reducing external environmental costs (Horbach, Rammer, & Rennings, 2012; Rennings, 2000; L. Zhang, Cao, Tang, He, & Li, 2019). GI, therefore, is also considered a vital means to achieve a win-win scenario between the environment and the economy (Barbieri, Ghisetti, Gilli, Marin, & Nicolli, 2016; Qi, Zou, & Xie, 2020).

For China, to tackle serious environmental issues and promote the development of the economy simultaneously, the government has made great efforts to encourage firms, universities, and other scientific institutions to engage more in GI (Qi et al., 2020). According to the statistical report on China's green patents (2014-2017) issued by the State Intellectual Property Office, GI activities in China have been very active since 2014, the capabilities of GI have continuously improved, and the application number of green patents has gradually increased. The application number of green patents in 2017 was approximately 1.8 times that in 2014, and the total application number of green patents in the three years reached 249,000 pieces. Moreover, two departments of the Chinese government jointly issued a document in 2019 named *Guidance on building a market-oriented green technology innovation system*[2], which further refined the roadmap and timetable for the construction of a green innovation system. Since then, GI has entered the highest programmatic document of the government for the first time, and the importance of GI has been strongly emphasized in China.

Given the great importance of GI, how to foster GI has always been the focus of research both for practitioners and researchers (Z. Huang, Liao, & Li, 2019; W. L. Lin, Ho, Sambasivan, Yip, & Mohamed, 2021; Zhou, Chen, & Chen, 2021). Over the past several decades, scholars have investigated the drivers of GI from different perspectives based on different theories. The drivers of GI can generally be classified into 4 categories: market pull factors, technology push factors, regulatory push-pull factors, and firm-level factors (Oduro, Maccario, & De Nisco, 2021; Sanni, 2018; Zubeltzu-Jaka, Erauskin-Tolosa, & Heras-Saizarbitoria, 2018). Looking at the specific determinants of GI that have been investigated, studies on how environmental management practices are associated with GI are relatively abundant in extant literature. However, previous literature is not conclusive in validating the link between EIs and GI. All possible results (i.e., positive, negative, neutral) have been found (D. Li, Zhao, Zhang, Chen, & Cao, 2018; Q. Zhang & Ma, 2021). These contradicting results indicate that the relationship between EIs and GI is context-dependent, and hence, we first investigate how EIs are associated with GI in the context of China. We further investigate whether the impact of EIs on GI varies

[2] http://www.gov.cn/xinwen/2019-05/14/content_5391394.htm, accessed on 29 September 27, 2021.

in the presence of factors that increase or reduce uncertainty.

Political uncertainty (PU) is likely to shift firms' behaviors and change the final outcomes (Wang et al., 2019). In the context of China, PU can arise if there is a turnover of local officials in a city. The reason lies in the fact that new officials may change the implementation of original policies due to the differences in capabilities, preferences, and promotion incentives among officials. Hence, the stability and continuity of the policies can be affected (Deng, Wu, & Xu, 2019). When facing the shock of PU, the perceived risk may lead firms to postpone their investments until the uncertainty is resolved (Julio & Yook, 2012). Some studies have proven that PU can have a negative influence on firms' behaviors (Luo and Zhang, 2020; Ni, 2019; Wang et al., 2019). However, little is known about how PU caused by the turnover of local officials affects the influence that EIs may have on GI in the extant literature. Hence, we explore the heterogeneous effect of EIs on GI from the perspective of PU in this study.

While PU increases uncertainty, there are other institutional factors that can reduce uncertainty and hence can have a different influence on the link between EIs and GI. We consider two important such factors in this study. Marketization degree is an important institutional factor that exerts a significant influence on firms' behaviors and further affects organization outcomes (Meyer, Estrin, Bhaumik, & Peng, 2009; North, 1990). Marketization degree can show the degree of a city that transformed from a planned economy towards a market economy. Generally, firms operating in an area with a high degree of marketization can face less uncertainty, sufficient legal infrastructure, less government intervention and high faith in government (K. Z. Lin, Cheng, & Zhang, 2017). Hence, a better development market is likely to have a positive effect on firms, which can reduce the uncertainty that firms face. However, previous studies have not investigated how marketization degree impacts the link between EIs and GI thus far. To bridge this existing gap, we analyze whether the influence on GI exerted by EIs varies under different degrees of marketization or not.

Apart from marketization degree, we also consider environmental regulations (ERs) as another institutional factor that helps to reduce uncertainty. ERs consist of a series of environmental policies that aim to guide firms' behaviors to alleviate their negative impacts on the natural environment (Eiadat, Kelly, Roche, & Eyadat, 2008). Stricter ERs are supposed to create a favorable context for firms to engage more in long-term orientation environmental initiatives so that ERs can address the adverse effect arising from uncertainty. If local governments strictly implement ERs, firms are more likely to adopt proactive environmental initiatives (R. Li & Ramanathan, 2018). However, how ERs can shape the link between EIs and GI also remains unclear in existing studies. Therefore, we study whether the impact of EIs on GI varies under different intensities of ERs.

In sum, this study attempts to answer one main question: how are EIs associated with GI in China? In addition, we study the effect of one factor (PU) that increases uncertainty and two more factors (marketization degree and ERs) that reduce uncertainty on the EIs-GI relationship. The research framework of our study is shown in Figure 1. This study is conducted at the city level. The reason lies in that the Chinese government issued a list of 113 environmental key cities at the end of 2002, with special emphasis on air pollution treatment. Since then, cities have attached importance to environmental protection and increased their EIs. Hence, we select key environmental cities as the search sample. The research period of this study spans from 2003 to 2016.

Figure 1

Our study is conducted in a Chinese research setting for two reasons. On the one hand, compared with other countries, China has special institutional arrangements for the promotion of local officials and environmental policies. In addition, the reform process of marketization is also uneven across different regions in China. The existence of these institutional differences also makes China a valuable research background. On the other hand, the asymmetry between economic development and environmental protection is a typical problem that developing countries are facing. The research questions investigated in this study can provide other developing countries (e.g., Brazil, India, etc.) with enlightenment in terms of how to improve the effectiveness of environmental investments and how to balance economic development and environmental protection.

Seeing the research framework, our research makes contributions both to the literature and practice. Our study is the first to investigate the impact of factors that increase or decrease uncertainty on the association between EIs and GI. By doing so, our yields valuable new knowledge in helping to support GI. Moreover, this study employs the resource-based view (RBV) as the theoretical underpinning. Our empirical results are helpful to advance the understanding of the RBV. From a practice perspective, the presence of various factors that increase or decrease uncertainty can influence the benefits that can be derived, which can provide insightful implications for managers and policymakers. Besides, this study focuses on a developing country context (China), and the results can be applied to similar developing countries.

2. Literature and hypotheses

2.1 The drivers of green innovation

Although GI is gaining growing attention from different fields, a standard terminology of GI is still lacking in the academic literature (Tariq et al., 2017). In the current literature, scholars have used several exchangeable terminologies for GI, such as sustainable innovation, environmental innovation, green innovation and eco-innovation. Despite trivial differences, these terminologies are actually synonymous and can point to the same issue (Oduro et al., 2021). We use the term green innovation (GI) in this study for the sake of continuity and simplicity.

Given that GI can play a critical role in achieving long-term sustainable development, the research interest in GI shows a steady growth, especially in the past few years (Z. Huang et al., 2019; Oduro et al., 2021; Xavier, Naveiro, Aoussat, & Reyes, 2017). However, GI still lacks a uniform or standard definition. A commonly accepted definition characterizes GI as innovation that “allows for new ways of addressing current and future environmental problems and decreasing energy and resource consumption, while promoting sustainable economic activity” (OECD, 2012). Thus, GI is expected to involve the generation of new ideas, goods, services, processes, or management systems in an attempt to reduce environmental pollution and achieve sustainability (D. Li, Tang, & Jiang, 2019; Rennings, 2000).

Scholars have investigated the drivers of GI well. Different theories have been employed to explain the factors that can trigger GI, such as the RBV (W. Cai & Li, 2018; Kiefer, González, & Carrillo‐hermosilla, 2018; W. L. Lin et al., 2021), institutional theory (W. Cai & Li, 2018; Ramanathan, Ramanathan, & Bentley, 2018), stakeholder theory (Bhuiyan, Huang, & de Villiers, 2021; Qi, Zeng, Chiming, Yin, & Zou, 2013), and upper-echelons theory (Arena, Michelon, & Trojanowski, 2018; Zhou et al., 2021). Grounding on these different theories, scholars have investigated the determinants of GI from different perspectives. For example, scholars investigate the antecedents of GI from the perspective that focuses on internal factors vs. external factors (W. Cai & Zhou, 2014; Tariq et al., 2017) and from the perspective that focuses on supply side factors vs. demand side factors (Horbach, 2008). Another popular method existing in the current literature is dividing the determinants of GI into 4 categories: market pull factors, technology push factors, regulatory push-pull factors and firm-level factors (Fernando & Wah, 2017; Horbach et al., 2012; Sanni, 2018; Zubeltzu-Jaka et al., 2018). Specifically, market factors include market demand for environmental-friendly products, green brand image, etc. (Ghisetti, 2017; R. J. Lin, Tan, & Geng, 2013). Technological factors consist of research and development (R&D) investments, copyrights, specialized knowledge capital, collaboration, equipment upgrades, employee training, etc. (Zubeltzu-Jaka et al., 2018). Regulatory factors can be regarded as the pressures from the government, such as environmental regulations, subsidies, taxes, etc. (Horbach, 2008). In addition to government pressures, pressures from suppliers, customers, competitors, employees, shareholders and industrial associations can also encourage firms to adopt GI strategies (Bossle, Dutra De Barcellos, Vieira, & Sauvée, 2016). Firm-level factors comprise firms’ size, age, capabilities, the quality of human resources, and environmental management systems, etc. (Rehfeld, Rennings, & Ziegler, 2007). Grounding on upper-echelons theory, scholars also investigate whether the personal characteristics of top managers in the firm can play an encouraging role in GI, for instance, work experience, CEO hubris, CEO education, politically connected CEO, gender, age, etc. (M. Huang, Li, & Liao, 2021; Zhou et al., 2021).

Overall, scholars have explored the drivers of GI from many perspectives grounding upon different theories.

2.2 The impact of environmental investments on green innovation

The RBV has been well utilized in the previous literature for analyzing the antecedents of GI, especially from the perspective of the internal side or firm-level side. We also employ the RBV to explain the impact of EIs on GI in this study. The RBV suggests that firms can gain competitive advantage through the acquiring and applying of valuable, rare, imperfectly imitable and nonsubstitutable (VRIN) resources and capabilities that they possess (Barney, 1991; Wernerfelt, 1984). If firms attempt to achieve sustainable competitive advantage, they have to accumulate or possess various resources and capabilities continuously.

With the ever-increasing awareness of GI and the increasing compliance pressures, firms may engage more in EIs (W. Cai & Zhou, 2014). EIs involve huge amounts of investment funds, and a long-term investment and hence are highly risky (Adams, Jeanrenaud, Bessant, Denyer, & Overy, 2016; Holmstrom, 1989). According to the RBV, when firms engage in EIs, it can help firms to deploy valuable and rare resources to generate and accumulate inimitable knowledge through experience, which can finally evolve into sustainable competitive advantage. Sharma and Vredenburg (1998) prove that firms that adopt more proactive environmental strategies can bring unique capabilities to themselves, which can further have implications for firms' competitive advantage. Meanwhile, the accumulated resources and capabilities during the process of implementing environmental management practices can also lay a solid foundation for GI (Blind, 2012; Rennings et al., 2006; Wagner, 2008). Hence, in addition to gaining competitive advantage, the increase in EIs can be beneficial for GI.

In existing studies, a strand of literature has analyzed the association between environmental management practices and GI and showed a positive relationship (D. Li et al., 2019; Nath & Ramanathan, 2015; Wagner, 2008). However, the literature is not always unanimous on this positive relationship, with some studies suggesting negative relationship (e.g., D. Li, Zhao, Zhang, Chen, & Cao, 2018; Castillo-Rojas et al., 2012), no relationship (e.g., Graves & Waddock, 1999) or more complex relationships (e.g., Ramanathan, 2018; Q. Zhang & Ma, 2021). These contradicting results indicate that the relationship between EIs and GI is context-dependent, and hence, we first test this hypothesis in the context of China.

Grounding on RBV, the increasing amounts of EIs can bring more resources and adequate support of capital for GI from the perspective of resource endowment, which can remove the main barrier of resource constraints for GI (X. Cai, Zhu, Zhang, Li, & Xie, 2020; Tariq et al., 2017). In addition, EIs, especially investments in pollution prevention, urgently need some advanced green technologies to realize the purposes of preventing or reducing the amount of pollution created at the source (Broberg, Marklund, Samakovlis, & Hammar, 2013; R. Li & Ramanathan, 2020). In this regard, an increase in EIs can provide more resources and capabilities for developing pollution prevention technologies in an attempt to resolve pollution created at the beginning, which can finally evolve into GI.

In sum, the increase in EIs can reduce the resource constraints required by GI, provide capabilities and resources for GI, and increase the incentives for adopting GI. On the basis of the above discussions, we test the following hypothesis in our context and hence put forward the hypothesis.

H1. In the context of Chinese cities, EIs have a significant and positive impact on GI.

2.3 Influence of political uncertainty

In China, local officials in charge of specific areas or cities are regularly transferred and the turnover of local officials is normal because of the top-down cadre exchange system (Deng et al., 2019; H. Li & Zhou, 2005). The regular exchange or transfer of cadres can prevent local officials from building too much power in a specific area (Xu, Chen, Xu, & Chan, 2016). In addition, the rotation of cadres can also reduce regional disparities and bridge administrative gaps via cadres' efforts (Deng et al., 2019). Typically, the tenure of city-level local officials is 5 years. However, it is also possible that local officials rotate before completing the five-year service term because of a sudden promotion, death, or misconduct (Xu et al., 2016).

Local officials have been treated as the key decision makers on the development of the local economy and social stability in China as they have great power in regional affairs and have huge rights to decide how to allocate the limited resources (Ni, 2019). If the government officials in a city change, owing to the different capabilities, preferences and incentive restrictions among local officials, the continuity and stability of government policies are likely to be disturbed (Mikesell, 1978; Rogoff & Sibert, 1988). Hence, the turnover of local officials can bring huge uncertainty, especially in policy implementation, personnel transfers and assignment of responsibilities. Thus, the turnover of local officials can be the main source of PU in China (Yee, Tang, & Lo, 2016).

As discussed earlier, the RBV can help to predict the positive effect of EIs on GI. However, this prediction can be correct only when the RBV is applied in stable and predictable environments (Kraaijenbrink, Spender, & Groen, 2010). Barney (2002) claims that the RBV can hold when the "rules of the game" remain relatively fixed. Hence, to go beyond the RBV, it is valuable to know how the effect of EIs on GI will be modified in unstable and unpredictable environments, for instance, when PU exists in a city.

According to real option theory, when faced with uncertainty, firms tend to postpone investment decisions until part or all of the uncertainties are solved. Accordingly, the option value of waiting to invest rises (Julio & Yook, 2012; Roper & Tapinos, 2016; L. Wang et al., 2019). Similarly, when facing the replacement of city heads, firms can focus more on any new and unforeseen decisions by the new official leaders and may not be able to go ahead with their planned EIs in full swing for achieving GI. Extending this logic further, a perceived risk of PU is likely to lead firms to delay their EIs until PU is resolved. Thus, the presence of higher levels of PU can weaken the positive impact of EIs on GI.

Although no direct study proves the negative effect of PU on the link between EIs and GI, a strand of similar studies have confirmed the negative effects of political turnover on firms' behaviors. Luo et al. (2017) find that firm risk increases significantly if the prefecture-city official replaces. Deng et al. (2019) demonstrate that political turnover can lead to more firm pollution discharges. Wang et al. (2019) find that the political promotion of local officials can impede innovation investment. Ni (2019) shows that the turnover of city heads can result in a decrease of average cash holdings in listed firms, especially for firms operated in cities with the lower quality of the government. Luo and Zhang (2020) prove that the turnover in mayor and/or municipal party secretary can negatively affect R&D investment. Building on the discussions above, we posit the second hypothesis.

H2. Political uncertainty will weaken the impact of EIs on GI.

2.4 Influence of marketization degree

Since the early 1990s, China has been undergoing a transition from a planned economy to a market economy through marketization. Marketization degree can reflect the level that a region transforms from a planned economy towards a market economy. However, marketization degree in different regions is significantly different owing to different resource endowments, geographic locations, and government policies (Hitt & Xu, 2016).

Generally, firms operating in a region with a higher marketization degree can confront a lower extent of government intervention, a high level of "rule by law", and a better market mechanism. A better market mechanism can reduce information asymmetries and lower the costs of market transactions, further facilitate market transactions of individuals and firms (Meyer et al., 2009). Besides, a better development market can also generate greater competitive pressures, sufficient legal infrastructure, high faith in government, and less uncertainty for the firms operated in this region (K. Z. Lin et al., 2017; Zeng, Qin, & Zeng, 2019). Hence, firms operating in a region with a high degree of marketization can have sufficient incentives to focus on long-term orientation operations and have more willingness to increase EIs, which can further generate more positive influence on GI.

Using the RBV as the theoretical lens, it claims that VRIN resources and capabilities can bring out a more sustainable competitive advantage in highly stable and mature environments (Barney, 1991; Wernerfelt, 1984). On the other hand, Kraaijenbrink et al. (2010) argue that the accuracy of the applicability of the RBV is also determined by the specific institutional context. If firms can have complete and undifferentiated property rights, the value of VRIN resources and capabilities in gaining sustainable competitive advantage can be enhanced (Kim & Mahoney, 2005). A region with a high degree of marketization can show that the environments are highly stable and mature, and it has a better environment for protecting property rights; hence, it is easier for firms to gain sustainable competitiveness. Extending this logic to the case of the influence of EIs on GI, the promotion effect can also be more pronounced in a region with a high degree of marketization.

A strand of similar research also confirms the positive moderating role exerted by marketization degree. Lu et al. (2009) show that the level of marketization degree can positively strengthen the influence of corporate governance on firms' export propensity. Li and Ramanathan (2020) confirm that the link between EIs and environmental performance is positively moderated by the institutional environment, which is also measured by the index of marketization degree. Based on the above discussions, we hypothesize the following:

H3. The impact of EIs on GI is more pronounced at higher degrees of marketization.

2.5 Influence of environmental regulations

Unlike marketization degree, which aims to help firms to operate in a more supportive environment, ERs are more direct policies that aim to guide firms' environmental behaviors (Eiadat et al., 2008).

In China, local governments have huge rights to decide how to implement environmental policies (Shen, Dennis, & Yang, 2017). If local governments implement ERs strictly, firms have to carry out more proactive environmental activities. Hence, how local governments implement environmental policies can result in different environmental outcomes. If firms operate in a city with a higher intensity of ERs, they are more likely to engage in proactive activities and increase their EIs (R. Li & Ramanathan, 2018). As noted previously, VRIN resources and capabilities can help achieve competitive advantage in stable and mature environments on the basis of the RBV. When a city can implement ERs strictly, it can help to create a stable context for firms to engage more in EIs; accordingly, the positive effect of EIs on GI can be magnified.

Previous studies have also proven that ERs can play a positive moderating role. Both D. Li et al. (2019) and D. Li, Zhao, et al. (2018) find ERs can strengthen the effect of environmental management practice (i.e., ISO 14001, quality management) on GI. Zhou et al. (2021) show that the promotion effect of highly educated CEOs on GI is more pronounced in regions with strict environmental pressures. In line with the discussions above, we put forward the following hypothesis.

H4. The impact of EIs on GI is more pronounced when environmental regulations are implemented more strictly.

3. Research design

3.1 Data collection and research sample

Multiple databases are used to obtain the relevant data. First, the Chinese Research Data Services (CNRDS) database is used to collect the data for GI. The CNRDS platform collects the data on green patents from the State Intellectual Property Office (SIPO) according to the classification standard of green patent released by the World Intellectual Property Office (WIPO). The data for EIs are obtained from the *China Environment Yearbook*. With regard to the changes in the city-level party secretary, we manually collect relevant data from www.people.cn, XinhuaNet, and Baidu Encyclopedia. These 3 official websites can jointly provide detailed information on local officials. The data for marketization degree are from the China market index database. The data for the remaining variables are from the China Stock Market Financial Database (CSMAR). We merge the data from different databases on a city-by-city basis. Given that the list of environmental key cities was released at the end of 2002, the data for EIs have been disclosed since 2003. However, the data for control variables are missing too much from 2017. Hence, we finally decide that the research period for this study spans from 2003 to 2016.

We select key environmental cities as the research sample because only these cities disclose the data of their EIs. At present, 113 cities in China are nominated as key environmental cities. Since the adjustment of the list of key environmental cities in 2011, 7 original cities (Sanya, Zhongshan, Foshan, Taizhou, Daqing, Weihai, Jiaxing) have been deleted, and 7 new cities (Sanmenxia, Nanchong, Deyang, Weinan, Yuxi, Zigong, Zhenjiang) have been added. We further exclude Haikou and Lasa because of missing too much data. Hence, a final sample of 104 cities is left in this study. Figure 2 shows the graphical view of included cities with respect to their location within China. Due to the lack of the values of several variables for several cities, we finally obtain 104 cities with 1370 observations.

****Figure 2****

3.2 Descriptions of Variables

3.2.1 Dependent variable: green innovation

In the extant literature, many different proxies have been adopted to capture GI, including green R&D investment, the number of green patents, the citation number of green patents and new product development (Xiang, Liu, Yang, & Zhao, 2020). It is difficult to measure GI from an input perspective, because there are no statistical data specific to green R&D (Arena et al., 2018; D. Li et al., 2019). Hence, it is easier and better to measure GI from an output perspective. Following Cai et al. (2020), Zhang and Ma (2021) and Li et al. (2018), we select the application number of green patents of a city in a given year as the proxy for GI. To tone down the effect of extreme observations and deal with the right skewness of the raw data, we take the natural logarithm of 1 plus the application number of green patents for the final measurement of GI (Bai et al., 2020; Kassinis & Vafeas, 2006; L. Wang et al., 2019). According to the components of green patents, green patents can be divided into two categories: green invention patents (GIP) and green utility patents (GUP). Generally, GIP represents a higher quality of GI than GUP. The total number of green patents equals the number of green invention patents plus the number of green utility patents. In line with the measurement of GI, we also use the same method to measure GIP and GUP.

3.2.2 Explanatory variable

3.2.2.1 Environmental investments

EIs refer to the funds invested in technology, equipment and processes that result in environmentally friendly products and processes (Qi et al., 2020; Xiang et al., 2020). Hence, we use the total amounts of funds that every city spends on environmental protection every year to measure EIs. By taking different levels of cities' economic development into account, EIs are further divided by industrial output value. It is worth mentioning that the data of city-level EIs are not available from 2011 to 2013 in the *China Environment Yearbook*. To avoid missing too many observations, we use the following method to supplement the data. Despite city-level data of EIs from 2011 to 2013 are not available directly from the *China Environment Yearbook*, EIs for each province are available. We then estimate EIs using Formula 1.

$$EIs = (EI_P * N_C)/N_P \qquad \text{(Formula 1)}$$

where EIs = Environmental investments for a particular city,

EI_P = Environmental investments for the entire province in which the city is located,

N_P = Number of environmental protection projects under construction in the province,

N_C = Number of environmental protection projects under construction in the city.

Thus, if there is no project under construction in a city, its EIs are 0.

3.2.2.2 Political uncertainty

In many developed countries, PU mainly comes from elections (Julio & Yook, 2012; D. Luo et al., 2017). However, as mentioned above, PU in China mainly comes from the turnover of local officials in a city (Yee et al., 2016). If there is a turnover of local officials, PU can exist because the enforcement of current policies and the formulation of future policies may become uncertain in the short term (S. Chen, Mao, & Feng, 2020). In China, the most important government officials in a city include the party secretary and the mayor. The party secretary is responsible for general policy and managing the party bureaucracy, while the mayor is in charge of managing the city administration (S. Chen et al., 2020). Generally, the party secretary is the highest-ranking official, and the mayor is the second-highest-ranking official. The party secretary plays a more important and powerful role than the mayor in a city (D. Luo et al., 2017; Ni, 2019; L. Wang et al., 2019). Hence, we use whether there is a turnover of the party secretary in a city to measure PU in this study. Similar to prior research S. Chen et al. (2020) and Yee et al. (2016), PU is captured via a categorical variable. It takes a value of 0 or 1 depending on whether the party secretary is replaced in a city or not. We allow for some time lag to account for the fact that it may take some time to see the influence caused by the turnover of the new party secretary (Li and Zhou, 2005; Luo et al., 2017). More precisely, if the turnover of the party secretary happens in the first half of the year (from January 1 to June 30), PU takes a value of 1 in the current year; if the turnover of the party secretary occurs in the second half of the year (from July 1 to December 30), PU takes a value of 0 in the current year but takes a value of 1 in the following year.

3.2.2.3 Marketization degree

Marketization index was constructed to measure the degree of marketization of a region. Hence, the scores of marketization index are widely adopted by the scholars as a proxy for marketization degree, especially in the Chinese research setting. Fan and Wang were the first to construct the marketization index in 2001. In 2019, Wang et al. (2019) updated the marketization index and released the newest version. More details of marketization index can refer to Wang et al. (2019). Following Chen et al., (2015) and Lin et al. (2017), we also employ the scores of marketization index as the proxy for marketization degree (MD). A higher marketization index scores denotes a better development market.

3.2.2.4 Environmental regulations

For the measurement of ERs, scholars have adopted different proxies, such as pollution abatement costs, pollutant discharge fees, environmental pollutants emission, etc. (Jaffe and Palmer, 1997; Kneller and Manderson, 2012; Zhao and Sun, 2016). In this study, environmental pollutants that each city releases to water and air are selected as the proxy for the intensity of ERs (Zhao & Sun, 2016). Owing to the availability of data, we only select 3 main environmental pollutants (industrial waste water, industrial dust, industrial sulfur dioxide). The comprehensive index method is further employed to gather three different environmental pollutants. More details for the data processing procedure can be found in Zhao and Sun (2016). In contrast to using the discharge standards rate of environmental pollutants instep 1 employed by Zhao and Sun (2016), we use the industrial output value that per unit environmental pollutants discharged instead. The final calculation results are used to represent ERs. The higher the results are, the higher the intensity of ERs is.

3.2.3 Control variables

To control for the influence of other potential variables on GI, following Li and Ramanathan (2020) and Yuan and Zhang (2020), we incorporate a set of control variables into the regression models. The control variables include per capita GDP (Per_GDP), industrial structure (Structure), fiscal expenditure on science and technology (Scitech), industrial scale (Scale), per capita foreign direct investment (Per_FDI), fixed-assets investments (Fixinvest), and population density (Density). The details of the measurements of all variables are presented in Table 1. To minimize the impact of outliers, all continuous variables included in this study are winsorized at the 1% and 99% levels.

****Table 1****

3.3 Regression model

We mainly use Stata 14 to conduct the whole analysis. To investigate the impact of EIs on GI, we construct Model (1). As discussed earlier, in an attempt to provide a more comprehensive picture, we classify green patents into green invention patents (GIP) and green utility patents (GUP). We include GIP and GUP into the regression model separately. α_i denotes city fixed effects, while λ_t means year fixed effect. ε_{it} is the disturbance term.

$$GI_{it}\ /GPI_{it}\ /GUI_{it} = c + \beta_1 EIs_{it} + \beta_2 Per\_GDP_{it} + \beta_3 Structure_{it} + \beta_4 Scitech_{it} + \beta_5 Scale_{it} + \beta_6 Per\_FDI_{it} + \beta_7 Fixinvest_{it} + \beta_8 Density_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \quad \text{(Model 1)}$$

Given that PU is a categorical variable, to examine the influence of PU on the link between EIs and GI, we employ the method of sub-sample regression and use Model (1) to conduct the analysis. We divide the whole sample by whether PU exists in a city. To examine the moderating effect of marketization degree and ERs, we incorporate the moderators (MD and ERs) and the interaction terms (EIs * MD and EIs * ERs) into separate regression models (see Model 2 and Model 3). The interaction terms are centered before incorporating into the models.

$$GI_{it}\ /GPI_{it}\ /GUI_{it} = c + \beta_1 EIs_{it} + \beta_2 MD_{it} + \beta_3 EIs_{it} * MD_{it} + \beta_4 Per\_GDP_{it} + \beta_5 Structure_{it} + \beta_6 Scitech_{it} + \beta_7 Scale_{it} + \beta_8 Per\_FDI_{it} + \beta_9 Fixinvest_{it} + \beta_{10} Density_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \quad \text{(Model 2)}$$

$$GI_{it}\ /GPI_{it}\ /GUI_{it} = c + \beta_1 EIs_{it} + \beta_2 ERs_{it} + \beta_3 EIs_{it} * ERs_{it} + \beta_4 Per\_GDP_{it} + \beta_5 Structure_{it} + \beta_6 Scitech_{it} + \beta_7 Scale_{it} + \beta_8 Per\_FDI_{it} + \beta_9 Fixinvest_{it} + \beta_{10} Density_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \quad \text{(Model 3)}$$

4. Empirical findings

4.1 Descriptive statistics and correlation analysis

Descriptive statistics of all variables are shown in Table 2. The mean values of GI are 4.948. Compared with GIP, the mean values of GUP are higher. Figure 3 presents the variation of the application number of different types of green patents over the years. As shown in Figure 3, the amounts of three different kinds of green patents increase steadily over years, which supports the idea that cities place an increased emphasis on GI. The mean value of EIs is only 0.154. With respect to PU, the average value is 0.259. This shows that the turnover of the party secretary only occurs in 25.9% of the cities. In terms of ERs, the mean values are higher than the median values. The results indicate that the intensity of ERs in more than half of the sample cities is higher than 3.227.

Table 2

Figure 3

The correlation matrix of all variables is shown in Table 3. For GI, GIP and GUP, any 2 of these 3 variables are correlated significantly and positively. However, EIs are negatively correlated with GI. EIs are also negatively correlated with GIP and GUP. Besides, PU correlates with GI, GIP, and GUP negatively and insignificantly, while PU correlates with EIs positively and statistically insignificantly. MD is negatively correlated with EIs, but MD is positively correlated with GI. The correlation between ERs and GI is positively negative, but the correlation between ERs and EIs turns out to be significantly positive. To examine the threat of multicollinearity, we also test the values of variance inflation factors (VIF). The highest values and the average values of VIF do not exceed 10. Hence, multicollinearity is not a problem in this study.

Table 3

4.2 The impact of environmental investments on green innovation

The results of the impact of EIs on GI are shown in Table 4. The overall impact of EIs on GI is significantly positive (β=0.2221, p< 0.01). In terms of GIP, EIs can also exert a significant and positive effect (β=0.2438, p< 0.01). The impact of EIs on GUP also presents similar results (β=0. 2354, p< 0.05). In sum, EIs can foster GI, GIP and GUP. Thus, H1 is supported.

Table 4

It is possible that some time is needed to see the influence of EIs on GI. Hence, we also examine the dynamic effect of EIs on GI. We incorporated one-year lagged and two-year lagged EIs into regression models and conduct the analysis separately. Relevant results are presented in Table 5. For GI, both one-year lagged and two-year lagged EIs can exert positive effect, but the positive effect shifts from significant to neutral (β=0.0555, p=n.s.; β=0.0241, p=n.s.). With respect to GIP and GUP, the results are similar. The positive effect still exists, but the coefficients and significance levels also fall. Taken together, we can find that EIs can stimulate GI significantly only in the current year, and the positive effect becomes weak in the following years.

Table 5

Table 5 The dynamic effect of EIs on GI

Variable	One-year lag			Two-year lag		
	GI_{t+1}	GIP_{t+1}	GUP_{t+1}	GI_{t+2}	GIP_{t+2}	GUP_{t+2}
EIs	0.0555	0.1434	0.0049	0.0241	0.1329	-0.0063
	(0.660)	(1.267)	(0.059)	(0.269)	(1.077)	(-0.071)
Per_GDP	0.1669	0.0777	0.2252	0.2469	0.1788	0.3144*
	(0.945)	(0.383)	(1.291)	(1.493)	(0.920)	(1.930)
Structure	0.0059	0.0066	0.0014	0.0091	0.0096	0.0030
	(1.039)	(1.049)	(0.228)	(1.519)	(1.523)	(0.450)
Scitech	15.9943***	15.8658***	15.7211***	12.5247***	12.1339***	10.8391***
	(5.206)	(4.943)	(4.729)	(4.652)	(4.223)	(3.335)
Scale	0.0022	0.0214	-0.0534*	-0.0336	-0.0142	-0.0772*
	(0.082)	(0.629)	(-1.805)	(-1.237)	(-0.417)	(-1.853)
Per_FDI	-0.0001	-0.0001	-0.0000	-0.0000	-0.0000	0.0000
	(-0.729)	(-0.899)	(-0.227)	(-0.094)	(-0.032)	(0.175)
Fixinvest	0.0837	0.0393	0.0882	0.0604	0.1194	-0.0813
	(0.412)	(0.160)	(0.449)	(0.312)	(0.494)	(-0.443)
Density	-0.0004	-0.0004	-0.0003	-0.0003	-0.0004*	-0.0001
	(-1.555)	(-1.620)	(-1.208)	(-1.279)	(-1.796)	(-0.535)
_cons	1.7562	1.6090	0.9615	1.1354	0.8641	0.2715
	(1.027)	(0.805)	(0.595)	(0.722)	(0.457)	(0.184)
City Fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1240	1240	1240	1145	1145	1145
Adj. R^2	0.9045	0.8600	0.8888	0.8921	0.8463	0.8728

Note: T-statistics are in parentheses, **p* < 0.1, ***p* < 0.05, ****p* < 0.01.

4.3 Influence of political uncertainty

As previously mentioned, PU may impede the positive impact of EIs on GI. To verify this hypothesis, the whole research sample is divided into two groups by whether PU exists in a city. Table 6 displays the relevant results. If no PU exists, the impact of EIs on GI remains positive and significant (β=0.1994, p<0.05). However, if PU exists, the positive impact of EIs on GI turns out to be statistically insignificant (β=0.1201, p=n.s.). With respect to the impact of EIs on GIP, EIs can also have a positive impact if there is no PU (β=0.2500, p<0.05), whereas the impact of EIs on GIP becomes statistically insignificant if PU exists (β=-0.0210, p=n.s.). The results of the impact of EIs on GUP are similar to the impact of EIs on GI. If there is no political turnover, the impact of EIs on GUP is significantly positive (β=0.2072, p<0.05); if there is a turnover of local officials, the impact of EIs on GUP is also statistically insignificant (β=0.1685, p=n.s.). In sum, we can conclude that the positive impact of EIs on GI can be weakened if PU exists in a city. Hence, H2 is also supported.

****Table 6****

4.4 Influence of marketization degree

Unlike PU that increases uncertainty, marketization degree is an institutional factor that helps to reduce uncertainty. Hence, we also take marketization degree into account and examine whether the impact of EIs on GI varies with the degree of marketization. Relevant results are displayed in Table 7. The effect of interaction term (EIs*MD) on GI is statistically insignificant (β=-0.0843, p=n.s.). It supports that marketization degree does not exert a moderating effect on the link between EIs and GI. H3 is not supported. For the link between EIs and GIP, marketization degree cannot play a moderating effect as well (β=-0.1431, p=n.s.). The results of the moderating effect of marketization degree on the link between EIs and GIP are also similar (β=-0.0479, p=n.s.). Taken together, marketization degree cannot exert a pronounced effect on shaping the association between EIs and GI.

****Table 7****

(I included the table in the main text for your reference)

Variable	(1) GI	(2) GIP	(3) GUP
EIs	0.7691*	1.1727**	0.5469
	(1.919)	(2.122)	(1.539)
MD	0.0672*	0.1033**	0.0251
	(1.673)	(2.065)	(0.641)
EIs*MD	-0.0843	-0.1431	-0.0479
	(-1.316)	(-1.644)	(-0.831)
Per_GDP	0.0832	0.0787	0.1350

	(0.469)	(0.394)	(0.725)
Structure	0.0010	-0.0024	-0.0005
	(0.168)	(-0.360)	(-0.079)
Scitech	18.5611***	19.2731***	17.4164***
	(5.889)	(5.689)	(5.175)
Scale	0.0105	0.0183	-0.0388
	(0.404)	(0.510)	(-1.199)
Per_FDI	-0.0002*	-0.0003*	-0.0001
	(-1.826)	(-1.741)	(-0.877)
Fixinvest	0.1623	0.0480	0.1945
	(0.969)	(0.227)	(1.235)
Density	-0.0003	-0.0005	-0.0002
	(-1.237)	(-1.628)	(-0.854)
_cons	2.1252	1.2299	1.4559
	(1.277)	(0.648)	(0.867)
City Fixed-effect	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes
N	1,370	1,370	1,370
Adj-R^2	0.911	0.866	0.894

4.5 Influence of environmental regulations

We also consider ERs that help to reduce uncertainty and examine whether the effect of EIs on GI varies under different intensities of ERs. Relevant results are shown in Table 8. Though the main effect disappears after incorporating the interaction term, the interaction term (EIs*ERs) can play a significant positive role in GI (β=0.0352, p<0.1). Hence, ERs can positively moderate the association between EIs and GI. H4 is confirmed. The moderating effect of ERs on the link between EIs and GIP has also been confirmed (β=0.0566, p<0.05). However, the moderating role that ERs plays on the link between EIs and GUP is not supported (β=0.0301, p=n.s.).

****Table 8****

Variable	(1) GI	(2) GIP	(3) GUP
EIs	0.0140	0.1349	0.0303
	(0.097)	(0.703)	(0.206)
ERs	0.0095	0.0175	0.0029

	(1.026)	(1.414)	(0.305)
EIs*ERs	0.0352*	0.0566**	0.0301
	(1.827)	(2.193)	(1.520)
Per_GDP	0.1082	0.1094	0.1667*
	(1.167)	(0.881)	(1.752)
Structure	0.0011	-0.0024	0.0008
	(0.325)	(-0.541)	(0.238)
Scitech	18.7940***	19.5999***	17.5891***
	(13.335)	(10.389)	(12.155)
Scale	0.0023	0.0048	-0.0410***
	(0.160)	(0.248)	(-2.765)
Per_FDI	-0.0002**	-0.0002**	-0.0001
	(-2.493)	(-2.309)	(-1.248)
Fixinvest	0.1756**	0.0610	0.2123**
	(1.973)	(0.512)	(2.323)
Density	-0.0003**	-0.0005**	-0.0002
	(-2.318)	(-2.428)	(-1.509)
_cons	2.3353***	1.6635	1.2184
	(2.740)	(1.458)	(1.393)
City Fixed-effect	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes
N	1,370	1,370	1,370
Adj-R^2	0.904	0.854	0.885

4.6 Robustness checks

We are aware that our study may suffer from the threat of endogeneity problems due to omitted variables and reverse causality. Hence, we also use several methods to address the potential endogeneity problems.

4.6.1 Incorporate province-year fixed effects

In the main analysis, we controlled for both city and year fixed effects. Using a two-way fixed effects model can help to mitigate the endogeneity problem resulting from some unobservable city-level characteristics and year-specific heterogeneity to some extent (Quan, Ke, Qian, & Zhang, 2021). However, the two-fixed effects model may still fail to control some policies or other influencing factors that change over time in each province, because each province may issue different policies to encourage GI activities in different years.

Following Z. Chen, Zhang, & Chen (2021) and L. Wang, Dai, & Kong (2021), we also incorporate province × year fixed effects to further control for all time-invariant and time-varying provincial characteristics. The results are shown in column (1) of Table 9. Note that only 1277 observations are left in our analysis, because 93 singleton observations have been dropped. The results are similar to our main estimation, thereby further consolidating the refinement of the causality.

****Table 9****

4.6.2 Propensity score matching design

Cities with higher EIs may have fundamentally different characteristics from cities with lower EIs. These city-level differences may also affect GI activities through channels other than EIs. To mitigate the endogeneity bias associated with differences in observed characteristics between cities with high EIs and cities with low EIs, we also leverage the propensity score matching (PSM) technique (Gao, Xu, Li, & Xing, 2021). We construct a dummy variable (*EIs_dummy*), which equals 1 if EIs in a city are higher than the samples' median, and 0 otherwise. Hence, the whole sample is divided into the treatment group (EIs_dummy=1) and the control group (EIs_dummy=0). We first adopt the Logit model to estimate the propensity scores. The covariate variables used in the Logit model are the same as the control variables included in Model 1. In the second step, we perform nearest-neighbor matching with a replacement procedure to match a treatment observation with a control observation on the basis of the propensity scores. Using the matched sample (1150 observations left), we conduct the regression again. The results are in column (2) of Table 9. The results are consistent with the main findings.

4.6.3 Placebo test

Following La Ferrara, Chong, & Duryea (2012) and L. Wang et al. (2021), we also conduct a placebo test to increase the credibility of our study. We construct a "false" EIs variable (*Placebo_EIs*) by assigning pseudo-EIs to each city randomly. We then reconduct our main regression by replacing EIs with Placebo_EIs and restore the estimated coefficients. We repeat this exercise 500 times. No causal effect is found between Placebo_EIs and GI. Moreover, the density of the estimated coefficient on Placebo_EIs (shown in Figure 4) is centered around 0 (Mean = 0.0021, S.D. = 0.0470). We also add a vertical line to show the real effect of EIs on GI in Figure 4. The real effect is obviously stronger than the estimated effect via the placebo test, thereby confirming that EIs can promote GI. Taken together, the empirical results can mitigate the concern of endogeneity and confirm that the increase in GI is mainly driven by EIs rather than some unobserved factors.

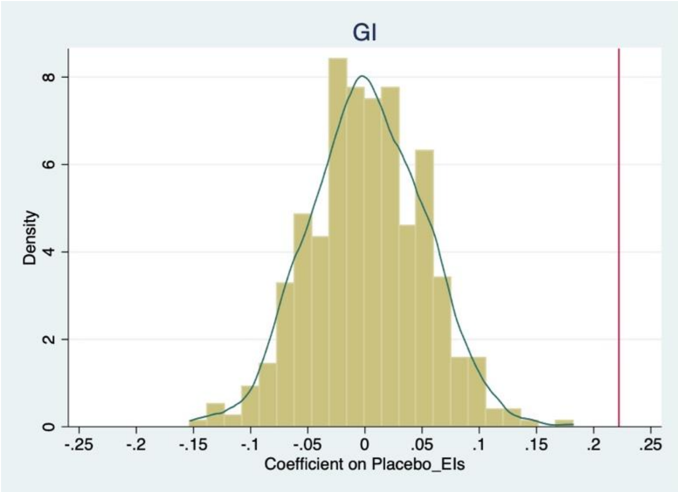

Figure 4 Distribution of the estimated coefficient on Placebo_EIs

4.6.4 Alternative measure of environmental investments

To overcome the potential measurement errors, we use an alternative measure of EIs. We use the natural logarithm of one plus total EIs directly to replace the aforementioned measurement of EI. The results are reported in column (3) of Table 9. The results confirm that EIs can spur GI.

4.6.5 Alternative proxy for green innovation

In addition to the measurement of GI used above, we also use an alternative measure of GI to verify our results. Following Cai et al. (2020), we use the ratio of the application number of green patents to the application number of total green patents by a city in a given year. Given that the value of the alternative measurement of GI ranges from 0 to 1, we use the Tobit model instead to perform the analyses again. The results are reported in column (4) of Table 9, indicating that EI can benefit GI.

4.6.6 Changing the research sample

There are 4 municipalities (Beijing, Tianjin, Shanghai and Chongqing) in China now. These 4 municipalities are also regarded as provinces rather than cities as they directly report to the central government (Deng et al., 2019; W. Luo & Zhang, 2020). Hence, we also exclude the observations of these 4 municipalities. 56 observations have been dropped, and we then conduct the analysis again. The results are shown in column (5) of Table 9 and again confirm our main findings.

Table 9 Robustness tests

Variable	(1)	(2)	(3)	(4)	(5)
	Add province-year fixed effects	PSM	Replacing EI	Replacing GI	Replacing Sample
EIs	0.2211***	0.2756***	0.0322**	0.0457***	0.2261***

	(3.201)	(3.173)	(2.445)	(5.231)	(2.722)
Per_GDP	-0.3114**	0.1306	0.1018	-0.0044	0.0114
	(-2.543)	(0.666)	(0.595)	(-0.578)	(0.065)
Structure	-0.0017	0.0007	0.0006	-0.0012***	0.0017
	(-0.332)	(0.108)	(0.108)	(-3.681)	(0.283)
Scitech	6.9759***	21.0688***	19.1457***	0.1962	19.5540***
	(3.593)	(5.878)	(5.832)	(1.014)	(5.697)
Scale	0.0066	0.0230	0.0023	0.0039**	0.0158
	(0.421)	(0.839)	(0.090)	(2.205)	(0.627)
Per_FDI	0.0002*	-0.0002*	-0.0002	-0.0000	-0.0001
	(1.676)	(-1.715)	(-1.442)	(-0.787)	(-0.656)
Fixinvest	-0.0564	0.0936	0.1716	0.0026	0.0676
	(-0.431)	(0.565)	(0.980)	(0.217)	(0.429)
Density	-0.0002	-0.0003	-0.0003	-0.0000	-0.0005
	(-1.344)	(-0.479)	(-1.054)	(-0.607)	(-1.434)
_cons	8.1382***	2.0078	2.1007	0.2875***	3.1633*
	(6.739)	(1.050)	(1.249)	(4.279)	(1.853)
City Fixed-effect	Yes	Yes	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes	Yes	Yes
N	1277	1150	1370	1370	1314
Adj-R^2/Chi^2	0.9718	0.9115	0.9107	177.48	0.9127

Note: T-statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

5. Discussion

Given the great importance of GI for achieving a win-win situation between the environment and the economy, our results highlight the importance of increasing EIs. The increase in EIs can provide significant incentives for GI. Our results also help to provide deeper insights into the understanding of the RBV. The RBV suggests that firms can gain sustainable competitive advantage through continuously accumulated VRIN resources and capabilities. In addition to gaining sustainable competitive advantage, the continuously accumulated VRIN resources and capabilities via the increase in EIs can also benefit GI.

Our results of dynamic test indicate the promotion effect of EIs on GI still exists, but the significant level falls gradually in the following two years. Our findings may be contradictory with some previous studies, which find it takes some time to see the effect of the antecedents on GI (Yuan & Xiang, 2017; Zhao & Sun, 2016). The reason may be that we use the application number of green patents rather than the authorized number of green patents to measure GI in this study. Generally, it needs some time to obtain authorized green patents, the applications for green patents can respond to EIs quickly, hence, we may not see a positive effect of EIs on GI in the following two years.

In addition, this study can advance our knowledge on the nature of the focal link, as our results show that the link between EIs and GI is contingent on the factors that increase or reduce uncertainty. PU, as the factor that increases uncertainty, can weaken the promotion effect of EIs on GI. In contrast, as an institutional factor that reduces uncertainty, ERs can strengthen the positive impact of EIs on GI. More specifically, ERs can strengthen the positive effect of EIs on GIP, but cannot strengthen the positive influence of EIs on GUP. The results suggest ERs are only effective in improving the positive effect of EI on higher quality innovation (GIP). The lower quality innovation is not affected by ERs.

Surprisingly, the degree of marketization cannot moderate the link between EIs and GI. The possible reason may be that marketization degree is a broader concept that contains many elements and is measured from many aspects (X. Wang et al., 2019). Hence, marketization degree is likely to affect firms' behaviors in many aspects (Hitt & Xu, 2016; Meyer et al., 2009), but not directly affect EIs. Combining these results, in an attempt to alleviate the negative influence of PU arising from the turnover of local officials, increasing the intensity of ERs can be more effective than enhancing the degree of marketization.

These moderating findings can also help us to understand the RBV deeply from another perspective. Kraaijenbrink et al. (2010) claim that the RBV can only be applied in stable and predictable environments. This argument has been partly confirmed as the effect of EIs on GI becomes neutral when PU exists in a region. However, even in highly stable and predictable environments, the positive effect of EIs on GI can only vary with different intensities of ERs, but not vary with different degrees of marketization. Hence, whether the RBV can hold or not is also shaped by the specific institutional context.

5.1 Policy implications

Our findings are not only valuable for managers and policy makers, but also valuable for similar developing countries. Given the crucial role that GI plays in enabling the win-win scenario between the economy and the environment, we highlight the importance of increasing EIs. For local governments and firms, the more investments in EIs, the more positive outcomes in GI. Besides, given that PU can weaken the positive effect of EIs on GI, it is important for local governments to find mechanisms to avoid the adverse effect caused by PU. New local officials should understand the development policies and the advantages of the city in advance, further maintain the continuity and stability of various policies and avoid changing the development policies frequently. New local officials should also try to minimize the adverse effect caused by the turnover at an early stage. Last, as the high intensity of ERs can strengthen the positive effect of EIs on GI, local governments should also implement ERs strictly. A city with stricter enforcement of ERs can not only force firms to increase EIs, but also alleviate the negative impact of PU, which can ultimately be beneficial for GI.

6. Conclusions

Using a sample of 104 environmental key cities in China over the period of 2003 to 2016, we first examine whether EIs can have a direct influence on GI in this study. We further incorporate the factors that increase or reduce uncertainty into the research framework and investigate the heterogenous effects of EIs on GI from different perspectives. This study finds that EIs can positively promote GI. EIs can also stimulate two different kinds of GI (GIP and GUI). From the dynamic perspective, EI can have a significant and positive influence on GI in the current year, but the positive effect becomes insignificant in the following years. Besides, PU, as a factor that increases uncertainty, can weaken the positive effect of EIs on GI. EIs are found to be more significant to GI in cities with no PU. Furthermore, the link between EIs and GI does not vary with different degrees of marketization, while the association between EIs and GI varies with the intensity of ERs. Compared with marketization degree, ERs can reduce uncertainty and have a pronounced effect on the association between EIs and GI.

Our study makes contributions to both the literature and practice. From a theoretical perspective, this study contributes to the literature by incorporating the factors that increase or reduce uncertainty into the research framework and exploring the effects of these factors on the link between EIs and GI. The empirical results are also helpful for advancing the understanding of the RBV. From a practical perspective, studying the impact of various factors that increase or reduce uncertainty on EIs and GI can yield valuable new knowledge in helping to support GI. Besides, this study focuses on a developing country context (China), and the results can be applied to similar developing countries.

Despite the contributions mentioned above, avenues for future study remain. First, this study only spans from 2003 to 2016, because of the availability of data. Future studies can extend the research period when the newest data are available. Second, our unit of analysis is a city. Future research can also examine the impact of EIs on GI at the firm-level to further confirm whether our results are robust. Last, the turnover of the party secretary is a special institutional arrangement in China (L. Wang et al., 2019). We use this special setting to capture PU in our study; hence, future studies can also use other proxies for PU under different institutional settings to confirm the robustness of our results.

Acknowledgement:

This research was funded by China Postdoctoral Science Foundation (No. 2021M691599) and Postdoctoral Research Foundation of Jiangsu Province (No. 2021K452C).

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Table 1 The measurements of all variables

Variable	Name	Measurement
Green innovation	GI	= Log (1+ the application number of green patents)
Green patent innovation	GIP	= Log (1+ the application number of green invention patents)
Green utility innovation	GUP	= Log (1+ the application number of green utility patents)
Environmental investments	EIs	= The amounts of environmental investments / Industrial output value*100%

Political uncertainty	PU	Categorical variable; if the turnover of party secretary occurs in the first half of year, PU =1 in current year; if the turnover happens in the second half of year, PU=0 in current year but PU=1 in the following year
Institutional environment	InsE	=Marketization index scores
Environmental regulations	ERs	=Using comprehensive index method to gather different environmental pollutants
Per capita GDP	Per_GDP	= Per capita GDP
Industrial structure	Structure	= GDP of the secondary industry / Total GDP
Science and Technology expenditure	Scitech	= Fiscal expenditure on science and technology / General fiscal expenditure
Industrial scale	Scale	= Industrial output value / The number of industrial firms
Per capita FDI	Per_FDI	= Per capita FDI
Fixed-asset investments	Fixinvest	= Fixed-asset investments / GDP
Population density	Density	= Population per square kilometer

Table 2 Descriptive statistics of all variables

Variable	N	Mean	SD	Median	Min	Max
GI	1370	4.948	1.726	4.871	1.386	8.931
GIP	1370	4.114	1.852	3.998	0	8.375
GUP	1370	4.343	1.633	4.284	0.693	8.053

EIs	1370	0.154	0.191	0.085	0.001	1.090
PU	1370	0.255	0.436	0	0	1
MD	1370	7.55	1.697	7.515	3.739	10.760
ERs	1370	4.394	3.825	3.227	0.285	20.28
Per_GDP	1370	10.42	0.711	10.47	8.757	11.81
Structure	1370	50.31	9.113	50.65	24.31	80.34
Scitech	1370	0.015	0.014	0.011	0.001	0.069
Scale	1370	2.332	1.683	1.887	0.435	12.48
Per_FDI	1370	232.4	336.1	92.74	0.428	1761
Fixinvest	1370	0.600	0.218	0.581	0.211	1.174
Density	1370	541.3	376.0	510.4	49.66	2348

Table 3 Correlation analysis of all variables

Variable	GI	GIP	GUP	EIs	PU	MD	ERs	Per_GDP	Structure	Scitech	Scale	Per_FDI	Fixinvest	Density
GI	1													
GIP	0.985***	1												
GUP	0.987***	0.949***	1											
EIs	-0.421***	-0.407***	-0.419***	1										
PU	-0.016	-0.024	-0.009	0.014	1									
MD	0.560***	0.527***	0.575***	-0.332***	-0.025	1								
ERs	-0.585***	-0.562***	-0.588***	0.418***	0.0290	-0.508***	1							
Per_GDP	0.786***	0.775***	0.777***	-0.351***	-0.027	0.548***	-0.473***	1						
Structure	-0.217***	-0.238***	-0.194***	0.043	0.011	-0.001	-0.146***	0.068**	1					
Scitech	0.708***	0.699***	0.703***	-0.330***	-0.004	0.538***	-0.415***	0.676***	-0.046*	1				
Scale	0.295***	0.312***	0.264***	-0.083***	-0.001	-0.0250	-0.104***	0.546***	0.141***	0.224***	1			
Per_FDI	0.602***	0.595***	0.599***	-0.268***	-0.017	0.486***	-0.412***	0.622***	-0.042	0.636***	0.160***	1		
Fixinvest	0.234***	0.238***	0.217***	-0.154***	-0.020	-0.017	-0.019	0.298***	0.084***	0.082***	0.390***	-0.055**	1	
Density	0.448***	0.426***	0.459***	-0.277***	-0.008	0.507***	-0.470***	0.268***	-0.024	0.383***	-0.091***	0.395***	-0.177***	1

Note: *p < 0.1, **p < 0.05, ***p < 0.01.

Table 4 The impact of EIs on GI

Variable	GI	GIP	GUP
EIs	0.2221***	0.2438***	0.2354**
	(2.706)	(2.634)	(2.587)
Per_GDP	0.1227	0.1388	0.1489
	(0.706)	(0.702)	(0.818)
Structure	0.0012	-0.0019	-0.0004
	(0.212)	(-0.299)	(-0.060)
Scitech	19.0288***	20.0126***	17.6153***
	(5.833)	(5.558)	(5.181)
Scale	0.0045	0.0088	-0.0414
	(0.174)	(0.247)	(-1.316)
Per_FDI	-0.0002	-0.0002	-0.0001
	(-1.545)	(-1.489)	(-0.748)
Fixinvest	0.1797	0.0715	0.1970
	(1.032)	(0.329)	(1.215)
Density	-0.0003	-0.0004	-0.0002
	(-1.192)	(-1.560)	(-0.841)
_cons	2.1304	1.2472	1.4694
	(1.274)	(0.650)	(0.873)
City Fixed-effect	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes
N	1370	1370	1370
Adj-R^2	0.9109	0.8652	0.8938

Note: T-statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 5 The dynamic effect of EIs on GI

Variable	One-year lag			Two-year lag		
	GI_{t+1}	GIP_{t+1}	GUP_{t+1}	GI_{t+2}	GIP_{t+2}	GUP_{t+2}
EIs	0.0555	0.1434	0.0049	0.0241	0.1329	-0.0063
	(0.660)	(1.267)	(0.059)	(0.269)	(1.077)	(-0.071)
Per_GDP	0.1669	0.0777	0.2252	0.2469	0.1788	0.3144*
	(0.945)	(0.383)	(1.291)	(1.493)	(0.920)	(1.930)
Structure	0.0059	0.0066	0.0014	0.0091	0.0096	0.0030
	(1.039)	(1.049)	(0.228)	(1.519)	(1.523)	(0.450)
Scitech	15.9943***	15.8658***	15.7211***	12.5247***	12.1339***	10.8391***
	(5.206)	(4.943)	(4.729)	(4.652)	(4.223)	(3.335)
Scale	0.0022	0.0214	-0.0534*	-0.0336	-0.0142	-0.0772*
	(0.082)	(0.629)	(-1.805)	(-1.237)	(-0.417)	(-1.853)
Per_FDI	-0.0001	-0.0001	-0.0000	-0.0000	-0.0000	0.0000
	(-0.729)	(-0.899)	(-0.227)	(-0.094)	(-0.032)	(0.175)
Fixinvest	0.0837	0.0393	0.0882	0.0604	0.1194	-0.0813
	(0.412)	(0.160)	(0.449)	(0.312)	(0.494)	(-0.443)
Density	-0.0004	-0.0004	-0.0003	-0.0003	-0.0004*	-0.0001
	(-1.555)	(-1.620)	(-1.208)	(-1.279)	(-1.796)	(-0.535)
_cons	1.7562	1.6090	0.9615	1.1354	0.8641	0.2715
	(1.027)	(0.805)	(0.595)	(0.722)	(0.457)	(0.184)
City Fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1240	1240	1240	1145	1145	1145
Adj. R^2	0.9045	0.8600	0.8888	0.8921	0.8463	0.8728

Note: T-statistics are in parentheses, $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

Table 6 Influence of political uncertainty

Variable	GI		GIP		GUP	
	PU=1	PU=0	PU=1	PU=0	PU=1	PU=0
EIs	0.1201	0.1994**	-0.0407	0.2500**	0.1685	0.2072**
	(0.747)	(2.090)	(-0.213)	(2.260)	(0.974)	(2.006)
Per_GDP	0.2389	0.0803	0.3774	0.0697	0.1272	0.1199
	(0.844)	(0.454)	(1.230)	(0.334)	(0.443)	(0.635)
Structure	0.0008	0.0012	-0.0020	-0.0015	-0.0020	0.0003
	(0.085)	(0.197)	(-0.173)	(-0.219)	(-0.198)	(0.052)
Scitech	22.1031***	18.9260***	25.7871***	19.7223***	17.6699***	17.7982***
	(4.720)	(5.376)	(4.486)	(5.112)	(3.918)	(4.990)
Scale	0.0200	0.0028	0.0564	-0.0040	-0.0514	-0.0288
	(0.546)	(0.109)	(1.325)	(-0.110)	(-1.148)	(-0.932)
Per_FDI	-0.0002	-0.0002	-0.0001	-0.0002	-0.0003	-0.0001
	(-1.185)	(-1.487)	(-0.572)	(-1.603)	(-1.404)	(-0.436)
Fixinvest	-0.0465	0.1779	-0.2087	0.0813	0.0436	0.1664
	(-0.154)	(0.915)	(-0.599)	(0.342)	(0.152)	(0.913)
Density	-0.0007*	-0.0003	-0.0012***	-0.0004	-0.0005	-0.0002
	(-1.778)	(-1.186)	(-2.865)	(-1.501)	(-1.133)	(-0.803)
_cons	1.3364	2.5545	-0.5515	1.9042	1.9733	1.7175
	(0.520)	(1.492)	(-0.195)	(0.949)	(0.771)	(0.982)
City Fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
N	350	1020	350	1020	350	1020
Adj-R^2	0.9164	0.9101	0.8865	0.8640	0.9007	0.8951

Note: T-statistics are in parentheses, $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Table 7 Influence of marketization degree

Variable	(1)	(2)	(3)

	GI	GIP	GUP
EIs	0.7691*	1.1727**	0.5469
	(1.919)	(2.122)	(1.539)
MD	0.0672*	0.1033**	0.0251
	(1.673)	(2.065)	(0.641)
EIs*MD	-0.0843	-0.1431	-0.0479
	(-1.316)	(-1.644)	(-0.831)
Per_GDP	0.0832	0.0787	0.1350
	(0.469)	(0.394)	(0.725)
Structure	0.0010	-0.0024	-0.0005
	(0.168)	(-0.360)	(-0.079)
Scitech	18.5611***	19.2731***	17.4164***
	(5.889)	(5.689)	(5.175)
Scale	0.0105	0.0183	-0.0388
	(0.404)	(0.510)	(-1.199)
Per_FDI	-0.0002*	-0.0003*	-0.0001
	(-1.826)	(-1.741)	(-0.877)
Fixinvest	0.1623	0.0480	0.1945
	(0.969)	(0.227)	(1.235)
Density	-0.0003	-0.0005	-0.0002
	(-1.237)	(-1.628)	(-0.854)
_cons	2.1252	1.2299	1.4559
	(1.277)	(0.648)	(0.867)
City Fixed-effect	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes
N	1,370	1,370	1,370
Adj-R^2	0.911	0.866	0.894

Note: T-statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 8 Influence of environmental regulations

Variable	(1) GI	(2) GIP	(3) GUP
EIs	0.0140	0.1349	0.0303
	(0.097)	(0.703)	(0.206)
ERs	0.0095	0.0175	0.0029
	(1.026)	(1.414)	(0.305)
EIs*ERs	0.0352*	0.0566**	0.0301
	(1.827)	(2.193)	(1.520)
Per_GDP	0.1082	0.1094	0.1667*
	(1.167)	(0.881)	(1.752)
Structure	0.0011	-0.0024	0.0008
	(0.325)	(-0.541)	(0.238)
Scitech	18.7940***	19.5999***	17.5891***
	(13.335)	(10.389)	(12.155)
Scale	0.0023	0.0048	-0.0410***
	(0.160)	(0.248)	(-2.765)
Per_FDI	-0.0002**	-0.0002**	-0.0001
	(-2.493)	(-2.309)	(-1.248)
Fixinvest	0.1756**	0.0610	0.2123**
	(1.973)	(0.512)	(2.323)
Density	-0.0003**	-0.0005**	-0.0002
	(-2.318)	(-2.428)	(-1.509)
_cons	2.3353***	1.6635	1.2184
	(2.740)	(1.458)	(1.393)
City Fixed-effect	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes
N	1,370	1,370	1,370
Adj-R^2	0.904	0.854	0.885

Note: T-statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 9 Robustness tests

Variable	(1) Add province-year fixed effects	(2) PSM	(3) Replacing EI	(4) Replacing GI	(5) Replacing Sample
EIs	0.2211***	0.2756***	0.0322**	0.0457***	0.2261***
	(3.201)	(3.173)	(2.445)	(5.231)	(2.722)
Per_GDP	-0.3114**	0.1306	0.1018	-0.0044	0.0114
	(-2.543)	(0.666)	(0.595)	(-0.578)	(0.065)
Structure	-0.0017	0.0007	0.0006	-0.0012***	0.0017
	(-0.332)	(0.108)	(0.108)	(-3.681)	(0.283)
Scitech	6.9759***	21.0688***	19.1457***	0.1962	19.5540***
	(3.593)	(5.878)	(5.832)	(1.014)	(5.697)
Scale	0.0066	0.0230	0.0023	0.0039**	0.0158
	(0.421)	(0.839)	(0.090)	(2.205)	(0.627)
Per_FDI	0.0002*	-0.0002*	-0.0002	-0.0000	-0.0001
	(1.676)	(-1.715)	(-1.442)	(-0.787)	(-0.656)
Fixinvest	-0.0564	0.0936	0.1716	0.0026	0.0676
	(-0.431)	(0.565)	(0.980)	(0.217)	(0.429)
Density	-0.0002	-0.0003	-0.0003	-0.0000	-0.0005
	(-1.344)	(-0.479)	(-1.054)	(-0.607)	(-1.434)
_cons	8.1382***	2.0078	2.1007	0.2875***	3.1633*
	(6.739)	(1.050)	(1.249)	(4.279)	(1.853)
City Fixed-effect	Yes	Yes	Yes	Yes	Yes
Year Fixed-effect	Yes	Yes	Yes	Yes	Yes
N	1277	1150	1370	1370	1314
Adj-R^2/Chi^2	0.9718	0.9115	0.9107	177.48	0.9127

Note: T-statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.