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"Risk" or "Opportunity"? The High Sensitivity of Corporate Green Innovation to Environmental Policy Uncertainty: Evidence from China

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Abstract: China is constantly promoting green economic transformation through environmental policy adjustment. However, what impact the uncertainty brought about by environmental policy adjustment will have on corporate green innovation has become an issue worth paying attention to. Based on the option theory, this paper establishes a logical framework to explain the impact of environmental policy uncertainty on corporate green innovation through risk-taking and uses the China environmental policy uncertainty and the data of A-share listed companies for empirical tests. The findings are as follows: in the Chinese institutional context, environmental policy uncertainty enhances corporate green innovation inputs and outputs, and effectively motivates corporations to improve their green innovation levels. The findings are as follows: in the Chinese institutional context, environmental policy uncertainty is perceived by firms as an opportunity rather than a risk, enhancing corporate green innovation inputs and outputs and effectively motivating corporations to improve their green innovation levels. The mechanism test shows that environmental policy uncertainty increases the level of corporate risk taking, thus stimulating green innovation. The mediating effect of corporate risk taking is supported. The heterogeneity analysis verifies the asymmetric influence of environmental policy uncertainty on corporate green innovation. This study reveals an important link between the external institutional environment and corporate green innovation in emerging economies, and the policy implication is that governments need to facilitate the transition to a green economy through sound environmental policy adjustments.

Keywords: environmental policy uncertainty; corporate risk taking; green innovation

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1. Introduction

Since the reform and opening up, China's economic growth miracle has relied heavily on the traditional sloppy development model, but the high energy consumption and pollution of this model have also brought about a series of environmental problems, resulting in an imbalance between China's current economic development and ecological development. The Chinese government attaches great importance to this contradiction and insists on promoting the new development concept of "green" and "innovation", emphasizing that green innovation is an important transformation path for China to achieve high-quality development. However, as a typical positive externality economic activity, innovation is both high-input and high-risk and is more sensitive to external environmental risks [1], leading to serious market failures in innovation activities. Especially compared with general innovation, green innovation has an environmental value attribute besides an economic attribute, which makes the market failure in the green innovation field more serious. According to the statistical results of green innovation patents disclosed in the National Intellectual Property Database, the proportion of green patent applications in China is still low, even below 10% of the total number of patent applications. In this context, policy support is often the common choice of governments from all countries, which tends to replace the market mechanism in order to dominate corporate green innovation activities, resulting in a high correlation between corporate green innovation and macro policies. This trend is more pronounced in developing countries [2].

Focusing on the situation of China, in recent years, with its economic transformation, environmental policies have also entered a period of accelerated adjustment, gradually moving from dependent policies to autonomous policies. The adjustment and reform of environmental policies will lead to the continuous increase in uncertainty, and prompt the adjustment of economic policies in regions to pursue the balanced development of economic and ecological benefits. Accordingly, in the context of the prominent environmental policy uncertainty and the coexistence of ecological risks and opportunities, the external investment environment has undergone profound changes. As the main body of micro-economic activities, corporations will need to adopt innovative strategies in order to cope with the adjustment of environmental policy in the fluctuating changes of macro-environmental policy uncertainty. At present, the discussion on this issue still needs to be in depth.

It is worth noting that in a situation of frequent policy adjustments and growing uncertainty, corporations' own risk appetite and willingness will directly influence green innovation investments. Uncertainty has two distinct sides, with good uncertainty promoting investment and bad uncertainty discouraging it [3]. For green innovation, environmental policy uncertainty may increase the risk of investment and lead to more stringent financial constraints, but it may also present potential opportunities for future growth [4]. Therefore, corporates have more options in dealing with environmental policy uncertainty, either by taking a cautious approach to avoid the potential risks of environmental policy uncertainty by lowering their risk-taking level and postponing green innovation decisions, or by being proactive, increasing their risk-taking level and persisting in green innovation activities to seek hidden opportunities from environmental policy uncertainty. It can be inferred that corporate risk taking is an important channel through which environmental policy uncertainty affects corporate green innovation. Unfortunately, there is limited discussion on the relationship between environmental policy uncertainty, corporate risk taking, and corporate green innovation. Therefore, based on the identification of the causal relationship between environmental policy uncertainty and corporate green innovation, this paper further adds corporate risk taking into a unified research framework, which not only helps to explain corporate green innovation strategies from an external macro-environmental perspective, but also provides the necessary micro empirical evidence to promote corporate green innovation.

In view of this, this paper focuses on the unique institutional context of China and adopts Chinese A-share-listed companies from 2010–2021 as a research sample to explore the selective impact of environmental policy uncertainty on corporate green innovation through the perspective of corporate risk taking. The marginal contribution of this paper is as follows: first, the existing literature focuses on the impact of the environmental policy itself on corporate green innovation, but the fluctuation in environmental policy will also change the external institutional environment, thus affecting corporate innovation decisions. Existing studies have paid little attention to this issue. This paper explores the impact of environmental policy uncertainty on corporate green innovation from the institutional factor of macro-environmental policy adjustment, which enriches the research on driving factors of corporate green innovation. Secondly, based on the perspective of corporate risk taking, this paper constructs the transmission framework of "uncertainty—corporate risk taking—green innovation", and provides new explanations for corporate green innovation decision making from the perspective of the external environment and internal governance. Thirdly, based on the multi-dimensional heterogeneity of regions and corporations, this in-depth paper discusses the different impacts of environmental policy uncertainty on corporate green innovation under different characteristics, which is helpful to understand the differences in innovation strategy selection for different research samples, and provides practical inspiration for the government to further understand the bias of environmental policies and precise policy implementation.

2. Literature Review

As an important driving factor of corporate green innovation, environmental policy has encouraged a wide range of academic studies and drawn contradictory conclusions. The early Porter hypothesis holds that environmental policies can help corporations experience innovation benefits and competitive advantages, so they will actively seek innovation under the stimulus of environmental regulations [5]. The significant compensatory effect of environmental regulations on innovation has also been demonstrated, which can be helpful for promoting green innovation among firms [6]. At the same time, environmental policies such as government interviews have a strong administrative binding force, so firms may be motivated to undertake green innovation activities under policy pressure [7]. However, another group of scholars holds the opposite view. They argue that the validity of Porter's hypothesis depends on factors such as the characteristics of the firm, its strategic choices, and the type of environmental regulations [8]. Research has shown that environmental regulation in the UK does not generate sufficient compensatory benefits for innovation in the short term, thus discouraging firms from green innovation [9]. Similarly, within China, there is no significant correlation between corporate green innovation and China's environmental regulatory instruments, further categorizing China's environmental policy instruments into administrative orders, market incentives, and social will, with different types of environmental policies having different trigger boundary conditions for corporate green innovation [10].

On the other hand, the uncertainty of the external environment is also an influencing factor for corporate green innovation. Some studies equate firms' innovation capital investment with ordinary investment from an uncertain environment, and find that policy uncertainty can have a temporary negative impact on firms' investment and productivity, reducing innovation capital investment [11,12]. Other scholars have compared policy per se with policy uncertainty, and found that firms have a strong ability to adapt to policy per se, but that policy changes and adjustments can weaken this ability to adapt, leading to a lack of clear expectations about the future and discouraging innovation investment [13]. In addition, uncertainty about climate policy can prompt firms to choose delayed innovation strategies [14]. However, some scholars hold the opposite view, arguing that policy uncertainty encourages firms to innovate. Uncertainty is a source of corporate profitability [15]. In a stable market environment, firms have relatively equal opportunities to profit, but when there is greater uncertainty in external markets, firms may earn more excess profits by expanding their innovation [16]. For example, as uncertainty in the trade environment increases, green technology innovation investment also increases [17].

Corporate risk taking affects the causal relationship between uncertainty and corporate green innovation. Corporate risk taking reflects the propensity of corporations to pay a price in the pursuit of high profits [18]. Firstly, part of the literature shows that uncertainty shocks alter corporate risk taking behavior and reduce the level of risk taking [19], but a converging macroeconomic outlook and intense market competition decrease the negative effects [20]. Some scholars have also found that rising uncertainty creates greater incentives for risk-taking and encourages corporations to take risks [21]. Secondly, at the interface between corporate risk taking and innovation, research findings suggest that corporations with higher levels of risk taking have a greater dynamic capacity to face uncertainty [22], which can effectively increase their tolerance for risk of failure and improve their willingness to take the risk, thus insisting on expanding the green innovation investment. Thirdly, regarding the mediating effect of firm risk taking, whether firms can continue to innovate when faced with uncertainty and how much resources they are willing to invest depends on their own willingness and ability to take risks, and a higher level of risk taking can help firms buffer their risks, offset the impact of policy changes on their innovation, and ensure the smooth implementation of innovation activities [23].

In summary, regarding the driver factors, corporate green innovation is not only closely related to environmental policy, but also closely linked to external uncertainty. The extensive research has built a solid theoretical framework for this paper, but there are still the following shortcomings: first, in terms of environmental policy, some scholars usually take a particular individual environmental policy as the research object, but the frequent adjustment and overlapping of multiple environmental policies over a period of time will lead to potential endogeneity, and there is a lack of literature on the impact of environmental policy uncertainty on corporate green innovation based on continuity and overall measurement. Second, in terms of uncertainty, existing studies have analyzed corporate green innovation mainly from the perspective of economic policy uncertainty, with the implicit assumption that the external environmental policy environment for corporate is relatively stable. Actually, environmental policy uncertainty is an important component of economic and environmental policy uncertainty, so how environmental policy volatility affects corporate green innovation needs to be further investigated. Thirdly, corporate risk taking is an important prerequisite feature of corporate internal governance and plays a significant role in corporate operational decisions and risk behavior. However, recent research examining the mediating effects of corporate risk taking is only in its infancy and the literature is relatively limited. Especially in emerging economies such as China, the economic system is still highly dependent on external policies, despite a significant increase in marketization. It is this unique Chinese economic system that provides a good experimental context for identifying how corporate risk taking affects the causal relationship between environmental policy uncertainty and corporate green innovation.

3. Mechanism Analysis

When corporations face environmental policy uncertainty, they may adopt two kinds of innovative strategies. First, the adjustment changes of environmental policies will release unstable signals to the market, resulting in a more complex market business environment and making it difficult for all kinds of market players to form clear judgments about future prospects. Based on risk-aversion motivation, corporations make more cautious decisions, tend to cancel or postpone green innovation activities, and instead increase liquid asset reserves to mitigate the impact of the current environmental policy adjustments [24]. In addition, uncertainty shocks increase market noise and amplify information asymmetries between supply and demand for funds, leading financial institutions to become more sensitive to uncertainty. At this time, financial institutions also require additional risk premium compensation out of the risk-aversion motivation, which is specifically manifested as shrinking the credit scale, increasing financing costs, or additional restrictive terms and other behaviors, leading to financing difficulties for corporations. Therefore, under the risk-aversion motivation, on the one hand, the active innovation willingness of corporations is reduced by the impact of environmental policy uncertainty. On the other hand, external finance constraints passively restrict corporations from carrying out innovation activities. The negative impact of environmental policy uncertainty on corporate green innovation is called the "crowding out effect".

Secondly, from the perspective of opportunity expectations, risks and opportunities coexist in an uncertain environment, and while changes in environmental policy may blur market prospects, they may also create new profit opportunities. If a corporate can seize the innovation opportunity in the uncertain environment, it will take the competitive initiative and form a long-term market advantage. Conversely, if a corporate chooses to delay investment in green innovation in an uncertain environment in order to avoid risk, it is similar to giving up potential growth opportunities to rivals and losing the competitive initiative. Therefore, a prudent strategy of deferring innovation based on the call option is not optimal. Environmental policy uncertainty may also stimulate a sense of risk taking among corporations, encouraging them to invest more in anticipated growth options and, in particular, to seize future expansion opportunities through innovative investment strategies, thereby creating a first-mover advantage [25]. It can be argued that corporate green innovation is, to some extent, an incremental function of environmental policy uncertainty, and the ensuing competitive advantage is the "risk premium" of environmental policy uncertainty [3]. In other words, environmental policy uncertainty has an "incentive effect".

Based on the above analysis, it is inconclusive whether environmental policy uncertainty currently promotes or inhibits corporate green innovation; hence, the competitive hypothesis H1 is proposed in this paper.

Hypothesis 1a. *Controlling for other factors, environmental policy uncertainty inhibits corporate green innovation.*

Hypothesis 1b. *Controlling for other factors, environmental policy uncertainty encourages corporate green innovation.*

How firms deal with uncertainty is more important than uncertainty itself [26], implying that firms' risk taking may play an important role in the mechanisms through which environmental policy uncertainty affects firms' green innovation. Firstly, from a a resource-dependence perspective, corporate risk-taking activities are highly resource-dependent. Environmental policy uncertainty increases the external finance constraint of corporations, which in turn makes it difficult for corporations to provide sufficient support to green innovation with limited resources, thus weakening their innovation capacity. At this point, corporations with different levels of risk taking will make different strategic choices. Corporations with low levels of risk taking will take a cautious approach to avoid potential investment losses in the face of a deteriorating macro environment and may interrupt or postpone green innovation. Corporations with high risk-taking levels have a higher risk tolerance for innovation failure and a strong resource mobilization ability [23], and are willing to invest more resources in green innovation to ensure the sustainability of innovation activities.

Second, it is inferred from real options theory that environmental policy uncertainty increases the future returns of corporations waiting for information [27]. At this point, if corporate green innovation is considered a future option, then the option value of delaying green innovation is an increasing function of environmental policy uncertainty [28], and the slope decreases gradually with the increase in corporate risk taking, resulting in the waiting option caused by environmental policy uncertainty to be lower. The most extreme case is where the corporation is fully tolerant of green innovation failures, and green innovation is not affected by environmental policy uncertainty, at which point waiting for uncertainty to reduce does not bring any additional benefits and the option value is zero. In other words, the option value of green innovation is highly correlated with corporate risk taking, and the higher the level of corporate risk taking, the stronger the corporation's willingness and ability to cope with the risk of uncertainty, thus reducing the option value and encouraging the corporation to invest in current green innovation. Therefore, in the face of environmental policy uncertainty, corporations with a high level of risk taking are more likely to persist in green innovation. Accordingly, Hypothesis 2 is proposed.

Hypothesis 2. *Corporate risk taking plays a positive mediating role in the relationship between environmental policy uncertainty and corporate green innovation.*

4. Study Design

4.1. Variable Selection

4.1.1. Dependent Variables

Most existing studies measure corporate green innovation behavior in terms of innovation inputs and innovation outputs [29], with the common indicator for innovation inputs being corporate green R&D expenditure and the indicators for innovation outputs, including the number of corporate green patents, etc. [30]. In the research design of this paper, corporate green R&D expenses and the number of green patent applications in the current year are used to reflect innovation inputs and outputs, respectively.

4.1.2. Independent Variables

Many scholars have used various methods to measure environmental policy uncertainty. For example, changes in local government environmental department officials can be used to measure uncertainty in environmental policy [31]. However, official turnover is a random event, which lacks the continuity of time series and the integrity of space cross section, so the results are uncertain and have some deviation. Therefore, on the basis of the economic policy uncertainty measurement framework [32], this paper adopted the text analysis method, and takes 10 mainstream media newspapers in mainland China as news sources, including Beijing Youth Daily, Guangzhou Daily, Jiefang Daily, People's Daily (Overseas Edition), News Morning, Southern Metropolis Daily, Xinjing Daily, Tonight Daily, Wen Wei Po, and Yangcheng Evening News. Then, we calculated the reporting frequency of keywords such as "environment", "policy", and "uncertainty", in order to obtain China's environmental policy uncertainty. The key terms are summarized in Table 1.

Table 1. Keywords of environmental policy uncertainty in China.

First-Level Keywords	Second-Level Keywords
Environment	Environment/environmental/protection/environmental regulation/pollution prevention
Policy	Policy/system/strategy/measures/regulations/ordinances/politics/governance/prevention/government/political commissar/state council/people's congress/president/general secretary/state leader/premier/environmental tax/ministry of ecological and environment/environmental protection department/environmental protection bureau
Uncertainty	Uncertainty/volatility/turbulence/unstable/unknown/unclear/unpredictable/unspecified

It is important to explain that the environmental policy uncertainty measurement framework in this paper makes the following optimizations compared with the economic policy uncertainty measurement framework: first, the media coverage for the economic policy uncertainty measurement framework is sourced from the South China Morning Post in Hong Kong, and as a regional media outlet, its relatively limited social influence can hardly fully reflect the overall policy fluctuations in mainland China [33]. The environmental policy uncertainty measurement framework combines the size of mainstream policy newspapers and readership in mainland China, and redefines the sources of media coverage to more comprehensively and accurately assess environmental policy uncertainty in China. Second, the keywords for the economic policy uncertainty measurement framework mainly uses English words, which have a large deviation from the meaning of Chinese words. The environmental policy uncertainty measurement framework copes with the problem by using Chinese words as the keywords [34]. The formula for calculating environmental policy uncertainty is shown in Equation (1).

$$EPU_i = AVE\left|C_{Eij} - \frac{\mu_{ij}}{\sigma_{ij}}\right| \Big/ AVE\left|C_{Eij} \cap C_{Pij} \cap C_{Uij} - \frac{\mu_{ij}}{\sigma_{ij}}\right| \quad (1)$$

EPU_i represents environmental policy uncertainty for each month, and i, j represent the month and newspaper type, respectively. C_{Eij}, C_{Pij} and C_{Uij} denote the frequency of media coverage of keywords for "environment", "policy", and "uncertainty", respectively. $C_{Eij} \cap C_{Pij} \cap C_{Uij}$ is the frequency of simultaneous coverage of keywords "environment", "policy", and "uncertainty". μ nd σ denote the mean and standard deviation, respectively. AVE means to calculate the average value. Finally, the environmental policy uncertainty measured according to Equation (1) is a monthly indicator, and we used the arithmetic mean of environmental policy uncertainty for 12 months each year as the annual environmental policy uncertainty.

4.1.3. Mediating Variables

Existing research measures of corporate risk taking mainly include earnings fluctuation, stock return fluctuation, asset−liability ratio, and capital expenditure [18,35,36]. Because of the high volatility of the Chinese stock market, earnings volatility is widely used to measure the risk-taking level of Chinese corporations. In this paper, the volatility of the current return on assets (Roa) of corporations was used to represent the risk-taking level of corporations (Risk1). The higher the earnings volatility, the higher the risk-taking level of corporations. The calculation method is shown in Equations (2) and (3). To mitigate the impact of industry and cycle, the industry-adjusted Adj_Roa was first obtained by subtracting the industry Roa average from the current period firm Roa. The standard deviation of industry-adjusted Adj_Roa was then calculated on a rolling basis, using every three years (t, t + 1, t + 2) as an observation period. Finally, the results were multiplied by 100 to measure the level of corporate risk taking [36]. In addition, to ensure the reliability of the results, we also used the annualized stock returns as a proxy for the level of corporate risk taking (Risk2), together with the mediation effect test.

$$\text{Adj\_Roa}_{i,t} = \text{Roa}_{i,t} - \frac{1}{X}\sum_{k=1}^{X}\text{Roa}_{i,t} \tag{2}$$

$$\text{Risk1}_{i,t} = \sqrt{\frac{1}{T-1}\sum_{t=1}^{T}\left(\text{Adj\_Roa}_{i,t} - \frac{1}{T}\sum_{t=1}^{T}\text{Adj\_Roa}_{i,t}\right)^2} \mid T = 3 \tag{3}$$

4.1.4. Control Variables

Other variables that may affect enterprise green innovation were selected as the control variables in this paper. The specific variables are defined in Table 2.

Table 2. Variable definitions.

	Variable	Definition
Dependent variable	LnRD	Ln(green R&D expenses)
	LnPatents	Ln(quantity of green patent applications + 1)
Independent variable	EPU	China Environmental Policy Uncertainty
Mediating variable	Risk1	Adjusted earnings volatility of listed company
	Risk2	Annualized stock return of listed company
Control variable	LnSize	Ln(total assets)
	LnIncome	Ln(current operating income)
	Cf	Net cash flow from operating activities/total assets
	Lev	Total liabilities/total assets
	PPE	Tangible assets/total assets
	Growth	Income Growth Rate
	Top1	Shareholding ratio of the largest shareholder
	Investor	Shares held by institutional investors
	Duality	If the chairman concurrently holds the position of general manager, Duality = 1; otherwise Duality = 0
	Boardsize	Ln(number of board members)
	Indep	Number of independent directors/number of directors
	Age	Ln(the difference between the current year and the IPO year)
	Sub	Ln(government subsidies)

4.2. Variable Selection

Following the previous theoretical mechanism analysis, we constructed corresponding empirical models to test the direct relationship between EPU and corporate green innovation and the mediating effect of corporate risk taking, as shown in Equations (4)–(6); where Y is the dependent variable, including LnRD and LnPatents; EPU is the independent variable, representing the China environmental policy uncertainty; and *Risk* is the mediating variable, representing the level of corporate risk taking. *Controls* are the control variables. Then, *i* represents the individual company and *t* represents the year. Considering the possible lag of innovation effect and potential endogeneity, all dependent variables are dealt with by one lag. φ_t, φ_{ind} represent the fixed effects for the year and industry, respectively, and $\varepsilon_{i,t}$ are random error terms.

$$Y_{i,t+1} = \beta_0 + \beta_1 EPUC_{i,t} + \beta_2 Controls_{i,t} + \varphi_t + \varphi_{ind} + \varepsilon_{i,t} \quad (4)$$

$$Risk_{i,t} = \alpha_0 + \alpha_1 EPUC_{i,t} + \alpha_2 Controls_{i,t} + \varphi_t + \varphi_{ind} + \varepsilon_{i,t} \quad (5)$$

$$Y_{i,t+1} = \gamma_0 + \gamma_1 EPUC_{i,t} + \gamma_2 Risk_{i,t} + \gamma_3 Controls_{i,t} + \varphi_t + \varphi_{ind} + \varepsilon_{i,t} \quad (6)$$

4.3. Data Sources and Descriptive Statistics

This paper takes 2010–2021 Chinese A-share listed companies as the research object, and the relevant data are obtained from the CNRDS and CSMAR databases and the relevant statistical yearbooks. In the process of data processing, the following criteria were used for screening: (1) samples of listed companies in the financial industry and insurance industry were removed; (2) excluding the sample observations of listed companies in the year of IPO; (3) samples of ST, PT, and delisted listed companies were removed during the study period; (4) excluding samples of companies that had not carried out green innovation activities; and (5) excluding samples with missing relevant variables. All of the continuous variables were winsorized at the top and bottom 1% to reduce extreme value interference.

Table 3 reports the descriptive statistical characteristics of the main variables. There are large gaps between the extreme values of LnRD and LnPatents, indicating that there are large differences in the green innovation level of corporates. The mean and standard deviation of EPU were 24.902 and 18.660, indicating that the EPU in China from 2010 to 2021 fluctuated greatly. Because of the frequent adjustment of environmental policies, the maximum value (86.253) and minimum value (0.335) could also reflect this. In general, the variables selected in this paper had an obvious trend of change during the research period, which can be tested in the next step.

Table 3. Descriptive statistics of the primary variables.

Variable	Mean	Med	Min	Max	SD
LnRD	17.7777	17.7992	8.7954	23.6465	1.5470
LnPatents	3.1683	3.0910	0.6931	6.9838	1.3515
EPU	24.902	18.757	0.335	86.253	18.660
Risk1	0.0292	0.0176	0.0015	0.2179	0.0353
Risk2	0.2369	0.0592	−0.6431	2.8014	0.6569
LnSize	22.0413	21.8436	19.9513	26.0191	1.2279
LnIncome	21.4409	21.2760	18.8525	25.5190	1.3936
Cf	0.0435	0.0410	−0.1374	0.2288	0.0655
Lev	0.4174	0.4109	0.0505	0.8678	0.2010
PPE	0.9267	0.9531	0.5556	0.9989	0.0809
Growth	0.1868	0.1256	−0.4309	2.1664	0.3664
Top1	0.3484	0.3330	0.0893	0.7380	0.1449
Investor	0.4405	0.4670	0.0041	0.9098	0.2456
Duality	0.2690	0.0000	0.0000	1.0000	0.4434
Boardsize	2.1498	2.1972	1.6094	2.7081	0.1950
Indep	0.3728	0.3333	0.3333	0.5714	0.0535
Age	1.8267	1.9459	0.0000	3.1354	0.9092
Sub	16.1595	16.1750	11.3543	20.3288	1.6597

5. Empirical Analysis

5.1. Basic Regression

Table 4 shows the results of the OLS baseline regression of EPU on LnRD and LnPatents. After controlling for other factors and fixed effects, the base regression showed that the regression coefficients of EPU on LnRD and LnPatents were 0.0016 and 0.0010, respectively, both significant at the 1% confidence level, so environmental policy uncertainty could positively affect both corporate green innovation inputs and outputs and improve the level of corporate green innovation. These findings provide new empirical evidence for the real options theory, where uncertainty allows corporations greater options to grow in the present rather than waiting for the future when their opportunity anticipation motive dominates, and encourages them to expand green innovation. Therefore, the results of the basic regression validate the incentive effect of environmental policy uncertainty on corporate green innovation and support H1b.

Table 4. Benchmark regression.

	(1)	(2)
	LnRD	**Patents**
EPU	0.0016 ***	0.0010 **
	(0.0004)	(0.0004)
Controls	Yes	Yes
Year Effect	Yes	Yes
Industry Effect	Yes	Yes
R^2	0.4720	0.2935
Observations	22,757	22,757

Note: Robust standard errors in parentheses; ***, and ** indicate significance levels of 1%, and 5%, respectively.

The general public perception is that uncertainty implies high risk and creates greater resistance to corporate innovation; however, in this study, this relationship was confirmed to be positive. According to option theory and also in the context of the current economic situation in China, the green innovation incentive effect of environmental policy uncertainty is in line with reality, and such a causal relationship only proves the effectiveness of China's economic policy adjustment. At present, in order to promote green economic transformation, the Chinese government has frequently introduced a series of macro-environmental policies. As a result, media reports on environmental policies have increased significantly in recent years, and the environmental policy uncertainty has increased accordingly, reflecting the large fluctuation in economic entities' expectations of the Chinese market at this stage. Policies such as the Environmental Protection Tax Law and environmental inspections have all stimulated the Chinese corporate green innovation drive to varying degrees, proving the rationality and effectiveness of these policies. Therefore, although environmental policy adjustments inevitably lead to increased uncertainty, reasonable policy design and adjustments can help corporations to offset the negative effects of uncertainty and stimulate their green innovation activities, thus achieving the policy effect of green economic transformation.

5.2. Robustness Check

5.2.1. Instrumental Variables Method

To ensure the reliability of the baseline regression results, a series of robustness tests were conducted. Firstly, there is the issue of endogeneity. Chinese environmental policies are based on a comprehensive consideration of the overall dynamics of economic performance, and it is hard for individual corporations to exert an influence on policy formulation and adjustment through central and local governments. The reverse causality between environmental policy uncertainty and corporate green innovation is negligible. Second, in order to eliminate potential missing variables that do not change with time, this paper controlled the year and industry fixed effects at the same time, and controlled a series of control variables that affect corporate green innovation, so as to minimize the endogenous interference caused by missing variables. Third, errors in the measurement of indicators could also lead to correlation problems between variables and error terms, undermining the consistency of the parameter estimates. Based on these potential endogeneity considerations, this paper applied a one-period lag to the dependent variables in the empirical design section and used the 2SLS instrumental variables approach to verify the robustness of the results.

The instrumental variables needed to satisfy the homogeneity and relevance conditions. This paper used the environmental policy uncertainty of the previous year as an instrumental variable (IV) [37]. The reasons for this approach were as follows: the environmental policy uncertainty of the previous year was strongly correlated with the current period's environmental policy uncertainty, which influenced corporate green innovation through the current uncertainty and satisfied the instrumental variable correlation premise. In addition, the current period's corporate green innovation activities had no impact on the environmental policy uncertainty of the previous year, which satisfied the requirement of homogeneity of the instrumental variable.

Table 5 shows the test results using the 2SLS regression. In the first stage of the regression, IV and EPU were significantly positively correlated, which verified the correlation between instrumental variables and endogenous variables, and proved that the selection of instrumental variables was reasonable. Next, it can be seen from the second stage that the regression coefficients of EPU on LnRD and LnPatents were positive and passed the significance level test, indicating that EPU could indeed play a positive role in stimulating green innovation input and output of corporations. In addition, the Cragg–Donald Wald F statistic was much larger than the critical value of the 10% confidence level, suggesting that the selection of instrumental variables passed the weak instrumental variable test, which was enough to prove that the benchmark regression results were robust.

Table 5. 2SLS IV regression.

	(1)	**(2)**	**(3)**
	1st-stage EPU	2nd-stage LnRD	2nd-stage Patents
EPU		0.0028 * (0.0017)	0.0019 ** (0.0021)
IV	0.2021 *** (0.0102)		
Controls	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes
Cragg-Donald Wald F statistic		455.654	
R^2		0.5027	0.2932
Observations		22,757	

Note: Robust standard errors in parentheses; ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

5.2.2. Replace Dependent Variable

Secondly, this paper re-measured the dependent variables. We calculated the ratio of green innovation investment cost to total assets (RD1) and the ratio of green innovation investment cost to operating income (RD2) to measure the intensity of corporate green R&D investment, which was used as a proxy indicator for corporate green R&D investment. At the same time, the green patents of corporates were divided into invention patents and non-invention patents, and the indicators of the invention patents (Invention) and non-invention patents (non-Invention) were obtained again according to the calculation method of the patent indicators, replacing the original corporate innovation output indicators for regression. Table 6 shows that the coefficients of EPU on both the R&D investment intensity and patent indicators were significantly positive at the 10% significance level, which was consistent with the results of the baseline regression, indicating that the incentive effect of economic policy uncertainty on corporate green innovation still existed after the replacement of indicators.

Table 6. Regression with an alternative dependent variable.

	(1)	(2)	(3)	(4)
	RD1	RD2	Invention	non-Invention
EPU	0.0001 *	0.0001 *	0.0009 *	0.0008 *
	(0.0000)	(0.0000)	(0.0005)	(0.0005)
Controls	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes	Yes
R^2	0.1552	0.1788	0.2896	0.2165
Observations	22,757	22,757	22,757	22,757

Note: Robust standard errors in parentheses; * indicates significance levels of 10%.

5.2.3. Reset Sample

Our study covered the period of 2010–2021, while the COVID-19 outbreak in China began in early 2020. In response to the epidemic, government departments took control measures such as prolonged shutdown and production, which were regarded as the impact of exogenous events for the study samples, which may have caused bias in the regression results. Therefore, we excluded the study samples from 2020–2021 for the robustness test. Table 7 shows that the regression coefficient of EPU was still significantly positive after excluding the 2020–2021 research samples, which was not materially different from the results of basic regression, which confirmed the reliability of the conclusions in this paper.

Table 7. Regression with a reset sample.

	(1)	(2)
	LnRD	Patents
EPU	0.0013 ***	0.0010 **
	(0.0004)	(0.0004)
Controls	Yes	Yes
Year Effect	Yes	Yes
Industry Effect	Yes	Yes
R^2	0.4594	0.2806
Observations	17,626	17,626

Note: Robust standard errors in parentheses; ***, and ** indicate significance levels of 1%, and 5%, respectively.

5.3. Channels Analysis

This paper uses the Sobel and Goodman Test method to investigate the mediating effect of corporate risk taking and to measure the specific mediating effect. In Table 8, we report the regression results with Risk1 and Risk2 as the mediating variables. Columns (1)–(2) take LnRD as the dependent variable. The results show that the regression coefficient of EPU on LnRD was significantly positive, which is the same as the previous research conclusion in this paper. Then, the regression coefficients of the mediating variables for Risk1 and Risk2 are both positive numbers, and through the 1% significance level test, the level of corporate risk taking is shown to be an important factor for motivating corporations to increase green innovation investment. In the Sobel and Goodman Test results, the Sobel Z value and Goodman Z value both passed the test and were significant, proving the existence of some mediating effects, of which the mediating effect of Risk1 accounted for 9.07% and the mediating effect of Risk2 accounted for 13.51%.

Table 8. Mediating effect regression.

	(1)	(2)	(3)	(4)
	LnRD	LnRD	Patents	Patents
EPU	0.0013 **	0.0013 **	0.0007 *	0.0008 *
	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Risk1	1.1770 ***		0.6636 ***	
	(0.2453)		(0.2682)	
Risk2		0.0969 ***		0.3542 ***
		(0.0198)		(0.1447)
Controls	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes	Yes
R^2	0.5985	0.5987	0.4630	0.4635
Observations	22,757	22,757	22,757	22,757
Sobel Z	3.194 ***	3.704 ***	2.896 ***	2.917 ***
Sobel Z-*p* value	(0.0014)	(0.0002)	(0.0038)	(0.0035)
Goodman-1 Z	3.158 ***	3.677 ***	2.854 ***	2.876 ***
Goodman-1 Z-*p* value	(0.0016)	(0.0002)	(0.0043)	(0.0040)
Goodman-2 Z	3.232 ***	3.732 ***	2.940 ***	2.961 ***
Goodman-2 Z-*p* value	(0.0012)	(0.0002)	(0.0033)	(0.0031)
Mediation effect %	9.07	13.51	21.64	21.95

Note: Robust standard errors in parentheses; ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

Columns (3)–(4) use LnPatents as the dependent variable. The main test results also proved that the level of corporate risk taking had a partial mediating effect in the process of EPU affecting the transmission mechanism of the corporate green innovation output. The mediation effect of Risk1 accounted for 21.64% and the mediation effect of Risk2 accounted for 21.95%. Therefore, the Sobel and Goodman Test was sufficient to prove the existence of a positive mediating effect on corporate risk taking, that is, EPU can stimulate corporate innovation by promoting corporate risk taking, which supports the establishment of hypothesis H2. As with the "expectation of opportunity" motivation described above, increased levels of corporate risk taking can encourage corporations to invest more in green innovation and improve their innovation performance in the face of environmental policy uncertainty. From a perceived stigma perspective, a higher level of risk taking means that corporations have a stronger sense of risk taking and management, that they have a more comprehensive understanding of the meaning of risk, and that they recognize that good risk taking is a driving force for business growth. No corporate can achieve long-term benefits without taking risks. From a capability stigma perspective, a high level of risk taking is usually accompanied by a strong ability to acquire and allocate resources to provide the necessary resources to support corporate risk activities as much as possible. Thus, the increased level of corporate risk taking contributes to a corporate willingness and ability to take risks, its tendency to take advantage of risk opportunities through timely and innovative investments, and its comfort in coping with uncertainty shocks from environmental policy changes.

5.4. Heterogeneity Analysis

5.4.1. Nature of Property Rights

Table 9 presents the results of the heterogeneity tests. First, according to the nature of the controlling shareholders of the listed companies, the research sample was divided into state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). Panel A is the result of the test with the nature of property rights as the characteristic variable. We can see that in columns (1)–(2) for the LnRD test, the coefficient of EPU remained significantly positive for both the SOEs and non-SOEs subgroups, indicating that differences in the nature of property rights did not block the green innovation incentive effect of EPU. However, by comparing the coefficient values of EPU, it was found that the incentive effect of environmental policy uncertainty on green innovation R&D investment was stronger among SOEs. In the regressions of (3)–(4) on LnPatents, the results show that the coefficient values of EPU were only significant in SOEs and failed the significance test in non-SOEs, indicating that the incentive effect of environmental policy uncertainty on green innovation patent output existed only in SOEs. The results of both the LnRD and LnPatents tests reflect SOEs were more sensitive to the green innovation incentive effect of environmental policy uncertainty, effectively demonstrating the asymmetric impact of environmental policy uncertainty on corporate green innovation in terms of the nature of property rights.

Table 9. Heterogeneity regression I.

Panel A: Nature of property rights				
	LnRD		LnPatents	
	(1) SOEs	(2) non-SOEs	(3) SOEs	(4) non-SOEs
EPU	0.0019 **	0.0013 ***	0.0012 **	0.0006
	(0.0008)	(0.0004)	(0.0005)	(0.0007)
Controls	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes	Yes
R^2	0.3711	0.5263	0.2512	0.3596
Observations	9826	12,931	9826	12,931
Panel B: Industry technical attributes				
	LnRD		LnPatents	
	(1) Tech	(2) non-Tech	(3) Tech	(4) non-Tech
EPU	0.0017 ***	0.0014 ***	0.0014 ***	0.0006
	(0.0009)	(0.0005)	(0.0005)	(0.0007)
Controls	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes	Yes
R^2	0.5554	0.3918	0.2660	0.2897
Observations	8801	13,956	8801	13,956
Panel C: Finance constraint				
	LnRD		LnPatents	
	(1) High-SA	(2) Low-SA	(3) High-SA	(4) Low-SA
EPU	0.0013 ***	0.0017 ***	0.0009	0.0001
	(0.0005)	(0.0006)	(0.0006)	(0.0006)
Controls	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes	Yes
R^2	0.3948	0.3600	0.2066	0.2898
Observations	11,379	11,378	11,379	11,378

Note: Robust standard errors in parentheses; ***, and ** indicate significance levels of 1%, and 5%, respectively.

The possible explanation for this is that, according to rent-seeking and resource-based theories, although environmental policy uncertainty triggers market volatility and credit tightening, the political affiliation of SOEs can play a role in smoothing out risk and rent-seeking gains, enhancing the resource acquisition ability of SOEs. On the other hand, the green innovation behavior of SOEs may be determined by the will and interests of the government, more from social and political goals. At this time, green innovation activities will not stop due to changes in the external environment, so the green innovation of SOEs is more stable than those of non-SOEs.

5.4.2. Industry Technical Attributes

Then, we discuss the heterogeneity of industry technical attributes, and according to the technical attributes of the industry to which the corporate belongs, the listed company is divided into high-tech corporations (Tech) and non-high-tech corporations (non-Tech). We refer to the "High-Tech Industry (Manufacturing) Classification" issued by the National Bureau of Statistics of China and the "Guidelines for the Industry Classification of Listed Companies (Revised in 2012)" issued by the China Securities Regulatory Commission to determine the industry code of high-tech-listed companies, specifically including chemical raw material and chemical product manufacturing, pharmaceutical manufacturing, railway, ship, aerospace, and other transportation equipment manufacturing, computer, communication, other electronic equipment manufacturing, instrumentation manufacturing, information transmission, software, information technology service industry, scientific research, and technical service industry.

Panel B shows the results. Columns (1)–(2) use LnRD as the dependent variable, and the results show that the estimated coefficient of EPU was 0.0019 for Tech and 0.0013 for non-Tech, both of which were highly significant, reflecting that both Tech and non-Tech chose to proactively increase their level of green innovation in the face of environmental policy adjustments. However, the green innovation investment motivation of non-Tech was significantly weaker than that of Tech under environmental policy uncertainty. For the tests in columns (3)–(4) with LnPatents as the dependent variable, the EPU regression coefficient was 0.0012 and significant at the 5% level for Tech, and the EPU regression coefficient was 0.0006 and insignificant for the non-Tech, implying that environmental policy uncertainty did not have a significant impact on the green innovation output of non-Tech.

The overall results reflect that Tech was more sensitive to the positive effects of environmental policy uncertainty than non-Tech. This is because Tech was able to enjoy government subsidies and tax incentives through a series of policy support, which helped them share the risk of green innovation and reduce the marginal cost of innovation, thus motivating Tech to increase their R&D investment and green innovation activities. In addition, the speed of high-tech product iteration and market competition was more stimulating, and green innovation activities were an immediate need for Tech compared with non-Tech, thus not inhibiting green innovation in times of external volatility due to risk-averse motives. Therefore, environmental policy uncertainty had a stronger incentive for green innovation for Tech, validating the heterogeneity due to differences in the industry technical attributes.

5.4.3. Finance Constraint

Next, this paper calculated the SA index to reflect the finance constraint of corporations [38]; if the finance constraint was higher than the median, it was defined as a high finance constraint sample, and vice versa, as a low finance constraint sample. Panel C reports the results. In columns (1)–(2) for tests of LnRD, the regression coefficients of EPU for corporations with a high finance constraint was 0.0013, and the regression coefficients of EPU for corporations with a low finance constraint was 0.0017, respectively, both of which being significant at the 1% confidence level, indicating that environmental policy uncertainty had a positive green innovation promotion effect on both samples. Similarly, in the results of (3)–(4) LnPatents, the EPU regression coefficient was positive but did not pass the significance level test, and the results of the between-group coefficient difference test were not statistically significant. Thus, the above evidence only suggests that the incentive impact of environmental policy uncertainty on corporate green innovation inputs was more significant in the low finance constraint sample.

On the one hand, policy uncertainty increased market volatility, tightened credit, increased the cost and difficulty of external financing for companies, and intensified finance constraints. On the other hand, corporations tend to increase their precautionary savings and cash holdings in response to uncertainty risk shocks. These two factors together led to a lack of financial support for green innovation activities in corporations with high financial constraints. On the contrary, corporations with lower financial constraints were able to maintain sufficient financial reserves in the face of rising environmental policy uncertainty, providing strong support for green innovation.

5.4.4. Geographical Location

Finally, based on the geographical location of the corporations, the samples were distinguished into three sub-samples: eastern region, central region, and western region. Table 10 Panel A uses LnRD as the dependent variable and showed that only the EPU regression coefficient of the eastern sub-sample was significant at the 5% confidence level, reflecting that environmental policy uncertainty could create green innovation incentives for corporations in the eastern region, but not for other regions. In Panel B, using LnPatents as the dependent variable, EPU also had a significant contribution to green innovation output for the eastern sub-sample of corporations, while on the contrary, it had a significant inhibitory effect on green innovation for the western corporations. These results confirm the asymmetrical effect of environmental policy uncertainty induced by geographical heterogeneity.

Table 10. Heterogeneity regression II.

Pannel A: LnRD			
	(1) East	(2) Center	(3) West
EPU	0.0010 ** (0.0004)	0.0026 (0.0040)	−0.0062 (0.0045)
Controls	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes
R^2	0.5350	0.4284	0.5588
Observations	14,224	4456	4077
Pannel B: LnPatents			
	(1) East	(2) Center	(3) West
EPU	0.0010 ** (0.0005)	0.0059 (0.0038)	−0.0066 * (0.0038)
Controls	Yes	Yes	Yes
Fixed Effect	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes
R^2	0.2889	0.4055	0.3932
Observations	14,224	4456	4077

Note: Robust standard errors in parentheses; **, and * indicate significance levels of 5%, and 10%, respectively.

Differences in resource endowments and marketization processes have led to serious imbalances in China's regional development. Limited by geographical conditions, institutional environment, and level of economic development, corporations in the central and western regions and northeast China lack good real investment opportunities, and their poor ability to cope with economic policy adjustment and market demand change restricted corporations in these regions to grasp innovation opportunities. In addition, the poor innovation environment in the Western region means that corporates were more willing to introduce technology as a substitute for independent innovation than high-cost innovation activities, and the introduction of technology was not effective at enhancing the level of corporate green innovation. It is thus easy to explain why environmental policy uncertainty had a disincentive effect on corporate green innovation in the western region.

6. Discussion and Contributions

6.1. Contributions of Study

By examining the intersection of policy environment adjustment and firms' green innovation behavior in China, this paper explains how environmental policy uncertainty affects green innovation through the mediating mechanism of firm risk taking. Building on the existing literature, the paper makes several contributions. First, the paper combines option theory with environmental policy uncertainty to propose a new macro policy explanation for firms' innovation behavior. Second, the paper adds to the literature on the consequences of environmental policy uncertainty in the context of frequent policy adjustments in China. Third, this paper constructs an analytical framework of "uncertainty-firm risk-taking-green innovation", which provides a new perspective on the mechanism of corporate green innovation decision making.

6.2. Limitations and Future Research

There are still some shortcomings in this paper. Firstly, this paper only uses textual analysis as a measure of environmental policy uncertainty, but the audience for paper media in the internet era has shrunk significantly, so it is still necessary to improve the method and take into account the role of online social media in the future. Secondly, in the process of environmental policy uncertainty affecting corporate green innovation, there are inevitably many other factors that play different mediating roles. This paper only focusedson corporate risk taking, which is a limited perspective, and there are other factors that need to be considered in future research.

6.3. Implications for Managers and Firms

In economic practice, the conclusions of this paper provide some policy references for the government's environmental policy adjustment and micro-corporate innovation. First of all, although the government can encourage corporations to proactively respond to risks and challenges by means of environmental policy adjustment and actively carry out innovation activities, it also needs to recognize that environmental policy uncertainty is accompanied by market volatility, which may have a risk impact on other economic activities. Therefore, when the government frequently adjusts the environmental policies, it should comprehensively consider the various effects of the environmental policies themselves and the uncertainties of the environmental policies on economic development, so as to seek a balance between the adjustment of environmental policies and the stable development of the economy. Secondly, the heterogeneity analysis of this paper is instructive for environmental policy adjustment. In the process of making environmental policies, the government should pay more attention to the heterogeneity caused by the differences in property rights, industry technical attributes, financial constraints, and geographical location. The government should take further targeted measures to optimize the market environment of non-state-owned corporates, non-high-tech corporates, high finance constraint corporates, and economically backward areas, so as to promote fair participation of all types of corporations in market competition. Finally, innovation activities are individual business behaviors of corporations, which depend more on internal management decisions than on external policies. Given the important role of risk taking for green innovation in an uncertain environment, corporate management needs to be aware of the significance of active risk taking for sustainable corporate value creation, actively search for a room for corporate innovation with a keen sense of the market, make reasonable use of capital market risk investment, increase resource investment in the process of corporate green innovation, and establish their own competitive advantage.

6.4. Conclusions

As an emerging economy, China's policy adjustments provide a good institutional context for this paper to discuss policy uncertainty. Based on option theory, this paper explains the theoretical mechanism through which environmental policy uncertainty affects corporate green innovation. The paper then empirically examines the objective manifestations and transmission paths of environmental policy uncertainty affecting corporate green innovation using data on environmental policy uncertainty and A-share-listed companies in China.

The findings are as follows: First, in the context of China, environmental policy uncertainty can increase firms' awareness of opportunities and thus create a clear incentive for firms to innovate green, which is reflected in the increase in environmental policy uncertainty, which positively promotes the increase in corporate green innovation input and patent output. A series of robustness tests show that this conclusion is still reliable. Second, the incentive effect of environmental policy uncertainty on corporate green innovation partly comes from the mediating effect of corporate risk taking. Uncertainty promotes the opportunity expectation motivation of corporations and encourages corporate risk taking, thus positively promoting corporate green innovation. Thirdly, the incentive effect of environmental policy uncertainty on green innovation is significantly asymmetric depending on the nature of property rights, industry technical attributes, finance constraints, and geographical location, with the incentive effect of environmental policy uncertainty concentrated on state-owned corporates, high-tech corporates, low finance constraint corporates, and corporates in the eastern region.

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