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Economic policy uncertainty and green innovation: Evidence from China

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ABSTRACT

Frequent economic policy adjustments lead to significant increases in economic policy uncertainty (EPU). Few studies have investigated whether EPU influences corporate green innovation. Using a sample of Chinese A-share listed firms from 2005 to 2019, we find strong evidence that EPU is significantly and negatively associated with corporate green innovation. Our moderating effect analysis shows that financial constraints exacerbate the negative impact of EPU on green innovation, while government environmental subsidies can significantly mitigate the negative EPU effect. Moreover, the negative relationship between EPU and green innovation is salient in privately owned enterprises, firms with less industry competition, and firms in regions with weak intellectual property protection. This study has important implications for policymakers regarding increasing government expenditure on environmental protection and strengthening intellectual property protection to promote corporate green innovation.

1. Introduction

Firms' production and operations are under great pressure from energy conservation and environmental protection due to global environmental problems. Green innovation, also known as environmental and sustainable innovation, has long served as a critical management strategy to address environmental issues (Rennings, 2000). Corporate green innovation can create social value by conserving energy and reducing emissions and also generate economic benefits by meeting stakeholders' expectation and expanding product markets, thereby resulting in a "win–win" strategy for firms' sustainable development (Ouyang et al., 2020).

Green innovation is a long-term development strategy that consumes substantial resources and is fraught with uncertainty (Tseng et al., 2013). Therefore, various factors need to be considered when making green innovation decisions. Among these factors, the predictability of government policies and regulations is crucial in making green innovation decisions (Li et al., 2021). Economic policy uncertainty (EPU) alters the environment in which firms operate and aggravates firms' ability to predict the timing, content, and potential impact of policy implementations (Gulen and Ion, 2016). Particularly in recent years, corporations have faced significant uncertainty due to events such as Brexit and COVID-19. Therefore, the economic consequences of policy uncertainty, such as whether and how policy uncertainty affects corporate decision making, including green innovation decisions, must be investigated. This study examines the impact of EPU on corporate green innovation because EPU and green innovation have emerged as critical issues in economic research.

Although a theoretical link between EPU and corporate green innovation has been established, empirical evidence is still unclear. Based on the waiting option view of real option theory, when faced with significant uncertainty, firms will adopt a wait-and-see attitude and postpone investment in innovative projects (Wang et al., 2017) because innovation is associated with high input costs, a long investment cycle, and a high degree of irreversibility (Hsu et al., 2014). Therefore, under high uncertainty, firms may find the waiting option to be valuable. Some empirical studies have documented that high uncertainty reduces corporate innovation (Bhattacharya et al., 2017; Shankar, 2020; Xu, 2020; Cui et al., 2021). Thus, it is reasonable to anticipate that as EPU rises, firms will become more cautious about the potential risks and sunk

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costs of innovation. Therefore, EPU may raise the waiting option value of innovation activities, thereby causing firms to postpone or reduce investment in green innovation projects.

Unlike the waiting option, the growth option suggests that the value of innovation is determined by its ability to provide a good development opportunity for firms. Innovation can improve competitive advantages and increase firm value in the long run (Kulatilaka and Perotti, 1998). Waiting may reduce firms' development opportunities, thereby resulting in high waiting costs; thus, delaying innovation even during high uncertainty periods is irrational. When the growth option value is greater than the waiting option value, the increased uncertainty motivates firms to innovate (Weeds, 2002). Firms may presume that achieving sustainable development will be difficult without innovation under high EPU. In this case, firms focus on the competitive advantages provided by green innovation and may increase green innovation during high EPU periods.

Based on the two theories that explain the effect of uncertainty on innovation, this study examines the relationship between EPU and corporate green innovation. China's setting is ideal for addressing the research question. First, China is in its later stage of transition from a planned to market economy (Feng et al., 2022; Yao et al., 2020). Economic policy changes are frequent, thereby resulting in high EPU in Chinese markets (Demir and Ersan, 2017; Cheng et al., 2020; Yao et al., 2021). Second, resource and environmental constraints have become increasingly problematic in China due to lax environmental protection. Thus, green innovation is significant to China's sustainable development, wherein corporations play an important role. Finally, when compared with developed economies, emerging markets need green innovation more urgently to promote environmental protection. China's experience in green innovation is an important model for other developing economies.

Using the panel data of Chinese A-share listed firms from 2005 to 2019, we find a significantly negative relationship between EPU and corporate green innovation. Our results are robust after several checks, such as using alternative measures of EPU and green innovation, considering the long-term impact of EPU on green innovation, controlling for additional corporate governance variables, and controlling for multiple fixed effects. Employing SA index as the measure of financial constraints, we find financial constraints exacerbate the negative effect of EPU on green innovation. We also examine the moderating effect of government environmental subsidies on the relationship between EPU and green innovation and find that government environmental subsidies can significantly alleviate the negative effect of EPU on green innovation. Moreover, our heterogeneity analysis shows that EPU has a significantly negative impact on green innovation in privately owned enterprises, small-scale firms, firms with high industry competition, and firms in regions with weak intellectual property rights protection.

We make several contributions to the literature. First, our research adds to the body of knowledge regarding the relationship between EPU and corporate decision making, especially in terms of corporate environmental performance. Most previous studies have focused on the impact of EPU on corporate financial decisions, such as investment strategy (Gulen and Ion, 2016), cash holdings (Phan et al., 2019), corporate innovation (He et al., 2020), and corporate mergers and acquisitions (Sha et al., 2020). Because environmental pollution has received widespread attention in recent years, some studies have focused on EPU and carbon emissions (Jiang et al., 2019; Yu et al., 2021, 2021b), corporate social responsibility (Yuan et al., 2022), and corporate green behavior (Hou et al., 2022). However, existing research on the relationship between EPU and corporate green innovation is still very limited. Zhu et al. (2021) and Li et al. (2021) explore the moderating effect of EPU on the relationship between environmental regulation and green innovation. Our study provides empirical evidence to enhance the understanding of the relationship between EPU and corporate green innovation.

Second, our research complements the literature on the influencing factors of green innovation to some extent. Prior studies have examined whether firm characteristics, government support, stakeholders, and degree of openness affect green innovation (Rehfeld et al., 2007; Albornoz et al., 2009; Kammerer, 2009; Fiorillo et al., 2022). For example, Fiorillo et al. (2022) find that the number of equity analysts following a firm is positively related to corporate green innovation. It is argued that higher analyst coverage encourages managers to invest more in innovation, thereby adding evidence to the informational role of analysts. Some studies have tackled the connection between EPU and green innovation. According to Zhu et al. (2021), an inverted U-shaped relationship exists between environmental regulation and green innovation in Chinese high-tech enterprises. They further documented that EPU has a negative moderating effect in such a relationship. Meanwhile, Cui et al. (2021) find that EPU exposure reduces corporate innovation by increasing business risk and financial distress, thereby providing firm-level evidence of the relationship between policy uncertainty and corporate innovation. The present study investigates the influencing factors of corporate green innovation from the perspective of EPU. We find that an increase in EPU reduces corporate commitment to green innovation, thereby providing new supporting evidence for the waiting option theory.

Finally, our findings have important policy implications. We discover that financial constraints worsen during times of high EPU, whereas funding constraints significantly impede corporate green innovation. Hence, government policies, such as green credits policy and subsidies for environmental protection, will play a significant role in encouraging corporate green innovation. We provide evidence that the Chinese government reduces expenditure on environmental protection during high EPU, which significantly reduces corporate green engagement. Furthermore, the negative relationship between EPU and green innovation is stronger in areas with weak intellectual property protection. Our findings suggest that governments should focus on mitigating the financial pressures on firms and strengthening intellectual property rights protection. Our study supplements the studies on green innovation by providing evidence from an emerging economy. The evidence from China is an important reference for other developing countries.

The remainder of this study is written as follows. Section 2 reports the relevant literature and research hypotheses, and Section 3 discusses the research design. Section 4 presents the empirical results, including the baseline results, robustness checks, moderating effect analysis, and heterogeneity tests. Section 5 concludes the study.

2. Hypotheses development

EPU studies document that firms cannot accurately predict the economic policies formulated by governments, and the effects of uncertainty after policy implementation are difficult to predict (Gulen and Ion, 2016). Therefore, the uncertain timing and implementation effects of economic policies result in high decision-making costs. Firms face higher sunk costs and default risks in an uncertain environment. Green innovation has high costs, a long investment period, and a high degree of uncertainty. Firms' commitment to green innovation is highly dependent on economic policies; thus, government environmental policies affect corporate green innovation (Li et al., 2021; Hu et al., 2021). Furthermore, due to the profit maximization goal, firms may only engage in green innovation to maximize corporate profits (Peng et al., 2021).

The real option theory is extensively used to explain investment decisions when firms face uncertainty. Real options are primarily derived from firm investment and development (Myers, 1977). Similar to the characteristics of options, firm innovation projects are irreversible and highly uncertain. Therefore, the value generated by innovation projects is very important to firms. According to the real option theory, given the high cost and irreversibility of innovative investment projects, top management is likely to delay innovation projects and enjoy the value of waiting option. When firms face increased uncertainty, the waiting option value rises, and they tend to postpone investment until more information becomes available (Gulen and Ion, 2016). Based on such a theory, studies document that EPU restrains firm investment expenditure and bond issuance (Gulen and Ion, 2016; Al-Thaqeb et al., 2020) and impedes innovation and R&D investment (Bhattacharya et al., 2017; Shankar, 2020; Xu, 2020; Cui et al., 2021). When EPU rises, so do the potential business risks and profit pressures that firms face. Firms may pursue short-term gains and avoid the potential risks and losses associated with innovation projects, thereby reducing green innovation. Therefore, we propose the following hypothesis:

H1a. EPU is negatively associated with corporate green innovation.

In contrast to the waiting option theory, the growth option considers whether innovation investment can add value from the perspective of a firm's overall strategy. This view argues that delaying investment in innovation is irrational if the cost of waiting is too high. The value of an innovation project is primarily determined by whether it can improve the firm's development prospects. Under uncertain conditions, innovation can help firms build a good corporate reputation and strengthen industry competitiveness (Kulatilaka and Perotti, 1998), whereas delaying innovation investment leads to fewer opportunities for development. Furthermore, firms may choose to innovate and increase innovation investment during high uncertainty to prevent competitors from seizing the opportunity (He et al., 2020). Therefore, managers frequently make trade-offs between the benefits and costs of waiting options to consider firms' development strategies. Once the firm pays more attention to the long-term value generated by innovation projects, they will invest in innovation even during high uncertainty (Weeds, 2002).

Studies have found that green innovation can improve financial performance by establishing a positive image for firms (Amores-Salvadó et al., 2014). Firms' competitive advantage can be enhanced by investing in innovation that reduces environmental damage (Chen et al., 2006; Eiadat et al., 2008). Innovation meets the needs of stakeholders and can play an important role in stakeholder management (Barnett, 2007). Furthermore, being innovative can attract more investment (Dowell et al., 2000). Therefore, we speculate that in the context of high EPU, firms are likely to use green innovation as an important development strategy to mitigate the potential negative impact of EPU. Hence, the following hypothesis is proposed:

H1b. EPU is positively associated with corporate green innovation.

3. Research design

3.1. Sample and data

Our original sample included all Chinese A-share listed companies from 2005 to 2019. Following Liu et al. (2012), we exclude financial firms, special treatment firms, and firm-year observations with missing information. The final sample consists of 19,779 firm-year observations. Appendix A shows the sample distribution by year. We obtain data on corporate green innovation from the Chinese Research Data Services Platform (CNRDS). Meanwhile, the data of the China EPU index are obtained from Baker et al. (2016), whereas those of firm characteristics are collected from the China Stock Market and Accounting Research (CSMAR) database.

3.2. Variable construction

3.2.1. Economic policy uncertainty

Following Chan et al. (2021), we obtain the China EPU index from Baker et al. (2016) and construct the annual EPU measure by calculating the arithmetic average of monthly EPU indexes in a year. We take the natural logarithm of EPU (*lnEPU*) to keep the dimensionality of all indicators consistent. In addition to the measure developed by Baker et al. (2016), the EPU indexes developed by Davis et al. (2019) and Huang and Luk (2020) are widely used in existing studies (Sun et al., 2021). We also construct alternative measures of EPU following Davis et al. (2019) and Huang and Luk (2020) for robustness checks.

3.2.2. Green innovation

We obtain data on patent applications from the CNRDS for all A-share listed companies and compare it with the "Green List of International Patent Classification" issued by the World Intellectual Property Organization. Based on the matching results, we count the number of corporate green patents. This method is consistent with Fang et al. (2021). Following Fang et al. (2021) and Ren et al. (2021), we use the total number of green patents applied by listed companies in a year to measure the green innovation engagement of sample firms. We use the natural logarithm of one plus a firm's total number of green patent applications to measure green innovation (*Greenpat*).

3.2.3. Control variables

Following previous research, we control for the following firm characteristics that may influence corporate green innovation: (1) Firm size (*Size*): Larger firms are generally considered to have higher levels of innovation engagement and more resources for green innovation projects (Gilinsky et al., 2012); (2) Firm leverage (*Lev*): Research has shown that firms with higher financial leverage outperform in terms of environmental, social, and corporate governance (Alareeni and Hamdan, 2020); (3) Return on assets (*ROA*): Firms with strong financial performance are likely to engage in green innovation (Arena et al., 2018); (4) Cash flow from operating activities (*CFO*): Firms' operating cash flows are frequently used to fund green innovation projects (Ley et al., 2016); (5) Capital intensity (*Density*): If capital grows faster than labor, green innovation efficiency tends to be higher (Feng et al., 2018); (6) Institutional ownership (*Inst*): Because institutional investors value corporate social responsibility and corporate reputation, they encourage green innovation (Dyck et al., 2019); (7) Book-to-market ratio (*BM*): Companies with low book-to-market ratios are able to create social wealth, and their innovative consciousness is strong; (8) Board independence (*Indep*): Boards with higher independence tend to perform better oversight functions and are more inclined toward social responsibility (Jizi et al., 2012); (9) Fixed assets investment (*Fix*): When a firm purchases fixed assets, such as equipment, the costs associated with fixed assets investment can be deducted from final product sales (Yang et al., 2012); (10) Operating income growth rate (*Growth*): Firms with high growth rates are more capable of achieving corporate social responsibility (Ben-Amar et al., 2015); and (11) Per capita GDP and financial development degree (*P_gdp, Findev*): The improvement of economic and financial development provides a favorable economic environment and credit resources for enhancing corporate green innovation (Nanda and Rhodes-Kropf, 2017). Appendix B defines all variables.

3.3. Baseline model

To examine the influence of EPU on corporate green innovation, we employ the following regression for our baseline regression:

$$Greenpat_{i,t+1} = \alpha_0 + \alpha_1 lnEPU_{i,t} + \sum_k \alpha_k controls_{k,i,t} + \varepsilon_{i,t+1} \quad (1)$$

where $Greenpat_{i,t+1}$ is the natural logarithm of one plus firm *i*'s total number of green patent applications in year $t + 1$. $lnEPU_{i,t}$ is the natural logarithm of the EPU index in year *t*. All continuous variables are winsorized at the upper and lower 1% levels to migrate the influence of extreme values. To partially alleviate the endogeneity problem, we regress $Greenpat_{i,t+1}$ in year $t + 1$ on independent variables that are one-year lagged. Firm- and year-fixed effects are controlled for, and standard errors are clustered at the firm level to address the potential heterogeneity and sequence correlation problems.

Table 1
Descriptive statistics
This table reports the descriptive statistics of the main variables. The sample contains 19,779 firm-year observations from 2005 to 2019. All continuous variables are winsorized at the upper and lower 1% levels. The definitions of the variables are reported in Appendix B.

Variables	Number	Mean	Standard deviation	Minimum	First quartile	Median	Third quartile	Maximum
Greenpat	19,779	0.432	0.864	0.000	0.000	0.000	0.693	3.871
lnEPU	19,779	5.391	0.738	4.174	4.817	5.200	5.899	6.674
Size	19,779	22.229	1.327	19.298	21.312	22.073	22.971	26.253
Lev	19,779	0.471	0.208	0.059	0.312	0.474	0.623	1.007
ROA	19,779	0.038	0.067	−0.278	0.013	0.036	0.068	0.234
CFO	19,779	0.048	0.072	−0.170	0.008	0.046	0.088	0.260
Density	19,779	12.540	1.130	9.361	11.870	12.516	13.185	15.704
Inst	19,779	0.474	0.233	0.004	0.309	0.496	0.653	0.915
BM	19,779	0.635	0.249	0.116	0.441	0.640	0.835	1.146
Indep	19,779	0.372	0.053	0.286	0.333	0.333	0.412	0.571
Fix	19,779	0.227	0.165	0.002	0.097	0.197	0.324	0.703
Growth	19,779	0.075	0.314	−1.784	−0.013	0.106	0.222	0.790
P_gdp	19,779	4.613	1.687	1.437	3.081	4.691	5.959	7.033
Findev	19,779	2.082	0.247	1.612	1.901	2.056	2.322	2.358

4. Empirical results

4.1. Descriptive statistics and correlation analysis

Table 1 reports the descriptive statistics of all variables. The average value, standard deviation, and median of green innovation (*Greenpat*) are 0.432, 0.864, and 0, respectively. These values suggest that the overall performance of Chinese listed firms' green innovation is still relatively low and there are large deviations across firms. The minimum and maximum values of *lnEPU* are 4.174 and 6.674, with a standard deviation of 0.738. The results indicate that EPU fluctuates significantly in the sample period from 2005 to 2019, thereby suggesting that firms face sizable EPU. The results of control variables are generally consistent with existing literature (Amore and Bennedsen, 2016; Li et al., 2017).

The correlation coefficient matrix in Table 2 reports the results of a single factor analysis. The correlation coefficient between *lnEPU* and *Greenpat* is −0.092 and is significant at the 1% level, which indicates a negative correlation between EPU and green innovation. The correlation coefficients among all control variables are relatively low, thereby suggesting that multicollinearity is not a problem in our study.[1]

4.2. Baseline results

Table 3 shows the regression results of the baseline model. Column (1) displays the regression results without the main variable, *lnEPU*. The results in Column (2) show a significantly negative relationship between EPU and green innovation. The difference in adjusted R^2 reported in Columns (1) and (2) suggests that EPU is a significant factor influencing green innovation.

For results of control variables, we find that firm size (*Size*), profitability (*ROA*), financial leverage (*Lev*), and fixed assets investment (*Fix*) are all positively related to green innovation, which is consistent with Alareeni and Hamdan (2020), and Arena et al. (2018). In contrast, Nanda and Rhodes-Kropf (2017) find a positive relationship between per capita GDP (*P_gdp*) and green innovation. Furthermore, Guan et al. (2021) found a negative relationship between operating income growth (*Growth*) and green innovation. Our findings suggest that during high EPU, firms choose to reduce their green innovation to avoid potential losses associated with innovation projects.

Overall, the baseline regression results support *Hypothesis 1a*. Our findings are consistent with the argument that when firms face increased uncertainty, the waiting option value rises and they tend to postpone investment and wait for more information to become available (Gulen and Ion, 2016).

4.3. Robustness checks

To assess the robustness of the baseline results and address potential endogeneity, we perform a series of robustness checks, such as using alternative measures of EPU and green innovation, considering the long-term effect of EPU on green innovation, controlling for additional corporate governance variables, and including multiple fixed effects in the baseline model.

4.3.1. Using alternative measures of EPU

As the economic situation becomes complex and changeable, the uncertainty of economics environment increases, and the measure of EPU has been given more attention in academic studies. In addition to the Baker et al. (2016) index, EPU indexes developed by Davis et al. (2019) and Huang and Luk (2020) are widely used in existing studies (Sun et al., 2021). The Baker et al. (2016) index uses Hong Kong's South China Morning Post as a newspaper source to calculate the China EPU index. Huang and Luk (2020) follow Baker's newspaper-based calculation method but obtain 114 mainland newspapers to construct news retrieval. Davis et al. (2019) construct the China EPU index based on two leading mainland newspapers: *The Renmin Daily* and *The Guangming Daily*.

For robustness checks, following Davis et al. (2019) and Huang and Luk (2020), we use *lnEPU1* and *lnEPU2* as alternative measures of EPU. Table 4 shows that our baseline results are robust when employing *lnEPU1* and *lnEPU2* to proxy EPU. Additionally, the results of control variables are generally consistent with the baseline regression.

4.3.2. Using alternative measures of green innovation

To test whether our baseline results are robust to different measures of green innovation, we use the natural logarithm of one plus the number of green invention patents (*GreenInva*) and green utility model patents (*GrennUma*), which are two subtypes of green patents, as alternative dependent variables in Eq. (1). Second, following Tebaldi and Elmslie (2013) and Hall and Helmers (2013), we use the natural logarithm of one plus firm *i*'s total number of granted green patents (*GreenGran*) as the alternative measure of green innovation for robustness checks. Third, we employ the proportion of green patent applications in the firm's total patent applications in a year (*RatioPat*), green invention patents in the firm's total invention patents (*RatioInva*), and green utility model patents in the firm's total utility model patents (*RatioUma*) as additional measures to reexamine the relationship

[1] Literature indicates no multicollinearity problem when VIF is less than 10 (Hair et al., 1995; Marquardt, 1970; Mason et al., 1989). The maximum value of variance inflation factor (untabulated) in our study is 2.33, which is far below 10 (the critical value of multicollinearity). Therefore, multicollinearity is not a problem in our study.

Table 2
Correlation matrix
This table reports the Pearson correlation coefficients of the main variables. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The definitions of the variables are reported in Appendix B.

	Greenpat	lnEPU	Size	Lev	ROA	CFO	Density	Inst	BM	Indep	Fix	Growth	P_gdp	Findev
Greenpat	1													
lnEPU	−0.092***	1												
Size	0.263***	0.226***	1											
Lev	0.034***	−0.126***	0.350***	1										
ROA	0.071***	−0.024***	0.079***	−0.358***	1									
CFO	0.029***	0.019***	0.039***	−0.171***	0.353***	1								
Density	0.020***	0.026***	0.294***	0.095***	−0.067***	0.094***	1							
Inst	0.036***	−0.155***	0.378***	0.192***	0.142***	0.123***	0.132***	1						
BM	0.039***	0.041***	0.499***	0.336***	−0.186***	−0.099***	0.241***	0.166***	1					
Indep	0.022***	0.110***	0.062***	−0.021***	−0.014*	−0.024***	0.007	−0.047***	−0.032***	1				
Fix	−0.026***	−0.167***	0.019***	0.072***	−0.094***	0.245***	0.599***	0.121***	0.127***	−0.063***	1			
Growth	0.053***	−0.015**	0.100***	−0.031***	0.347***	0.096***	0.032***	0.043***	−0.001	−0.002	−0.020***	1		
P_gdp	0.126***	0.884***	0.261***	−0.163***	−0.012*	−0.011	0.027***	−0.192***	−0.033***	0.133***	−0.194***	−0.003	1	
Findev	0.134***	0.812***	0.263***	−0.162***	−0.001	−0.006	0.031***	−0.182***	−0.139***	0.129***	−0.186***	0.006	0.936***	1

Table 3
The relationship between economic policy uncertainty (EPU) and corporate green innovation
This table examines the impact of EPU on corporate green innovation. The regression model is

$$Greenpat_{i,t+1} = \alpha_0 + \alpha_1 lnEPU_{i,t} + \sum_k \alpha_k controls_{k,i,t} + \varepsilon_{i,t+1}$$

$Greenpat_{i,t+1}$ is the natural logarithm of one plus firm *i*'s total number of green patent applications in year *t*+1. $lnepu_{i,t}$ is the natural logarithm of the China EPU index in year *t*. The sample includes 19,779 firm-year observations from 2005 to 2019. All continuous variables are winsorized at the upper and lower 1% levels. The definitions of the control variables are reported in Appendix B. We cluster the standard errors at the firm level. t statistics are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent variable	$Greenpat_{t+1}$	
	(1)	(2)
lnEPU		−0.680***
		(−15.259)
Size	0.052***	0.042***
	(3.374)	(3.089)
Lev	0.125**	0.125**
	(2.477)	(2.477)
ROA	0.286***	0.286***
	(3.256)	(3.256)
CFO	−0.065	−0.036
	(−1.029)	(−0.885)
Density	0.002	0.002
	(0.214)	(0.214)
Inst	−0.177***	−0.168***
	(−2.949)	(−2.433)
BM	−0.036	−0.036
	(−0.860)	(−0.860)
Indep	0.091	0.086
	(0.623)	(0.232)
Fix	0.205***	0.205***
	(2.785)	(2.785)
Growth	−0.020*	−0.018*
	(−1.718)	(−1.069)
P_gdp	−3.317***	0.334***
	(−15.539)	(10.496)
Findev	25.328***	−0.114
	(15.637)	(−0.737)
Constant	−37.027***	1.587***
	(−15.735)	(4.234)
Firm-fixed effects	Yes	Yes
Year-fixed effects	Yes	Yes
Observations	19,779	19,779
Fisher F(Prob > F)	13.23(0.000)	15.38(0.000)
Adjusted-R^2	0.053	0.057

between EPU and green innovation. Table 5 shows that the coefficients of *lnEPU* are still significantly negative when using the above alternative measures in Columns (1)–(6). Our baseline results are further confirmed.

4.3.3. Controlling for corporate governance variables

Corporate green innovation and corporate governance may be linked. Studies have shown that firms with poor corporate governance produce fewer green patents (Amore and Bennedsen, 2016). First, CEO duality reduces management effectiveness, thereby negatively impacting corporate innovation (Blibech and Berraies, 2018). Second, separating equity ownership and business control can reduce agency costs and information asymmetry in the innovation process (Belloc, 2012). Third, studies show that board size has a significantly positive relationship with green innovation. A larger board facilitates access to knowledge and external resources, thereby promoting green innovation (Zhao et al., 2022).

Following the literature, we add the separation of equity ownership and business control (*Separation*), natural logarithm of board size (*Board*), and Chairman-CEO duality (*Dual*) as additional control variables to reexamine the relationship between EPU and green innovation. Table 6 shows that the impact of the separation of ownership and

Table 4
Robustness check: Alternative measures of EPU
This table presents the impact of EPU on green innovation when we use alternative measures of EPU. *lnEPU1* and *lnEPU2* are the EPU index obtained from Davis et al. (2019) and Huang and Luk (2020), respectively. The regression model is
$Greenpat_{i,t+1} = \alpha_0 + \alpha_1 lnEPU_{i,t} + \sum_k \alpha_k controls_{k,i,t} + \varepsilon_{i,t+1}$
The definitions of all variables are reported in Appendix B. We cluster the standard errors at the firm level. t statistics are shown in parentheses. All continuous variables are winsorized at the upper and lower 1% levels. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent variable	$Greenpat_{t+1}$	
	(1)	(2)
lnEPU1	−3.180***	
	(−15.259)	
lnEPU2		−2.380***
		(−15.259)
Size	0.052***	0.052***
	(3.374)	(3.374)
Lev	0.125**	0.125**
	(2.477)	(2.477)
ROA	0.286***	0.286***
	(3.256)	(3.256)
CFO	−0.065	−0.065
	(−1.029)	(−1.029)
Density	0.002	0.002
	(0.214)	(0.214)
Inst	−0.177***	−0.177***
	(−2.949)	(−2.949)
BM	−0.036	−0.036
	(−0.860)	(−0.860)
Indep	0.091	0.091
	(0.623)	(0.623)
Fix	0.205***	0.205***
	(2.785)	(2.785)
Growth	−0.020*	−0.020*
	(−1.718)	(−1.718)
P_gdp	0.157***	1.148***
	(6.811)	(14.035)
Findev	1.230***	−2.318***
	(8.244)	(−9.420)
Constant	−4.035***	10.536***
	(12.434)	(12.434)
Firm-fixed effects	Yes	Yes
Year-fixed effects	Yes	Yes
Observations	19,779	19.779
Fisher F(Prob > F)	15.38(0.000)	15.38(0.000)
Adjusted-R^2	0.057	0.057

control, board size, and CEO duality on green innovation are consistent with Blibech and Berraies (2018), Belloc (2012) and Zhao et al. (2022). Importantly, the relationship between log EPU and green innovation is still negatively significant after adding the three governance variables.

4.3.4. Multiple fixed effects

Zhang et al. (2017) control for unobservable factors that change over time at the industry and province level, which affect green innovation. Following Zhang et al. (2017), we control for year-industry fixed effects and year-region fixed effects to re-estimate the baseline regression shown in Eq. (1). Column (1) of Table 7 controls for year-industry fixed effects, Column (2) controls for year-region fixed effects, and Column (3) includes both. The significantly negative coefficients of *lnEPU* confirm that higher EPU reduces corporate green innovation when the influence of unobservable factors is addressed.

4.4. Moderating effect analysis

4.4.1. Financial constraints

When EPU increases, the value of waiting option will increase significantly for firms with greater financial constraints because it becomes more difficult for those firms to access financing due to increased EPU. Literature indicates that funding constraints hinder R&D projects (Hottenrott and Peters, 2012; Amore et al., 2013; Hall et al., 2015), therefore, we expect that firms with higher financial constraints are more inclined to reduce green innovation when EPU is high.

Following Hadlock and Pierce (2010), we use SA index as the measure of financial constraints to examine whether financial constrains moderate the impact of EPU on green innovation.[2] The regression equation is shown as follows:

$$Greenpat_{i,t+1} = \beta_0 + \beta_1 lnEPU_{i,t} + \beta_2 SA_{i,t} + \beta_3 lnEPU_{i,t} \times SA_{i,t} + \sum_k \beta_k controls_{k,i,t} + \varepsilon_{i,t+1} \quad (2)$$

We add SA, which refers to SA index, and *lnEPU* × *SA* in the baseline regression to examine whether financial constrains moderate the impact of EPU on green innovation. The results in Table 8 show a negative coefficient of *lnEPU* × *SA*, indicating that financial constraints exacerbate the negative impact of EPU on green innovation. Our results suggest that when EPU increases, financially constrained firms reduce green innovation significantly because funding constraints hinder green innovation. .

4.4.2. Government environmental protection subsidies

To control environmental pollution and promote sustainable corporate development, Chinese governments provide a large number of R&D subsidies to firms every year, including subsidies for environmental governance, energy conservation and emission reduction projects, as well as awards for environmental protection achievements. Government subsidies can provide financial support for green innovation, guide the implementation of green innovation projects, and reduce the risk and cost of green innovation (Bai et al., 2019; Raz and Ovchinnikov, 2015). Therefore, environmental protection subsidies provided by governments can promote green innovation. When EPU increases, the value of waiting option will decrease for firms with more government subsidies compared with firm with less government subsidies. Therefore, we expect that government environmental subsidies can mitigate the negative effect of EPU on green innovation.

We employ *EnvirSub*, which is calculated as the total government environmental subsidies received by a firm divided by its total operating income as the measure of government's environmental subsidy. *EnvirSub* and *lnEPU* × *EnvirSub* are added in the baseline regression to examine the moderating effect of government environmental subsidies on the relationship between EPU and green innovation. The regression equations are as follows:

$$Greenpat_{i,t+1} = \gamma_0 + \gamma_1 lnEPU_{i,t} + \gamma_2 EnvirSub_{i,t} + \gamma_3 lnEPU_{i,t} \times EnvirSub_{i,t} + \sum_k \gamma_k controls_{k,i,t} + \varepsilon_{i,t+1} \quad (3)$$

Table 9 reports the regression results. The coefficient of *EnvirSub* is positive, which is in line with our expectation. Importantly, the coefficient of *lnEPU* × *EnvirSub* is significantly positive, indicating that government environmental subsidies can significantly alleviate the negative impact of EPU on green innovation. The result has important implications for policymakers regarding increasing government expenditure on environmental protection to promote corporate green innovation.

4.5. Heterogeneity analysis

Our findings reveal the impact of EPU on green innovation, but they

[2] Following Duan and Jin (2019), we use KZ index (Lamont et al., 2001) and WW index (Whited and Wu, 2006) as alternative measures of financial constraints for robustness checks. The untabulated results confirm that financial constraints exacerbate the negative effect of EPU on green innovation.

Table 5

Robustness check: Alternative measures of green innovation

We use the natural logarithm of one plus the number of green invention patents (*GreenInva*), green utility model patents (*GrennUma*), and granted green patents (*GreenGran*) as the alternative measures of green innovation. Additionally, we employ the proportion of total green patent applications in the firm's total patent applications (*RatioPat*), green invention patents in the firm's total invention patents (*RatioInva*), and green utility model patents in the firm's total utility model patents (*RatioUma*) as the alternative measures of green innovation to reestimate the relationship between EPU and green innovation. The regression model is

$$Greenpat_{i,t+1} = \alpha_0 + \alpha_1 lnEPU_{i,t} + \sum_k \alpha_k controls_{k,i,t} + \varepsilon_{i,t+1}$$

The definitions of all variables are reported in Appendix B. We cluster the standard errors at the firm level. t statistics are shown in parentheses. All continuous variables are winsorized at the upper and lower 1% levels. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent variable	$GreenInva_{t+1}$	$GreenUma_{t+1}$	$GreenGran_{t+1}$	$RatioPat_{t+1}$	$RatioInva_{t+1}$	$RatioUma_{t+1}$
	(1)	(2)	(3)	(4)	(5)	(6)
lnEPU	−0.311***	−0.680***	−0.140***	−0.100***	−0.122***	−0.075***
	(−8.411)	(−17.299)	(−3.714)	(−4.861)	(−6.784)	(−4.340)
Size	0.047***	0.028**	0.045***	−0.002	−0.002	−0.002
	(3.430)	(2.502)	(3.141)	(−0.359)	(−0.407)	(−0.437)
Lev	0.109**	0.081**	0.087*	−0.006	−0.007	−0.011
	(2.486)	(2.323)	(1.943)	(−0.291)	(−0.413)	(−0.637)
ROA	0.203***	0.204***	−0.015	0.053	0.035	0.040
	(2.702)	(3.221)	(−0.202)	(1.360)	(1.032)	(1.196)
CFO	−0.058	−0.022	−0.008	−0.043	−0.031	−0.039
	(−1.088)	(−0.480)	(−0.150)	(−1.473)	(−1.222)	(−1.546)
Density	−0.002	0.004	0.010	−0.001	−0.002	−0.001
	(−0.212)	(0.626)	(1.208)	(−0.363)	(−0.473)	(−0.258)
Inst	−0.148***	−0.047	−0.126**	−0.026	−0.022	−0.016
	(−2.920)	(−1.102)	(−2.412)	(−1.121)	(−1.109)	(−0.816)
BM	−0.040	−0.010	0.043	0.031*	0.029**	0.028**
	(−1.087)	(−0.352)	(1.156)	(1.918)	(2.083)	(2.021)
Indep	−0.034	0.174	0.157	0.002	−0.012	0.001
	(−0.296)	(1.540)	(1.185)	(0.044)	(−0.260)	(0.013)
Fix	0.188***	0.107**	0.171***	0.058*	0.048*	0.045*
	(3.061)	(2.172)	(2.789)	(1.928)	(1.892)	(1.779)
Growth	−0.012	−0.016*	−0.029***	−0.002	−0.000	−0.001
	(−1.214)	(−1.827)	(−2.918)	(−0.349)	(−0.095)	(−0.158)
P_gdp	0.161***	0.308***	−0.049*	−0.048***	−0.058***	−0.039***
	(6.135)	(11.614)	(−1.888)	(−3.402)	(−4.809)	(−3.274)
Findev	0.017	−0.088	0.284**	0.041	0.052	0.036
	(0.127)	(−0.733)	(2.302)	(0.655)	(0.967)	(0.663)
Constant	0.216	1.917***	−1.999***	−0.163	−0.280**	−0.096
	(0.686)	(6.563)	(−5.736)	(−0.991)	(−1.992)	(−0.688)
Firm-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,779	19,779	19,779	19,779	19,779	19,779
Fisher F(Prob > F)	9.81(0.000)	15.77(0.000)	9.96(0.000)	9.12(0.000)	9.12(0.000)	9.32(0.000)
Adjusted-R^2	0.047	0.041	0.054	0.042	0.043	0.043

may not reflect the differences of such an effect in different settings. Therefore, we investigate the heterogeneity of the EPU effect in terms of state control, firm size, industry competition, and the level of intellectual property protection in the region where a firm is located.

4.5.1. State control

Although the number of privately owned firms in China is gradually increasing, state-owned enterprises (SOEs) continue to account for a large proportion of listed companies. SOEs and privately controlled firms have different access to financing, business objectives, and development strategies. Non-SOEs' primary goal is to maximize profits, whereas SOEs have weaker profit maximization incentives and more political and social goals, such as job retention, environmental protection, and social stability maintenance, among others (Lin et al., 1998). Furthermore, as a key pillar of the Chinese economy, SOEs have greater access to government subsidies and preferential policies. SOEs naturally have political connections due to ownership arrangements, which can reduce information asymmetry between firms and policymakers (Wellman, 2017). Therefore, SOEs would be less sensitive to changes in economic policy.

We speculate that the negative relationship between EPU and green innovation will be stronger in non-SOEs than in SOEs. We divide our entire sample into two groups based on the firms' ultimate control. Table 10 shows the results of the subsample analysis in Columns (1) and (2). The findings show that the negative relationship between EPU and green innovation is significant in the *non-SOE* subsample but not in the *SOE* subsample. According to the findings, privately owned firms have less access to resources and thus reduce green innovation significantly during high EPU periods.

4.5.2. Firm size

The impact of EPU on green innovation may differ depending on firm size. When facing financial distress, larger firms are more likely to raise capital, receive subsidies, and take on greater risk (Otchere et al., 2020). As a result, we anticipate that the negative relationship between log EPU and green innovation will be more pronounced in small firms than in large firms. Following Luo et al. (2022), we divide the sample based on the median value of firm size. A firm size above the median is included in the *High Size* subsample and in the *Low Size* subsample, otherwise. As presented in Columns (3) and (4) of Table 10, the negative impact of EPU on green innovation is more significant in small firms, which is consistent with our expectation.

4.5.3. Industry competition

Green innovation decisions, as an important component of corporate innovation, cannot be made independently of corporate development strategies. According to Kulatilaka and Perotti (1998), in the case of imperfect competition, R&D investment made during uncertainty can assist the corporation in gaining a competitive advantage. By developing a real option model with R&D competition, Weeds (2002) discovers that

Table 6
Robustness check: Controlling for corporate governance variables
This table reports the impact of EPU on green innovation after adding the corporate governance variables, e.g., the separation of equity ownership and business control (*Separation*), the natural logarithm of board size (*Board*), and Chair-CEO duality (*Dual*) as control variables as additional controls. The regression model is
$Greenpat_{i,t+1} = \alpha_0 + \alpha_1 lnEPU_{i,t} + \sum_k \alpha_k controls_{k,i,t} + \varepsilon_{i,t+1}$
The definitions of all variables are reported in Appendix B. All continuous variables are winsorized at the upper and lower 1% levels. We cluster the standard errors at the firm level. t statistics are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent variable	$Greenpat_{t+1}$			
	(1)	(2)	(3)	(4)
lnEPU	−0.680***	−0.682***	−0.692***	−0.692***
	(−15.263)	(−15.137)	(−15.108)	(−15.109)
Size	0.053***	0.052***	0.049***	0.049***
	(3.386)	(3.248)	(3.041)	(3.001)
Lev	0.124**	0.136***	0.132**	0.132**
	(2.456)	(2.632)	(2.496)	(2.500)
ROA	0.286***	0.308***	0.327***	0.327***
	(3.253)	(3.444)	(3.529)	(3.542)
CFO	−0.063	−0.052	−0.049	−0.047
	(−1.011)	(−0.827)	(−0.759)	(−0.735)
Density	0.002	0.002	0.000	0.000
	(0.208)	(0.168)	(0.017)	(0.027)
Inst	−0.185***	−0.168***	−0.162***	−0.171***
	(−3.013)	(−2.707)	(−2.600)	(−2.684)
BM	−0.037	−0.040	−0.041	−0.042
	(−0.890)	(−0.958)	(−0.975)	(−0.988)
Indep	0.091	0.190	0.154	0.202
	(0.623)	(1.107)	(1.002)	(1.156)
Fix	0.204***	0.200***	0.206***	0.205***
	(2.779)	(2.675)	(2.690)	(2.676)
Growth	−0.020*	−0.021*	−0.018	−0.018
	(−1.719)	(−1.751)	(−1.457)	(−1.465)
P_gdp	0.335***	0.337***	0.345***	0.345***
	(10.501)	(10.494)	(10.554)	(10.551)
Findev	−0.118	−0.121	−0.134	−0.133
	(−0.760)	(−0.774)	(−0.848)	(−0.837)
Separation	0.107*			0.0114*
	(1.764)			(1.794)
Board		0.037*		0.025*
		(1.023)		(1.688)
Dual			−0.014*	−0.013*
			(−1.759)	(−1.730)
Constant	1.588***	1.528***	1.724***	1.676***
	(4.235)	(3.895)	(4.420)	(4.177)
Firm-fixed effects	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes
Observations	19,779	19,779	19,779	19,779
Fisher F(Prob > F)	14.86	14.68	14.52	13.54
	(0.000)	(0.000)	(0.000)	(0.000)
Adjusted-R^2	0.053	0.053	0.052	0.052

the expected value of preemption right is greater than the value of the waiting option. Therefore, an increase in uncertainty may motivate firms to innovate. Atanassov et al. (2015) find that the positive impact of political uncertainty on R&D investment is stronger in firms facing greater product market competition. Therefore, we expect that in a fiercely competitive environment, firms will be more active in green innovation to gain competitive advantages and better cope with uncertainties.

We employ the widely used *HHI* to measure industry competition. The calculation of the *HHI* is as follows (Spiegel, 2021):

$$HHI = \sum_{t=1}^{N} \left(\frac{X_i}{X}\right)^2 \quad i = 1, 2, \ldots, N \tag{6}$$

where X_i represents firm i's size, X presents the total market size, N presents the total number of firms in the industry, and $\frac{X_i}{X}$ represents firm

Table 7
Robustness check: Controlling for multiple fixed effects
This table reports the results of the impact of EPU on green innovation after controlling for firm, firm-industry, and firm-region fixed effects. The regression model is
$Greenpat_{i,t+1} = \alpha_0 + \alpha_1 lnEPU_{i,t} + \sum_k \alpha_k controls_{k,i,t} + \varepsilon_{i,t+1}$
The definitions of all variables are reported in Appendix B. All continuous variables are winsorized at the upper and lower 1% levels. We cluster the standard errors at the firm level. t statistics are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent variable	$Greenpat_{t+1}$		
	(1)	(2)	(3)
lnEPU	−0.042***	−0.040***	−0.040***
	(−3.909)	(−3.805)	(−3.813)
Size	0.055***	0.039***	0.050***
	(3.733)	(2.681)	(3.461)
Lev	0.109**	0.120**	0.107**
	(2.207)	(2.417)	(2.195)
ROA	0.294***	0.310***	0.307***
	(3.359)	(3.616)	(3.580)
CFO	−0.076	−0.113*	−0.089
	(−1.236)	(−1.817)	(−1.451)
Density	−0.010	−0.004	−0.012
	(−1.061)	(−0.414)	(−1.261)
Inst	−0.133**	−0.143**	−0.125**
	(−2.363)	(−2.410)	(−2.202)
BM	0.071**	0.060*	0.063*
	(2.111)	(1.779)	(1.909)
Indep	0.153	0.119	0.183
	(1.085)	(0.812)	(1.296)
Fix	0.172**	0.231***	0.203***
	(2.379)	(3.245)	(2.884)
Growth	−0.008	−0.005	−0.006
	(−0.734)	(−0.487)	(−0.551)
P_gdp	−0.253***	−0.247***	−0.261***
	(−5.405)	(−5.261)	(−5.589)
Findev	−0.005	0.007	−0.018
	(−0.064)	(0.096)	(−0.257)
Constant	−0.733**	−0.497	−0.621**
	(−2.377)	(−1.625)	(−2.034)
Firm-fixed effects	Yes	Yes	Yes
Year-industry fixed effects	Yes	No	Yes
Year-region fixed effects	No	Yes	Yes
Observations	19,779	19,779	19,779
Fisher F (Prob > F)	6.21(0.000)	7.37(0.000)	6.38(0.000)
Adjusted-R^2	0.058	0.052	0.065

i's market share. When the industry is a complete monopoly, *HHI* is equal to 10,000, and when all firms in the industry have the same size, *HHI* is equal to $\frac{1}{N}$. *HHI* fluctuates within the range of [$\frac{1}{N}$, 10,000], and a larger *HHI* value indicates lower industry competition. If the firm's *HHI* is above the sample median, it is included in the *LowCompe* group; otherwise, it is included in the *HighCompe* group. The findings in Columns (5) and (6) of Table 10 show that the negative impact of EPU on green innovation is more pronounced in firms in less competitive industries. Therefore, industry competition moderates the EPU effect on green innovation.

4.5.4. Intellectual property protection

The level of intellectual property protection also affects the relationship between EPU and green innovation. First, externalities exist in R&D activities, and intellectual property protection reduces the risk of firms infringing on their innovative products while increasing the benefits of innovation (Wu and Tang, 2016). Second, intellectual property protection can encourage firms to disclose R&D information, which can help investors reduce information asymmetry about corporate innovation projects.

Following Wu and Tang (2016), we use regional patent enforcement to measure the degree of intellectual property protection. Specifically, regional intellectual property protection is calculated as one minus the

Table 8
Moderating effect: Financial constraints
We use SA index (Hadlock and Pierce, 2010) as the measure of financial constraints. The regression equation is as follows:
$Greenpat_{i,t+1} = \beta_0 + \beta_1 lnEPU_{i,t} + \beta_2 SA_{i,t} + \beta_3 lnEPU_{i,t} \times SA_{i,t} + \sum_k \beta_k controls_{k,i,t} + \varepsilon_{i,t+1}$
The definitions of all variables are reported in Appendix B. All continuous variables are winsorized at the upper and lower 1% levels. We cluster the standard errors at the firm level. t statistics are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent variable	$Greenpat_{t+1}$
lnEPU	−0.669***
	(-15.521)
SA	−0.011***
	(-2.888)
SA × *lnEPU*	−0.015***
	(-3.743)
Size	0.052***
	(3.339)
Lev	0.167***
	(3.311)
ROA	0.242***
	(2.761)
CFO	−0.157**
	(-2.241)
Density	0.002
	(0.207)
Inst	−0.179***
	(-2.952)
BM	−0.054
	(-1.256)
Indep	0.095
	(0.650)
Fix	0.222***
	(2.993)
Growth	−0.020*
	(-1.736)
P_gdp	0.325***
	(10.521)
Findev	−0.288*
	(-1.776)
Constant	1.985***
	(5.159)
Firm-fixed effects	Yes
Year-fixed effects	Yes
Observations	19,779
Fisher F(Prob > F)	14.41(0.000)
Adjusted-R^2	0.054

Table 9
Moderating effect: Government subsidies on environmental protection
The regression equation is as follows:
$Greenpat_{i,t+1} = \gamma_0 + \gamma_1 lnEPU_{i,t} + \gamma_2 EnvirSub_{i,t} + \gamma_3 lnEPU_{i,t} \times EnvirSub_{i,t} + \sum_k \beta_k controls_{k,i,t} + \varepsilon_{i,t+1}$
EnvirSub is calculated as the total government subsidies received by a firm divided by its total operating income. The definitions of all variables are reported in Appendix B. All continuous variables are winsorized at the upper and lower 1% levels. We cluster the standard errors at the firm level. t statistics are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent variable	$Greenpat_{t+1}$
lnEPU	−0.756***
	(-6.399)
EnvirSub	0.400**
	(2.869)
lnEPU × *EnvirSub*	0.621***
	(6.356)
Size	0.094**
	(2.279)
Lev	0.021
	(0.162)
ROA	0.439*
	(1.783)
CFO	0.049
	(0.307)
Density	−0.014
	(-0.443)
Inst	−0.227*
	(-1.934)
BM	−0.136
	(-1.419)
Indep	0.546*
	(1.829)
Fix	0.456**
	(2.140)
Growth	0.039
	(0.931)
P_gdp	0.422***
	(4.929)
Findev	−0.682
	(-1.580)
Constant	−2.009**
	(-2.475)
Firm-fixed effects	Yes
Year-fixed effects	Yes
Observations	4793
Fisher F (Prob > F)	9.32(0.000)
Adjusted-R^2	0.045

ratio of the number of patent infringement dispute cases accepted in each region to the total number of patents granted in that region in a year. The greater the value, the better the region's protection of intellectual property rights. The sample is divided based on the median value of intellectual property protection. If the level of intellectual property protection in the region where the firm is located exceeds the median value, it is classified as *HighProtect*; otherwise, it is classified as *LowProtect*. The results in Columns (7) and (8) of Table 10 indicate that the negative relationship between EPU and green innovation is significant in firms located in regions with weak intellectual property rights protection.

5. Conclusion and discussion

We examine the impact of EPU on green innovation using data from Chinese firms. The results show a significant negative relationship between EPU and corporate green innovation. Additionally, we examine the moderating effect of financing constraints and government environmental protection subsidies on the impact of EPU on green innovation. We have evidence that financial constraints exacerbate the impact of EPU on green innovation, while government environmental subsidies mitigate the negative EPU effect. We further examine heterogeneity from four perspectives, e.g., state control, firm size, industry competition, and regional intellectual property protection. The negative impact of EPU on green innovation is significant in non-SOEs, small-scale firms, firms with less industry competition, and firms located in regions with weak intellectual property protection. Our findings have important implications for policymakers. Government's policies, such as green credits policy and subsidies for environmental protection, can play a significant role in promoting corporate green innovation. In addition, to encourage firms to increase green innovation, intellectual property protection should be strengthened.

This study also has several limitations. We were unable to investigate the impact of EPU on green innovation in non-listed companies due to data constraints. Future research can investigate the impact of green innovation on corporate competitiveness, financial performance, and corporate reputation during high EPU. It is also interesting to investigate the spillover effects in corporate green innovation and supply chain

Table 10
Heterogeneity analysis
This table presents the heterogeneity of the impact of EPU on green innovation. *SOE (Non-SOE)* subsample includes stated-owned (non-stated-owned) firms. *High Size* (*Low Size*) subsample includes firms with firm size above (below) the sample median. *HighCompe* (*LowCompe*) subsample includes firms with industry competition (HHI) below (above) the sample median. *High Protect (Low Protect)* subsample includes firms with a degree of regional intellectual property protection above (below) the sample median. The regression model is

$$Greenpat_{i,t+1} = \alpha_0 + \alpha_1 lnEPU_{i,t} + \sum_k \alpha_k controls_{k,i,t} + \varepsilon_{i,t+1}$$

The definitions of all variables are reported in Appendix B. All continuous variables are winsorized at the upper and lower 1% levels. We cluster the standard errors at the firm level. t statistics are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent variable	$Greenpat_{t+1}$							
	SOE	*Non_SOE*	*High Size*	*Low Size*	*HighCompe*	*LowCompe*	*High Protect*	*Low Protect*
lnEPU	−0.023	−0.053***	−0.042*	−0.047***	−0.030	−0.041**	0.012	−0.090***
	(−1.410)	(−2.877)	(−2.747)	(−2.627)	(−1.708)	(−2.502)	(0.662)	(−5.738)
Size	0.071**	0.080***	0.045***	0.108***	0.093***	0.048***	0.058**	0.056***
	(2.257)	(3.931)	(2.753)	(2.995)	(4.235)	(2.581)	(2.451)	(3.111)
Lev	0.212**	0.030	0.101**	0.068	0.050	0.103	−0.012	0.181***
	(2.033)	(0.449)	(2.296)	(0.576)	(0.728)	(1.545)	(−0.151)	(3.000)
ROA	0.411**	0.356***	0.235***	0.526**	0.243*	0.225**	0.381**	0.274***
	(1.989)	(2.990)	(3.190)	(2.361)	(1.877)	(2.028)	(2.472)	(2.598)
CFO	0.132	−0.173*	−0.026	−0.170	0.019	−0.105	−0.077	−0.034
	(1.259)	(−1.920)	(−0.424)	(−1.449)	(0.235)	(−1.213)	(−0.793)	(−0.405)
Density	−0.013	−0.021*	−0.001	−0.027	−0.015	−0.008	0.002	−0.020*
	(−0.698)	(−1.647)	(−0.067)	(−1.409)	(−1.112)	(−0.616)	(0.148)	(−1.675)
Inst	−0.154	−0.059	−0.079	−0.128	−0.236***	−0.126*	−0.136	−0.141**
	(−1.358)	(−0.802)	(−1.330)	(−1.183)	(−2.878)	(−1.830)	(−1.398)	(−2.073)
BM	0.093*	−0.009	0.038	0.060	−0.014	0.057	−0.032	0.138***
	(1.662)	(−0.186)	(1.031)	(1.064)	(−0.273)	(1.407)	(−0.543)	(3.287)
Indep	0.293	0.119	0.313**	0.032	0.329*	0.097	0.196	0.188
	(1.356)	(0.508)	(2.059)	(0.136)	(1.735)	(0.544)	(0.968)	(1.003)
Fix	0.104	0.279**	0.049	0.225	0.178**	0.198*	0.084	0.224***
	(0.797)	(2.456)	(0.786)	(1.523)	(1.983)	(1.951)	(0.740)	(2.625)
Growth	−0.030	−0.017	−0.009	0.033	−0.010	−0.020	−0.018	−0.001
	(−1.268)	(−1.028)	(−0.983)	(1.170)	(−0.644)	(−1.417)	(−0.970)	(−0.059)
P_gdp	−0.202**	−0.195**	−0.043	−0.391***	−0.079	−0.288***	−0.147	−0.250***
	(−2.461)	(−2.521)	(−0.829)	(−4.979)	(−1.102)	(−4.664)	(−1.232)	(−4.282)
Findev	−0.057	0.111	0.112	−0.061	0.021	−0.057	−0.082	0.103
	(−0.481)	(0.891)	(1.372)	(−0.500)	(0.203)	(−0.603)	(−0.612)	(1.086)
Constant	−1.171*	−1.143***	−0.918***	−1.533**	−1.533***	−0.488	−0.953**	−0.728*
	(−1.736)	(−2.881)	(−2.695)	(−2.039)	(−3.350)	(−1.218)	(−1.962)	(−1.901)
Firm-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7203	9620	10,142	9637	8970	10,809	7203	9620
Fisher F (Prob > F)	6.85(0.000)	8.89(0.000)	6.55(0.000)	9.95(0.000)	6.83(0.000)	9.64(0.000)	3.67(0.000)	15.06(0.000)
Adjusted-R^2	0.107	0.033	0.022	0.099	0.057	0.063	0.107	0.033

management when firms face high EPU.

Declaration of competing interest

No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication. I would like to declare on behalf of my co-authors that the work described is original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

Data availability

The data that has been used is confidential.

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Appendix A. Sample distribution

This table shows the distribution of the sample by year. We select the samples as follows: (1) considering the particularity of financial firms with the main business of providing financial services, we exclude such firms from the sample; (2) given that the abnormal financial observations of special treatment (ST) firms will interfere with the regression results, we exclude ST firms from the sample; and (3) we exclude firm-year observations with missing information. The final sample consists of 19,779 firm-year observations.

Year	Observations before screening	Observation after screening	The proportion of total sample (%)
2005	981	738	3.73%
2006	1002	785	3.97%
2007	1051	746	3.77%
2008	1144	817	4.13%
2009	1214	921	4.66%
2010	1307	969	4.90%
2011	1589	1049	5.30%
2012	1808	1307	6.61%
2013	1927	1494	7.55%
2014	1930	1560	7.89%
2015	2019	1568	7.93%
2016	2178	1676	8.47%
2017	2326	1822	9.21%
2018	2613	2035	10.29%
2019	2673	2292	11.59%
Total	25762	19779	100%

Appendix B. Variable definitions

The appendix presents the definitions of the variables used in this study.

Variables	Definitions
Measure of green innovation	
Greenpat	The natural logarithm of one plus the total number of green patent applications
GreenGran	The natural logarithm of one plus the number of granted green patents
GreenInva	The natural logarithm of one plus the number of green invention patents
GreenUma	The natural logarithm of one plus the number of green utility model patents
RatioPat	The proportion of the total number of green patent applications in the firm's total patent applications
RatioInva	The proportion of the number of green invention patents in the firm's total of invention patents
RatioUma	The proportion of the number of green utility model patents in the firm's total utility model patents
Measure of EPU	
lnEPU	The natural logarithm of the China EPU index, which is obtained from Baker et al. (2016), calculated as the mean value of monthly EPUs in a year
lnEPU1	The natural logarithm of the China EPU index, which is obtained from Davis et al. (2019), calculated as the mean value of monthly EPUs in a year
lnEPU2	The natural logarithm of the China EPU index, which is obtained from Huang and Luk (2020), calculated as the mean value of monthly EPUs in a year
Control variables	
Size	Firm size calculated as the natural logarithm of total assets
Lev	Financing leverage calculated as the book value of debt divided by the book value of total assets
ROA	Operating income divided by the book value of total assets
CFO	Cash flow from operating activities to total assets
Density	Firm's capital intensity calculated as the natural logarithm of total fixed assets divided by the number of employees
Inst	Institutional ownership calculated as the total shareholding ratio of all institutional investors
BM	Book-to-market ratio calculated as the ratio of the firm's book value of equity to total market value
Indep	Board independence calculated as the number of independent directors divided by the total number of directors on the board
Fix	Fixed assets investment calculated as fixed assets divided by total assets
Growth	The growth rate of income from the main business calculated as (income from main business in year *t*–income from main business in year *t-1*)/income in year *t-1* multiplied by 100%
P_gdp	GDP per capita calculated as gross domestic product/country population
Findev	The level of financial development measured by the amount of RMB credit funds used by financial institutions/gross domestic product
Other variables	
Separation	The separation rate of equity ownership and management control in the firm, which is calculated as the proportion of the control right owned by the actual controller minus the proportion of the ownership held by the actual controller (Claessens et al., 2000)
Board	The size of the board of the firm
Dual	A dummy variable that equals one if the CEO is the chairperson of the board and zero otherwise
SA	SA index, which is used to measure financing constraints
EnvirSub	The total government subsidies received by a firm divided by its total operating income in a year

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