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How does climate policy uncertainty affect green technology innovation at the corporate level? New evidence from China

Shuhai Niu [a], Juan Zhang [a], Renfu Luo [b], Yanchao Feng [a,*]

[a] Business School, Zhengzhou University, Zhengzhou, 450001, China
[b] School of Advanced Argicultural Sciences, Peking University, Beijing, 100871, China

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ABSTRACT

The frequent occurrence of extreme weather reminds us to focus more attention on sustainable development. A panel of Chinese A-share listed companies is selected as a research sample to explore how climate policy uncertainty has an effect on companies' green technology innovation. According to the empirical findings, corporate green technology innovation is negatively related to the uncertainty of climate policy. By affecting their R&D investments and risk tolerance, corporations' ability to develop in green technologies has been impacted by the uncertainty of climate policy. We also note that due to the nature of business ownership, the detrimental effect of uncertain climate policy on green technology innovation varies slightly between companies. While environmental regulations reinforce the negative impact of climate policy uncertainty, government subsidies can significantly mitigate this negative impact. These results have important theoretical and practical implications for the development of green economy theory and the realization of energy efficiency in various countries.

1. Introduction

Today's world is plagued by a common problem: climate change, which presents a common challenge for all of humanity (Berrang-Ford et al., 2011). In order to address climate change, countries have already adjusted their development policies. At the 27th United Nations Climate Change Conference in 2022, governments from around the world showcased how they are responding to climate change through legislation, policies, and judicial channels. China is a sensitive and significant impact area of global climate change, and in 2015 and 2020, the Chinese government proposed and adjusted its national autonomous contribution target in line with the *Paris Agreement*. President Xi Jinping proposed the "double carbon target," which declares that China aspires to reach peak CO2 emissions by 2030 and carbon neutrality by 2060, at the 75th General Debate of the United Nations General Assembly in September 2020. The "1 + N″ climate policy framework, designed by the Chinese government, consists of a number of policies and actions centered on the "double carbon" target. By optimizing the energy structure, developing green finance, and encouraging companies to innovate in green and low-carbon technology, the policy framework seeks to realize the goals of carbon peaking and carbon neutrality. However, recently, extreme weather changes and abnormal climate events have become more prominent (Wang et al., 2021). This quandary has compelled the Chinese government to actively implement relevant climate policies to address these challenges, as well as to develop a comprehensive green growth model to assist China in meeting the ecological goals associated with these obligations. In this context, this study intends to examine whether climate policy uncertainty can raise the amount of green technology innovation in companies and what mechanisms climate policy uses to influence corporate green technology innovation.

Political concerns are becoming more significant in the pursuit of sustainable economic growth (Wang and Shen, 2016; Wang et al., 2019; Wu et al., 2020), a growing body of research discusses how to integrate climate policy into policymaking frameworks to mitigate economic volatility caused by uncertainty (Drouet et al., 2015; Victor, 2015). In recent decades, a series of international conferences to develop climate policy have been held around the world to work out the best measures to enable the world to effectively reduce emissions and address climate change. Among the many agreements, there are three that have had the most profound impact on humanity in terms of climate issues, namely: *United Nations Framework Convention on Climate Change*(UNFCCC), *Kyoto*

* Corresponding author. No. 100 Kexue Avenue, High-tech Development District, Zhengzhou City, Henan Province, China.
E-mail addresses: niush@zzu.edu.cn (S. Niu), zj15890392015@gs.zzu.edu.cn (J. Zhang), luorf.ccap@pku.edu.cn (R. Luo), m15002182995@163.com (Y. Feng).

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Protocol, and *Paris Agreement*. These three core documents provide China with the foundation upon which to modify its climate and advance global climate governance. Chinese government established the National Climate Change Coordination Group in 1990 to address climate as a development issue, and in 2007, the *National Program for Addressing Climate Change* in China was issued as the basic basis for formulating domestic climate policy. From 1992 to 2022, more than 50 Chinese government agencies jointly or independently issued 229 climate policies (Wu et al., 2020). Fig. 1 shows the major climate policies enacted by the world and China in recent years.

In addition to policy tools, technological innovation is also one of the ways to support a green and low-carbon economy. Corporations, as major contributors to energy consumption and pollution emissions,

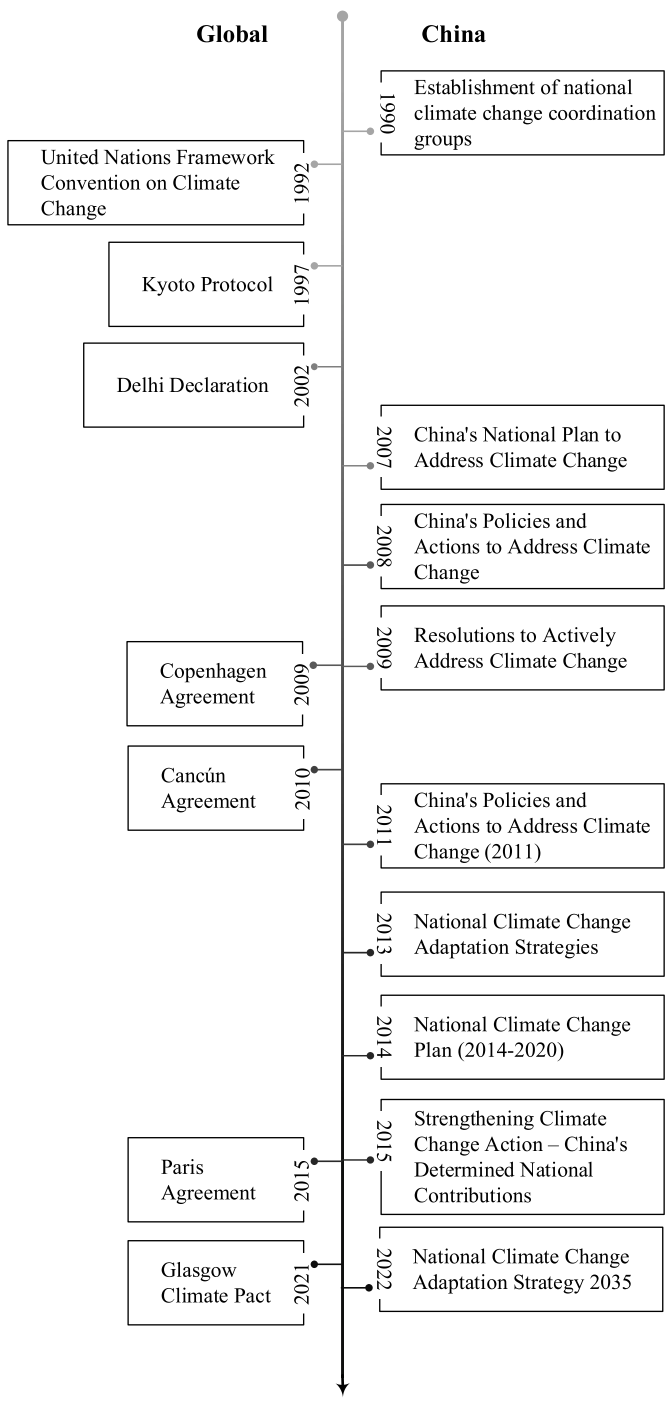

Fig. 1. Topic issues of global and Chinese climate policy.

determine the level of regional carbon emissions (Han and Cao, 2021). For emerging economies, achieving sustainable development of companies has become an important issue (He et al., 2019). Green technology innovations are technologies and processes developed by companies to achieve pollution reduction and clean production (Barbieri et al., 2020). The Chinese government has urged industry participants to actively engage in green innovation and proactively develop green patents that are advantageous to environmental protection in recent years. The State Intellectual Property Office of China reports that between 2016 and 2021, 160,000 technology effects with lower carbon emissions were granted in China, making up 34.0% of the total worldwide. China has consequently emerged as a significant innovator in green technologies.

In the face of changes in public policy, companies tend to adopt different strategies to respond (Sarkar, 2008). Aggressive climate policies lead institutional investors to increase their investments in green projects (Yu et al., 2022; Chen et al., 2021; Ginbo et al., 2021), and that corporate act to support green projects in order to gain public investment and support. Given this, it is essential to take climate change as a new influencing variable for corporate decisions. However, it has not been established whether climate policy volatility acts on corporate-level green technology innovation activities (Hong et al., 2020). This paper hopes to explore this issue through an empirical study and fill the research gap. Meanwhile, China has a huge volume of greenhouse gas emissions, faces the dual pressure of international responsibility for emission reduction and domestic economic transformation, which has received wide attention from the international community. Therefore, we focused our research on China.

Some scholars have demonstrated why and how uncertainty affects corporation' innovation activities and investment spending (Engle et al., 2020; Drobetz et al., 2018; Xu et al., 2022), but this paper uses CPU metrics to re-explore this issue, providing empirical evidence. On the one hand, the path of climate policy's initiation and implementation is fraught with uncertainty, and the policy science school in public economics believes that any policy inevitably has a lag of three periods, such as the time lag in policy understanding, policy formulation and policy effectiveness (Pülzl and Treib, 2017). Similarly, there are three time lags in the implementation of climate policies. Sometimes climate policies are implemented when other changes occur in the climate, and sometimes the implementation of climate policies is not strong enough to reach the governance goals because of the low level of awareness of the policy implementer who practice them. On the other hand climate policies may delay business investment decisions. As climate change uncertainty makes it difficult for policy makers to distill clear response strategies, it also becomes challenging for businesses to establish action plans through policy signals as policy implementer. This hinders companies from making strong investment decisions early on.

Additionally, it is important to take note of the ways in which CPU influence business innovation in green technology. On the basis of earlier studies, we propose the two mechanisms listed below. Intuitively, companies should invest more in green technologies in response to tighter climate policies. However, R&D investment is irreversible, investors may be tempted to postpone investing in green technology as a precautionary measure in light of significant sunk costs and inadequate knowledge. The value of waiting increases with the degree of uncertainty (Golub et al., 2020). This investment choice by the corporate can also be explained using the real options approach (Fuss et al., 2008; Bloom, 2009; Dixit and Dixit, 1994). On the other hand, climate policy uncertainty may increase corporation' expectations of losses and reduce corporation' risk-taking capacity (Tran, 2019; Wen et al., 2022). Because companies believe that high-risk investment projects can make them obtain higher economic returns, they are willing to bear high risks. But when climate policy uncertainty rises, it also increases the probability that companies will lose money on high-risk investments.

As we detail in the following section, relatively little research has been done in academia on the mechanisms between climate policy uncertainty and corporate green technology innovation. This paper leverages information from Chinese A-share listed companies to produce some empirical findings that corroborate our hypotheses. We discover that CPU significantly reduce the incentive of corporations to invest in green technologies, and these effects vary by business type, but government subsidies can mitigate this negative impact. After extensive robustness checks, including substitution variables and the use of instrumental variables, the empirical results remained quality-unchanged.

This paper significantly enhances the value of the existing literature. First, this paper provides a new research perspective for studies related to climate policy uncertainty. Most of the literature has examined economic policy uncertainty. The climate-induced policy uncertainty studied in this paper has better micro-economic implications than studies of broad economic policy uncertainty. Second, this study provides a new perspective for exploring climate risk and corporate-level green innovation, which further provides empirical support for the application of green technologies and the realization of global emission reduction targets, with win-win benefits for both national economy and ecological benefits. Finally, we do a heterogeneity analysis for companies in different industries and with different property rights, which improves the practical value of the research results.

The rest of this article is as follows. Section 2 provides a summary of the literature. Section 3 interprets the data and builds the model. Section 4 provides insights into the empirical results. Further analysis is provided in section 5. Finally, section 6 concludes with a summary and policy suggestions. Fig. 2 depicts the theoretical framework of the article.

2. Literature review

2.1. Climate change and business investment

Companies making investments are influenced by a variety of factors such as free cash flow, nature of ownership, board characteristics, and investor sentiment (Richardson, 2006; Denis and Sibilkov, 2010; Grundy and Li, 2010; Shahid and Abbas, 2019). There is a lot of well-established literature on the determinants of business investment, but there are few studies on the impact of climate risk on investment decisions. Some researchers have concluded that investors' decisions are influenced by concerns about climate change (Engle et al., 2020). Climate risk increases the uncertainty of a corporate's operations and exacerbates financial distress (Kling et al., 2021), at which point companies should increase their investments. Tests of behavioral finance theory suggest that investor attention may be affected by climate change, thereby increasing stock market volatility (Xia et al., 2022). However, real options theory advocates a trade-off between immediate and delayed investment to obtain more information to reduce uncertainty (Cooper and Priestley, 2011; Ioulianou et al., 2017; Tserlukevich, 2008). In the context of frequent climate change, since the value of deferring investment decisions increases with higher uncertainty, real options theory suggests that investments should be reduced in such cases. Although climate risk has now been shown to affect companies' investment decisions, the answer to the question of whether the impact on companies' investments is positive or negative is not unique.

2.2. Climate policy uncertainty and green markets

Climate risks are often accompanied by uncertainty. Drouet et al. (2015) points out that further research is needed to understand and quantify climate change uncertainty, and that strategies to address climate change must include all relevant uncertainties to mitigate the risks posed by uncertainty. Gavriilidis (2021) quantifies the extent of climate change by extracting the frequency of keywords such as "climate", "policy", and "uncertainty" from U.S. newspaper news, and calls this indicator the Climate Policy Uncertainty Index (Shang et al., 2022). In the empirical literature, research on how CPU affect green markets mainly focuses on energy markets and stock markets, while some studies explore how uncertainty affects corporate decision-making (Chen et al., 2021; Tian et al., 2022; Lv and Li, 2023).

Hemrit and Benlagha (2021) investigate the impact of CPUs on renewable energy volatility using a GARCH-MIDAS model and an index of climate policy uncertainty. According to Shang et al. (2022), CPUs increase market consumption of renewable energy while decreasing demand for non-renewable energy sources. According to Liang et al. (2022), fluctuations in climate-related policies and regulations have no effect on natural gas prices in the short term, but stretching the timeline, a significant negative effect is seen. Yan (2022) develop the China Daily Climate Policy Uncertainty Index to investigate whether and how coal pricing is affected by uncertainty when it is present in climate policy. Based on monthly returns in the market for renewable energy, Xu et al. (2022) attempted to assess the economic effects of CPU and discovered that the CPU index has a high informational value. The CPU index strongly forecasts increasing renewable energy reporting when compared to other policy uncertainty indexes. The Green Equity Index (GEI) and Green Bond Index (GBI) responses to the U.S. and climate policy uncertainty (CPU) were examined by Husain et al. (2022). They discovered that CPU has a favorable effect on green markets at times of high uncertainty. The study by Bouri et al. (2022) has similar conclusions, green stocks have better performance in stocks than brown energy stocks, and Bouri's research also highlights the CPU's ability to predict stock prices. Azimli (2023) argues that higher CPU negatively impact company value. Golub et al. (2020) developed a conceptual model of corporate behavior, proposing that uncertainty promotes a twofold deferral strategy, which involves postponing expenditures in implementing abatement technologies and purchasing and retaining (banking) emission allowances. Ren et al. (2022) argues that CPU reduce total factor productivity through two channels, which hinder R&D investment and reduce corporate free cash flow. Research by Fuss et al. (2008) suggests that uncertainty can cause the market to delay investment in environmentally friendly but more costly technologies.

Overall, there are currently enough research to give a thorough examination of the financial effects of climate policy, but few of these studies have combined corporate green innovation with CPUs to study how the former affects the latter and how it works. This research offers empirical references and perspective inspiration for future studies by micro-perspectivizing the mechanism of the influence of climate policy uncertainty on corporate green investment.

3. Data and methodology

3.1. Empirical mode

In order to investigate the binding effect of CPU on corporate green technology innovation, the basic econometric model constructed in this study is:

$$GTI_{it} = \alpha + \beta CPU_{t-1} + \gamma X_{it} + Year_t + Ind_i + \varepsilon_{it} \tag{1}$$

where GTI_{it} denotes green technology innovation; CPU_{t-1} is the CPU index, considering the time lag effect of the policy, the CPU returns with a lag period; X_{it} represents control variables, including company size, financial leverage ratio (*lev*), revenue growth rate (*grow*), R&D investment (*rd*), equity concentration (*ec*), current ratio (*current*), institutional ownership ratio (*ins*); $year_t$ and ind_i represent time-fixed effects and individual fixed effects, respectively; ε_{it} is a random error term. The variable *i* represents the corporate and *t* represents the year.

3.2. Data and variables

3.2.1. Dependent variable

The explanatory variables of the article were expressed using the

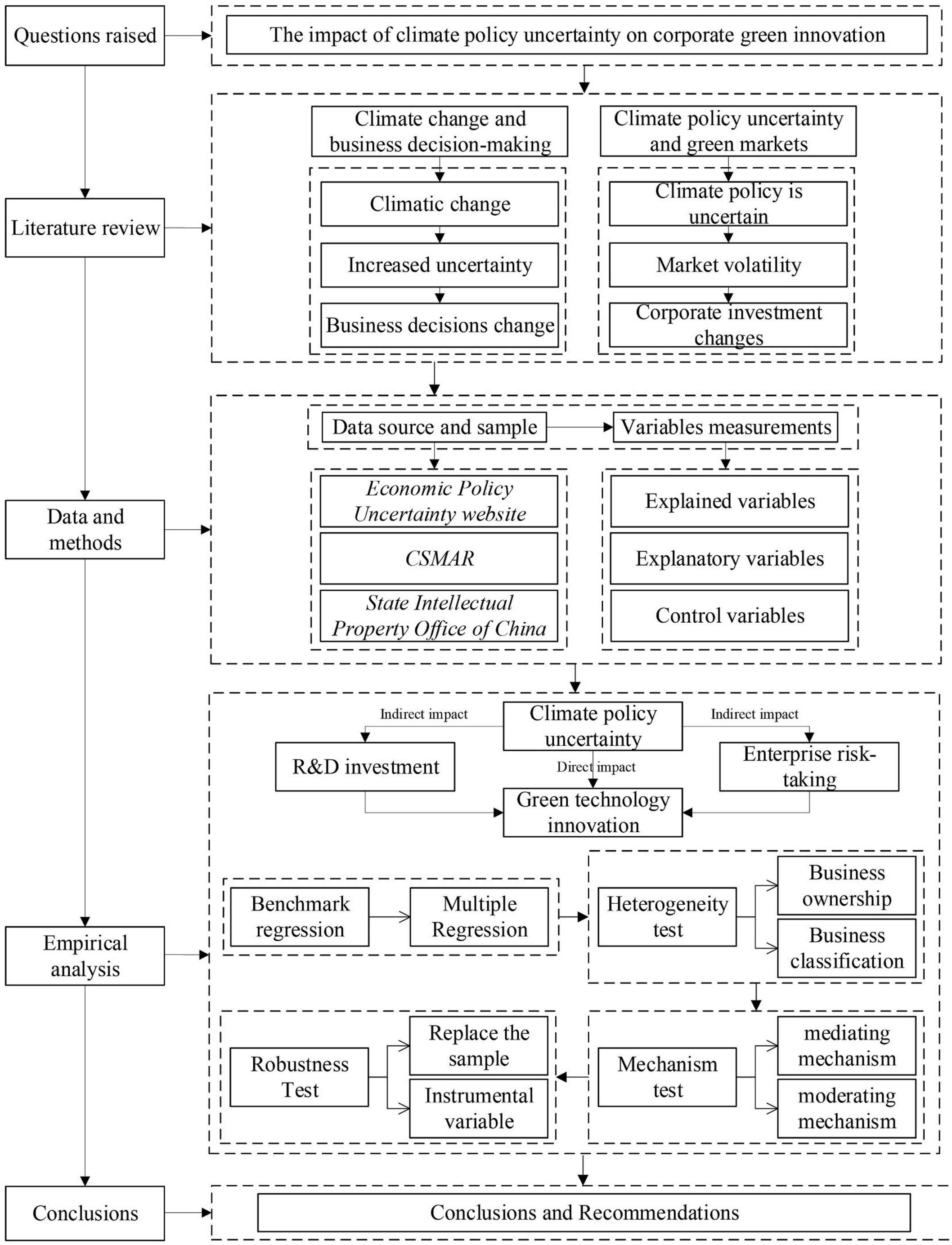

Fig. 2. Flowchart of the research progress.

CPU index constructed by Gavriilidis (2021) and converted monthly data to annual data by taking an average, dividing the original data by 100 and taking the logarithm.

3.2.2. *Explanatory variable*

The outcome of corporate innovation activities can be measured using patent data. Considering the obvious lag in patent granting, this paper uses the number of green patent applications as an indicator to measure corporate green technology development (Earnhart, 2004; Kammerer, 2009). Therefore, referring to Ghisetti and Quatraro (2017), the number of green invention patent applications of companies is used to measure green technological innovation, denoted as GTI, and the natural logarithm of the indicator is taken by adding 1 to eliminate the effect of the magnitude.

3.2.3. *Control variables*

In the regression analysis, we added a number of control variables based on the pertinent literature (Anginer et al., 2014; Bostandzic and Weiss, 2018). These include: (1)Company size (*size*): the logarithm of the corporate's total assets; (2) Financial leverage ratio (*lev*): the ratio of equity capital to total assets in the balance sheet; (3) Revenue growth rate (*grow*): revenue growth rate; (4)Investment in research and development (*rd*): the logarithm of the number of funds used by a company to develop new technologies or new productst; (5)Equity concentration (*ec*): the share of the first largest shareholder's shareholding in the total shares of the company; (6)Current Ratio (*current*): the ratio of total current assets to total current liabilities; (7)Institutional shareholding ratio (*ins*): the ratio of the total number of shares held by institutional investors to the total number of shares.

3.3. Data source

Our empirical analysis, which spans the years 2009–2020, uses data from Chinese A-share listed companies as the original sample. The data are processed in this research based on the original sample in the manner described below. (1) Subtract samples with a significant amount of missing values. (2) We apply a top and bottom 1% tail reduction to continuous variables to eliminate the effect of extreme values. A total of 17,323 annual observations were made for the 2605 A-share listed companies that made up the final sample.

The green patent data of companies are obtained from the green list of international patent classification introduced by WIPO and compared and searched in the State Intellectual Property Office. CPU was obtained from the Economic Policy Uncertainty website.[1] Other corporate related data are obtained from CSMAR database. The variable's descriptive statistics are displayed in Table 1.

4. Results and discussion

4.1. Baseline regression

In this paper, we include CPU as the core explanatory variable for corporate green innovation and use model (1) for regression estimation. In Table 2, we gradually include control variables in the model. The first column presents the results without any control variables, the coefficient of the explained variable is 0.110, which passes the significance test. Then, we gradually add control variables to the model, the coefficient of CPU turns positive after adding control variables, and it increased as we added more control variables. This shows that companies' green innovation behavior is indeed affected by CPU. Increased climate policy uncertainty has significantly dampened corporation' output of green patents.

4.2. Heterogeneity analysis

State-owned corporations, as opposed to non-state-owned corporations, incur a greater responsibility of environmental protection rules while pursuing the maximization of economic gains due to the unique institutional framework. Coupled with the low-cost nature of local government intervention in state-owned companies, state-owned companies respond positively to the government's climate policies. To examine the variations in how CPU affect companies according on the type of property rights, the sample is split into two categories to account for the variations in the nature of listed companies' property rights: state-owned companies and non-state-owned companies. Set dummy variable *SOEs*, when the company is a state-owned corporate, *SOEs* are assigned a value of 1, otherwise 0. We regress the model (1) again and show the results in Table 3.

When $SOEs = 1$, the coefficient of *CPU* is -0.418, and when $SOEs = 0$, the coefficient of *CPU* is -0.606, both of which pass the significance test, suggest that CPUs inhibit green innovation output of both SOEs and non-SOEs, with non-SOEs being more affected. This may be because state-owned corporations, in comparison to non-state corporations, are responsible for social stability, employment, financial stability, and environmental protection. As a result, state-owned corporations are more likely to drive climate policies, which in turn leads to more active green innovation behavior. In addition, state-owned corporations also have a higher likelihood of receiving government subsidies, giving them more funds to invest in green innovation initiatives, compared to non-state-owned companies that may face more financial constraints and participate more cautiously in risky R&D activities such as green investments in the context of fluctuating environmental policies.

Next, we divide companies into labor-intensive, technology-intensive, capital-intensive, and resource-intensive companies according to their factor intensity,[2] the results of the regression are presented in Table 4: CPU significantly hinders corporate green innovation across a variety of businesses. In contrast to capital- and labor-intensive corporations, technology- and resource-intensive corporations are more affected by CPU. The possible reason for the above results is that the unpredictability and contingency of technology-intensive companies will bring a high failure rate, and innovative companies often generate limited and unstable cash flow, which will negatively affect the incentives of banks and financial institutions to grant loan operations to technology-based companies, and thus green innovation activities of technology-intensive companies may not receive sufficient financial support. Most of the resource-intensive companies use a large amount of natural resources for production, which inevitably results in increased harm to the environment overall. Compared with other industries that rely on less natural resources, resource-intensive companies are more affected by policies, may face the problem of soaring costs and falling profits, and the shortage of funds may bring about a decrease in green innovation. Capital-intensive companies themselves have a large

Table 1
Descriptive statistics.

Variable	N	Mean	S.D	Min	Max
Lcpu	16980	1.198	0.502	0.593	1.999
lapply	17323	0.543	0.95	0	7.335
Size	17323	21.99	1.201	19.918	25.782
lev	17323	0.399	0.192	0.054	0.869
roa	17323	0.038	0.063	−0.257	0.196
growth	17206	0.112	0.447	−0.715	2.327
rd	17203	17.821	1.451	13.589	21.645
ec	17323	34.233	14.247	9.19	73.029
liquidity	17323	0.565	0.172	0.143	0.9
ins	17312	0.375	0.237	0	3.267
current	17323	2.566	2.604	0.374	16.89

[1] https://www.policyuncertainty.com/climate_uncertainty.html.

[2] Resource-intensive industries include: mining; labor-intensive industries include: textile clothing and apparel industry, textile industry, non-metallic mineral products industry, the comprehensive utilization of waste resources, furniture manufacturing, metal products, machinery and equipment repair industry, metal products industry, wood processing and wood, bamboo, rattan, palm, grass products industry, agro-food processing industry, leather, fur, feathers and their products and footwear, other manufacturing, food manufacturing, arts and education, sports and recreational goods manufacturing, rubber and plastic products, printing and recording media reproduction, paper and paper products industry; capital-intensive industries include: ferrous metal smelting and rolling processing, printing and recording media reproduction, paper and paper products industry. Food Manufacturing Industry, Cultural, Educational, Industrial, Sports and Recreational Goods Manufacturing Industry, Rubber and Plastic Products Industry, Printing and Recorded Media Reproduction Industry, Paper and Paper Products Industry; capital-intensive industries include: ferrous metal smelting and rolling processing industry, chemical fiber manufacturing industry, chemical raw materials and chemical products manufacturing industry, wine, beverages and refined tea manufacturing industry, petroleum processing, coking and nuclear fuel processing industry, pharmaceutical manufacturing, and Non-ferrous metal smelting and rolling processing industry; technology-intensive industries, including: electrical machinery and equipment manufacturing, computer, communications and other electronic equipment manufacturing, automobile manufacturing, railroad, shipbuilding, aerospace and other transportation equipment manufacturing, general equipment manufacturing, instrumentation manufacturing, special equipment manufacturing.

Table 2
Baseline regression results.

Variables	GTI								
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
cpu	0.110*	−0.152***	−0.145**	−0.156***	−0.520***	−0.523***	−0.523***	−0.523***	−0.517***
	(1.87)	(-2.58)	(-2.45)	(-2.59)	(-6.46)	(-6.48)	(-6.46)	(-6.46)	(-6.46)
size		0.248***	0.244***	0.245***	0.105***	0.106***	0.107***	0.107***	0.138***
		(29.47)	(25.54)	(25.57)	(9.70)	(9.82)	(9.59)	(9.59)	(12.05)
lev			0.049	0.050	0.205***	0.203***	0.202***	0.202***	0.224***
			(1.24)	(1.24)	(4.66)	(4.64)	(4.63)	(4.63)	(5.09)
growth				0.018	0.035**	0.035**	0.035**	0.035**	0.030*
				(1.19)	(2.09)	(2.08)	(2.08)	(2.08)	(1.80)
lrd					0.196***	0.196***	0.196***	0.196***	0.175***
					(26.27)	(26.29)	(26.30)	(26.29)	(23.48)
ec						−0.000	−0.000	−0.000	−0.001
						(-0.50)	(-0.40)	(-0.40)	(-0.83)
ins							−0.012	−0.010	−0.016
							(-0.35)	(-0.28)	(-0.48)
current								−0.009****	−0.006***
								(2.90)	(1.96)
liquidity									0.536***
									(10.00)
Constant	0.220**	−4.767***	−4.710***	−4.716***	−4.544***	−4.547***	−4.566***	−4.566***	−5.187***
	(2.00)	(-23.64)	(-22.10)	(-21.99)	(-19.05)	(-19.09)	(-18.82)	(-18.96)	(-20.78)
Observations	16,981	16,981	16,981	16,863	14,251	14,251	14,242	14,242	14,242
R-squared	0.009	0.103	0.103	0.104	0.156	0.156	0.156	0.157	0.163

Notes: t-statistics are in parentheses. *, **, and *** respectively represent significance at the 10%, 5%, and 1% levels.

Table 3
Heterogeneity test based on corporate property rights.

Variables	SOEs	N-SOEs
	Model 1	Model 2
cpu	−0.413***	−0.637***
	(-3.47)	(-5.85)
Constant	−5.858***	−4.333***
	(-15.97)	(-12.76)
Control	YES	YES
Observations	4277	9965
R-squared	0.186	0.153

Notes: t-statistics are in parentheses. *, **, and *** respectively represent significance at the 10%, 5%, and 1% levels.

Table 4
Heterogeneity test based on industry differences.

Variables	Resources	Labor	Capital	Technology
	Model 1	Model 2	Model 3	Model 4
cpu	−0.223	−0.388***	−0.291**	−0.789***
	(-0.46)	(-3.49)	(-2.24)	(-5.69)
Constant	−9.689***	−4.403***	−3.416***	−5.108***
	(-6.51)	(-10.74)	(-9.79)	(-11.40)
Control	YES	YES	YES	YES
Observations	412	2933	3938	6687
R-squared	0.357	0.146	0.129	0.176

Notes: t-statistics are in parentheses. *, **, and *** respectively represent significance at the 10%, 5%, and 1% levels.

number of technical equipment and funds, and their production processes have the characteristics of high productivity and low consumption, allowing them to quickly adapt to changes in climate policy and achieve the "innovation compensation effect" through resource reallocation to counteract the "compliance cost effect". Finally, labor-intensive companies are less dependent on technology and equipment, and there is not much demand for technological innovation, so climate policy uncertainty has no obvious impact on technological innovation of labor-intensive companies.

4.3. Test of mechanism

4.3.1. Test of mediating mechanism

Executives find it more challenging to weigh the future advantages and dangers of green investments when climate policy uncertainty is high. Because of the irreversibility of R&D investment, such as the irreversible expenditure on scientific researchers, machinery and raw materials, etc., so when the uncertainty of climate policy increases, companies will face a more complex internal and external environment, in order to ensure that companies can operate normally, companies will automatically avoid risks, strengthen prevention, disperse unsystematic risks, adopt a more cautious attitude to allocate funds, companies may reduce investment in high-risk activities such as green innovation.

In order to determine the mediating function of R&D expenditure in the influence of CPU on corporate green innovation, we built a mediating effect model. The amount of money invested in technology R&D by corporations each year is used in this article to illustrate R&D investment(*RD*). In Column (2) of Table 5, CPU significantly and negatively affects corporate R&D investment at the 1% level, indicating that if there are fluctuations in climate policies, corporations will spend less human and financial resources on new technologies and products. According to the regression results in the third column, The regression coefficient of RD is significantly positive, demonstrating a considerable positive association between it and corporate green technology innovation. Collectively, these results suggest that R&D investment acts as a part mediator role between CPU and green technology innovation.

Second, we assume that corporate risk tolerance can be used as a mediating variable to transmit the consequences of climate policy uncertainty to companies' green technology innovation. Due to the uncertainty of climate policies, future financing difficulties will increase, resulting in an increase in financing costs, which in turn will lead to a decrease in the company's risk tolerance, which will lead to a conservative use of corporate funds, reduce investment in high-risk, high-yield projects, and be willing to invest in low-risk, low-yield projects, so that companies will reduce investment in green R&D activities. In this article, we use Return on Total Assets (Ratio of net profit to average total assets) to measure a company's risk tolerance and record it as an *roa*. As shown in Table 5 columb (6), a corporate's output of green technology increases as its tolerance for risk rises. However, given that the corporate's tolerance for risk is known to be declining as climate risk volatility

Table 5
Mediating effect test.

Variables	GTI	RD	GTI	GTI	roa	GTI
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
cpu	−0.517***	−0.217***	−0.477***	−0.517***	−0.056***	−0.497***
	(-6.46)	(-2.76)	(-6.12)	(-6.46)	(-12.01)	(-6.17)
rd			0.101***			
			(4.58)			
roa						0.352***
						(2.89)
Constant	−5.187***	0.084	−5.198***	−5.187***	−0.095***	−5.154***
	(-20.79)	(0.43)	(-20.92)	(-20.79)	(-7.34)	(-20.61)
Control	YES	YES	YES	YES	YES	YES
Observations	14,242	14,208	14,208	14,242	14,242	14,242
R-squared	0.163	0.872	0.165	0.163	0.227	0.164

Notes: t-statistics are in parentheses. *, **, and *** respectively represent significance at the 10%, 5%, and 1% levels.

rises in column (5), so the corporate's risk tolerance as a mediating variable makes a negative connection between CPU and corporate's green technology innovation.

4.3.2. *Test of moderating mechanism*

As the most direct financial tool, government subsidies will not only affect corporate financing, but also affect corporate innovation decisions, which in turn will act on the CPU and corporate green technology innovation activities (Li et al., 2021). Government support through subsidies and other policies has provided companies with sufficient R&D funds, reduced the financing pressure faced by companies, and thus enhanced the enthusiasm of companies to carry out green technology innovation activities. Environmental regulations may influence the interaction between CPU and corporate green innovation activities as a binding force (Kneller and Manderson, 2012; Rubashkina et al., 2015). If environmental pollution penalties are increased, companies will respond by implementing green investments in advance, and increasing the intensity of environmental regulations will force companies to increase green investments and enhance green innovation productivity. When the government promulgates environmental regulation policies, companies must comply with environmental regulations in order to maintain their credibility, increase green capital investment to carry out green technological innovation and combat pollution emissions.

This section discusses how government subsidies and environmental regulations act as moderating variables on CPU and corporate green innovation. We define government subsidies as the sum that corporate receive from the government each year, which is recorded as *sub*, and use the share of completed investment in industrial pollution control as a percentage of industrial value added in the province where the corporate is located to represent environmental regulation, which is recorded as *regul*. We use the following model for regression analysis:

$$GTI_{it} = \alpha + \beta CPU_{t-1} + \beta_1 sub + \beta_2 sub * CPU_{t-1} + \gamma X_{it} + Year_t + Ind_i + \varepsilon_{it} \tag{2}$$

$$GTI_{it} = \alpha + \beta CPU_{t-1} + \beta_1 regul + \beta_2 regul * CPU_{t-1} + \gamma X_{it} + Year_t + Ind_i + \varepsilon_{it} \tag{3}$$

Table 6 Column (2) shows the results of empirical analysis of the moderating effect of government subsidies, and the empirical results show that the coefficient of CPU is −0.459, which is significant at 1% statistical level, and the coefficient of the interaction term between the CPU index and government subsidies (sub*CPUt-1) is 0.0004, which is significant at 5% statistical level, which indicates that the government subsidies weakly inhibit the inhibitory effect of CPU on companies' green investment. Column (4) shows the results of the empirical analysis of the moderating effect of environmental regulation. The empirical results show that the coefficient of CPU is −0.319, which is significant at 1% statistical level, and the coefficient of the interaction term of CPU and environmental regulation (regul*CPUt-1) is 0.0512, which is significant at 5% statistical level, indicating that the environmental regulation likewise weakens the inhibitory effect of CPU on companies' green investment.

Table 6
Moderating effect test.

Variables	GTI			
	Model 1	Model 2	Model 3	Model 4
cpu	−0.5171***	−0.4598***	−0.5171***	−0.5290**
	(-6.46)	(-5.92)	(-6.46)	(-6.40)
sub		0.0003*		
		(1.88)		
sub*CPU		0.0004**		
		(2.39)		
regul				0.0470**
				(3.99)
regul*CPU				0.0514**
				(-2.49)
Constant	−5.1872***	−4.1596***	−5.1872***	−5.5234***
	(-20.79)	(-17.09)	(-20.79)	(-20.45)
Control	YES	YES	YES	YES
Observations	14,242	14,187	14,242	13953
R-squared	0.163	0.191	0.163	0.164

Notes: t-statistics are in parentheses. *, **, and *** respectively represent significance at the 10%, 5%, and 1% levels.

4.4. *Robustness test*

In this section, we replace the time span of the sample and use the instrumental variables method to verify the reliability of the above empirical results.

To minimize the effects of the financial crisis and the COVID, we narrowed the time range of the sample data, keeping just the years

Table 7
Robustness Test: Using subsample regression.

Variables	GTI	2011–2019
	Model 1	Model 2
lcpu	−0.517***	−4.513***
	(-6.46)	(-4.88)
Constant	−5.187***	2.988**
	(-20.79)	(2.29)
Control	YES	YES
Observations	14,242	11,896
R-squared	0.163	0.033
Number of stkcd		2308

Notes: t-statistics are in parentheses. *, **, and *** respectively represent significance at the 10%, 5%, and 1% levels.

2011–2019. The outcomes of the sample subinterval estimation are displayed in Table 7. The outcomes are very compatible with those of the reference model.

To reduce endogenous bias, we used Global Average Surface Temperature (*GMST*) as an instrumental variable for the CPU. A valid instrumental variable needs to meet both correlation and exogenous conditions. On the one hand, GMST is one of the key indicators for in-depth understanding of the impact of human activities on global climate change, which can directly reflect climate fluctuations and is also one of the reference factors for climate policy formulation, so GMST is highly correlated with CPU. On the other hand, GMST depends on global natural conditions, which influence climate policy formulation and generally do not directly affect the output of green technologies or products, therefore the instrumental variable is exclusive.

The second column of Table 8 demonstrates that the CPU increases with increasing GMST. The third column shows the regression results of the second stage in the 2SLS method, with no change in the significance or sign of the core variables compared to the baseline regression results. Robustness analysis shows that our benchmark regression results are valid and reliable.

Table 8
Robustness Test: Instrumental variable method.

Variables	OLS	first	two
	GTI	cpu	GTI
	Model 1	Model 2	Model 3
cpu	−0.517***		−0.253***
	(-6.46)		(-5.65)
GMSF		1.416***	
		(41.75)	
Constant	−5.187***	−1.159***	−5.809***
	(-20.79)	(-12.31)	(-34.05)
Control	YES	YES	YES
Observations	14,242	14,242	14,242
R-squared	0.163	0.135	0.152

Notes: t-statistics are in parentheses. *, **, and *** respectively represent significance at the 10%, 5%, and 1% levels.

5. Conclusions and policy implications

This study emphasizes the impact of policy uncertainty on companies' green technology innovation, a relatively little-addressed topic to date. Using a sample of Chinese a-share listings from 2009 to 2020, we provide new evidence that climate policy uncertainty has a negative impact on green innovation. This effect appears to be mediated by companies' R&D investment and risk tolerance. We also find that the disincentive effect of CPU on green innovation is greater in resource-intensive and technology-intensive industries. Our analysis suggests that strict environmental regulations and higher government subsidies can mitigate the negative impact of climate policy volatility.

Firstly, uncertainty associated with economic policies can have a negative impact on companies' environmental innovation efforts, so improving the relative predictability and transparency of government policies is likely to have a significant role in improving green technological innovation, creating a favorable macroeconomic policy environment, reducing economic policy uncertainty at the source, and creating a good environment conducive to green investment by companies.

Secondly, the findings of this paper show that the level of R&D of companies is greatly constrained by capital, for which the financial and monetary sectors should promptly improve the level of capital supply to ease the financial pressure of companies particularly private and small companies, which in China have greater difficulty in obtaining financing from banks and usually have a higher cost of capital. Meanwhile, the government should broaden the service areas of the financial market, enhance the role of various financial institutions in the financial industry, and develop financing channels and financing methods, so that the restrictions faced by Chinese companies in fundraising can be reduced, and investment can be promoted.

Finally, in order to avoid "one-size-fits-all" general policies, the heterogeneous characteristics of companies, such as their ownership structure and industry characteristics, should be fully taken into account. Different incentives should also be adopted for various corporate types in order to strengthen their resistance to changes in external environmental policies and boost their enthusiasm for green innovation. To maximize their capacity for innovation, businesses should take into account their particular resource endowments and characteristics while making green investments.

Credit author statement

Shuhai Niu: Conceptualization, Methodology, Writing-original draft, Writing-review & editing, Visualization. Juan Zhang: Validation, Formal analysis, Investigation, Resources, Writing-original draft, Visualization. Renfu Luo: Writing-review&editing, Methodology, Visualization, Supervision. Yanchao Feng: Investigation, Resources, Data collection.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Anginer, D., Demirguc-Kunt, A., Zhu, M., 2014. How does competition affect bank systemic risk? J. Financ. Intermediation 23, 1–26. https://doi.org/10.1016/j.jfi.2013.11.001.

Azimli, A., 2023. The impact of climate policy uncertainty on corporate value: does corporate social responsibility engagement matter? Finance Res. Lett. 51, 103456 https://doi.org/10.1016/j.frl.2022.103456.

Barbieri, N., Marzucchi, A., Rizzo, U., 2020. Knowledge sources and impacts on subsequent inventions: do green technologies differ from non-green ones? Res. Pol. 49, 103901 https://doi.org/10.1016/j.respol.2019.103901.

Berrang-Ford, L., Ford, J.D., Paterson, J., 2011. Are we adapting to climate change? Glob. Environ. Change-Human Policy Dimens. 21, 25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012.

Bloom, N., 2009. The impact of uncertainty shocks. Econometrica 77, 623–685. https://doi.org/10.3982/ecta6248.

Bostandzic, D., Weiss, G.N.F., 2018. Why do some banks contribute more to global systemic risk? J. Financ. Intermediation 35, 17–40. https://doi.org/10.1016/j.jfi.2018.03.003.

Bouri, E., Iqbal, N., Klein, T., 2022. Climate policy uncertainty and the price dynamics of green and brown energy stocks. Finance Res. Lett. 47, 102740 https://doi.org/10.1016/j.frl.2022.102740.

Chen, X., Fu, Q., Chang, C.P., 2021. What are the shocks of climate change on clean energy investment: a diversified exploration. Energy Econ. 95, 105136 https://doi.org/10.1016/j.eneco.2021.105136.

Cooper, I., Priestley, R., 2011. Real investment and risk dynamics. J. Financ. Econ. 101 (1), 182–205. https://doi.org/10.1016/j.jfineco.2011.02.002.

Denis, D.J., Sibilkov, V., 2010. Financial constraints, investment, and the value of cash holdings. Rev. Financ. Stud. 23 (1), 247–269. https://doi.org/10.1093/rfs/hhp031.

Dixit, R.K., Dixit, A.K., 1994. Pindyck R S. Investment under Uncertainty. Princeton university press.

Drobetz, W., El Ghoul, S., Guedhami, O., Janzen, M., 2018. Policy uncertainty, investment, and the cost of capital. J. Financ. Stabil. 39, 28–45. https://doi.org/10.1016/j.jfs.2018.08.005.

Drouet, L., Bosetti, V., Tavoni, M., 2015. Selection of climate policies under the uncertainties in the fifth assessment report of the IPCC. Nat. Clim. Change 5, 937. https://doi.org/10.1038/nclimate2721.

Earnhart, D., 2004. Regulatory factors shaping environmental performance at publicly-owned treatment plants. J. Environ. Econ. Manag. 48, 655–681. https://doi.org/10.1016/j.jeem.2003.10.004.

Engle, R.F., Giglio, S., Kelly, B., Lee, H., Stroebel, J., 2020. Hedging climate change news. Rev. Financ. Stud. 33, 1184–1216. https://doi.org/10.1093/rfs/hhz072.

Fuss, S., Szolgayova, J., Obersteiner, M., Gusti, M., 2008. Investment under market and climate policy uncertainty. Appl. Energy 85, 708–721. https://doi.org/10.1016/j.apenergy.2008.01.005.

Gavriilidis, K., 2021. Measuring Climate Policy Uncertainty. https://doi.org/10.2139/ssrn.3847388.
Ghisetti, C., Quatraro, F., 2017. Green technologies and environmental productivity: a cross-sectoral analysis of direct and indirect effects in Italian regions. Ecol. Econ. 132, 1–13. https://doi.org/10.1016/j.ecolecon.2016.10.003.
Ginbo, T., Di Corato, L., Hoffmann, R., 2021. Investing in climate change adaptation and mitigation: a methodological review of real-options studies. Ambio 50, 229–241. https://doi.org/10.1007/s13280-020-01342-8.
Golub, A.A., Lubowski, R.N., Piris-Cabezas, P., 2020. Business responses to climate policy uncertainty: theoretical analysis of a twin deferral strategy and the risk-adjusted price of carbon. Energy 205, 117996. https://doi.org/10.1016/j.energy.2020.117996.
Grundy, B.D., Li, H., 2010. Investor sentiment, executive compensation, and corporate investment. J. Bank. Finance 34 (10), 2439–2449. https://doi.org/10.1016/j.jbankfin.2010.03.020.
Han, X.Y., Cao, T.Y., 2021. Study on corporate environmental responsibility measurement method of energy consumption and pollution discharge and its application in industrial parks. J. Clean. Prod. 326, 129359 https://doi.org/10.1016/j.jclepro.2021.129359.
He, L.Y., Zhang, L.H., Zhong, Z.Q., Wang, D.Q., Wang, F., 2019. Green credit, renewable energy investment and green economy development: empirical analysis based on 150 listed companies of China. J. Clean. Prod. 208, 363–372. https://doi.org/10.1016/j.jclepro.2018.10.119.
Hemrit, W., Benlagha, N., 2021. Does renewable energy index respond to the pandemic uncertainty? Renew. Energy 177, 336–347. https://doi.org/10.1016/j.renene.2021.05.130.
Hong, H., Karolyi, G.A., Scheinkman, J.A., 2020. Climate finance. Rev. Financ. Stud. 33, 1011–1023. https://doi.org/10.1093/rfs/hhz146.
Husain, S., Sohag, K., Wu, Y.R., 2022. The response of green energy and technology investment to climate policy uncertainty: an application of twin transitions strategy. Technol. Soc. 71, 102132 https://doi.org/10.1016/j.techsoc.2022.102132.
Ioulianou, S., Trigeorgis, L., Driouchi, T., 2017. Multinationality and corporate value: the role of real options awareness. J. Corp. Finance 46, 77–96. https://doi.org/10.1016/j.jcorpfin.2017.06.011.
Kammerer, D., 2009. The effects of customer benefit and regulation on environmental product innovation. Empirical evidence from appliance manufacturers in Germany. Ecol. Econ. 68, 2285–2295. https://doi.org/10.1016/j.ecolecon.2009.02.016.
Kling, G., Volz, U., Murinde, V., Ayas, S., 2021. The impact of climate vulnerability on corporates' cost of capital and access to finance. World Dev. 137, 105131 https://doi.org/10.1016/j.worlddev.2020.105131.
Kneller, R., Manderson, E., 2012. Environmental regulations and innovation activity in UK manufacturing industries. Resour. Energy Econ. 34, 211–235. https://doi.org/10.1016/j.reseneeco.2011.12.001.
Li, Y.Y., Zhang, Y.R., Lee, C.C., Li, J., 2021. Structural characteristics and determinants of an international green technological collaboration network. J. Clean. Prod. 324, 129258 https://doi.org/10.1016/j.jclepro.2021.129258.
Liang, C., Umar, M., Ma, F., Huynh, T.L.D., 2022. Climate policy uncertainty and world renewable energy index volatility forecasting. Technol. Forecast. Soc. Change 182, 121810. https://doi.org/10.1016/j.techfore.2022.121810.
Lv, W., Li, B., 2023. Climate policy uncertainty and stock market volatility: evidence from different sectors. Finance Res. Lett. 51, 103506.
Pülzl, H., Treib, O., 2017. Implementing public policy. Handbook of public policy analysis. Routledge 115-134. https://doi.org/10.1016/j.frl.2022.103506.
Ren, X.H., Zhang, X., Yan, C., Gozgor, G., 2022. Climate policy uncertainty and corporate-level total factor productivity: evidence from China. Energy Econ. 113, 106209 https://doi.org/10.1016/j.eneco.2022.106209.
Richardson, S., 2006. Over-investment of free cash flow. Rev. Account. Stud. 11, 159–189. https://doi.org/10.1007/s11142-006-9012-1.
Rubashkina, Y., Galeotti, M., Verdolini, E., 2015. Environmental regulation and competitiveness: empirical evidence on the Porter Hypothesis from European manufacturing sectors. Energy Pol. 83, 288–300. https://doi.org/10.1016/j.enpol.2015.02.014.
Sarkar, R., 2008. Public policy and corporate environmental behaviour: a broader view. Corp. Soc. Responsib. Environ. Manag. 15, 281–297. https://doi.org/10.1002/csr.167.
Shahid, M.S., Abbas, M., 2019. Does corporate governance play any role in investor confidence, corporate investment decisions relationship? Evidence from Pakistan and India. J. Econ. Bus. 105, 105839 https://doi.org/10.1016/j.jeconbus.2019.03.003.
Shang, Y.F., Han, D., Gozgor, G., Mahalik, M.K., Sahoo, B.K., 2022. The impact of climate policy uncertainty on renewable and non-renewable energy demand in the United States. Renew. Energy 197, 654–667. https://doi.org/10.1016/j.renene.2022.07.159.
Tian, H., Long, S.B., Li, Z.X., 2022. Asymmetric effects of climate policy uncertainty, infectious diseases-related uncertainty, crude oil volatility, and geopolitical risks on green bond prices. Finance Res. Lett. 48, 103008 https://doi.org/10.1016/j.frl.2022.103008.
Tran, Q.T., 2019. Economic policy uncertainty and corporate risk-taking: international evidence. J. Multinatl. Financ. Manag. 52–53, 100605 https://doi.org/10.1016/j.mulfin.2019.100605.
Tserlukevich, Y., 2008. Can real options explain financing behavior? J. Financ. Econ. 89 (2), 232–252. https://doi.org/10.1016/j.jfineco.2007.11.003.
Victor, D.G., 2015. Embed the social sciences in climate policy. Nature 520, 27–29. https://doi.org/10.1038/520027a.
Wang, C.C., Geng, L.N., Rodriguez-Casallas, J.D., 2021. How and when higher climate change risk perception promotes less climate change inaction. J. Clean. Prod. 321, 128952 https://doi.org/10.1016/j.jclepro.2021.128952.
Wang, Y., Shen, N., 2016. Environmental regulation and environmental productivity: the case of China. Renew. Sustain. Energy Rev. 62, 758–766. https://doi.org/10.1016/j.rser.2016.05.048.
Wang, Y., Sun, X.H., Guo, X., 2019. Environmental regulation and green productivity growth: empirical evidence on the Porter Hypothesis from OECD industrial sectors. Energy Pol. 132, 611–619. https://doi.org/10.1016/j.enpol.2019.06.016.
Wen, H.W., Lee, C.C., Zhou, F.X., 2022. How does fiscal policy uncertainty affect corporate innovation investment? Evidence from China's new energy industry. Energy Econ. 105, 105767 https://doi.org/10.1016/j.eneco.2021.105767.
Wu, H.T., Hao, Y., Ren, S.Y., 2020. How do environmental regulation and environmental decentralization affect green total factor energy efficiency: evidence from China. Energy Econ. 91, 104880 https://doi.org/10.1016/j.eneco.2020.104880.
Xia, L., Gao, S., Wei, J.C., Ding, Q.Y., 2022. Government subsidy and corporate green innovation-Does board governance play a role? (vol 161, 112720, 2022. Energy Pol. 168, 113115 https://doi.org/10.1016/j.enpol.2022.113115.
Xu, Y.A., Li, M., Yan, W., Bai, J.C., 2022. Predictability of the renewable energy market returns: the informational gains from the climate policy uncertainty. Resour. Pol. 79, 103141 https://doi.org/10.1016/j.resourpol.2022.103141.
Yan, W.L., 2022. The dynamic spillover effects of climate policy uncertainty and coal price on carbon price: evidence from China. Finance Res. Lett. 103400 https://doi.org/10.1016/j.frl.2022.103400.
Yu, S.W., Zheng, Y.L., Hu, X., 2022. How does climate change affect corporates' investment efficiency? Evidence from China's listed renewable energy corporates. Bus. Strat. Environ. https://doi.org/10.1002/bse.3349.