Journal of Cleaner Production 363 (2022) 132645

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Effect of policy uncertainty on environmental innovation

Khine Kyaw

NTNU Business School, Norwegian University of Science and Technology, Klaebuveien 72, 7030, Trondheim, Norway

A R T I C L E I N F O

Handling Editor: Mingzhou Jin

Keywords:
Policy uncertainty
Environmental innovation
Environmental sustainability
Climate change
Sustainable development

A B S T R A C T

Uncertainty in economic policies and regulations incentivizes firms to delay investments in environmental research and developments (R&D) or postpone environmental projects that are costly to undo. A consequence of those decisions is that firms innovate less for the environment. Using 1026 U.S. firm data (equivalent to 13,241 firm-year observations) this study shows that a negative effect of policy uncertainty – a drop in environmental innovation – does not surface in the short term but in the longer term, i.e., in 5–6 years' time. The negative effect, nevertheless, dissipates after six years. These findings are of relevance to other developed countries as well as emerging countries that have a relatively higher uncertainty in their economic policies and regulations. In sum, the results call for attention from governments and regulators around the world: ***uncertainty in policies and regulations are detrimental to combating climate change and promoting environmental sustainability***.

1. Introduction

United Nations Sustainable Development goal 13 calls for urgent actions to combat climate change. Accordingly, businesses find ways to reduce emissions such as greenhouse gas to reduce further destruction of the ozone layer, while restoring damages that have already been done the environment (www.UN.org). To do so, businesses need to discover alternative ways of doing the 'usual business' – i.e., businesses need to innovate in their product, process and/or approach. However, environmental innovations are long term processes which require long term commitments from the firms, in terms of strategy formulations, decision making processes, organizational environment, and investments in research and developments (R&D).

Critical to long-term investments and strategy formulations is predictability in governmental policies and regulations. Concerns about economic policies and regulations tend to intensify in the wake of an economic situation which can potentially have negative effects on businesses, such as at the onset of a global financial crisis. Thus, uncertainty in economic policies can thwart firms' willingness to plan and commit for long term while reversing the reversable investment decisions. In other words, uncertainty in policies and regulations – policy uncertainty – can have a negative impact on firms' innovation process. This paper addresses this by attending to the question: ***does policy uncertainty affect firms' environmental innovation?***

This study contributes to the literature in several ways. First, despite the ample evidence in the literature that uncertainty influences firms' investment decisions, relatively little is known about the influence uncertainty has on environmental innovation. Studies have shown that the effects of economic factors are different across different types of investments, i.e., investments in tangible assets versus investments in intangible assets (Becker-Blease and Paul, 2006; Derrien and Kecskes, 2013). Meanwhile, R&D investment (i.e., investment in intangible assets) is critical for environmental innovation. Although R&D investments are highly susceptible to uncertainty due to the long horizon and the risks involved, some empirical evidence shows a positive effect of uncertainty on R&D investments (see for example, Stein and Stone, 2013.) Therefore, it is unclear whether policy uncertainty affects environmental innovation. Second, understanding the effects policy uncertainty have on firms' environmental innovation will contribute to the wider debate on climate change. Third and finally, despite the evidence in the literature that governmental policies affect environmental innovation, the effect of an uncertainty in the governmental policies is yet to be explored. Xu (2020) has examined the effect of policy risk on the number of patents granted to a firm, but the study has not distinguished whether the patents granted is directed towards addressing the environmental issues or not. Similarly, Bhattacharya et al. (2017) focus on firms' efforts towards technological innovation to promote a nation's long-term economic growth and competitive advantage. Unlike those papers, this study sheds more light specifically on a firm's effort to innovate for the environment.

The paper is structured as follows: Section 2 provides an overview of the literature, while Section 3 describes the data, variables and methodology. Section 4 presents the results, and Section 5 concludes.

E-mail address: khine.kyaw@ntnu.no.

https://doi.org/10.1016/j.jclepro.2022.132645
Received 30 May 2021; Received in revised form 26 May 2022; Accepted 7 June 2022
Available online 11 June 2022
0959-6526/

2. Literature review

2.1. Environmental innovation

Environmental innovation is critical in combating climate change and promoting environmental sustainability. Hellstrom (2007) notes that innovation can take one of five forms: (1) introduction of a new good, (2) introduction of a new method of production, (3) opening a new market, (4) use of a new source of raw materials or half-manufactured goods, and/or (5) creating a new organization of an industry. Environmental innovation is mainly driven by external factors such as the government (Horbach, 2008), customers (Huang et al., 2016), peer group (Yalabik and Fairchild, 2011), and the general public (Liao et al., 2020).

In the context of climate change, environmental innovation may involve, among many others, reducing environmental impacts through waste minimization (Norberg-Bohm, 1999), introducing new products that are environmental friendly through technologies (Blatt-Mink, 1998; Godil et al., 2021; Tabrizian, 2019), incorporating environmental concerns into corporate strategies and decision makings (Murphy and Gouldson, 2000; Wijethilake et al., 2018), learning from and integrating partners along a supply chain (Kong et al., 2020; Lisi et al., 2019).

Nevertheless, may it be a new waste minimization program, new technologies, new corporate strategies and decision-making process, or learning from and integrating partners along a supply chain, they all involve long term planning and execution. A new waste minimization program involves careful planning, testing and implementation over the years. New technologies require investments in long term R&Ds projects – labor and financial resources predominantly. Formulation of new corporate strategies and implementation of a new decision-making process need organizational adjustments. Or, establishing a relationship with the partners along a supply chain can take years. As Tyfield et al. (2015) point out, there also is a need for a skilled workforce who can serve environmental innovations that may emerge. Thus, environmental innovation is a long-term process. Song et al. (2019) show that to promote green product innovation firms need to shape the organizational climate in order that creativity prospers. Organization climate that is receptive to new ideas fosters creative thinking, which can enhance resource use efficiency and green creativity (Song et al., 2019). Along the line, Kyaw et al. (2021) show that inclusive corporate environment is positively linked to firms' innovation. However, an organizational change takes a long time.

The literature has identified various external and internal factors that affect environmental innovation. External factors motivate a firm to innovate. For instance, market competition (Wang et al., 2021a,b), investors (Wang et al., 2022) and parties along the value-chain (Darnall et al., 2010) encourage a firm to innovate. In other words, external factors put pressure on the management of a firm to orientate towards environmental innovation (Zhou et al., 2021).

A firm's ability to address the external pressures, however, depends on the firm's internal factors (Wang and Jiang, 2021; Zhang et al., 2020). For instance, to increase the chance of a successful innovation, firms need to build up its human capital resource. The quality, such as the experience and qualification, and the morale of the employees are instrumental for the ability to develop a successful environmental innovation (Kyaw et al., 2021; Wang et al., 2021a,b). Because a 'knowledge pool' is built up over a long horizon, it requires firms' long-term planning and commitments. Furthermore, the key to building human capital and making the necessary physical investments for innovation is a firm's ability to generate financial capital, not only at the present but also in the future (Desheng et al., 2021; Wang et al., 2022; Yang et al., 2022; Zhang et al., 2022). And governmental policies and regulations affect a firm's ability to generate the funds in the future.

Governmental policies and regulations provide the context that influences a firm's environmental innovation either directly or indirectly. Subsidies, environmental tax, carbon emission reduction measures, and/or green credit policy have a direct effect on firms' environmental innovation (Zhao and Sun, 2016; Tsai and Liao, 2017; Li and Zeng, 2020; Wang et al., 2021a,b; Chen et al., 2022; Xiang et al., 2022; Zhang et al., 2022). That is, governmental policies and regulations influence the level of financial capital available for environmental innovation. They can also indirectly affect the external factors a firm is subject to. Chen et al. (2022) find that environmental regulations and government policies can indirectly affect corporate environmental innovation through the competition in the banking sector. Moreover, government may introduce measures that can indirectly motivate a firm's desire to innovate (Shen et al., 2021; Zhou et al., 2021). For instance, Zhang et al. (2022) show that when the Chinese government adopt a policy to improve the speed and the disclosure of air quality data for the public, environmental innovation in firms has increased. Moreover, government's industrial policy such as solar and energy policies (Pegels and Lütkenhorst, 2014; Song and Zhou, 2021; Yang et al., 2022; Zhu and Tan, 2022), carbon emissions trading scheme (Zhou and Wang, 2022), environmental protection law (Liu et al., 2021), and/or green credit policy (Chen et al., 2022; Zhang et al., 2022) have shown to exert positive effects on environmental innovation.

All in all, governmental policies and regulations exert both direct and indirect effects on environmental innovation in firms. However, innovation entails long-term planning and investments in human and physical infrastructure. Thus, predictability in governmental policies and regulations is paramount if firms were to plan, take the risk and invest for a long horizon. That is, uncertainty in governmental policies can have detrimental effects on firms' environmental innovation.

2.2. Uncertainty

Firms do not operate in vacuum, but in the framework set by politicians and regulatory institutions. In other words, firms are subject to decisions made by politicians and regulatory institutions. Uncertainty regarding the timing, content and potential impact of policy decisions affects the economic environment within which a firm operates and thus has important economic consequences for firms. Reports by The International Monetary Fund (IMF) on 2012–2013 world economic outlook suggest that uncertainty in economic policy – fiscal, monetary and regulatory – contributed to the economic depression in 2008–2009 and the slow subsequent recoveries across the globe (IMF, 2012,2013). Thus, policy uncertainty easily translates into uncertain financial situation ahead at the firm level. Consequently, policy uncertainty is associated with greater stock price volatility, reduced employment and reduced investments (Baker et al., 2016) while households cut back their spending (Gilchrist et al., 2014). At a more granular level, managerial cognition of policy uncertainty at the macro level translates the uncertainty into strategy and organizational outcomes (Yang et al., 2019). In this respect, Yang et al. (2019) show that in China, managers' perception of business and social pressures is positively associated with proactive environmental strategy. Chatjuthamard et al. (2020) show that economic policy uncertainty effects managerial risk taking. The authors find that as economic uncertainty heightened managers became extra cautious and choose sub-optimal investment decisions (see also Gulen and Ion, 2015; Panousi and Papanikolaou, 2012).

Economic literature has distinguished the influence of different types of uncertainty on R&D investments. Stein and Stone (2013) find that the market's anticipated firm-level volatility as indicated by the implied volatility from equity options is positively related to R&D investments. Since the uncertainty at firm-level can be diversified away, Xu (2020) examine the effect of the aggregate policy risk, an uncertainty that affects the general economic environment rather than a specific firm. The author finds that the aggregate policy risk has negative impact on firms' R&D investments. From a cross-country data, Bhattacharya et al. (2017) find that uncertainty regarding the national election outcomes along the liberal-conservative spectrum, and thus the relative importance of economic policies, affect negatively a nation's technological innovation directed towards a nation's long-term economic growth. Thus, uncertainty in the policies that can affect the economic environment, rather than a firm-specific uncertainty or the relative importance of various policies, is of relevance and interest for the environmental innovation study here.

Policy uncertainty arises from uncertainty concerning future policies. And it can instigate market- and economy-wide uncertainty. Public economics literature has documented evidence in support of the preposition that policy uncertainty, in particular tax policy uncertainty, can adversely affect firms' investments (see for example, Rodrik, 1991; Dixit and Pindyck, 1994.) Policy uncertainty imposes a price, explicitly and/or implicitly, on the costs of carbon emissions, recycling program, and so on. Consequently, firms seek to address the environmental issues at a lowest possible cost. However, the uncertainty regarding the stringency, nature and timing of the policies to come into effect may encourage firms to delay the investments that can potentially address the environmental issues.

2.3. Theoretical underpinnings for uncertainty-innovation link: adjustment cost vs investment lag

Bernanke (1983) and McDonald and Siegel (1986), among others, have provided the theoretical framework where uncertainty – uncertainty over the future price – enters the investment decisions through adjustment costs. Firms consider adjustment costs – i.e., reversibility of investments – when making investment decisions. When reversibility is costly, i.e., adjustment costs are high, the real-option feature of investment changes as the value of the option to wait increases. This consequently changes the optimal timing of an investment. Empirical evidence is in support of the theoretical predictions. For example, Gulen and Ion (2016), among others, show that firms delay investments in fixed assets when faced with policy uncertainty (see also, Bloom, 2009.)

The framework by Bar-Ilan and Strange (1996) focuses on convexity in the profit function (see also Hartman, 1972; Abel, 1983). Authors claim that profit function is convex when there is some lag before new investments become productive. In investment irreversibility framework of Bernanke and others, firms delay investments in order to avoid learning of low prices after it has made an investment decision involving high adjustment cost. In this framework, the benefit of waiting rises as the likelihood of observing a low price rises with uncertainty. On the contrary, in investment-lag framework, due to some lag before an investment can become operational a firm that has waited can miss out on an opportunity to enter the market immediately when a high price is observed. In other words, the opportunity cost of waiting does not depend on the price during the delay, but on the price in the future. And the opportunity cost of waiting increases with uncertainty as longer lags increase the likelihood of higher prices. The implicit assumption in this framework is that firms' profits in bad states are bounded below as the adjustment costs are relatively low. Hence, with investment lags, it is possible that uncertainty hastens the decision to invest in order to avoid learning of high prices while the investments are not operative yet. Bar-Ilan and Strange (1996) show numerically that the lag-effect can thus dominate the adjustment-cost-effect. Stein and Stone (2013) provide empirical evidence in support of this theory.

Complementing the frameworks are studies that have examined different types of investments – investments in tangible assets such as capital expenditures versus investments in intangible assets such as R&D investments. Those studies generally have documented that different types of investment exhibited different sensitivities to economic factors (Becker-Blease and Paul, 2006; Derrien and Kecskes, 2013; Xu, 2020). R&D investments represent investments for innovation, but capital expenditures are investments in physical assets. Yet, both types of investment involve some investment lag: relatively longer in the case of R&D investments compared to the case of capital expenditures. Moreover, capital expenditures culminate in a productive operation, but R&D investments may or may not yield a positive outcome. Thus, R&D investments are linked to *potential* generation of positive outcomes in a distant future, while capital expenditures produce tangible outcomes in a near future.

Moreover, environment innovations are subject to certain policy uncertainty. For instance, as information becomes available over time the world becomes aware of certain environmental damages that were unknown before. In response, policies and regulations change as the benefits of policy/regulatory interventions outweighs the costs of non-interventions (Baker and Adu-Bonnah, 2008; Kalamova et al., 2012.) Therefore, policies change as policymakers acquire new information.

Thus, R&D investments and consequently environmental innovations will be highly susceptible to uncertainty and firms may postpone investment decisions as uncertainty looms (adjustment cost effect) – i.e., uncertainty can pause firms' investments in innovative activities. This together with the lag effect posits that there may appear certain pattern in firms' environmental innovation as uncertainty looms.

Based on the above discussions, we formulate the following hypotheses:

H1. negative effects of policy uncertainty on firm environmental innovation will not be prevalent in the short run.

H2. policy uncertainty negatively affects firm environmental innovation in the longer run.

3. Data, variables and methodology

We collect environmental innovation data on US firms from Thomson Reuters Refinitiv database. The database collects data points on a wide range of concepts related to firm environmental innovation from various publicly available information sources, ranging from company reports such as the annual reports, corporate social responsibility reports, and so on, to news media and NGO websites. The collected data points are then converted into environmental innovation score using percentile rank scoring approach. Thus, the environmental innovation score represents a firm's performance in terms of environmental innovation. The resulting environmental innovation score reflects a firm's capacity to reduce the environmental costs and burdens for its customers, and thereby creating new market opportunities through new environmental technologies and processes or eco-designed products. The score encapsulates a firm's input into and output from activities targeted towards environmental improvement or mitigation of environmental degradation. Thomson Reuters began the data collection in 2002. Thus, the sample period covers the period from 2002 through 2020.

The environmental innovation score covers a total of 36 data points. Those data points cover:

3.1. Product innovation

- whether the company has one or more product line or service that is designed to have positive effects on the environment, or is environmentally labeled and marketed
- whether the company develops products or technologies for use in the clean, renewable energy (such as wind, solar, hydro and geothermal and biomass power) or for water treatment, purification, or that improve water use efficiency
- the presence of specific products which are designed for reuse, recycling or the reduction of environmental impacts
- the percentage of revenue from environmental products and services offered by the company, or the percentage of green products or services

3.2. Process innovation

- the amount of fleet 's average CO_2 and CO_2 equivalent, NO_x, SO_x, VOC, ozone depleting substances the company emitted

- the proportion of company sites or subsidiaries that are certified with any environmental management system (ISO-14000),
- whether the company evaluates projects on the basis of environmental or biodiversity risks
- whether the company participates in any emission trading initiative, or committed to divest from fossil fuel

3.3. Innovation in business model

- whether the company engages in development of new product/services to overcome the threats of climate change to the existing business model of the company or take climate change as a business opportunity and develop new products/services,
- the amount of environmental investment and expenditures for environmental protection or to prevent, reduce, control environmental aspects, impacts, and hazards, and
- the amount of research and development expenditures for development of products and services focusing on improving the environmental impact reduction and innovation
- take-back procedures and recycling programmes to reduce the potential risks of products entering the environment; or company-generated initiatives to restore the environment.

The elements covered in the environmental innovation score represents firms' innovation in line with United Nations Sustainable Development goal 13 on climate action. The higher is the score, the more innovative is a company in addressing climate change and environmental sustainability.

Data on policy uncertainty index is collected from policyuncertainty.com. Baker et al. (2016) provide policy uncertainty index constructed from newspaper coverage frequency. The index reflects the frequency of articles in 10 leading newspapers in the U.S. that contain the terms: "economic'' or "economy"; "uncertain'' or "uncertainty"; and one or more of "Congress,'' "deficit,'' "Federal Reserve,'' "legislation,'' "regulation,'' or "White House'' (Baker et al., 2016). The resulting policy uncertainty index covers 11 categories: (1) monetary policy, (2) fiscal policy, (3) government spending, (4) taxes, (5) health care, (6) national security, (7) entitlement programs, (8) regulations, (9) financial regulation, (10) trade policy, and (11) sovereign debt. Thus, the index proxies for movements in policy-related uncertainty. An increase in the index value means an increase in policy uncertainty. Studies have shown that policy uncertainty index spikes near tight presidential elections, Gulf Wars I and II, the 9/11 attacks, the failure of Lehman Brothers, the 2011 debt ceiling dispute, and other major battles over economic policies (Baker et al., 2016).

Fig. 1 plots the evolution of policy uncertainty index since its inception in 1985. The index exhibits clear spikes around events that are associated with significant negative economic consequences, such as 9/11 terror attack in 2001, the financial crisis of 2008 and the covid-19 pandemic in 2019.

The regression estimated to investigate the effect of policy uncertainty on firm environmental innovation is:

$$Environmental\ innovation_{i,(t+s)} = \alpha_i + \beta_1 Policy\ uncertainty_t + \sum \beta_j\ controls_{i,t} + Industry\ effect + \varepsilon_{i,(t+s)}, \quad (1)$$

where subscript i and t denote firm and year respectively. To control for a delay effect of policy uncertainty on environmental innovation, we use firm i environmental innovation in the future year(s), i.e., time $(t + s)$, where s varies from 1 to 8. In other words, equation (1) estimates the effect of policy uncertainty today on environmental innovation in one to eight years later. Also included in the model are firm-level controls as well as industry and year controls. Standard errors are clustered at the firm and calendar year to correct for potential cross-sectional and serial correlation in the error term $\varepsilon_{i,t+s}$ (Petersen, 2009).[1]

Environmental innovation variable, *env_innovation*, is the environmental innovation score from Thomson Reuters Refinitiv scaled by 100. The policy uncertainty variable, *policy_uncertainty*, is measured as the natural logarithm of the arithmetic average of the policy uncertainty index in the four quarters of a calendar year. To control for possible confounding firm-level effects, we include controls for firm-level effects. Firm size (*size*) is measured as the natural logarithm of firm total assets. Financial risk is estimated through financial leverage (*leverage*), calculated as the ratio of total debt to total equity. Profitability (*roa*) is calculated as the ratio of net income to total assets. Investment opportunities (*mkt2book*) is estimated as the ratio of market value of equity to book value of equity. Market risk (*volatility*) is a stock's average annual price movement to a high and low from a mean price for each year.

To be included in the analyses, firms must have complete information on all the variables in Equation (1) for at least five consecutive years. Application of the criteria resulted in a sample consisting of 13,241 firm-year observations across 1026 firms.

4. Results

Table 1 shows that there is a wide range of environmental innovation in the sample firms with an average innovation lies in the 20th rank percentile. An average firm in the sample has 9.67 billion in total assets (anti-log of 16.085), reflecting the fact that Thomson Reuters Refinitiv database maintains data on relatively large firms (i.e., firms that are in S&P500, NASDAQ 100 or Russell 1000, etc.). Further firms on average have market value of equity 4.65 times book value of equity indicating that the sample firms have high growth opportunities.

Since our variable of interest is the environmental innovation in firms, Table 2 summarizes a further breakdown on the variable. Panel A shows that an increasing environmental innovation (on average) over the years. At the start of the sample period in 2002, an average environmental innovation lies at 0.03 rank percentile, but in 2020, it has risen to 0.33, a tenfold increase over a period of about two decades. This shows an increasing effort by firms to address the environmental issues over the years. The last column shows that the information on environmental innovation data is more widely available in the recent years than in the earlier years. The data availability for the year 2020 is very low at 1%, reflecting the need for tremendous time and resources to collect and audit the information to construct the environmental innovation score. Panel B provides breakdown of environmental innovation by ICB industry classification. Majority of the sample consists of firms from Consumer Discretionary (17%), Industrials (16%) and Financials (15%). In terms of environmental innovativeness, Consumer Staples (0.31), industrials (0.29), and Basic Materials (0.29) and Technology (0.29) excel, while Financials (0.10), Energy (0.09), and Health Care (0.08) lag behind by a good margin.

Pairwise correlations in bold reported in Panel A of Table 3 indicate that the correlations between environmental innovation, and firm size,

[1] We also estimate with standard errors that are robust to general model-specifications. The results are qualitatively similar and are available upon request.

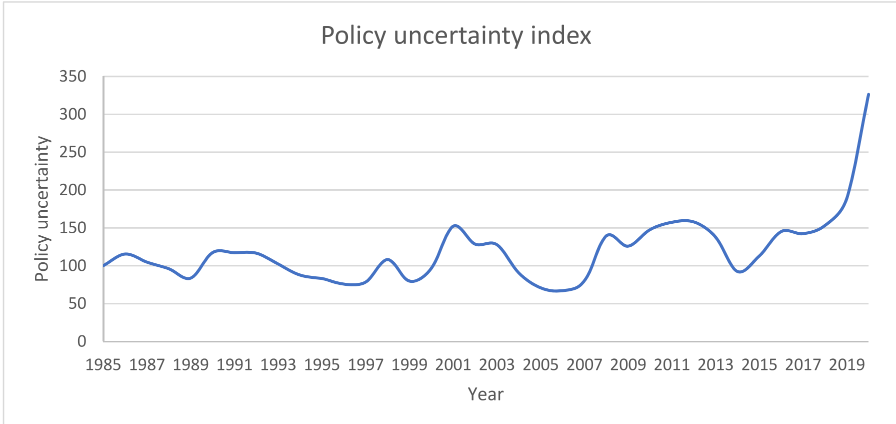

Fig. 1. Policy uncertainty index
This figure plots the Baker et al. (2016) index of policy uncertainty between 1985 and 2020.

Table 1
Descriptive StatisticsThis
table presents summary statistics for the variables. The yearly data covers U.S. firms for the period from 2002 through 2020. Environmental innovation variable, *env_innovation*, is the environmental innovation score from Thomson Reuters Refinitiv scaled by 100. Policy uncertainty variable, *policy_uncertainty*, is measured as the natural logarithm of the arithmetic average of the policy uncertainty index in the four quarters of a calendar year. *size* is the natural logarithm of firm total assets. *leverage* is the ratio of total debt to total equity. *roa* is the ratio of net income to total assets. *mkt2book* is the ratio of market value of equity to book value of equity. *volatility* is a stock's average annual price movement to a high and low from a mean price for each year.

	mean	sd	median	N
env_innovation	0.2033	0.2929	0.0000	13,241
epu	4.8329	0.2950	4.9372	13,241
size	16.085	1.4160	15.914	13,241
debtratio	0.2456	0.1986	0.2014	13,241
roa	0.0516	0.0817	0.0470	13,241
mkt2book	4.6521	24.312	2.4703	13,241
volatility	26.392	9.1310	24.700	13,241

profitability and growth opportunities are positive and statistically significant at 5% level. This suggests that larger firms, more profitable firms, and firms with high growth opportunities exhibit higher environmental innovation. Panel B provides the correlation between environmental innovation and policy uncertainty at various lags. The first column shows positive association between policy uncertainty and environmental innovation at one-to three-year intervals, although the association is stronger in the one-year time gap than it is in two- or three-year time gaps. In other words, the association between policy uncertainty and environmental innovation in two or three years in the future is respectively 0.09 and 0.04, while the association between policy uncertainty and environmental innovation in the next year is 0.16. However, there is no significant association between policy uncertainty today and environmental innovation in four years' time and beyond. The correlation between policy uncertainty today and environmental innovation at five-year intervals is negative but insignificant. It is worth noting here that correlations show only an association between variables. Also, firms usually make three-to five-year plans. Thus, the associations observed here might be a manifestation of firms' planning horizon. This is further indicated by a highly positive association between environmental innovations in shorter horizons than in longer horizons. For example, the correlation between environmental innovation in year *(t+1)* and year *(t+2)* – a one-year interval – is 0.89 while the correlation between environmental innovation in year *(t+1)* and year *(t+6)* – a five-year interval – is 0.59.

Table 2
Environmental innovation
This
table provides a detailed breakdown of environmental innovation in the U.S. firms over the years from 2002 through 2020. Panel A gives a summary on the evolution of environmental innovation over the years, while Panel B reports breakdown of the variable across industries. Industry Classification Benchmark (ICB) classifications are used for the industry breakdown.

Panel A: environmental innovation over the years

year	mean	sd	N	% of total
2002	0.0291	0.1300	378	3%
2003	0.0301	0.1282	394	3%
2004	0.0278	0.1192	525	4%
2005	0.0478	0.1574	594	4%
2006	0.0564	0.1736	601	5%
2007	0.1343	0.2610	613	5%
2008	0.1695	0.2744	750	6%
2009	0.1914	0.2897	854	6%
2010	0.2120	0.2941	884	7%
2011	0.2338	0.3018	893	7%
2012	0.2472	0.3021	895	7%
2013	0.2468	0.3034	895	7%
2014	0.2466	0.3029	891	7%
2015	0.2553	0.3050	858	6%
2016	0.2687	0.3146	824	6%
2017	0.2799	0.3151	780	6%
2018	0.2947	0.3201	756	6%
2019	0.3260	0.3214	705	5%
2020	0.3298	0.3164	151	1%
Overall	0.2033	0.2929	13,241	100% (=13,241)

Panel B: environmental innovation across industries	mean	sd	N	% of total observations
Basic Materials	0.2912	0.3253	586	4%
Consumer Discretionary	0.1675	0.2701	2305	17%
Consumer Staples	0.3139	0.3237	735	6%
Energy	0.0925	0.2293	968	7%
Financials	0.1036	0.2317	2000	15%
Health Care	0.0824	0.1932	1179	9%
Industrials	0.2926	0.3195	2178	16%
Real Estate	0.2239	0.3032	723	5%
Technology	0.2906	0.3069	1459	11%
Telecommunication	0.1953	0.2686	303	2%
Utilities	0.2837	0.3150	805	6%
Overall	0.2033	0.2929	13,241	100% (=13,241)

We first test the effect of policy uncertainty with only industry and year controls in Panel A of Table 4. We begin with this model to exclude potential confounding effect policy uncertainty may have on firm-level control variables and thus are interested to see the effect produced by

Table 3
CorrelationsThis
table presents correlations. Table 1 provides the definition of variables. Those values in bold represent statistical significance at 5% level. Suffix *(t+1)* indicates environmental innovation in the following year, while suffix *(t+1)* indicates environmental innovation in the two years forward, and so on.

Panel A correlations between the variables	env_innovation	epu	size	debtratio	roa	mkt2book	volatility
env_innovation	1						
epu	**0.2081**	1					
size	**0.1927**	**0.0195**	1				
debtratio	0.0017	**0.0656**	**0.3853**	1			
roa	**0.0539**	**−0.0441**	**−0.1325**	**−0.4352**	1		
mkt2book	**0.0238**	0.0072	**−0.0309**	**−0.0468**	**0.0703**	1	
volatility	**−0.1624**	**−0.0253**	**−0.3184**	**0.034**	**−0.1800**	−0.0146	1

Panel B correlations between policy uncertainty and environmental innovation at various intervals		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)	epu	1							
(2)	env_innovation (*t+1*)	**0.1584**	1						
(3)	env_innovation (*t+2*)	**0.0944**	**0.891**	1					
(4)	env_innovation (*t+3*)	**0.0417**	**0.805**	**0.8939**	1				
(5)	env_innovation (*t+4*)	0.0024	**0.7257**	**0.8066**	**0.8945**	1			
(6)	env_innovation (*t+5*)	−0.0156	**0.6518**	**0.7278**	**0.8076**	**0.8958**	1		
(7)	env_innovation (*t+6*)	−0.0061	**0.5868**	**0.6628**	**0.7382**	**0.8166**	**0.9059**	1	
(8)	env_innovation (*t+7*)	0.004	**0.5349**	**0.601**	**0.675**	**0.7491**	**0.8308**	**0.9125**	1
(9)	env_innovation (*t+8*)	0.0134	**0.4925**	**0.5555**	**0.6192**	**0.6931**	**0.7686**	**0.8436**	**0.9195**

policy uncertainty on its own. Policy uncertainty variable has positive and statistically significant effect in the first four columns (i.e., environmental innovation from one-to four-year forward). The effect however turns negative in five- and six-years forward and dissipates from seventh year onwards.

With the initial observations, we re-estimate the model, this time with firm-level control variables as specified in Equation (1). Panel B of Table 4 summarizes estimation results from Equation (1) with different time gaps. Fig. 2 offers a graphical representation of the coefficients values for the variable *epu*. The coefficient for policy uncertainty variable, our variable of interest, is positive and statistically significant in the first four years (columns (1)–(4)). Then the sign shifts to being negative and statistically significant in Year 5 and 6 (columns (5)–(6)). From seventh year onwards the coefficients of policy uncertainty variable become statistically insignificant, indicating a dissipated effect. The results suggest that an increase in the level of policy uncertainty does not have negative effect on environmental innovation in the short term (i.e., in one to four years) as anticipated (*Hypothesis 1*). This suggests that resources and efforts put in to planning in the previous years enable a firm to continue in its innovation journey. The smaller magnitude of policy uncertainty variable in column (1) compared to those in columns (2) through (4) suggests that there is an initial dent in environmental innovation as the firms cut back on reversible actions as policy uncertainty looms. But irreversible actions continue. The 'real' effects of policy uncertainty show in five-to six-years' time where the coefficients of policy uncertainty variable exhibit a significant negative sign (columns (5)–(6)). The results suggest that the effect of policy uncertainty dissipates seven years after the initial event of policy uncertainty. This is indicated by the insignificant coefficient for policy uncertainty variable in columns (7) and (8) in Panels A–B of Table 4. In other words, the reduced efforts to innovate when faced with policy uncertainty in column (1) and the subsequent rebound in the innovative efforts in the subsequently years, i.e., in columns (2)–(4), appear to equilibrate each other from the seventh year onwards. The fact that a depression in environmental innovation occurs over the span of five-six years suggests that it can take a significant amount of time before the negative effects of policy uncertainty surface (*Hypothesis 2*).

Besides, firm-level controls show that larger and more profitable firms have higher environmental innovation as larger firms are more subject to external pressures to innovate while firm profitability gives financial support needed for an innovation. Financial risk as indicated by variable *debtratio* shows a negative and statistically significant effect on firm environmental innovation. Thus, firms that are financially constrained (highly leveraged) will have relatively less capacity to innovate. That is, firms that are highly leveraged have high financial risk. As a result, they will be less likely to engage in risky endeavors such as investing in R&Ds. This will have a negative effect on firm environmental innovation.

In light of the theoretical framework, the lower coefficient value of policy uncertainty in column (1) compared to those in columns (2) through (4) suggest that policy uncertainty instigates a reduction in innovative activities in firms as adjustment-cost theory posits. This finding is consistent with the empirical evidence in the literature that uncertainty (in the market, prices, or election outcome) discourages firms from engaging in R&D investments (Bhattacharya et al., 2017; Xu, 2020.)[2] Moreover, one may argue that the results indicate simply a displacement in environmental innovation activities rather than a reduction in the environmental innovation. However, with the data and methods employed, it is not possible to ascertain whether the negative effects of policy uncertainty represent a delay that is later remedied by increasing activity. On the other hand, the positive sign of the coefficient for policy uncertainty variable in column (1) appears to support also the prediction by investment-lag theory that firms may not hastened to reduce innovative activities as policy uncertainty looms. Despite this, our measure of environmental innovation comprises of both the efforts put into and the outcomes from a firm's activities relevant to environmental improvement or mitigation of environmental degradation. This and the lagged negative effect of policy uncertainty observed in columns (5) and (6) together suggest that the lower positive effect of policy uncertainty in column (1) is a result of a reduction in the inputs for environmental innovation, which consequently is observed as a reduction in the innovative outputs in five- and six-years down the line. Therefore, the results suggest that firms shy away from environmental innovative activities when faced with a rising policy uncertainty. However, due to the input-output lag associated with innovative investment activities, the negative effect of policy uncertainty prevails only after some years have elapsed.

[2] We attempted to re-estimate Equation (1) with environmental R&D investments as the dependent variable. Due to the availability of environmental R&D investments data for just 0.72% of the sample, however, the exercise would not have yielded any meaningful results.

Table 4
Policy uncertainty and environmental innovation
This table reports firm-level regression results and the policy uncertainty index from Baker et al. (2016). The data are yearly and cover the period from 2002 through 2020. Equation (1) is estimated with standard errors clustered at the firm and calendar year. Suffix *(t+1)* indicates environmental innovation in the following year, while suffix *(t+1)* indicates environmental innovation in the two years forward, and so on. *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

Panel A: without firm-level control	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	env_innovation *(t+1)*	env_innovation *(t+2)*	env_innovation *(t+3)*	env_innovation *(t+4)*	env_innovation *(t+5)*	env_innovation *(t+6)*	env_innovation *(t+7)*	env_innovation *(t+8)*
epu	0.780***	1.670***	2.726***	2.176***	−1.234***	−0.324***	0.793*	0.132
	(0.0676)	(0.149)	(0.260)	(0.219)	(0.219)	(0.0879)	(0.429)	(0.146)
Constant	−3.666***	−7.980***	−13.09***	−10.40***	6.278***	1.918***	−3.450*	−0.220
	(0.331)	(0.724)	(1.268)	(1.066)	(1.055)	(0.419)	(2.092)	(0.717)
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clustered by firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clustered by year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,158	11,125	10,101	9079	8070	7113	6214	5351
R-squared	0.172	0.160	0.148	0.136	0.124	0.120	0.115	0.113
Panel B: with firm-level control	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	env_innovation *(t+1)*	env_innovation *(t+2)*	env_innovation *(t+3)*	env_innovation *(t+4)*	env_innovation *(t+5)*	env_innovation *(t+6)*	env_innovation *(t+7)*	env_innovation *(t+8)*
epu	0.688***	1.542***	2.508***	2.045***	−1.160***	−0.296***	0.742*	0.168
	(0.0655)	(0.143)	(0.249)	(0.208)	(0.208)	(0.0835)	(0.406)	(0.138)
size	0.0683***	0.0731***	0.0778***	0.0807***	0.0826***	0.0832***	0.0823***	0.0814***
	(0.00219)	(0.00231)	(0.00246)	(0.00263)	(0.00281)	(0.00299)	(0.00320)	(0.00344)
debtratio	−0.0922***	−0.0996***	−0.105***	−0.0957***	−0.0862***	−0.0772***	−0.0587***	−0.0341
	(0.0142)	(0.0153)	(0.0164)	(0.0179)	(0.0194)	(0.0208)	(0.0227)	(0.0246)
roa	0.135***	0.158***	0.168***	0.181***	0.196***	0.167***	0.149***	0.184***
	(0.0280)	(0.0300)	(0.0326)	(0.0348)	(0.0380)	(0.0409)	(0.0434)	(0.0460)
mkt2book	1.76e-05	5.45e-05	1.81e-05	−7.11e-06	−6.01e-05	−1.20e-05	0.000212	−0.000614***
	(8.96e-05)	(7.92e-05)	(8.15e-05)	(8.88e-05)	(8.84e-05)	(8.58e-05)	(0.000150)	(0.000225)
volatility	−0.000644**	−0.000288	−7.02e-05	−5.29e-05	−0.000172	−0.000526	−0.00101**	−0.00136***
	(0.000296)	(0.000312)	(0.000331)	(0.000353)	(0.000381)	(0.000412)	(0.000444)	(0.000486)
Constant	−4.293***	−8.518***	−13.27***	−11.05***	4.593***	0.449	−4.523**	−1.702**
	(0.325)	(0.700)	(1.214)	(1.017)	(1.002)	(0.400)	(1.985)	(0.683)
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clustered by firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clustered by year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,158	11,125	10,101	9079	8070	7113	6214	5351
R-squared	0.253	0.248	0.242	0.235	0.226	0.224	0.219	0.219

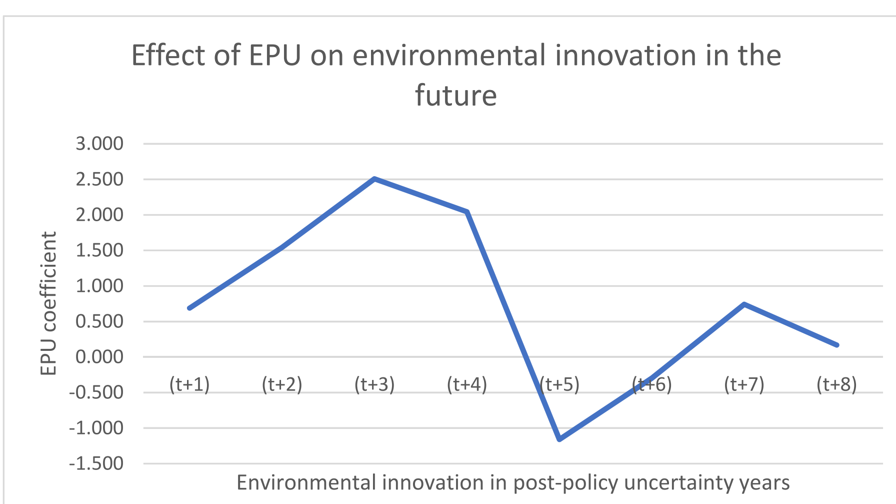

Fig. 2. EPU coefficient across year-ahead environmental innovation
This figure plots the EPU coefficients from Table 4 Panel B.

5. Conclusions

Worldwide efforts to combat climate change require innovations for the environment, i.e., environmental innovation. Environmental innovation may include innovations in the products businesses offer (e.g., the use of environmentally friendly packaging), the production process (e.g., an increased use of renewable energy), and/or the business model (e.g., retake/recycling program). However, environmental innovation requires long term planning and commitments, and uncertainty in the government and regulatory policies can dissuade businesses from making the planning and investments necessary to innovate for the environment. Therefore, uncertainty in governmental policies and regulations can influence firm environmental innovation.

This study shows that policy uncertainty indeed has a persistent, negative effect on firms' environmental innovation. The results indicate that in the short term (i.e., between one to four years), negative effects of policy uncertainty might not surface due to the input-output lag arising from irreversible long-term investments made in the previous years. However, negative effects of policy uncertainty surface in five to six years. The results also show that negative effects of policy uncertainty dissipate within seven years. This study finds that policy uncertainty hampers firms' environmental innovation. However, due to the input-output lag associated with investments for innovation, the negative effect of policy uncertainty surfaces only after some years have elapsed.

This study highlights the effects policy uncertainty has on environmental innovation, a topic that is relatively unexplored to date. The empirical literature on environmental innovation has focused mainly on the effects governmental policies such as governmental subsidies, environmental tax, green credit policy and so on have on environmental innovation (Zhao and Sun, 2016; Tsai and Liao, 2017; Li and Zeng, 2020; Wang et al., 2021a,b; Chen et al., 2022; Xiang et al., 2022; Zhang et al., 2022). Complementing the findings in the literature, this study shows that an uncertainty in the governmental policies can also affect environmental innovation. In addition, findings in this study further understanding on the consequences of economic uncertainty. In the economic literature Gulen and Ion (2016), Stein and Stone (2013), Bloom (2009), Bar-Ilan and Strange (1996), Abel (1983), and Hartman (1972), among others, have shown that policy uncertainty affects investments in firms. This study, then, links policy uncertainty to environmental innovation. In addition, this study provides empirical evidence towards the theoretical frameworks proposed in the literature on firm investments. Findings in this study indicate that the effect policy uncertainty has on environmental innovation is in support of both the investment lag theory and adjustment cost theory. That is, either theory alone cannot explain the effect of policy uncertainty on environmental innovation. Finally, understanding the effect policy uncertainty has on firms' environmental innovation is particularly relevant for the wider debate on climate change.

Findings in this study are of relevance for policymakers and governments around the globe. First, uncertainty associated with economic policies, may it be in terms of nature, stringency, timing or durability, has negative effect on firms' efforts towards environmental innovation as postulated by Bernanke (1983) and the others. However, the negative effect does not prevail immediately due to the investment lag (Bar-Ilan and Strange, 1996; Abel, 1983; Hartman, 1972). In other words, policy uncertainty can lead to suboptimal environmental innovation. The long horizon involved in the investments for environmental innovation coupled with the uncertain outcomes associated with the investments make environmental innovations very much sensitive to not only the governmental policies in place (for example, Chen et al., 2022; Xiang et al., 2022; Zhang et al., 2022, etc.), but also the uncertainty in the governmental policies. Thus, a regime where governmental policies are relatively predictable is likely to facilitate optimal innovation in terms of environmental improvement and/or mitigation of environmental degradation. Second, the economic policies and regulations in the U.S. exhibit relatively more predictable compared to other countries in the world such as in the emerging economies. Thus, the findings here serve as a lower bound for the effects one can expect to observe from policy uncertainty in other markets. Hence, to policymakers and governments around the globe, the results in this study underline the importance of mitigating policy uncertainty in order to encourage environmental innovation. It is important to note that if policymakers were to introduce a change in policy parameters they should do so in a predictable manner, for instance periodic adjustments with proper announcements, in order to not hamper environmental innovation. Besides, firms and the market learn the credibility of policy signals over time. Hence, a history of unpredictable policy changes will have effects far beyond the current episode as firms will have learned to react negatively in the future. Finally, this study sheds lights on a means by which policymakers can foster environmental innovation in firms if a country were to join in on addressing the United Nations Sustainable Development goal on climate change.

Findings in this study open up venues for future research. Due to the relatively nascent nature of the topic, the availability of relevant data on the topic is limited at present. However, as more data become available over time and across markets, future studies could investigate the effect of policy uncertainty in different market context – liberal market economies versus coordinated market economies, for example. Also, future studies could delve further into potential mechanism(s) through which policy uncertainty affects environmental innovation to give more insights into the relationship.

CRediT authorship contribution statement

Khine Kyaw: Conceptualization.

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.

References

Abel, A.B., 1983. Optimal investment under uncertainty. Am. Econ. Rev. 73 (1), 228–233.
Baker, E., Adu-Bonnah, K., 2008. Investment in risky R&D programs in the face of climate uncertainty. Energy Econ. 30, 465–486.
Baker, S.R., Bloom, N., Davis, S.J., 2016. Measuring economic policy uncertainty. Q. J. Econ. 131, 1593–1636. https://doi.org/10.1093/qje/qjw024.
Bar-Ilan, A., Strange, W.C., 1996. Investment lags. Am. Econ. Rev. 86 (3), 610–622.
Becker-Blease, J.R., Paul, D.L., 2006. Stock liquidity and investment opportunities: evidence from index additions. Financ. Manag. 35, 35–51.
Bernanke, B.S., 1983. Irreversibility, uncertainty, and cyclical investment. Q. J. Econ. 98 (1), 85–106.
Bhattacharya, U., Hsu, P.-H., Tian, X., Xu, Y., 2017. What affects innovation more: policy or policy uncertainty? J. Financ. Quant. Anal. 52 (5), 1869–1901.
Blatt-Mink, B., 1998. Innovation towards sustainable economy – the integration of economy and ecology in companies. Sustain. Dev. 6, 49–58. https://doi.org/10.1002/(SICI)1099-1719(199808)6:2<49::AID-SD84>3.0.CO;2-I.
Bloom, N., 2009. The impact of uncertainty shocks. Econometrica 77, 627–685.
Chatjuthamard, P., Wongboonsin, P., Kongsompong, K., Jiraporn, P., 2020. Does economic policy uncertainty influence executive risk-taking incentives? Finance Res. Lett. 37, 101385 https://doi.org/10.1016/j.frl.2019.101385.
Chen, W., Zhu, Y., He, Z., Yang, Y., 2022. The effect of local government debt on green innovation: evidence from Chinese listed companies. Pac. Basin Finance J. 17, 101760.
Chen, Y., Yao, Z., Zhong, K., 2022. Do environmental regulations of carbon emissions and air pollution foster green technology innovation: evidence from China's prefecture-level cities. J. Clean. Prod. 350, 131537.
Darnall, N., Henriques, I., Sadorsky, P., 2010. Adopting proactive Environmental strategy: the influence of stakeholders and firm size. J. Manag. Stud. 47 (6), 1072–1094.
Derrien, F., Kecskes, A., 2013. The real effects of financial shocks: evidence from exogenous changes in analyst coverage. J. Finance 68, 1755–1780.
Desheng, L., Jiakui, C., Ning, Z., 2021. Political connections and green technology innovations under and environmental regulation. J. Clean. Prod. 298, 126778.
Dixit, A.K., Pindyck, R.S., 1994. Investment under Uncertainty. Princeton University Press, Princeton.

Gilchrist, S., Sim, J.W., Zakrajsek, E., 2014. Uncertainty, Financial Frictions, and Investment Dynamics, NBER Working Paper 20038. https://doi.org/10.3386/w20038.

Godil, D.I., Yu, Z., Sharif, A., Usman, R., Khan, S.A.R., 2021. Investigate the Role of Technology Innovation and Renewable Energy in Reducing Transport Sector CO2 Emission in China: A Path toward Sustainable Development. Sustainable Development. https://doi.org/10.1002/sd.2167. *forthcoming.*

Gulen, H., Ion, M., 2016. Policy uncertainty and corporate investment. Rev. Financ. Stud. 29, 523–564.

Gulen, H., Ion, M., 2015. Policy uncertainty and corporate investment. Rev. Financ. Stud. 29 (3), 523–564. https://doi.org/10.1093/rfs/hhv050.

Hartman, R., 1972. The effects of price and cost uncertainty on investment. J. Econ. Theor. 5 (2), 258–266.

Hellstrom, T., 2007. Dimensions of environmentally sustainable innovation: the structure of Eco-innovation concepts. Sustain. Dev. 15, 148–159. https://doi.org/10.1002/sd.309.

Horbach, J., 2008. Determinants of environmental innovation – new evidence from German panel data sources. Res. Pol. 37 (1), 163–173. https://doi.org/10.1016/j.respol.2007.08.006.

Huang, S.S., Hu, Z.P., Liu, C.S., Yu, D.J., Yu, L.F., 2016. The relationship between regulatory and customer pressure, green organizational responses, and green innovation performance. J. Clean. Prod. 112 (6), 3423–3433. https://doi.org/10.1016/j.jclepro.2015.10.106.

International Monetary Fund, 2012. World Economic Outlook: Coping with High Debt and Sluggish Growth. IMF Press, October.

Kalamova, M., Johnstone, N., Haščič, I., 2012. Implications of policy uncertainty for innovation in environmental technologies: the case of public R&D budgets. In: Costantini, V., Mazzanti, M. (Eds.), The Dynamics of Environmental and Economic Systems. Springer, Dordrecht.

Kong, T., Feng, T., Huang, Y., Cai, J., 2020. How to convert green supply chain integration efforts into green innovation: a perspective of knowledge-based view. Sustain. Dev. 28 (5), 1106–1121. https://doi.org/10.1002/sd.2062.

Kyaw, K., Treeponkaruna, S., Jiraporn, P., 2021. Stakeholder Engagement and Firms' Innovation: Evidence from LGBT-Supportive Policies. Corporate Social Responsibility and Environmental Management, pp. 1–14. https://doi.org/10.1002/csr.2150.

Li, Dan, Zeng, T., 2020. Are China's intensive pollution industries greening? An analysis based on green innovation efficiency. J. Clean. Prod. 259, 120901.

Liao, Z., Weng, C., Shen, C., 2020. Can public surveillance promote corporate environmental innovation? The mediating role of environmental law enforcement. Sustain. Dev. 28, 1519–1527. https://doi.org/10.1002/sd.2101.

Lisi, W., Zhu, R., Yuan, C., 2019. Embracing green innovation via green supply chain learning: the moderating role of green technology turbulence. Sustain. Dev. 28, 155–168. https://doi.org/10.1002/sd.1979.

Liu, Y., Wang, A., Wu, Y., 2021. Environmental regulation and green innovation: evidence from China's new environmental protection law. J. Clean. Prod. 297, 126698.

McDonald, R., Siegel, D., 1986. The value of waiting to invest. Q. J. Econ. 101 (4), 707–727.

Murphy, J., Gouldson, A., 2000. Environmental policy and industrial innovation: integrating environment and economy through ecological modernization. Geoforum 31, 33–44. https://doi.org/10.1016/S0016-7185(99)00042-1.

Norberg-Bohm, V., 1999. Stimulating 'green' technological innovation: an analysis of alternative policy mechanisms. Pol. Sci. 32, 13–38. https://doi.org/10.1023/A:1004384913598.

Pegels, A., Lütkenhorst, W., 2014. Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV. Energy Pol. 74, 522–534.

Petersen, M.A., 2009. Estimating standard errors in finance panel data sets: comparing approaches. Rev. Financ. Stud. 22, 435–480. https://doi.org/10.1093/rfs/hhn053.

Rodrik, D., 1991. Policy uncertainty and private investment in developing countries. J. Dev. Econ. 36, 229–242.

Shen, F., Liu, B., Luo, F., Wu, C., Chen, H., Wei, W., 2021. The effect of economic growth target constraints on green technology innovation. J. Environ. Manag. 292, 112765.

Song, L., Zhou, X., 2021. Does the green industry policy reduce industrial pollution emissions? Evidence from China's national eco-industrial park. Sustainability 13, 6343.

Song, W., Wang, G., Ma, X., 2019. Environmental innovation practices and green product innovation performance: a perspective from organizational climate. Sustain. Dev. 28, 224–234. https://doi.org/10.1002/sd.1990.

Stein, L.C.D., Stone, E.C., 2013. The Effect of Uncertainty on Investment, Hiring, and R&D: Causal Evidence from Equity Options. Working paper.

Tabrizian, S., 2019. Technological innovation to achieve sustainable development – renewable energy technologies diffusion in developing countries. Sustain. Dev. 27, 537–544. https://doi.org/10.1002/sd.1918.

Tsai, K.H., Liao, Y.C., 2017. Innovation capacity and the implementation of eco-innovation: toward a contingency perspective. Bus. Strat. Environ. 26 (7), 1000–1013.

Tyfield, D., Ely, A., Geall, S., 2015. Low carbon innovation in China: from overlooked opportunities and challenges to transitions in power relations and practices. Sustain. Dev. 23, 206–216. https://doi.org/10.1002/sd.1588.

Wang, K., Jiang, W., 2021. State ownership and green innovation in China: the contingent roles of environmental and organizational factors. J. Clean. Prod. 314, 128029.

Wang, M., Li, Y., Li, J., Wang, Z., 2021a. Green process innovation, green product innovation and its economic performance improvement paths: a survey and structural model. J. Environ. Manag. 297, 113282.

Wang, M., Zhang, X., Hu, Y., 2021b. The green spillover effect of the inward foreign direct investment: market versus innovation. J. Clean. Prod. 328, 129501.

Wang, Q., Wang, H., Chang, C., 2022. Environmental performance, green finance and green innovation: what's the long-run relationships among variables? Energy Econ. 110, 106004.

Wijethilake, C., Munir, R., Appuhami, R., 2018. Environmental innovation strategy and organizational performance: enabling and controlling uses of management control systems. J. Bus. Ethics 151, 1139–1160. https://doi.org/10.1007/s10551-016-3259-7.

Xiang, X., Liu, C., Yang, M., 2022. Who is financing corporate green innovation? Int. Rev. Econ. Finance 78, 321–337.

Xu, Z., 2020. Economic policy uncertainty, cost of capital, and corporate innovation. J. Bank. Finance 111, 105698.

Yalabik, B., Fairchild, R.J., 2011. Customer, regulatory, and competitive pressure as drivers of environmental innovation. Int. J. Prod. Econ. 131 (2), 519–527. https://doi.org/10.1016/j.ijpe.2011.01.020.

Yang, D., Wang, A.X., Zhou, K.Z., Jiang, W., 2019. Environmental strategy, institutional force, and innovation capability: a managerial cognition perspective. J. Bus. Ethics 159, 1147–1161. https://doi.org/10.1007/s10551-018-3830-5.

Yang, Q., Zheng, M., Chang, C., 2022. Energy policy and green innovation: a quantile investigation into renewable energy. Renew. Energy 189, 1166–1175.

Zhang, C., Zhou, B., Tian, X., 2022. Political connections and green innovation: the role of a corporate entrepreneurship strategy in state-owned enterprises. J. Bus. Res. 146, 375–384.

Zhang, S., Zhang, M., Qiao, Y., Li, X., Li, S., 2022. Does improvement of environmental information transparency boost firms' green innovation? Evidence from the air quality monitoring and disclosure program in China. J. Clean. Prod. 357, 131921.

Zhang, Y., Sun, J., Yang, Z., Wang, Y., 2020. Critical success factors of green innovation: technology, organization and environment readiness. J. Clean. Prod. 264, 121701.

Zhao, X., Sun, B., 2016. The influence of Chinese environmental regulation on corporation innovation and competitiveness. J. Clean. Prod. 112, 1528–1536.

Zhou, F., Wang, X., 2022. The carbon emissions trading scheme and green technology innovation in China: a new structural economics perspective. Econ. Anal. Pol. 74, 365–381.

Zhou, M., Govindan, K., Xie, X., Yan, L., 2021. How to drive green innovation in China's mining enterprises? Under the perspective of environmental legitimacy and green absorptive capacity. Resour. Pol. 72, 102038.

Zhu, Z., Tan, Y., 2022. Can green industrial policy promote green innovation in heavily polluting enterprises? Evidence from China. Econ. Anal. Pol. 74, 59–75.