Essays on Sustainability, Corporate Disclosure, and Economic Uncertainty

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Kai Huang

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ABSTRACT

This thesis consists of three essays. Essay one investigates the relationship between accounting conservatism, specifically bad news timeliness, and corporate environmental disclosure. This study identifies a significant negative relationship between the timeliness of bad news disclosure and corporate environmental disclosure. Further analysis indicates that socio-political pressures moderate this relationship. Specifically, while firms generally align with stakeholder preferences by promptly disclosing negative earnings news, those with executives in government-nominated positions tend to increase environmental disclosure due to stronger socio-political pressures. Additionally, the negative association between bad news timeliness and environmental disclosure is weaker among heavy polluters, who face stricter environmental regulations. This study underscores how top management strategically handles the disclosure environmental information.

Essay two explores the impact of oil price uncertainty (OPU) on corporate green innovation disclosure behaviour. Drawing on textual analysis of annual and social responsibility reports from Chinese listed companies, the study constructs an innovative measure of green innovation disclosure intensity. It identifies a significantly positive relationship between oil price volatility and the level of green innovation disclosure, suggesting that firms respond to energy uncertainty by enhancing transparency about their environmental sustainability. Robustness checks and endogeneity analyses confirm these findings. Furthermore, the analysis reveals that firm-level characteristics, such as environmental performance, legitimacy demands, and political connections, moderate this relationship. The positive effect is amplified in firms exposed to higher regional environmental regulation intensity and market-based green initiatives. This essay contributes to the growing literature on

corporate sustainability by demonstrating the role of energy uncertainty in shaping corporate transparency in green innovation.

Essay three examines the interplay between firms' oil price uncertainty sensitivity and corporate green innovation in the context of geopolitical tensions. Using a unique measure of firm-level geopolitical tensions derived from destination country-firm data in the China Customs Dataset, the study finds that firms more exposed to OPU are more likely to engage in green innovation. Geopolitical tensions significantly amplify this relationship, with tensions originating from supplier countries further amplifying the urgency for green innovation efforts. Additional analyses reveal that domestic supply chain alliances and improved supply chain efficiency reduce urgency of green innovation when facing heightened uncertainties. Moreover, we find that the interacted impacts of OPU exposure and geopolitical tensions on green innovation are more pronounced in firms with higher international exposure, lower government subsidies, and greater competitive pressures. This essay underscores the influence of external shocks, such as energy and geopolitical crises, in driving firms toward sustainable innovation strategies.

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CHAPTER ONE

INTRODUCTION

1.1. Motivation and objectives

Corporate transparency and innovation are critical for fostering trust, sustainability, and long-term competitiveness in today's rapidly evolving business environment. The increasing complexity of global markets, coupled with the mounting socio-political and environmental pressures, demands a nuanced understanding of how firms strategically respond to external uncertainties. This thesis aims to contribute to this discourse by examining the intricate interplay between corporate disclosure, innovation, and external pressures, specifically focusing on three key aspects: the timeliness of bad news, energy market uncertainties, and geopolitical risks. The motivation for this thesis arises from the growing need to understand how firms navigate these challenges to enhance transparency, meet stakeholder expectations, and drive sustainable innovation.

The first motivation stems from the growing importance of corporate environmental responsibility and the strategic role of financial reporting. While bad news timeliness, promptly reflecting negative information in earnings, is considered a hallmark of financial transparency and accountability (Watts, 2003; Ruch & Taylor, 2015), its relationship with environmental disclosure remains underexplored. Managers may strategically limit environmental disclosures if bad news timeliness satisfies stakeholders' transparency demands, reflecting concerns about the costs and risks associated with such disclosures, including litigation and reputational damage (Matsumura et al., 2014; Fabrizio & Kim, 2019). Conversely, socio-political pressures, particularly in politically dynamic settings like China, can compel firms to increase environmental disclosures despite conservative reporting practices. Executives with political connections, for instance, may prioritize aligning with government expectations to secure resources and enhance legitimacy (Clarkson et al., 2008; Li et al., 2008). Investigating this interplay contributes to understanding how firms manage the dual demands of financial reporting and environmental transparency in response to external pressures.

The second essay delves into the relationship between oil price uncertainty and green innovation disclosure. Oil price volatility introduces significant challenges to firms, including increased operational costs, supply chain disruptions, and uncertainties in profitability and investment decisions (Henriques & Sadorsky, 2011; Hu et al., 2023a). These dynamics may heighten stakeholder concerns, compelling firms to demonstrate their resilience and commitment to sustainable development through transparent disclosures. However, while innovation disclosures can reduce information asymmetry and build stakeholder trust, they also present strategic risks, such as exposing proprietary information and potentially raising unrealistic market expectations about future performance (Berger & Han, 2007; Ellis et al., 2012). This contradiction raises an important question: how do firms navigate the trade-offs between transparency and competitive positioning in times of energy market volatility? Essay two aims to investigate how OPU influences corporate green innovation disclosure behaviours, offering new insights into the motivations and challenges of voluntary disclosure under uncertainty.

The third essay aims to investigate how geopolitical tensions, alongside oil price uncertainty, shape corporate green innovation outputs. Geopolitical crises disrupt global supply chains and exacerbate economic uncertainties, compelling firms to rethink their innovation and investment priorities (Roscoe et al., 2022; Lee et al., 2023). While geopolitical risks are often associated with reductions in long-term investments due to heightened uncertainty (Khoo, 2021;

Moradlou et al., 2024), they can also incentivize firms to pursue green innovation as a resilience strategy. Green investments serve as hedges against oil market volatility and mitigate dependency on vulnerable supply chain regions (Lee et al., 2021; Dutta et al., 2020). This essay aims to extends the literature by constructing a novel measure of geopolitical tensions using firm-level supply chain data, providing empirical evidence on how these intertwined risks influence green innovation commitment.

1.2. Essay One

Essay one explores the relationship between the timeliness of bad news and environmental disclosure in the context of China. It finds that firms with higher-quality accounting information tend to disclose less environmental information. However, this negative relationship is moderated by several factors: firms with politically connected executives (those holding government-nominated positions) face greater social and political pressures to disclose environmental information, reducing the impact of bad news timeliness on disclosure. Similarly, heavy polluters, due to stricter environmental regulations, show an insignificant negative relationship between bad news timeliness and environmental disclosure. The findings align with socio-political theories, suggesting that social disclosure is driven by pressures from institutional and public stakeholders (Magness, 2006). These results are robust even after addressing endogeneity issues through instrumental variable (IV) 2SLS estimations and accounting for various fixed effects. Additionally, the study highlights that reduced analyst attention, explains the negative link between accounting conservatism and environmental disclosure. It also finds that firms under financial constraints disclose more environmental information to improve access to financing and increase disclosure under competitive pressure.

Essay one contributes to the literature by examining the relationship between bad news timeliness and firm green disclosure. Prior research has linked conservative financial reporting to reduced CSR disclosure (Cho et al., 2020), In addition, it has been found that bad news timeliness enhances financial reporting credibility (Ruch & Taylor, 2015) and facilitates targeted communication with key stakeholders (Guo et al., 2020). Our study shoes that there is a significant negative relationship between the timeliness of bad news disclosure and corporate environmental disclosure. We further explore the moderating role of political connections in this relationship, showing that firms with government-nominated executives face greater socio-political pressures, driving stricter adherence to environmental disclosure policies. This interplay underscores the strategic communication dynamics in firms and highlights the influence of political ties. Our findings suggest that policymakers should consider the nuanced role of political connections and regulatory constraints in shaping environmental and financial reporting standards, thereby enhancing corporate transparency and promoting sustainability. Our research aligns with broader interests in stronger integration between financial reporting and environmental responsibility (De Villiers et al., 2011).

1.3. Essay Two

Essay two investigates how firms adjust their voluntary disclosures on green innovation in response to energy uncertainties, with a focus on the impact of OPU on corporate green innovation disclosures. We innovatively employ textual analysis to develop a corporate green innovation disclosure index. The findings reveal a significantly positive relationship between OPU and green innovation disclosure, supported by robust analyses and endogeneity checks. Firms with stronger environmental performance, higher legitimacy demands, and political connections are more likely to increase green innovation disclosures under OPU. Additionally, the study shows that China's carbon trading pilot scheme and stringent regional environmental regulations positively moderate this relationship, demonstrating how regulatory frameworks encourage firms to align their strategies with environmental objectives.

This paper makes four key contributions to the literature. First, it provides new evidence on voluntary innovation disclosure by firms in the context of OPU, supporting signalling theory by showing that OPU increases voluntary green innovation disclosures (e.g., Amin et al., 2023; Yang & Song, 2023). Unlike patents, which are mandatory and protected, voluntary disclosures include innovation plans and progress, offering novel insights into disclosure practices under OPU. Second, it expands the literature on corporate voluntary disclosure in the face of energy uncertainties, highlighting that heightened transparency through green innovation disclosures mitigates stakeholders' concern arising from OPU. This study focuses on green innovation disclosures, advancing understanding of corporate strategies under energy-related risks. Third, it advances the debate on environmental reputation, demonstrating that firms with stronger environmental commitments, indicated by ISO certifications and high environmental ratings, are more likely to disclose green innovations under OPU, satisfying stakeholder expectations. Finally, the study sheds light on the role of regional policy orientation and market-based initiatives like China's carbon trading pilot scheme, showing that firms in regions with strong environmental policies and stricter carbon regulations are more proactive in green innovation disclosures. The results emphasize the influence of policy frameworks and market mechanisms in shaping corporate sustainability.

1.4. Essay Three

Essay three explores the relationship between oil price uncertainty, geopolitical risks, and corporate green innovation, revealing how firms strategically adapt to external uncertainties. The findings indicate that firms more sensitive to oil price uncertainty tend to increase investments in green innovation, particularly during geopolitical intensions, with the effects being most pronounced when tensions arise from supplier countries in times of geopolitical tensions. However, domestic supply chain alliances and supply chain efficiency negatively moderate these effects by providing operational stability and resilience, which may reduce the immediate urgency for green innovation. These supply chain management allows firms to focus on maintaining current operations rather than pursuing long-term innovation strategies. Additionally, heterogeneity analysis shows that firms with higher international exposure, less government support, and greater competitive pressures are more likely to engage in green innovation as a strategic response, highlighting the complex interplay between firm-specific factors and external shocks.

Essay three makes four key contributions to the literature. First, it extends existing research on oil price fluctuations and firm behaviour. We examine the varying sensitivity of firms to oil price volatility and its influence on green innovation, providing evidence that supports previous findings on the decline in innovation investment during periods of OPU (e.g., Amin et al., 2023; Yang & Song, 2023). Second, it explores the interaction of oil price sensitivity and geopolitical risks in supplier and customer countries on corporate green innovation. Our results enrich the literature by providing empirical evidence on how firms navigate multiple external risks in a complex global market, building on work by Lee et al. (2023). Third, the study advances understanding of supply chain dynamics as moderating factors in the relationship between external pressures and green innovation. Our results show that domestic supply chain alliances and supply chain efficiency stabilize operations and reduce dependency on international supply chains, thereby tempering the urgency for innovation. These findings expand on previous research (e.g., Hsieh et al., 2018; Kamalahmadi et al., 2022) by emphasizing the dual role of supply chain stability in fostering resilience and constraining flexibility. Lastly, the paper highlights firm-level heterogeneity in green innovation responses, integrating factors such as international exposure, financial constraints, competition intensity, and government subsidies to demonstrate how firm-specific characteristics interact with external uncertainties, contributing nuanced insights to the strategic management literature.

1.5. Research output

1.5.1 Journal submission

- Essay two has been submitted to the International Review of Economics and Finance and is under the minor revision process.

1.5.2 Conference presentations

- Essay one was presented at:
    - The 32nd European Financial Management Association (EFMA) conference, June 28 - July 1, 2023. Cardiff Business School, Cardiff University, UK.
    - The 14th Financial Markets and Corporate Governance Conference (FMCG 2024), 2 - 4 April 2024. Monash University Malaysia. (Best paper award for Accounting Information/Disclosure Practices/Earnings Quality).
- Essay two was presented at:
    - The 2024 Annual Meeting of The International Society for the Advancement of Financial Economics (ISAFE2024), 08-10 July 2024. Kasetsart University - Sriracha campus, Pattaya, Thailand.
    - The 2024 New Zealand Finance Meeting, 5 - 7 December 2024. The Auckland Centre for Financial Research at the Faculty of Business, Economics and Law, Auckland University of Technology.
- Essay Three was presented at:

- The 2024 Massey Sustainable Finance Conference (MSFC2024), 02-03 December 2024.

1.6. Structure of the thesis

The structure of the thesis is organized as follows. Chapter 2 presents the first essay, which investigates the effect of firm bad news timeliness on firm environmental performance in China. Chapter 3 presents the second essay, which examines the influence of OPU on firm green innovation disclosure. The third essay studies the effect of OPU and geopolitical tensions on firm green innovation, which is presented in Chapter 4. Chapter 5 concludes the thesis by outlining the main findings and implications of the three essays and discusses the limitations of the thesis and future research.

CHAPTER TWO

ESSAY ONE

Does bad news timeliness affect corporate environmental disclosure: The moderating effect of socio-political pressures

Abstract

Utilizing a large dataset from Chinese listed firms, we find a notable negative association between bad news timeliness (i.e. disclosing bad news on earnings more promptly than good news) and corporate environmental disclosure. Further investigation reveals that socio-political pressures play a moderating role in the relationship between the two variables of interest. We observe that although firms have adopted the policy of promptly reflecting negative news in their earnings, firms with the executives in a government-nominated position increase their environmental disclosure due to heightened socio-political pressures. Moreover, we observe that the negative relationship between bad news timeliness and environmental disclosure is less significant for heavy polluters, who are subject to stricter environmental regulations. This study highlights that top management strategically manages the different types of information disclosed to the public, and therefore, we encourage policymakers to explore strategies for fostering corporate information transparency.

Keywords: Bad news timeliness, corporate environmental disclosure, political connection, regulatory constraints

2.1. Introduction

Managers must strategically handle various types of information disclosed to the public. We investigate whether corporate accounting reporting policies impact corporate environmental disclosure, given the growing importance of corporate environmental responsibility and the significance of account reporting policies. Economic and environmental sustainability are both critical to corporations' long-term development (Wu et al., 2020). Although corporations have increased their participation in environmental responsibility activities (Porter & Kramer, 2018; Vastola et al., 2017), evidence on executives' strategic decisions on environmental information disclosure remains limited (Orlitzky et al., 2003; Busch & Friede, 2018). It is conceivable that greater environmental information disclosure may not always be advantageous for corporations. A high level of environmental information disclosure can bring benefits to firms, such as improved reputation and legitimacy, better stakeholder relationships, and reduced cost of capital (Cho & Patten, 2007; Zeng et al., 2012; Kim & Lyon, 2015; Fonseka et al., 2019). However, increasing environmental disclosure imposes costs on firms (Fabrizio & Kim, 2019).

As one of the most critical attributes of financial reporting, the timeliness in incorporating bad news has captured the interest of both regulators and scholars (Zhong & Li, 2017; Zhang et al., 2022). We utilize bad news timeliness, which refers to the speed with which bad news is reflected in earnings (Young, 2018), to study the dynamic relationship between conservative financial reporting and environmental information disclosure.

It is reasonable to expect that managers might strategically reduce the release of environmental information if the firm has satisfied stakeholders' requirement on information transparency by adopting the policy of promptly reflecting negative news in their earnings. Positive accounting theory posits that conservative financial reporting serves as an efficient governance mechanism, aiming to mitigate information asymmetry and agency problems (Watts, 2003; Lafond & Watts, 2008; Francis, et al., 2013). This theory suggests that by providing a more cautious presentation of a firm's financial position, bad news timeliness enhances the transparency and reliability of financial information (Ruch & Taylor, 2015), addressing the information asymmetry prevalent between managers and stakeholders. If bad news timeliness meets stakeholders' demand for information transparency, managers may decrease environmental disclosure.

However, it is also possible that corporations may increase the release of environmental information although have adopted the policy of promptly reflecting negative news in their earnings due to heightened socio-political pressures. According to the socio-political theories, a firm's exposure to social and political pressure is a significant factor that determines the level of corporate environmental information disclosures (Parker, 2005; Clarkson et al., 2008). Firms facing higher exposure to social and political pressure intend to provide more environmental disclosures (Clarkson et al., 2008; Dobler et al., 2015). Given the unique political dynamics in China, we explore the moderating effect of executives' political connection on the relationship between the bad news timeliness and environmental information disclosure. The Chinese government controls the allocation of key scarce resources (Gwartney & Lawson, 2009), and thus emerges as a paramount stakeholder in the operations of firms, including both state-owned enterprises (SOEs) and non-SOEs (Li et al., 2008). Allen et al. (2005) document that political power, as an alternative to market power, plays a critical role in a firm's success or even existence in China.

Following Zhang et al. (2016), we classify the political connections of firm executives as ascribed bureaucratic connections or achieved political connections based on whether the executive were former members or are current members of the People's Congress or the Political Consultative Conference. Ascribed bureaucratic connections (the past government work experience) buffer organizations from competitive and regulatory forces by gaining advantages in information, influence, and legitimacy (Hillman, 2005), but executive with past government work experience may not have strong incentives to pursue political objectives. While due to the shared interests with the government, executives who are current members of the People's Congress or the Political Consultative Conference have a higher exposure to political pressure (Zhang et al., 2016). Consequently, these executives might exhibit stronger incentives to align corporate actions with governmental objectives, such as promoting environmental sustainability, to secure regulatory favour and resource access (Zhang et al., 2016).

Furthermore, we explore the association between bad news timeliness and environmental information disclosure considering regulatory constraints. In 2003, the Chinese Ministry of Ecology and Environment introduced Document No. 60, singling out 15 industries as primary pollutants due to their pronounced pollutant emissions. Consequently, local governments were directed to intensify oversight on firms in these sectors, compelling them to curtail pollutant discharges. Compared to their counterparts in non-heavy polluting sectors, firms in these highly polluting industries grapple with heightened environmental regulations, which manifest as increased operational costs and potential constraints to their regular business activities (Colwell & Joshi, 2013). Executives in these high-pollution sectors are subject to amplified socio-political pressures. While there's an inherent expectation to reduce their pollution footprint, there's also an indirect push to amplify their environmental disclosure as a means to demonstrate compliance and transparency (Matsumoto & Szidarovszky, 2020). The rationale behind this is straightforward, e.g., highly regulated firms must adhere to both governmental environmental regulations and industry benchmarks to sustain their business operations (Shahbaz et al., 2015).

Using a large sample of firms listed on the Shanghai and Shenzhen Stock Exchanges from 2010 to 2017, we find a significantly negative association between bad news timeliness and corporate environmental disclosure, consistent with a substitutive relation between the two. To mitigate potential endogeneity problems arising from simultaneity and omitted variable bias, we conduct the instrumental variable generalized method of moments (IV-GMM) analysis and control for multiple fixed effects, including industry-year and province-year fixed effects, and our baseline results remain robust. We find that socio-political pressures moderate the negative relationship between bad news timeliness and corporate voluntary environmental disclosure. We find the negative relationship between bad news timeliness and corporate environmental disclosure becomes insignificant among firms with executives who are current members of the

People’s Congress or the Political Consultative Conference and firms from heavy polluting industries. Executives occupying current government-appointed positions have dual identities both in the government and in the firm, and prior research suggests that they are likely to prioritize government initiatives to protect their political interests (Wang et al., 2019a). High polluting firms, grappling with stringent policy constraints, are compelled to disclose environmental information to demonstrate compliance and transparency.

We contribute to the existing literature in two major ways. Firstly, we illuminate the interplay between conservative accounting reporting and firm disclosure policies, underscoring the notion that the disclosure equilibrium is contingent on the supply and demand for information. Given that bad news timeliness mitigates information asymmetry (Watts, 2003), the subsequent demand for disclosure is diminished, resulting in an observable negative relation between the two. Cho et al. (2020) find that firms adopting conservative financial reporting are less likely to disclose CSR information. Our research augments existing literature by illustrating that bad news timeliness not only enhances the credibility of financial reporting (Ruch & Taylor, 2015) but also serves as a medium for nuanced communication with a select group of stakeholders (Guo et al., 2020). Our findings imply that there exists a strategic interplay in firms’ communication regarding environmental information, influenced by the degree of bad news timeliness. However, we acknowledge the intricate nature of this association, given that both environmental disclosure and bad news timeliness are endogenous choices made by firms. While studies such as Abeysekera & Lu (2021) and Alipour et al. (2019) have examined the relationship between financial disclosure quality and sustainability disclosure quality, these works focus primarily on accruals quality. In contrast, our research centres on the timeliness of bad news. Additionally, while Xi & Xiao (2022) explore the connection between environmental disclosure and accounting conservatism, our study innovatively proposes the moderating role of political connections in this relationship. This distinction is crucial as it highlights not only the different facets of financial reporting but also underscores the specific mechanisms through which political ties can influence the dynamics between environmental disclosure and accounting conservatism. By addressing these nuanced elements, our research contributes uniquely to the understanding of strategic communication in firms, particularly in how they manage environmental information in the presence of political influences. Secondly, our findings illuminate the interplay between socio-political pressures and firm disclosure policies. We reveal that firms that adopt conservative accounting reporting policy, particularly where executives have government-appointed roles, face greater pressure to adhere to stringent environmental disclosure policies. This suggests an opportunity for policymakers to reevaluate and fine-tune environmental and financial reporting standards to promote corporate transparency and responsibility, echoing the broader discourse for stronger connections between financial reporting and environmental sustainability (De Villiers et al., 2011). In conclusion, the policy implications of our study primarily revolve around the role of political connectedness and regulatory constraints, thereby advocating for a nuanced approach by governments in promoting eco-friendly practices.

The remainder of the study is organized as follows: Section 2.2 discusses the literature review and hypothesis development. Section 2.3 reports the data, variable construction, and the regression model. Section 2.4 presents the empirical results and robustness tests. Section 2.5 concludes the study.

2.2. Literature review and hypothesis development

2.2.1. Bad news timeliness and environmental information disclosure

The relationship between accounting information quality and sustainability disclosure is a significant research topic, as high-quality accounting information is considered a key attribute of firms that benefits investors and helps mitigate unethical behaviors—such as earnings management—often driven by information asymmetry (Dichev et al., 2013; Rezaee & Tuo, 2019). Additionally, increasing attention from corporations, regulators, and investors highlights the importance of sustainability performance information in assessing firms' financial performance and accounting information quality (Jain et al., 2016; Khan et al., 2016; Rezaee & Tuo, 2019).

Literature suggests that firms can gain favor from social and political stakeholders by demonstrating their commitment to sustainable development and responsible environmental stewardship (Gray, 2006). By disclosing environmental engagement, firms can enhance their public image and demonstrate their commitment to sustainability (Neu et al., 1998). This builds trust and credibility with stakeholders, including customers, investors, and regulators (Amran et al., 2015). Hong and Kacperczyk (2009) find that investors, especially institutions, tend to invest in projects that align with social norms, while pension funds tend to favor socially responsible stocks. Environmental disclosure can help firms identify and manage environmental risks and liabilities, such as regulatory compliance issues, reputational risks, and potential environmental liabilities. Additionally, the disclosure of environmental engagement enhances a firm's access to government-controlled resources (Liu et al., 2021).

According to socio-political theories, social disclosure is "a reaction to the pressure exerted by institutional and public stakeholders" (Magness, 2006). Within this framework, certain political pressures (threats to legitimacy) are expected to be directed at firms that disclose relatively less information on environmental issues (Hrasky, 2012). In the absence of environmental disclosure standards, stakeholders rely on voluntary environmental reporting (Ren et al., 2020). In such cases, voluntary environmental reporting serves either, at best, to legitimize corporate activities or, at worst, to present a misleading view of corporate environmental performance (Gatti et al., 2019). Literature indicates that some environmental reporting is unrelated to corporate environmental performance and is incomplete, particularly in the non-disclosure of bad news (de Freitas et al., 2020). The failure to provide complete and accurate environmental information can result in penalties and legal action against the firm for misrepresentation or fraud (Ding, 2022). Additionally, the failure to disclose environmental risks and impacts can cause significant reputational damage, leading to a loss of public trust and confidence in the firm (Matozza, 2019). Therefore, firms may face pressure to withhold information about their environmental practices to maintain a competitive advantage over their peers (Villena & Dhanorkar, 2020).

TBN refers to the practice of recognizing losses and liabilities as soon as they are anticipated or probable, while delaying the recognition of gains and assets until they are realized (Watts, 2003a). By recognizing losses and liabilities early, a firm signals that it is not attempting to conceal bad news from investors or stakeholders. By recognizing potential losses promptly, a firm can take steps to manage those risks and mitigate their impact (García Lara et al., 2016). Additionally, Biddle et al. (2022) provide empirical evidence that TBN can reduce bankruptcy risk and benefit stakeholders by alleviating cash appreciation and earnings management. It is indicated that conservative financial reporting can serve as an efficient governance mechanism that mitigates information asymmetries and agency problems (Francis, et al., 2013; Lafond & Watts, 2008; Watts 2003). TBN has been widely acknowledged for enhancing the transparency of firms' financial information (Ruch & Taylor, 2015).

Accordingly, based on socio-political theories and the characteristics of environmental disclosure, we argue that by disclosing bad earnings news more promptly than good news, firms can build trust and confidence among stakeholders, ultimately strengthening their legitimacy. To alleviate possible litigation risks associated with incomplete environmental disclosures and to mitigate potential conflicts of interest regarding environmental disclosures, managers may strategically reduce environmental information disclosure by reporting other accomplishments (Patten, 2002), such as conservative financial reporting. Based on these arguments, we propose the following hypothesis:

Hypothesis 1a (H1a): The timeliness of bad earnings news is negatively associated with corporate environmental disclosure.

Stakeholder theory suggests that firms engaging in TBN practices are more likely to enhance corporate transparency, thereby reinforcing stakeholder trust. Recognizing losses promptly signals ethical corporate conduct and a strong commitment to accountability, further reinforcing a firm's legitimacy and credibility (García Lara et al., 2016). This approach aligns with the growing societal expectations that corporations should proactively disclose environmental risks and impacts, particularly in an era where sustainability and corporate social responsibility are gaining prominence (Deegan & Shelly, 2014).

Empirical evidence supports the argument that TBN can mitigate bankruptcy risks and reduce opportunistic earnings management, thereby aligning corporate behavior with stakeholder interests (Biddle et al., 2022). Firms that adopt conservative financial reporting practices are more likely to demonstrate a commitment to transparency and ethical behavior, a principle that extends to their environmental disclosure strategies (Francis et al., 2013; Watts, 2003). By proactively disclosing environmental information, firms can enhance their reputation as responsible corporate entities and strengthen their long-term sustainability commitments (Cormier & Magnan, 2015). Based on these arguments, we propose the following hypothesis:

Hypothesis 1b (H1b): The timeliness of bad earnings news is positively associated with corporate environmental disclosure.

2.2.2. The moderating effects of political connections and environmental policy constraints

Socio-political theories, including legitimacy theory, stakeholder theory and political economy theory, offer sufficient explanations for corporate environmental disclosures, particularly when they are discretionary. According to the legitimacy theory, environmental disclosure is a function of the social and political pressure facing the firm (Gray et al., 1995; Parker, 2005). It is predicted that firms facing greater exposure to public pressure regarding environmental concerns will provide more environmental disclosures (Neu et al., 1998; Clarkson et al., 2008). Political economy theory is another relevant perspective that highlights the relationship between political power and economic interests. In this view, firms having political power or seeking to influence political favouritism may disclose more environmental information as a way of shaping public opinion and regulatory outcomes in their favour.

According to Zhang et al. (2016), political connections between enterprises and governments can be categorized into two types. The first is the chairman's previous government work experience, as the political connection and personal ties before entering the firm, which can be defined as ascribed bureaucratic connection. The second is prestigious appointment to state organizations such as congresses or political councils, as the formation of these political ties result from chairmen' or their firms' achievements, which can be defined as achieved political connections. Executives who are currently a member of congresses or political councils are more likely to follow the government's initiatives to consolidate their political status. In addition to serving shareholders, they are also under stronger social and political pressure because the social reputation of the firm can be tied to their political career (Wu et al., 2012). According to Zhang et al. (2016) when business executives also hold a government-nominated position, such as a position in National People's Congress, Local People's Congress, Chinese People's Political Consultative Conference, or Local People's Political Consultative Conference, the firm's compliance or active alignment with government expectations will increase significantly. In addition, the reciprocity principle in social relationships suggests that businesses political connections can be beneficial to firms, but it also implies that governments will expect something in return (Aronson et al., 2005). This payback for current and future government support may take the form of business activities with a clear social purpose, such as environmental engagement (Li et al., 2015). Therefore, holding a government-nominated position, such as serving on the congresses or political councils, is indicative of an ongoing quid pro quo relationship between business organisations and the government (Swanson, 1999). The government provides political recognition, social status and prestige, in response to which, firms need to continuously contribute to environmental responsibilities.

H2a: The negative relationship between bad news timeliness and environmental disclosure will become less pronounced in firms with executives holding a government-nominated position.

With the legacy of a planned economy, government intervention in China is mainly exemplified by industry regulations (Ortega et al., 2012). In the name of national interests, the government controls licenses and permits for some key industries and regulates their operations heavily (Eaton, 2013). Firms cannot survive without meeting the corresponding standards in the operation (Gallagher, 2006). As a result, industries that are heavily regulated by the government are highly dependent on the government for permit approval/renewal, access to government-controlled resources and preferential treatment (Eaton, 2013). Hence, heavily regulated firms are under greater pressure to the norms and expectations of the institutional environment in which they operate. We expect that firms subject to heavy regulatory constraints are more likely to commit to environmental responsibilities. Therefore, the negative correlation between accounting conservatism and environmental performance will be weakened in heavy polluters.

H2b: The negative relationship between bad news timeliness and environmental disclosure will become less pronounced in heavy polluting firms.

2.3. Research design

2.3.1. Data and sample

The financial data used in this paper is collected from the China Stock Market and Accounting Research (CSMAR) database, environmental disclosure scores are obtained from the Hexun CSR database, and the macroeconomic data is collected from China's National Bureau of Statistics website. All firms listed on the Shanghai and Shenzhen Stock Exchanges from 2010 to 2017 are included in the initial sample. The sample period is adopted because the data on environmental disclosure is only available to 2017. We then exclude: (1) firms from the financial sector, (2) B-share and H-share stocks, and (3) observations with missing information. The final sample used includes 12,160 firm-year observations. All continuous control variables are winsorized at the top and bottom 1% levels to mitigate the concern of outliers.

2.3.2. Measures of corporate environmental disclosure

We employ two measures to investigate the level of corporate environmental disclosure. The first measure is a continuous variable denoted as *ER*, which is constructed according to the industry-year adjusted Hexun environmental disclosure score for each firm in a year. Hexun[1] is a top-ranked rating agency that provides professional financial and CSR rating of listed firms using a disclosure-oriented evaluation framework. Raw data of Hexun environmental responsibility scores from 0 to 30. This measurement is widely used by Chinese CSR studies such as Ma et al. (2020), Hu et al. (2018) and Zhang et al. (2021). Because Hexun evaluation system varies across years and industries, referring to the method of Li et al. (2021), we make industry-year adjustment for this measure. The industry-year adjusted score (*ER*) is calculated as a firm's Hexun score minus the mean value for all firms in the same industry-year.

According to the Guidelines on Enhancing Environmental Information Disclosure of Listed Firms issued by the Shanghai Stock Exchange in 2008, Chinese listed firms should actively disclose the following corporate environmental information in their annual social responsibility reports: (1) the environmental protection policies, objectives, and effects; (2) the total annual resource consumption; (3) the environmental protection investment and

[1] Hexun started to launch the CSR rating database in 2010. Listed firms' social responsibility reports and their annual reports are evaluated by Hexun based on the framework of stakeholder theory. Environmental responsibility is evaluated through five dimensions including environmental awareness, environmental certification, environmental input, sewage discharge and energy conservation. The environmental responsibility score adopts the weighted sum of the above five dimensions (10%, 15%, 25%, 25% and 25%, respectively).

environmental technology development; (4) the types, quantity, concentration, and destination of pollutants discharged; and (5) the construction and operation of the firm's environmental protection facilities. Referring to Sarfraz et al. (2020) and Xu et al. (2020), we construct a comprehensive environmental disclosure measurement denoted as *Disclosure*, which covers four major dimensions, namely, legal consciousness, social evaluation, eco-friendly production, and green management[2]. The disclosure data is collected from the CSMAR database. The four dimensions contain a total of eleven disclosure indicators as shown in Appendix C. A disclosure factor takes a value of 1 if a firm reaches the relevant criteria, and 0 otherwise. Then we add up the scores of the 11 items as the environmental disclosure variable denoted as *Disclosure*.

2.3.3. Measurement of bad news timeliness

The measure of bad news timeliness (BNT) in this study follows the methodology of Basu (1997) and Khan & Watts (2009), which captures the asymmetric timeliness in recognizing bad versus good news in earnings—an essential feature of conditional conservatism.

We begin with the baseline cross-sectional regression model from Basu (1997):

$$X_i = \beta_0 + \beta_1 D_i + \beta_2 R_i + \beta_3 D_i R_i + \varepsilon_i \quad (1)$$

where X_i is earning per share divided by the beginning-of-period stock price; R_i is the stock return of firm i in a year; D_i is a dummy variable equal to one if R_i is less than zero, and zero otherwise.

Building on this, Khan & Watts (2009) developed a firm-year specific measure of conservatism by modelling both β_2 and β_3 as linear functions of firm characteristics:

$$GScore = \beta_2 = \mu_0 + \mu_1 SIZE_i + \mu_2 MB_i + \mu_3 LEV_i \quad (2)$$

$$CScore\ (BNT) = \beta_3 = \omega_0 + \omega_1 SIZE_i + \omega_2 MB_i + \omega_3 LEV_i \quad (3)$$

[2] Legal consciousness examines whether firms have violated laws and regulations on environment. The social evaluation dimension reflects the recognition of a firm's environmental performance. The eco-friendly production dimension identifies whether a firm adopts the eco-friendly production modes. The green management dimension explores whether environmental factors are considered in daily operations.

where $SIZE_i$ is the natural logarithm of firm i's total assets, MB_i is the ratio of the market value of equity to its book value, LEV_i is firm i's leverage ratio. Coefficient β_2 (*GScore*) captures the timeliness of earnings in response to good news, and β_3 (*CScore*) represents the incremental sensitivity of earnings to bad news relative to good news. Hence, $\beta_2 + \beta_3$ reflects the timeliness of bad news, and β_3 itself is used as a proxy for conditional conservatism.

Substituting equations (2) and (3) into (1), we get the full model for estimating firm-year BNT (β_3):

$$X_i = \beta_0 + \beta_1 D_i + R_i(\mu_0 + \mu_1 SIZE_i + \mu_2 MB_i + \mu_3 EV_i) + D_i R_i(\omega_0 + \omega_1 SIZE_i + \omega_2 MB_i + \omega_3 LEV_i) + \varepsilon_i \quad (4)$$

Using annual cross-sectional regressions, we estimate the coefficients ω_0 to ω_3 and then compute the *CScore* (β_3) for each firm-year observation. This serves as the key independent variable representing bad news timeliness in this study.

2.3.4. Control variables

We control for other variables that may affect corporate environmental disclosure based on the literature (Anagnostopoulou et al., 2021; Cho et al., 2020; Pan & Zhao, 2021). Those factors include a dummy variable (*SOE*) equals one if a firm is state-owned, and zero otherwise; market-to-book value (*M/B Ratio*); growth in sales (*Sales Growth*); debt to assets ratio (*LEV*); firm size, calculated as the natural logarithm of total assets (*Size*); R&D expenses scaled by Sales (*R&D/Sales*); profitability calculated as net profit over total assets (*ROA*); shareholding of the largest shareholder (*Top1*); the natural logarithm of the number of board of directors (*Board Size*); the proportion of independent directors on the board (*Independence*); a dummy variable equals one if the firm hires an international Big-4 auditor firm, and zero otherwise (*Big 4*); and provincial GDP growth rate where a listed firm is headquartered (*GDP Growth*). Detailed definitions of variables are shown in Appendix A. All continuous variables are winsorised at the 1% and 99% levels.

2.3.5. Methodology

To examine the influence of bad news timeliness on corporate environmental information disclosure, we employ the following regression model:

$$\begin{aligned}Environmental\ Disclosure_{i,t} &= \alpha + \beta_1 BNT_{i,t} + \beta_2 SOE_{i,t} + \beta_3 Top1_{i,t} + \beta_4 Board\ Size_{i,t} \\ &+ \beta_5 Borad\ Independence_{i,t} + \beta_6 M/B\ Ratio_{i,t} + \beta_7 Sales\ Growth_{i,t} \\ &+ \beta_8 LEV_{i,t} + \beta_9 Big4_{i,t} + \beta_{10} Size_{i,t} + \beta_{11} R\&D/Sales_{i,t} + \beta_{12} ROA_{i,t} \\ &+ \beta_{13} GDP\ Growth\ Rate_{i,t} + \varepsilon_{i,t} \qquad (5)\end{aligned}$$

where *Environmental Disclosure* is measured by *ER* and *Disclosure* respectively. *BNT* is the variable to measure bad news timeliness. To address the unobserved firm characteristics and time-varying heterogeneity, we control for firm and year fixed effects.

2.4. Empirical results

2.4.1. Descriptive statistics and correlation matrix

Table 2.1 Panel A presents the descriptive statistics for the main variables used in this study. The mean value of *ER* is -0.035 (the max value in sample is 28.340) and *Disclosure* is 1.510 (the max value in sample is 9), indicating that the overall environmental disclosure level of sample firms is low. The mean value of BNT is -0.001, which is close to zero, suggesting that, on average, Chinese firms tend to report good news more promptly than bad news. This finding is consistent with prior studies, such as Pan and Zhao (2022). The statistics of control variables are generally consistent with the previous literature (Pan & Zhao, 2021; Guo et al., 2020). The mean of *SOE* is 0.421, indicating that 42.1% of the observations in our sample are SOEs. Panel B shows the distribution of samples by industry. Industries with high environmental engagement tend to be those with more pollution, such as mining, transportation, electric power and construction; while those with less pollution, such as information transmission and leasing, have low environmental engagement scores. We report the correlation coefficients between key variables in Appendix B, which indicates that multi-collinearity is not a concern in this study.

Table 2.1. Descriptive statistics
Panel A Summary statistics

	(1) Mean	(2) Standard deviation	(3) Minimum	(4) First quartile	(5) Median	(6) Third quartile	(7) Maximum
Hexun ER	-0.035	4.925	-16.630	-2.464	-1.125	0.000	28.340
Disclosure	1.510	1.902	0.000	0.000	1.000	2.000	9.000
BNT	-0.001	0.435	-1.974	-0.057	0.000	0.082	1.974
M/B	2.098	1.776	0.200	0.889	1.582	2.686	9.250
Sales Growth	0.194	0.443	-0.510	-0.016	0.113	0.277	2.789
R&D/Sales	0.004	0.014	0.000	0.000	0.000	0.000	0.087
ROA	0.040	0.048	-0.131	0.014	0.035	0.064	0.184
LEV	0.435	0.211	0.053	0.263	0.431	0.599	0.888
Size	22.180	1.238	19.860	21.290	22.030	22.910	25.840
Board Size	2.149	0.195	1.609	2.079	2.197	2.197	2.708
Independence	0.372	0.052	0.333	0.333	0.333	0.429	0.571
Big4	0.056	0.229	0.000	0.000	0.000	0.000	1.000
Top1	0.353	0.150	0.089	0.233	0.334	0.455	0.748
SOE	0.421	0.494	0.000	0.000	0.000	1.000	1.000
GDP Growth	0.078	0.020	0.033	0.066	0.075	0.087	0.146

Panel B Sample distribution by industry

Industry	**Number of observations**	***Hexun ER***	***Disclosure***
Mining Industry	222	5.581	3.090
Transportation, Warehousing and Postal Services	427	4.165	1.555
Construction Industry	309	3.231	1.848
Electricity, Heat, Gas and Water Production and Supply	374	2.612	1.385
Manufacturing Industry	8,101	1.954	1.706
Public Administration, Social Security and Social Organization	306	1.677	0.627
Hotels and Catering Services	16	1.656	1.500
Whole-sales and Retail Trade	671	1.607	0.718
Water Conservancy, Environment and Public Facilities Management	87	1.563	1.494
Real Estate	368	1.446	1.038
Scientific Research and Technology Services	62	1.371	1.532
Culture, Sports and Entertainment	70	1.164	0.500
Agriculture, Forestry, Animal Husbandry and Fishery	247	1.160	0.960
Residential services, repairs and other services	65	0.815	0.600
Leasing and Commercial Service	127	0.787	0.551
Information Transmission, Software, and Information Technology Services	696	0.784	0.628

This table reports the descriptive statistics of the main variables used in the study. The sample consists of firms listed on the SHSE and SZSE from 2010 to 2017 (12,148 observations). Panel A shows the summary statistics of the main variables used in this study. Panel B shows the sample distribution by industry. Industry classification is based on Industry Classification and Code of China's National Economy (GB/4754-2011). Detailed definitions of variables are reported in Appendix A.

2.4.2. Baseline results

The baseline regression results are shown in Table 2.2. *BNT* is negatively associated with the two environmental disclosure indicators *ER* and *Disclosure* in Columns (1) and (2), respectively. This supports Hypothesis 1 that firms with greater bad news timeliness is associated with lower environmental information disclosure. Our results indicate that managers strategically reduce the release of environmental information if the firm has satisfied stakeholders' requirement on information transparency by promptly reflecting negative news in their earnings. *Firm size* is positively associated with *ER* and *Disclosure*. In addition, *LEV* is negatively correlated with corporate environmental disclosure quality, indicating that high leverage will limit environmental engagement, which is consistent with the result of Anagnostopoulou et al. (2021).

Table 2.2. Baseline regression: bad news timeliness and corporate environmental disclosure

	(1) ***ER***	**(2)** ***Disclosure***
BNT	-0.423***	-0.073**
	(-2.996)	(-2.016)
M/B	0.042	-0.039***
	(1.049)	(-2.774)
Sales Growth	0.021	-0.062
	(0.172)	(-1.592)
R&D/Sales	10.417*	2.720
	(1.684)	(1.318)
ROA	2.463	0.255
	(1.389)	(0.686)
LEV	-0.852	-0.403**
	(-1.515)	(-2.168)
Size	0.678***	0.136**
	(4.740)	(2.549)
Board Size	-0.051	-0.148
	(-0.077)	(-0.906)
Independence	1.204	0.327
	(0.698)	(0.724)
Big4	0.905	0.076

	(1.428)	(0.447)
Top1	-0.638	-0.179
	(-0.809)	(-0.666)
SOE	0.034	0.000
	(0.081)	(0.000)
GDP Growth	-3.529	0.314
	(-0.759)	(0.210)
Constant	-15.139***	-0.719
	(-4.115)	(-0.609)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	12,148	12,148
Adjusted R^2	0.381	0.664

This table presents the results of the baseline regression. It reports the influence of bad news timeliness (*BNT*) on the two measures of corporate environmental disclosure, including industry-year adjusted Hexun environmental disclosure rating (*ER*) and environmental disclosure score (*Disclosure*). Definitions of variables are in Appendix A. *t*-statistics are reported in parentheses. Robust standard errors are clustered at industry level[3]. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.4.3. The impact of political connections

China's unique institutional setting leads to strong political interference in firms, so firms will seek various ways of establishing political connections to increase their legitimacy (Li et al., 2015; Li & Zhang, 2010). Following Li et al. (2015) and Li and Zhang (2010), we define two types of political connections in Chinese listed firms. Ascribed political connection is defined as a firm whose board chairperson has previously held a government-nominated position before they become the chairperson. While achieved political connection is identified when a firm's board chairperson currently holds a position in National People's Congress, Local People's Congress, Chinese People's Political Consultative Conference, or Local People's Political Consultative Conference. Past government work experience enables executives with common language, shared experience, and network relationships with government officials. As such, past government work experience enables them to have good

[3] Standard errors are clustered at the industry level to account for intra-industry correlation. I have also tested robustness using firm-level clustering in Appendix D, and the results remain consistent.

communication channels and better opportunities to obtain resources, apply for subsidies and appeal penalties (Hillman, 2005). However, executives with ascribed political connection are now firm executives rather than government bureaucrats, so they would be more concerned about firm development rather than political objectives. On the contrary, executives with current government-nominated positions have dual identities. They may prioritize government expectations to protect their political interests and strengthen their political position (Wang et al., 2019a).

We re-run baseline regressions adding the interaction term of *BNT*Ascribed bureaucratic connection* and *BNT*Achieved political connection* respectively, and the results are shown in Table 2.3. The results show that ascribed bureaucratic connection can enhance the substitution effects of bad news timeliness on environmental disclosure. We attribute this to ascribed bureaucratic connection, which gives firms more access to government resources they rely on, reducing the incentive to build social identification, thereby reducing environmental information disclosure. In contrast, the negative association between bad news timeliness and environmental disclosure becomes insignificant when firms with executives having achieved political connection, which is consistent with H2a. We argue that the dual role of those executives induces them to please government via increasing environmental disclosure.

Table 2.3. The impact of political connection

	Ascribed bureaucratic		***Achieved political***	
	(1) ***ER***	**(2)** ***Disclosure***	**(3)** ***ER***	**(4)** ***Disclosure***
BNT	-0.289*	-0.053	-0.394***	-0.066*
	(-1.763)	(-1.286)	(-2.735)	(-1.695)
*BNT *Ascribed bureaucratic connection*	-1.032**	-0.269***		
	(-2.622)	(-3.199)		
*BNT *Achieved political connection*			-0.563	-0.156
			(-1.126)	(-0.908)
Ascribed bureaucratic connection	0.149	0.074		
	(0.694)	(1.297)		
Achieved political connection			-0.369	-0.008
			(-1.634)	(-0.093)
M/B	0.031	-0.039***	0.044	-0.038***

	(0.768)	(-2.677)	(1.070)	(-2.699)
Sales Growth	0.025	-0.064	0.005	-0.063
	(0.204)	(-1.620)	(0.042)	(-1.616)
R&D/Sales	10.168	2.473	10.165	2.465
	(1.647)	(1.275)	(1.658)	(1.256)
ROA	2.599	0.391	2.605	0.272
	(1.424)	(0.975)	(1.456)	(0.718)
LEV	-0.833	-0.374*	-0.840	-0.396**
	(-1.487)	(-1.981)	(-1.500)	(-2.121)
Size	0.633***	0.134**	0.696***	0.139**
	(4.580)	(2.418)	(4.761)	(2.605)
Board Size	-0.012	-0.145	-0.007	-0.141
	(-0.018)	(-0.872)	(-0.011)	(-0.856)
Independence	1.212	0.310	1.351	0.265
	(0.709)	(0.626)	(0.798)	(0.569)
Big4	0.876	0.066	0.898	0.075
	(1.367)	(0.386)	(1.426)	(0.441)
Top1	-0.606	-0.199	-0.669	-0.182
	(-0.787)	(-0.734)	(-0.865)	(-0.674)
SOE	0.030	-0.027	0.037	0.007
	(0.068)	(-0.216)	(0.086)	(0.060)
GDP Growth	-3.374	0.031	-3.658	0.328
	(-0.735)	(0.021)	(-0.783)	(0.223)
Constant	-14.204***	-0.677	-15.656***	-0.795
	(-3.969)	(-0.549)	(-4.279)	(-0.675)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	12,070	12,070	12,122	12,122
Adjusted R^2	0.382	0.663	0.382	0.664

This table reports the regression results regarding the moderating effect of political connection on the relationship between bad news timeliness and corporate environmental disclosure. Columns (1) and (2) show the regression with the interaction term *BNT*Ascribed bureaucratic connection*. Columns (3) and (4) show the regression with the interaction term *BNT*Achieved political connection*. Variable descriptions are summarized in Appendix A. *t*-statistics are reported in parentheses. Robust standard errors are clustered at industry level. The superscripts *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.4.4. The impact of environmental regulatory constraints

For high polluting firms, the pressure to release environmental information will be higher, because legitimacy may affect their survival (Colwell & Joshi, 2013). Government monitoring of pollution control and environmental protection will directly affect the operating certification of highly polluting firms (Matsumoto & Szidarovszky, 2020; Shahbaz et al., 2015), thus changing the attitude of firms towards more environmental participation. Therefore, we expect that under the pressure of environmental policy regulation, the negative association between bad news timeliness and environmental disclosure will become insignificant.

In 2003, Chinese Ministry of Ecology and Environment issued document No. 60, which announced 15 types of highly polluting industries as key polluters. It is required that key polluters should be closely monitored by local governments. According to the classification of key polluters by the Ministry of Ecology and Environment, we divide the full sample into two subsamples: key polluters and non-key polluters. Table 2.4 shows the subsample regression analysis of accounting conservatism and environmental disclosure. The negative association between bad news timeliness and environmental disclosure becomes insignificant in key polluters. The result supports H2b that when facing policy constraints, executives need to increase environmental disclosure to reduce litigation risk, and therefore, the substitute effect of bad news timeliness on environmental disclosure becomes insignificant.

Table 2.4. The impact of environmental policy constraints

	Non-key polluters		Key polluters	
	(1)	(2)	(3)	(4)
	ER	***Disclosure***	***ER***	***Disclosure***
BNT	-0.406**	-0.089**	-0.658	0.006
	(-2.589)	(-2.330)	(-1.182)	(0.034)
M/B	0.032	-0.043**	0.135	0.045
	(0.943)	(-2.510)	(0.189)	(0.376)
Sales Growth	0.052	-0.051	0.262	-0.151
	(0.425)	(-1.480)	(0.329)	(-0.469)
R&D/Sales	10.126	2.885	24.108	-0.166
	(1.516)	(1.624)	(0.816)	(-0.022)
ROA	2.102	0.045	1.830	1.524
	(1.465)	(0.116)	(0.121)	(0.608)
LEV	-0.634	-0.421**	-4.195	1.250
	(-1.233)	(-2.340)	(-0.680)	(0.835)
Size	0.561***	0.128**	1.454	0.166
	(3.509)	(2.161)	(1.390)	(0.420)
Board Size	0.167	-0.110	3.555	-0.839
	(0.267)	(-0.731)	(0.767)	(-0.675)
Independence	1.074	-0.003	8.102	2.961
	(0.598)	(-0.007)	(0.518)	(0.867)
Big4	1.250*	0.102	-1.900	0.145
	(1.856)	(0.536)	(-0.663)	(0.109)

Top1	-0.621	-0.169	-3.600	-0.966
	(-0.795)	(-0.576)	(-0.402)	(-0.395)
SOE	0.089	-0.006	-7.205***	0.228
	(0.200)	(-0.056)	(-5.100)	(0.745)
GDP Growth	-1.109	0.890	-39.938	-5.736
	(-0.213)	(0.604)	(-0.975)	(-0.714)
Constant	-13.119***	-0.776	-34.842	0.293
	(-3.036)	(-0.592)	(-1.236)	(0.031)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	11,082	11,082	1,066	1,066
Adjusted R^2	0.423	0.639	0.153	0.693

This table reports the moderating effect of environmental policy constrains on the relationship between bad news timeliness and corporate environmental disclosure. The full sample is divided into key and non-key polluters. Key polluters are identified by the Ministry of Ecology and Environment. Variable descriptions are summarized in Appendix A. *t*-statistics are reported in parentheses. Robust standard errors are clustered at industry level. The superscripts *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.4.5. Mechanism analysis: Analyst attention

Bad news timeliness reduces information asymmetry and protects stakeholders' interests (Mora & Walker, 2015). Analysts' monitoring plays a similar role in improving firms' transparency (Langberg & Sivaramakrishnan, 2008; Chen et al., 2016). Therefore, we suspect that disclosing bad news on earnings more promptly than good news will reduce the attention from analysts, and therefore, firms are able to reduce their environmental disclosure accordingly. On the contrary, more analyst attention means that firms bear more pressure from external public opinion (Chen et al., 2016), as such, firms have to put additional effort on environmental disclosure to enhance reputation (Pan & Zhao, 2021). Therefore, we expect that the attention of analysts is a channel to explain the substitution effect of bad news timeliness on environmental disclosure.

We utilize a mediator test to examine whether analyst attention explains why conservative accounting reporting can substitute environmental disclosure. Following Crawford et al. (2012) and Piotroski and Roulstone (2004), we construct two variables to measure the degree of analyst's attention. *Analyst Attention* is measured as the natural logarithm of one plus the number of financial analysts that follow a firm in a year; and *Report Attention* is the natural logarithm of one plus the number of research reports about a firm in a year. Results in Panels A and B of Table 2.5 (the first stage analyses) indicate that accounting conservatism is negatively associated with *Analyst Attention* and *Report Attention*. In the second stage of the regression, we incorporate *Analyst Attention* and *Report Attention* individually as mediator variables into the baseline regression model. The coefficients of *Analyst Attention* and *Report Attention* are both negative and significant. The results confirm our expectation that analysts will pay less attention to firms with greater bad news timeliness, and therefore firms could reduce their environmental disclosure accordingly.

Table 2.5. Mechanism analysis: Analyst and report attention
Panel A: Analyst attention

	(1) *Analyst Attention*	(2) *Disclosure*	(3) *ER*
BNT	-0.044**	-0.094**	-0.558***
	(-2.088)	(-2.185)	(-2.889)
Analyst Attention		-0.059**	-0.287**
		(-2.053)	(-2.228)
M/B	0.128***	-0.024	0.009
	(10.796)	(-1.191)	(0.165)
Sales Growth	-0.024	-0.049	-0.037
	(-0.928)	(-0.799)	(-0.210)
R&D/Sales	0.081	2.574	11.012**
	(0.076)	(1.051)	(2.164)
ROA	4.465***	0.457	5.355**
	(13.168)	(0.834)	(2.116)
LEV	-0.052	-0.562**	0.532
	(-0.433)	(-2.622)	(0.938)
Size	0.512***	0.161**	0.691***
	(14.432)	(2.035)	(4.047)
Board Size	0.085	-0.014	0.755
	(0.771)	(-0.074)	(0.939)
Independence	0.248	0.528	3.808*
	(0.742)	(0.853)	(1.916)
Big4	0.196**	-0.084	0.685
	(2.564)	(-0.390)	(0.715)
Top1	-0.429**	-0.288	-1.819*
	(-2.147)	(-1.001)	(-1.724)
SOE	-0.058	0.016	-0.069
	(-0.587)	(0.089)	(-0.096)
GDP Growth	0.187	1.361	-3.903
	(0.166)	(0.634)	(-0.712)

Constant	-9.673***	-2.484	-16.791***
	(-12.359)	(-1.498)	(-3.971)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	9,102	9,102	9,102
Adjusted R-squared	0.658	0.656	0.378

Panel B: Report attention	(1)	(2)	(3)
	Report Attention	*Disclosure*	*ER*
BNT	-0.071**	-0.115***	-0.468**
	(-2.615)	(-2.664)	(-2.478)
Report Attention		-0.046**	-0.223**
		(-2.149)	(-2.448)
M/B	0.172***	-0.024	0.039
	(12.634)	(-1.200)	(0.698)
Sales Growth	-0.018	-0.061	0.008
	(-0.519)	(-1.095)	(0.048)
R&D/Sales	-0.691	2.469	10.801*
	(-0.580)	(1.001)	(1.964)
ROA	6.180***	0.614	5.395**
	(13.893)	(1.086)	(2.148)
LEV	-0.050	-0.519**	0.355
	(-0.387)	(-2.633)	(0.616)
Size	0.673***	0.180**	0.861***
	(15.425)	(2.501)	(5.301)
Board Size	0.121	-0.041	0.315
	(0.938)	(-0.226)	(0.390)
Independence	0.183	0.553	3.075
	(0.485)	(0.945)	(1.596)
Big4	0.265**	-0.099	0.773
	(2.535)	(-0.468)	(0.825)
Top1	-0.651**	-0.238	-1.447
	(-2.368)	(-0.793)	(-1.515)
SOE	-0.079	0.056	-0.096
	(-0.588)	(0.319)	(-0.131)
GDP Growth	0.068	0.602	-7.428
	(0.051)	(0.286)	(-1.165)
Constant	-12.989***	-2.808*	-18.978***
	(-14.145)	(-1.825)	(-4.770)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	9,154	9,154	9,154
Adjusted R-squared	0.656	0.658	0.372

This table presents the 2SLS regression results using *Analyst Attention* and *Report Attention* as the mechanism through which bad news timeliness affects corporate environmental disclosure. *Analyst Attention* is the natural logarithm of one plus the number of analysts (teams) that cover a firm in a year. *Report Attention* is one plus the natural logarithm of the number of analyst research reports about a firm in a year. Panel A presents the results of *Analyst Attention*. Panel B presents the results of *Report Attention*. The first stage analysis results are reported in Column (1) in each panel. Results of the second stage regressions are shown in Columns (2) and (3) in each panel. Definitions of other variables are in

Appendix A. *t*-statistics are reported in parentheses. Robust standard errors are clustered at industry level. The superscripts *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.4.6. Mechanism analysis: Pressure from short-term lenders

Short-term lenders benefit from a firm's bad news timeliness because it limits the firm's downside risks and helps reduce the risk of bankruptcy (Balakrishnan et al., 2016). Therefore, firms with higher bad news timeliness are more favoured by short-term lenders, which leads to more short-term loan supports (Balakrishnan et al., 2016). However, the relationship between short-term lenders and firms is primarily one of borrowing and lending, with lenders placing greater emphasis on the firm's default risk and less on long-term developmental needs. They prefer firms to allocate more resources to the production and operations of their core business (Clinch et al., 2019). As a result, the pressures from short-term lenders may lead firms to prioritize debt repayment over environmental concerns, impacting lenders' ability to recover funds and encouraging firms to reduce environmental disclosures (Brown, 2018).

We examine whether the timeliness of bad news can reduce a firm's environmental disclosures by increasing corporate short-term debts, as presented in Table 2.6. Following prior studies (e.g., Van der Wijst & Thurik, 1993), we employ the short-term debt to total assets ratio (*DebtTA*) to measure the extent to which a firm relies on short-term borrowing. In the first stage, we assess whether the presence of bad news timeliness increases firms' access to short-term loans. As shown in Column (1), the coefficient on *BNT* is positive and significant at the 5% level, indicating that bad news timeliness increases firms' short-term borrowing. Subsequently, we include *DebtTA* as a mediator variable in our baseline regression, and the results in Columns (2) and (3) show that *DebtTA* has a significant negative impact on two environmental disclosure indicators, with significance levels at 5% for both. Overall, Table 2.6

demonstrates that bad news timeliness increases the impact of short-term borrowing on firms, thereby reducing their environmental disclosures.

Table 2.6. Mechanism analysis: Pressure from short-term lenders

	(1) ***DebtTA***	**(2)** ***Disclosure***	**(3)** ***ER***
BNT	0.004**	-0.079*	-0.325**
	(2.211)	(-1.955)	(-2.158)
DebtTA		-0.487**	-2.370**
		(-2.058)	(-2.298)
M/B	-0.000	-0.047***	0.050
	(-0.602)	(-3.030)	(1.043)
Sales Growth	-0.004	-0.062	0.010
	(-1.656)	(-1.624)	(0.075)
R&D/Sales	0.167**	3.270	10.196
	(2.452)	(1.573)	(1.599)
ROA	-0.128***	0.290	2.216
	(-4.302)	(0.754)	(1.113)
LEV	0.323***	-0.486***	-0.320
	(19.337)	(-2.696)	(-0.534)
Size	-0.011***	0.163***	0.740***
	(-2.925)	(3.124)	(4.433)
Board Size	0.002	0.031	0.276
	(0.217)	(0.201)	(0.435)
Independence	0.007	0.484	1.065
	(0.306)	(1.132)	(0.664)
Big4	0.000	0.094	1.143*
	(0.019)	(0.502)	(1.747)
Top1	-0.014	0.039	-1.566*
	(-0.774)	(0.144)	(-1.971)
SOE	-0.013	0.012	0.170
	(-1.580)	(0.098)	(0.364)
GDP Growth	-0.144	1.057	-4.181
	(-1.565)	(0.651)	(-0.800)
Constant	0.231**	-2.713**	-15.746***
	(2.600)	(-2.431)	(-3.943)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	11,360	11,360	11,360
Adjusted R-squared	0.779	0.653	0.408

This table presents the 2SLS regression results using *DebtTA* as the mechanism through which bad news timeliness affects corporate environmental disclosure. *DebtTA* is the firm's short-term debt to its total assets. The first stage analysis results are reported in Column (1) in each panel. Results of the second stage regressions are shown in Columns (2) and (3) in each panel. Definitions of other variables are in Appendix A. *t*-statistics are reported in parentheses. Robust standard errors are clustered at industry level. The superscripts *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.4.7. Endogeneity

Our baseline results may be subject to endogeneity. For example, it is possible that there are unobservable factors that affect both bad news timeliness and environmental disclosure policies. In this section, we address the potential endogeneity issue by controlling for multiple fixed effects and conducting the IV-GMM analysis.

2.4.7.1. Controlling for multiple fixed effects

The baseline regression considers the influence of the unobserved firm characteristics and time-varying heterogeneity, so firm and year fixed effects are controlled for. We add industry×year fixed effects and province×year fixed effects in Table 2.7 to address the concern that unobserved factors across industries and provinces may affect corporate environmental disclosure. The results in Table 2.7 show that bad news timeliness is still significantly and negatively associated with environmental disclosure indicators after controlling for multiple fixed effects.

Table 2.7. Controlling for multiple fixed effects

	(1)	(2)	(3)	(4)
	ER	***Disclosure***	***ER***	***Disclosure***
BNT	-0.504***	-0.075**	-0.394***	-0.063*
	(-3.029)	(-2.130)	(-2.754)	(-1.682)
M/B ratio	0.040	-0.037**	0.040	-0.043***
	(0.902)	(-2.639)	(1.085)	(-2.683)
Sales Growth	0.015	-0.065	0.058	-0.061
	(0.123)	(-1.650)	(0.471)	(-1.542)
R&D/Sales	10.595*	2.497	6.877	2.474
	(1.731)	(1.259)	(1.090)	(1.307)
ROA	2.485	0.251	1.848	0.358
	(1.394)	(0.696)	(1.041)	(0.956)
LEV	-0.785	-0.419**	-0.867	-0.392**
	(-1.368)	(-2.137)	(-1.550)	(-2.192)
Size	0.665***	0.133**	0.713***	0.128**
	(4.383)	(2.619)	(5.408)	(2.385)
Board Size	-0.009	-0.104	0.046	-0.107
	(-0.014)	(-0.644)	(0.072)	(-0.640)
Independence	1.178	0.325	1.210	0.319
	(0.663)	(0.686)	(0.713)	(0.691)
Big4	0.832	0.097	1.028	0.083

	(1.302)	(0.574)	(1.612)	(0.499)
Top1	-0.589	-0.075	-0.608	-0.189
	(-0.743)	(-0.273)	(-0.898)	(-0.673)
SOE	0.051	0.009	0.097	0.020
	(0.120)	(0.079)	(0.210)	(0.173)
GDP Growth Rate	-3.820	0.878	78.556	-15.859
	(-0.800)	(0.540)	(1.321)	(-0.731)
Constant	-13.883***	-1.703	-15.097***	-1.419
	(-3.701)	(-1.550)	(-4.521)	(-1.269)
Firm FE	Yes	Yes	Yes	Yes
Industry-year FE	Yes	Yes		
Province-year FE			Yes	Yes
Observations	12,148	12,148	12,148	12,148
Adjusted R^2	0.377	0.666	0.394	0.664

This table presents the robustness test by controlling for multiple fixed effects. Column (1) and (2) presents the results of the regression controlling for firm and industry-year fixed effects. Column (3) and (4) presents the results of the regression controlling for firm and province-year fixed effects. Variable descriptions are summarized in Appendix A. *t*-statistics are reported in parentheses. Robust standard errors are clustered at industry level. The superscripts *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.4.7.2. IV-GMM analysis

To address potential endogeneity concerns—specifically reverse causality and omitted variable bias—we employ the two-stage least squares (IV-2SLS) estimation method using instrumental variables. Regarding reverse causality, while our baseline assumption is that bad news timeliness (BNT) affects corporate environmental disclosure, it is also plausible that firms with lower environmental disclosure tendencies may adopt more conservative financial reporting to signal transparency, thereby reversing the causal direction. The IV approach helps to isolate exogenous variation in BNT that is not influenced by firms' environmental disclosure decisions, allowing us to make more credible causal inferences. Concerning omitted variables, unobservable firm-level characteristics, such as corporate culture or managerial risk preferences, may jointly influence both BNT and environmental disclosure. Even with firm and year fixed effects, such unobserved heterogeneity can bias the estimated relationship. By using external instruments that affect BNT but are plausibly unrelated to these unobservable factors, the IV strategy mitigates this source of bias.

We employ the IV-2SLS estimation method with two instrumental variables: *TerrainRoughness* and *Confu_100km*. These instruments isolate the exogenous variation in *TBN*, which may be endogenous in the baseline regression. *TerrainRoughness* reflects geographic heterogeneity, a factor historically influencing regional economic development and institutional environments. Firms located in regions with rugged terrain face greater operational risks, such as logistical challenges and natural disasters (Carter et al., 2019), which may incentivize them to adopt more conservative financial reporting practices to buffer against uncertainty. Thus, *TerrainRoughness* plausibly correlates with *TBN*. Furthermore, geographic features—such as terrain—are exogenous to firm-level decisions, including environmental disclosure practices. While terrain may influence historical economic conditions, it is unlikely to directly affect contemporary environmental reporting, except through its impact on accounting conservatism. This satisfies the exclusion restriction required for valid instruments.

Confu_100km, the natural logarithm of the number of Confucian temples within a 100-kilometer radius of a firm, captures the cultural and ethical legacy of Confucianism, which emphasizes values such as prudence, long-term orientation, and risk aversion—principles closely aligned with accounting conservatism (Du et al., 2022). Regions with a stronger Confucian heritage may institutionalize these values, leading to higher levels of conservatism. The distribution of Confucian temples—as a historical and cultural phenomenon—is determined by pre-modern societal factors, such as imperial policies and migration patterns, and is unrelated to contemporary firm-level environmental disclosure practices, except through its indirect influence on accounting conservatism. This ensures that *Confu_100km* affects environmental disclosure only via accounting conservatism, satisfying the exogeneity condition.

The results, reported in Table 4, show that both instrumental variables are significantly related to *TBN* in the first stage, with a Cragg–Donald Wald F-statistic of 13.745, exceeding the threshold of 10, ruling out weak instrument concerns. Additionally, the Kleibergen–Paap rk LM statistic is highly significant at the 1% level, confirming that the model is not under-identified. The fitted values from this regression are used as the instrumented values for TBN in the second stage of the IV-2SLS estimation. The second-stage results indicate that the coefficients for *Fitted_TBN* are negative and statistically significant at the 5% level in both Columns (2) and (3) of Table 4, suggesting a robust negative relationship between accounting conservatism and environmental disclosure. Moreover, the p-values for Hansen's J statistic are 0.712 and 0.225, both exceeding the 0.1 threshold, implying that we fail to reject the null hypothesis of instrument exogeneity. Overall, our baseline results remain robust after addressing endogeneity employing the IV-2SLS analysis.[4]

Table 2.8. The IV-2SLS analysis

First stage		**Second stage**		
	(1)		**(2)**	**(3)**
	TBN		***ER***	***Disclosure***
TerrainRoughness	0.595*	*Fitted_TBN*	-4.036***	-1.466**
	(1.72)		(-3.868)	(-2.130)
Confu_100km	0.2867***	*MB*	0.042	-0.038**
	(3.17)		(0.928)	(-2.494)
MB	0.002	*Growth*	0.050	-0.056
	(0.28)		(0.384)	(-1.043)
Growth	0.010	*R&D/Sales*	8.662	2.917
	(0.56)		(1.408)	(1.502)
R&D/Sales	-0.240	*ROA*	1.581	-0.354
	(-0.51)		(0.924)	(-0.611)
ROA	-0.227	*LEV*	0.050	-0.093
	(-0.94)		(0.088)	(-0.326)
LEV	0.209***	*Size*	0.372*	0.009
	(3.65)		(1.735)	(0.099)
Size	-0.112***	*Board*	-0.523	-0.227
	(-4.65)		(-0.762)	(-1.134)
Board	-0.091	*Independence*	0.751	0.122
	(-1.49)		(0.426)	(0.268)
Independence	-0.225	*Big4*	1.110*	0.127
	(-1.30)		(1.757)	(0.607)

[4] Following Khan and Watts (2009) and Anagnostopoulou et al. (2021), we use other variables, *Age* and *InvestmentCycle*, to instrument TBN. The results are shown in Appendix D, and the IV-2SLS analysis also passes.

Big4	0.072	*Top1*	-0.817	-0.118
	(1.38)		(-0.753)	(-0.434)
Top1	-0.166	*SOE*	0.107	0.125
	(-1.66)		(0.235)	(0.714)
SOE	0.063	*GDPG*	0.545	2.045
	(1.12)		(0.111)	(1.188)
GDPG	1.110***			
	(2.49)			
Kleibergen–Paap rk LM statistic	11.025***	Hansen's J statistic (p-value)	0.712	0.226
Cragg–Donald Wald F-statistic	13.745			
Firm FE	Yes	Firm FE	Yes	Yes
Year FE	Yes	Year FE	Yes	Yes
Observations	10,649	Observations	10,665	10,665

This table presents the impact of TBN on corporate environmental disclosure using instrumental variable estimation. Two instrumental variables (IVs) are employed: (1) *TerrainRoughness*, which represents the topographic relief or elevation variation of the city where the firm is located, and (2) *Confu_100km*, which represents the natural logarithm of the number of Confucian temples located within a 100-kilometer radius of the enterprise, incremented by 1. In the first-stage analysis, *TerrainRoughness* and *Confu_100km* are regressed on *TBN*, with firm-specific independent variables included. In the second-stage analysis, the fitted values generated from the first-stage estimation are employed as the instrumental variable for *TBN*, and the baseline regression is rerun. Detailed definitions of variables are given in Appendix A. The *t*-statistics are reported in parentheses. Robust standard errors are clustered at the industry level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 4. The IV-2SLS analysis

First stage		**Second stage**		
	(1) ***TBN***		**(2)** ***ER***	**(3)** ***Disclosure***
TerrainRoughness	0.595*	*Fitted_TBN*	-4.036***	-1.466**
	(1.72)		(-3.868)	(-2.130)
Confu_100km	0.2867***	*MB*	0.042	-0.038**
	(3.17)		(0.928)	(-2.494)
MB	0.002	*Growth*	0.050	-0.056
	(0.28)		(0.384)	(-1.043)
Growth	0.010	*R&D/Sales*	8.662	2.917
	(0.56)		(1.408)	(1.502)
R&D/Sales	-0.240	*ROA*	1.581	-0.354
	(-0.51)		(0.924)	(-0.611)
ROA	-0.227	*LEV*	0.050	-0.093
	(-0.94)		(0.088)	(-0.326)
LEV	0.209***	*Size*	0.372*	0.009
	(3.65)		(1.735)	(0.099)
Size	-0.112***	*Board*	-0.523	-0.227
	(-4.65)		(-0.762)	(-1.134)

Board	-0.091	*Independence*	0.751	0.122
	(-1.49)		(0.426)	(0.268)
Independence	-0.225	*Big4*	1.110*	0.127
	(-1.30)		(1.757)	(0.607)
Big4	0.072	*Top1*	-0.817	-0.118
	(1.38)		(-0.753)	(-0.434)
Top1	-0.166	*SOE*	0.107	0.125
	(-1.66)		(0.235)	(0.714)
SOE	0.063	*GDPG*	0.545	2.045
	(1.12)		(0.111)	(1.188)
GDPG	1.110***			
	(2.49)			
Kleibergen–Paap rk LM statistic	11.025***	Hansen's J statistic (p-value)	0.712	0.226
Cragg–Donald Wald F-statistic	13.745			
Firm FE	Yes	Firm FE	Yes	Yes
Year FE	Yes	Year FE	Yes	Yes
Observations	10,649	Observations	10,665	10,665

This table presents the impact of TBN on corporate environmental disclosure using instrumental variable estimation. Two instrumental variables (IVs) are employed: (1) *TerrainRoughness*, which represents the topographic relief or elevation variation of the city where the firm is located, and (2) *Confu_100km*, which represents the natural logarithm of the number of Confucian temples located within a 100-kilometer radius of the enterprise, incremented by 1. In the first-stage analysis, *TerrainRoughness* and *Confu_100km* are regressed on *TBN*, with firm-specific independent variables included. In the second-stage analysis, the fitted values generated from the first-stage estimation are employed as the instrumental variable for *TBN*, and the baseline regression is rerun. Detailed definitions of variables are given in Appendix A. The *t*-statistics are reported in parentheses. Robust standard errors are clustered at the industry level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.4.8. Heterogeneity analysis

Environmental disclosure has its unique purpose and provides different benefits compared with bad news timeliness. In this section, we examine the heterogeneous factors on the impact of bad news timeliness on environmental disclosure.

2.4.8.1. Financial constraints

We conjecture that the substitute effect of bad news timeliness varies with the level of the firm's financial constraints, e.g., to ease access to financing, firms need to release more environmental information when they have severe financial constraints. We adopt three measures to gauge the degree of financial constraints, namely Whited-Wu (*WW*) index, Financing-constraint (*FC*) index, and absolute value of Size-age (SA) index (*absSA*). A higher the value of the indexes denotes greater financial constraints.[5] According to the median of the financing constraint measures, we conduct subsample analysis. The results are shown in Table 2.9. From Panel A, Panel B and Panel C, we find that the association between bad news timeliness and environmental disclosure becomes insignificant in firms with high financial constraints. The results support our conjecture that when facing greater financial constraints, executives need to adjust their strategies to cater to powerful stakeholders by releasing more environmental information to enhance their access to financing. As the Chinese government provides the unique green credits policy and subsidies for environmental protection, commitment to green activities would help to mitigate corporate financial constraints (Chang et al., 2020).

Table 2.9. Heterogeneity analysis: Financial constraints
Panel A. WW index

	Low WW (Low constraint)		**High WW (High constraint)**	
	(1)	**(2)**	**(3)**	**(4)**
	ER	***Disclosure***	***ER***	***Disclosure***
BNT	-0.693***	-0.112**	0.061	0.012
	(-3.802)	(-2.242)	(0.429)	(0.198)
M/B	0.142	0.003	-0.093**	-0.043**
	(1.441)	(0.083)	(-2.479)	(-2.274)
Sales Growth	-0.155	-0.045	0.077	-0.062
	(-0.818)	(-0.638)	(0.451)	(-1.064)
R&D/Sales	9.917	2.341	11.107**	3.057
	(0.727)	(0.758)	(2.443)	(1.200)
ROA	2.887	-0.754	2.267	0.697
	(1.142)	(-0.638)	(1.132)	(1.225)
LEV	-0.685	-0.761**	-0.708	0.055
	(-0.705)	(-2.021)	(-1.197)	(0.164)
Size	1.146***	0.247***	0.333	0.032

[5] The WW index (Whited & Wu, 2006) and FC index (Fee et al., 2009) consider several characteristic factors of enterprises, such as cash flow, sales growth, long-term debt to total assets, firm size, dividend policy, and the firm's three-digit industry sales growth. While the SA index (Hadlock & Pierce, 2010) only considers the size and age of a firm, which takes into fewer factors but reduces the effect of endogeneity. The construction of the indexes is presented in Appendix A.

	(3.355)	(2.888)	(1.436)	(0.335)
Board Size	-0.255	0.006	-1.118	-0.408
	(-0.230)	(0.019)	(-1.403)	(-1.262)
Independence	1.699	0.624	-2.411	-0.648
	(0.593)	(0.917)	(-0.954)	(-0.720)
Big4	1.058	-0.045	-0.618	-0.371
	(1.411)	(-0.203)	(-0.374)	(-1.164)
Top1	-0.445	0.519	1.399	-0.971**
	(-0.331)	(1.084)	(0.787)	(-2.287)
SOE	-0.329	0.180	0.520	-0.187
	(-0.344)	(0.779)	(0.725)	(-0.888)
GDP Growth	-8.795	0.009	4.759	-1.982
	(-0.944)	(0.004)	(0.806)	(-0.926)
Constant	-25.996***	-3.578*	-4.564	2.358
	(-3.125)	(-1.754)	(-0.795)	(1.176)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	6,873	6,873	5,275	5,275
Adjusted R^2	0.375	0.675	0.431	0.633

Panel B. FC index

	Low FC (Low constraint)		**High FC (High constraint)**	
	(1)	**(2)**	**(3)**	**(4)**
	ER	***Disclosure***	***ER***	***Disclosure***
BNT	-0.627***	-0.088*	-0.120	-0.032
	(-3.729)	(-1.820)	(-0.704)	(-0.516)
M/B	0.064	-0.040	-0.050	-0.041***
	(0.567)	(-1.277)	(-0.978)	(-2.986)
Sales Growth	-0.185	-0.042	0.035	-0.103*
	(-1.042)	(-0.707)	(0.221)	(-1.800)
R&D/Sales	23.318	1.017	5.208	3.385**
	(1.635)	(0.234)	(0.792)	(2.523)
ROA	2.541	-0.322	1.899	1.037
	(0.992)	(-0.445)	(0.809)	(1.186)
LEV	-3.349***	-0.489	0.547	-0.101
	(-3.318)	(-1.512)	(0.664)	(-0.288)
Size	0.771***	0.212**	0.096	0.110
	(2.982)	(2.396)	(0.296)	(1.275)
Board Size	0.056	-0.169	-0.921	-0.423*
	(0.052)	(-0.649)	(-0.892)	(-1.673)
Independence	2.848	0.310	-3.431*	0.243
	(1.140)	(0.476)	(-1.721)	(0.290)
Big4	1.659**	0.137	-1.308	-0.179
	(2.433)	(0.618)	(-0.880)	(-0.389)
Top1	-0.995	-0.130	1.865	0.566
	(-0.894)	(-0.286)	(1.407)	(1.058)
SOE	-1.292***	0.146	1.475	-0.232
	(-2.897)	(0.713)	(1.248)	(-0.659)
GDP Growth	-10.126	2.364	6.367	-3.214

	(-1.213)	(1.122)	(0.887)	(-1.239)
Constant	-16.130**	-2.313	-0.311	0.033
	(-2.448)	(-1.045)	(-0.042)	(0.016)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	6,647	6,647	5,501	5,501
Adjusted R^2	0.356	0.672	0.453	0.644

Panel C. absSA index

	Low *absSA* (Low constraint)		**High *absSA* (High constraint)**	
	(1)	**(2)**	**(3)**	**(4)**
	ER	***Disclosure***	***ER***	***Disclosure***
BNT	-0.911**	-0.141**	-0.054	-0.061
	(-2.535)	(-2.177)	(-0.407)	(-1.233)
M/B	0.110	-0.037	-0.035	-0.029
	(1.148)	(-1.161)	(-0.568)	(-1.485)
Sales Growth	0.238	-0.104	0.058	-0.002
	(0.920)	(-1.552)	(0.438)	(-0.043)
R&D/Sales	13.168	4.758	5.252	2.143
	(1.191)	(1.424)	(1.217)	(0.813)
ROA	4.453	0.886	1.766	-0.207
	(0.903)	(0.832)	(0.850)	(-0.393)
Board Size	2.592*	-0.089	-2.132**	-0.654**
	(1.717)	(-0.187)	(-2.649)	(-2.257)
Independence	0.245	0.163	0.579**	0.145*
	(0.678)	(1.061)	(2.340)	(1.694)
Big4	0.217	-0.297	-0.184	0.005
	(0.197)	(-0.969)	(-0.173)	(0.020)
Top1	-1.073	-1.142	2.385	1.106
	(-0.327)	(-1.177)	(1.106)	(1.510)
SOE	1.606	0.448	1.016	-0.164
	(0.750)	(0.939)	(1.151)	(-0.709)
LEV	-2.274	-0.689	-0.790	0.169
	(-0.964)	(-0.974)	(-0.801)	(0.415)
Size	0.644	-0.094	-0.228	-0.004
	(0.342)	(-0.157)	(-0.428)	(-0.031)
GDP Growth	-7.996	1.503	-1.046	0.628
	(-0.636)	(0.490)	(-0.179)	(0.358)
Constant	-7.066	-0.612	-12.276**	-1.586
	(-1.013)	(-0.321)	(-2.040)	(-0.730)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	4,270	4,270	7,878	7,878
Adjusted R^2	0.397	0.665	0.344	0.679

This table reports the subsample analysis concerning financial constraints. Panel A reports the subsample analysis according to above and below median WW. Panel B reports the subsample analysis according to above and below median FC. Panel C reports the subsample analysis according to above and below median *absSA* (Absolute value of SA index). A higher WW index, FC index, or *absSA* reflects a greater level of financing constraints. Definitions of variables are in Appendix A. *t*-statistics are reported in parentheses. Robust standard errors are clustered at industry level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.4.8.2. Industry competition

A firm's survival depends on how it responds to market competition, which encourages executives to develop appropriate strategies to compete effectively (Yadav et al., 2016). The pressures posed by competition put tremendous pressure on executives to find scarce resources and create strategic value to gain a competitive advantage (Ruf et al., 2001). A growing body of evidence highlights those efforts in social and environmental practices can improve firm image, and increase consumer satisfaction with green products, thus enabling firms to differentiate themselves from competitors in the market (Yadav et al., 2016). In the fierce competition environment, gaining consumer recognition is an important factor to increase market shares (Tsendsuren et al., 2021). Existing literature has provided evidence that consumers consider environmental responsibility in their purchasing decisions (Luo & Bhattacharya, 2006). Therefore, we expect that in a highly competitive industry, executives will not reduce environmental information disclosure even they have adopted conservative accounting reporting.

To verify the above expectations, two widely used industry concentration indexes, e.g., the Herfindahl-Hirschman index (*HHI*) and *CR4* are employed. The *HHI* indicates the industry concentration, e.g., the lower the index, the higher the competition in the industry. *CR4* is the sum of the market share (revenue) of the top four largest enterprises in an industry. The smaller the *CR4* index, the fiercer the competition. Panels A and B in Table 2.10 show that when industry competition is high, the negative relationship between bad news timeliness and environmental disclosure becomes insignificant. The results verify our expectation that executives intend to release more environmental information when they face intensive competition, as such, the substitution effect of bad news timeliness on environmental disclosure becomes insignificant.

Table 2.10. Heterogeneity analysis: Industry competition

Panel A. Subsample analysis between high HHI and low HHI

	High HHI (Low Competition)		**Low HHI (High Competition)**	
	(1)	**(2)**	**(3)**	**(4)**
	ER	***Disclosure***	***ER***	***Disclosure***
BNT	-0.475**	-0.113**	-0.143	0.011
	(-2.566)	(-2.381)	(-0.663)	(0.197)
M/B	0.005	-0.034	0.031	-0.042*
	(0.106)	(-1.572)	(0.436)	(-1.728)
Sales Growth	-0.013	-0.040	0.123	-0.103
	(-0.084)	(-0.938)	(0.499)	(-1.418)
R&D/Sales	7.169	-1.144	12.896*	2.421
	(0.802)	(-0.558)	(1.792)	(0.980)
ROA	0.404	0.516	3.911	0.046
	(0.211)	(0.653)	(1.396)	(0.121)
LEV	-1.430	-0.496*	-0.289	-0.301
	(-1.540)	(-1.742)	(-0.374)	(-0.783)
Size	0.530***	0.125	0.735***	0.155**
	(3.055)	(1.272)	(2.766)	(2.462)
Board Size	1.066	-0.036	-1.198	-0.326
	(1.123)	(-0.158)	(-1.192)	(-1.416)
Independence	3.116	0.155	-0.740	0.168
	(1.569)	(0.190)	(-0.271)	(0.308)
Top1	0.642	0.155	0.671	-0.085
	(0.956)	(0.584)	(0.520)	(-0.355)
Big4	-0.168	-0.127	-1.122	0.116
	(-0.142)	(-0.248)	(-0.935)	(0.297)
SOE	0.314	0.097	0.152	-0.061
	(0.398)	(0.892)	(0.282)	(-0.264)
GDP Growth	0.641	0.149	-8.785	1.578
	(0.087)	(0.084)	(-1.159)	(0.457)
Constant	-15.095***	-1.068	-13.029*	-0.481
	(-3.346)	(-0.443)	(-1.907)	(-0.329)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	6,007	6,007	6,141	6,141
Adjusted R^2	0.391	0.664	0.385	0.658

Panel B. Subsample analysis between high CR4 and low CR4

	High CR4 (Low Competition)		**Low CR4 (High Competition)**	
	(1)	**(2)**	**(3)**	**(4)**
	ER	***Disclosure***	***ER***	***Disclosure***
BNT	-0.419**	-0.102**	-0.250	-0.025
	(-2.259)	(-2.265)	(-1.113)	(-0.445)
M/B	0.002	-0.031	0.065	-0.037**

	(0.052)	(-1.540)	(1.002)	(-2.037)
Sales Growth	-0.046	-0.051	0.079	-0.111
	(-0.326)	(-1.250)	(0.347)	(-1.639)
R&D/Sales	7.547	-1.083	11.507	2.950
	(0.874)	(-0.553)	(1.581)	(1.268)
ROA	0.373	0.474	3.928	0.049
	(0.206)	(0.632)	(1.516)	(0.125)
LEV	-1.213	-0.384	-0.281	-0.243
	(-1.495)	(-1.558)	(-0.349)	(-0.670)
Size	0.522***	0.106	0.722***	0.180***
	(3.011)	(1.098)	(2.910)	(3.064)
Board Size	0.906	-0.045	-1.020	-0.266
	(0.996)	(-0.203)	(-1.083)	(-1.179)
Independence	3.132*	0.367	-0.105	0.253
	(1.705)	(0.462)	(-0.039)	(0.512)
Big4	0.628	0.094	0.761	-0.076
	(0.944)	(0.372)	(0.749)	(-0.375)
Top1	-0.272	-0.117	-0.712	0.154
	(-0.234)	(-0.235)	(-0.662)	(0.408)
SOE	0.334	0.101	-0.017	-0.081
	(0.442)	(0.995)	(-0.035)	(-0.361)
GDP Growth	0.514	0.337	-8.215	1.779
	(0.073)	(0.200)	(-1.175)	(0.541)
Constant	-14.707***	-0.809	-13.483**	-1.284
	(-3.311)	(-0.342)	(-2.291)	(-0.952)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	5,469	5,469	6,659	6,659
Adjusted R^2	0.349	0.654	0.386	0.664

This table reports the subsample analysis concerning industry competition, proxied by HHI and CR4. Panel A reports the results according to above and below median HHI respectively, and panel B reports the results according to above and below median CR4 respectively. HHI and CR4 refers to two indexes of market concentration, and the higher the index, the lower the market competition. Variable descriptions are summarized in Appendix A. *t*-statistics are reported in parentheses. Robust standard errors are clustered at industry level. The superscripts *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

2.5. Conclusion

We investigate the association between bad news timeliness and environmental disclosure in China's setting. Firms with better accounting information quality are found to reduce their environmental disclosure. Further analysis indicates that firms with achieved political connections (executives hold a government-nominated position) are subject to more social and political pressures to release environmental information, which weakens the negative impact of bad news timeliness on corporate environmental disclosure. In addition, heavy polluters are subject more environmental regulatory constraints, and therefore, the negative relationship between bad news timeliness and corporate environmental disclosure is insignificant for heavy polluters. The results support the socio-political theories that social disclosure is a reaction to the pressure exerted by institutional and public stakeholders (Magness, 2006). The results remain robust after addressing endogeneity concerns using the IV 2SLS estimations and controlling for multiple fixed effects. We further find that the reduced attention from analysts due to providing conservative financial reporting explains the negative relationship between accounting conservatism and environmental disclosure. In addition, when facing greater financial constraints, firms have to release more environmental information to enhance their access to financing and they intend to release more environmental information when they face intensive competition.

This study has important policy implications. Our results highlight that adopting conservative financial reporting can function as an efficient mechanism that affects corporate environmental disclosure. Particularly, this study highlights that top management strategically manages the different types of information disclosed to the public, and therefore, we encourage policymakers to explore strategies for fostering corporate information transparency.

2.6. Appendix

Appendix A. Variable description

Variable	Description
ER	Industry-year adjusted Hexun environmental responsibility score. Following Li et al. (2021), it is calculated as Hexun environmental responsibility score minus its mean value for all firms in the same industry in a year. The higher the score is, the higher the firm's environmental performance.
Disclosure	Environmental information disclosure score (ranged from 0 to 11). The higher the score, the higher environmental disclosing quality.
BNT	A higher *BNT* indicates a firm discloses bad accounting news more promptly than good news.
M/B Ratio	The ratio of market value to its book value of equity.

Sales Growth	Change in sales between years t and t-1.
LEV	Total liabilities scaled by total assets.
Size	The natural logarithm of total assets.
Board Size	The natural logarithm of the total number of directors on the board.
Independence	The proportion of independent directors to the total number of directors on the board.
Big4	A dummy variable equals one if the auditor of the firm is one of international 'Big4' audit firms, and zero otherwise.
Top1	The largest shareholding ratio.
SOE	A dummy variable equals one if the ultimate controller of a firm is a government agency or a state-owned enterprise, and zero otherwise.
R&D/Sales	R&D expenses scaled by total sales.
ROA	Return on assets, calculated as net profit after tax/total assets.
GDP Growth Rate	The per capita GDP growth rate of the province where the firm is located.
Age	Age of firm, measured as number of years since listing.
InvestmentCycle	Proxy of a firm's investment-cycle length, calculated as depreciation divided by lagged total assets.
Ascribed bureaucratic connection	A dummy variable equals one when the chairman has previous government experience.
Achieved political connections	A dummy variable equals one when the chairman is appointed to state organs such as National People's Congress, Local People's Congress, Chinese People's Political Consultative Conference, or Local People's Political Consultative Conference.
HHI	The Herfindahl-Hirschman index that proxies the industry concentration, calculated as the sum of the squares of market shares of all firms in a particular market. The lower the index, the higher the competition in the industry sector.
CR4	The sum of the market share (revenue) of the top four largest firms in an industry. The smaller the index, the fiercer the competition.
Analyst Attention	The natural logarithm of one plus the number of analysts (teams) that cover a firm in a year.
Report Attention	The natural logarithm of one plus the number of analyst research reports about a firm in a year.
DebtTA	The firm's short-term debt to its total assets.
WW	Following Whited & Wu (2006), the *WW* index is calculated as: $WW = (0.091*CF) - (0.062*DIVPOS) + (0.021*TLTD) - (0.044*LNTA) + (0.102*ISG) - (0.035*SG)$ where *CF* is ratio of cash flow divided by total assets; *DIVPOS* is a dummy variable equals to one if the firm pays dividend, and otherwise zero; *TLTD* is long-term debt to total assets; *LNTA* is the natural logarithm of total assets; *ISG* is an industry's average sales growth; and *SG* is a firm's sales growth. A higher value of the *WW* index implies a greater level of financial constraints.
FC	Following Fee et al. (2009), the *FC* index is calculated as: $\mathrm{P}\left(QUFC = 1 \text{ or } 0 \middle| Z_{i,t}\right) = \frac{e^{Z_{i,t}}}{1+e^{Z_{i,t}}}$

	$Z_{i,t} = \alpha_0 + \alpha_1 Size_{i,t} + \alpha_2 Lev_{i,t} + \alpha_3 (\frac{CashDiv}{Ta})_{i,t} + \alpha_4 MB_{i,t} + \alpha_5 (\frac{NWC}{Ta})_{i,t} + \alpha_6 (\frac{EBIT}{Ta})_{i,t}$ where *Size* is the natural logarithm of total asset; *Lev* is total liabilities/total assets; *CashDiv* is cash dividends paid by a firm in a year; *MB* is a firm's market value/book value; *NWC* is net working capital=working capital - monetary funds - short-term investments; EBIT is earnings before interest and tax.
absSA	Absolute values of the SA index (*absSA*). Following Hadlock & Pierce (2010), the SA index is calculated as: $SA = -0.737 * Size + 0.043 * Size^2 - 0.040 Age$ where *Size* is the natural logarithm of total asset; *Age* is the operating year of the firm. A higher absolute value of the *SA* index implies a greater level of financial constraints.
Keypolluter	A dummy variable equals to one if the firm is identified as a key-polluter, and zero otherwise.

Appendix B. Correlation matrix

		1	2	3	4	5	6	7	8	9	10	11	12
1	*BNT*	1.000											
2	*Top1*	-0.064***	1.000										
3	*Board Size*	-0.065***	0.020**	1.000									
4	*Independence*	-0.006	0.040***	-0.463***	1.000								
5	*M/B ratio*	0.121***	-0.089***	-0.197***	0.062***	1.000							
6	*Sales Growth*	0.004	-0.004	-0.024***	-0.002	0.050***	1.000						
7	*R&D/Sales*	0.003	-0.094***	-0.049***	0.044***	0.149***	-0.007	1.000					
8	*ROA*	-0.038***	0.098***	-0.015*	-0.020**	0.287***	0.173***	0.009	1.000				
9	*Big4*	-0.068***	0.125***	0.105***	0.020**	-0.114***	-0.034***	-0.023**	0.033***	1.000			
10	*LEV*	-0.039***	0.076***	0.168***	-0.017*	-0.487***	0.041***	-0.129***	-0.393***	0.105***	1.000		
11	*Size*	-0.222***	0.219***	0.277***	0.011	-0.533***	0.051***	-0.061***	-0.023**	0.331***	0.521***	1.000	
12	*GDP Growth Rate*	0.029***	-0.012	0.062***	-0.028***	-0.079***	0.002	-0.054***	-0.015	-0.076***	0.063***	-0.136***	1.000

This table reports the correlation coefficients between key independent variables. Definitions of variables are in Appendix A. The superscripts *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Appendix C. Dimensions Indicator name

I1: Legal consciousness

1. Whether a firm discloses environmental protection concept, environmental policy, environmental management organization structure, circular economy development mode, green development.
2. Whether a firm discloses a series of management systems, such as relevant environmental management systems, systems, regulations and responsibilities, formulated by the firm.
3. Whether a firm is subject to environmental violations, environmental petition cases or sudden environmental accidents.

I2: Social evaluation

1. Whether a firm received any environmental awards.
2. Whether a firm discloses special environmental protection activities, environmental protection and other social public welfare activities that the firm participates in.
3. Whether a firm discloses the establishment of an emergency mechanism for major environmental emergencies, the emergency measures taken, and the treatment of pollutants.

I3: Eco-friendly production

1. Whether a firm adopts a clean production.
2. Whether a firm discloses the implementation of the "three simultaneous" system.
3. Whether a firm discloses the establishment of an emergency mechanism for major environmental emergencies, the emergency measures taken, and the treatment of pollutants.

I4: Green management

1. Whether a firm has an ISO 14001 certification.
2. Whether a firm has an ISO 9001 certification.

Appendix D. Baseline regression using firm level clustering

	(1) ***ER***	**(2)** ***Disclosure***
TBN	-0.423***	-0.073**
	(-2.998)	(-2.020)
Constant	-15.139***	-0.719
	(-4.115)	(-0.609)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	12,148	12,148
Adjusted R^2	0.381	0.664

This table reports the results of the regression as follows:

$$Green_{i,t} = \beta_0 + \beta_1 TBN_{i,t} + \sum_k \beta_k Controls_{k,i,t} + \epsilon_{i,t}$$

$Green_{i,t}$ represents two measures of corporate environmental disclosure, including industry-year-adjusted Hexun environmental disclosure rating (*ER*) and environmental disclosure score (*Disclosure*). The regression controls for firm and year fixed effects. Definitions of variables are provided in Appendix A. The *t*-statistics are reported in parentheses. Robust standard errors are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

CHAPTER THREE

ESSAY TWO

In the heat of the moment, secrets will out: Oil price uncertainty and firm green innovation disclosure

Abstract

This study investigates the relationship between oil price uncertainty and corporate green innovation disclosure behaviour. Drawing on a textual analysis of annual reports and social responsibility reports of Chinese listed companies, we construct a measure for the intensity of corporate green innovation disclosure. We find a significantly positive relationship between oil price volatility and the level of green innovation disclosure. This relationship remains robust after conducting robustness tests and addressing potential endogeneity. Further analysis reveals that this positive association is affected by several firm-level factors, including environmental performance, legitimacy demands, and political connections. Additionally, the positive relationship is more pronounced in firms subject to higher regional environmental regulation intensity and market-based green initiatives. Our findings contribute new evidence to corporate sustainable development, demonstrating that energy uncertainty significantly influences information transparency in green innovation disclosure.

Keywords: Oil price uncertainty; Green innovation disclosure; Government social objective; China

3.1. Introduction

The heightened interest in sustainability, particularly oil price uncertainty (OPU), has become a central topic in both academic and industrial discourse (Hu et al., 2023a). OPU refers to the unpredictability of crude oil prices caused by geopolitical factors, market supply-demand fluctuations, or macroeconomic changes (Yang & Song, 2023). Existing literature underscores the profound impacts of oil price fluctuations on businesses, including higher operational costs, supply chain disruptions, exchange rate volatility, and energy policy uncertainty (Hu et al., 2023a; Smith & Jones, 2021). Heightened uncertainty may intensify stakeholders' concerns, thereby requiring companies to demonstrate their efforts in addressing these uncertainties through disclosures (Orij, 2010). While existing studies explore the impact of OPU on innovation commitment (Amin et al., 2023; Yang & Song, 2023), a gap remains in understanding how oil price fluctuations influence green innovation disclosure. This information is valuable to stakeholders and policymakers as it enhances transparency regarding innovation. This paper aims to explore how OPU influences corporate green innovation disclosure behaviour, revealing the motivations, challenges, and implications of these disclosures in the pursuit of sustainable development.

Oil price volatility creates uncertainties that affect firm profitability, valuations, and investment decisions (Henriques & Sadorsky, 2011), making it challenging for stakeholders to gauge a company's soundness. Firm green innovation disclosure is crucial for shaping stakeholder perceptions, boosting investor confidence, and ensuring regulatory compliance (Clarkson et al., 2008; Patten, 2002). In China, companies have the discretion to voluntarily disclose green innovation initiatives in their annual reports. According to proprietary cost theory, companies, when deciding on whether and when to disclose innovation information, balance the benefits of disclosure, such as gaining investor trust and improving reputation, against the concern to protect their competitive advantage (Berger & Han, 2007; Imhof et al., 2022). While voluntary disclosure can showcase a company's green innovation efforts to the public, it may also expose sensitive research and development information to competitors. Thus, firms face the dilemma of whether, and to what extent, to voluntarily disclose their green innovation behaviour.

On one hand, OPU may reduce the level of green innovation disclosures. Disclosure might allow competitors to obtain key information, enabling them to take actions that could weaken the company's market position and competitiveness (Ellis et al., 2012). Moreover, since innovation projects often involve high uncertainty, disclosing innovation information may lead to inflated market expectations or concerns regarding the company's future performance. The failure of an innovation project could result in a significant decline in investor confidence (Greve, 2011). Additionally, disclosing green innovation during periods of high OPU may pose risks to stakeholders. While stakeholder theory indicates that voluntary disclosures can meet stakeholder demands, improve transparency, and demonstrate sustainability efforts (Phan et al., 2021), conflicting interests among stakeholders may compel firms to weigh the benefits of transparency against potential downsides.

Conversely, oil price uncertainty may increase green innovation disclosures, as explained by asymmetric information and signalling theories (Phan et al., 2021). OPU often leads to declines in corporate profitability, which can reduce shareholder returns and increase concerns regarding future financial performance (Thi Huong Vuong et al., 2024; Song & Yang, 2022). In response to these pressures, firms may increase green innovation disclosures as a strategic tool to mitigate stakeholder concerns. By providing transparency on sustainability initiatives, firms reduce information asymmetry and signal their commitment to long-term sustainable goals (López-Santamaría et al., 2021; Morellec & Schürhoff, 2011). Such disclosures are particularly effective in enhancing corporate credibility during periods of external uncertainty, helping to reassure stakeholders of the firm's capacity to manage sustainability risks (Stocken, 2000; Willems & Faulk, 2019). Furthermore, increased green innovation disclosures enable firms to showcase proactive efforts in addressing environmental challenges, thereby reinforcing stakeholder confidence in their ability to navigate future uncertainties (Orij, 2010).

Selecting China as the research context for examining OPU's impact on firm green innovation disclosure is grounded in several factors. Foremost, China's status as the world's largest net oil importer and second-largest oil consumer uniquely positions it at the nexus of oil market dynamics and firm behaviour. The National Bureau of Statistics of China highlights that the nation's dependency on oil imports has been rising, surpassing 70% in 2018, which makes Chinese firms particularly susceptible to oil price shocks (National Bureau of Statistics, 2018). Moreover, a lack of transparency in information is a major concern in Chinese financial market development. Information asymmetry, coupled with less mature regulatory and investor protection mechanisms, suggests that Chinese firms may exhibit distinct responses to oil price volatility compared to firms in more developed markets (Hu et al., 2022). Additionally, there is growing interest in exploring the relationship between oil prices and market dynamics within the Chinese context (Cong et al., 2008; Zeng et al., 2012). Although previous research has explored the link between oil price shocks and stock market fluctuations in China (Cong et al., 2008; Wei et al., 2019), the dynamic relationship between oil market shocks and firm disclosure behaviour remains underexplored. This gap presents a unique opportunity to contribute to the literature by examining how Chinese firms navigate the challenges posed by oil price volatility and the extent to which this influences their environmental claims and actions.

Utilising data from China's A-share market from 2008 to 2023, this study explores the relationship between OPU and firm green innovation disclosure. Based on a textual analysis of the annual reports and social responsibility reports of Chinese listed companies, we construct a measure for corporate green innovation disclosure, following Xie et al.'s (2019) method. The regression analysis indicates a significant positive relationship between OPU and the level of green innovation disclosures. To ensure robustness, additional tests control for economic policy uncertainty beta, firm fixed effects, and industry-province and firm-province fixed effects. Furthermore, to validate our findings, alternative measurements of OPU are adopted. We also employ lagged variable and instrumental variable approaches to rigorously address potential endogeneity.

We investigate moderating factors influencing the relationship between OPU and green innovation disclosure. Drawing on stakeholder and legitimacy theories, Goss and Roberts (2011) emphasise the importance of aligning corporate strategies with the interests of a broader range of stakeholders. Similarly, Deegan et al. (2000) argue that firms facing greater legitimacy demands are more likely to enhance legitimacy through disclosure mechanisms. Our findings indicate that both corporate environmental performance and legitimacy demands positively amplify the relationship between OPU and green innovation disclosure. In China's politically influenced environment, we also find that corporate political connections strengthen the positive relationship between OPU and green innovation disclosure. Furthermore, China's carbon trading pilot scheme, part of its broader strategy to combat climate change and reduce carbon emissions, as well as the stringency of regional environmental regulations, positively influence corporate green innovation disclosure. These findings underscore the complex interplay between corporate responses to energy risks and the critical role of regulatory activism in promoting voluntary green innovation disclosure, enhancing informational transparency for both stakeholders and policymakers.

The contributions of this paper are fourfold. First, leveraging the context of OPU, our research provides new evidence in the debate on voluntary innovation disclosure by firms. According to proprietary cost theory, as suggested by studies such as Verrecchia (1993), Imhof et al. (2022), and Berger and Han (2007), firms should protect their innovation information and avoid proactive disclosure to prevent leaks of confidential information and increased competition. Conversely, information asymmetry theory and signalling theory suggest that firms can signal their activities to the outside world through information disclosure, thereby mitigating information asymmetry between firms and stakeholders to gain trust and understanding (Pan et al., 2020). Our study fills a gap in the existing literature by supporting signalling theory. While previous studies have examined the relationship between OPU and patents (Amin et al., 2023; Yang & Song, 2023), the outcomes of innovation and innovation disclosure differ. First, patents are mandatory disclosures and are legally protected, while corporate innovation disclosures are voluntary and thus not protected due to their voluntary nature. Second, patents represent innovation output, whereas disclosures may include plans and progress on innovation. Interestingly, both Amin et al. (2023) and Yang and Song (2023) find that OPU reduces the number of patents and citations, yet we find that OPU increases firms' voluntary information disclosures related to green innovation. This finding not only provides new theoretical perspectives but also significant insights on corporate disclosure practices.

The second contribution of this study is expanding the existing literature on corporate voluntary disclosure in the context of heightened energy uncertainties, particularly regarding environmental responsibility. Oil price fluctuations heighten investor concerns regarding firms' exposure to energy-related risks (Maghyereh & Abdoh, 2020), and firms can alleviate these concerns through enhanced transparency from voluntary disclosures. While previous studies, such as those by Phan et al. (2021), Hasan et al. (2022b), and Benlemlih et al. (2024), have examined OPU's impact on corporate social responsibility (CSR) behaviour, their focus has primarily been on CSR or environmental performance overall. In contrast, our study explicitly centres on the disclosure of green innovation. Our study is unique, as oil price volatility directly affects the cost of oil, an essential input, creating uncertainties in profitability, valuations, and investment decisions (Henriques & Sadorsky, 2011). Such information asymmetry may heighten stakeholder concerns regarding firm transparency. Companies engage in voluntary disclosure not only to reduce information asymmetry between shareholders and management but also to lower their cost of capital (De Villiers & Van Staden, 2011). By releasing information transparently, companies signal their social commitments to external stakeholders, addressing concerns and enhancing credibility (Pan et al., 2020). Our findings provide new empirical evidence, demonstrating how firms respond to OPU by fostering green innovation disclosure, thereby advancing the understanding of corporate voluntary disclosure under conditions of energy uncertainty.

The third contribution of this study advances the ongoing debate on the impact of environmental reputation on corporate green innovation disclosure. Clarkson et al. (2008) suggest that companies are motivated to disclose ‘good news’ to distinguish themselves from firms with ‘bad news’, thus avoiding the adverse selection problem. As a result, firms with superior environmental reputations, due to proactive environmental strategies, are incentivised to voluntarily disclose more environmental information to inform investors and stakeholders (Clarkson et al., 2008). Similarly, studies by Zeng et al. (2012) and Huang and Kung (2010) indicate that firms with a stronger environmental reputation are more likely to disclose environmental information. Our findings show that the impact of OPU on green innovation disclosure is more significant for firms with stronger environmental commitments, as indicated by holding ISO environmental certifications and receiving higher third-party environmental ratings. This suggests that, when facing heightened energy uncertainties, firms with stronger environmental reputations are more likely to increase their green innovation disclosures in response to heightened stakeholder expectations. Our conclusions also differ from De Villiers and Van Staden's (2011) argument that firms with poor environmental reputations tend to disclose more environmental information, as well as from Nadeem’s (2021) perspective on restorative justice in response to stakeholder pressure following corporate environmental violations.

Our results also provide new evidence on how regional policy orientation and market-based green initiatives promote corporate green innovation disclosure. In China, regional policy orientation plays a pivotal role in shaping firms' voluntary behaviours, closely linked to the nation's economic policy framework (Shen et al., 2020). Our findings reveal that the effect of OPU is more pronounced in firms located in regions with stronger environmental policy orientation. This finding aligns with Sun and Yang (2024), who find that government environmental target constraints can significantly drive firms' green innovation. Our study expands on this by focusing specifically on green innovation disclosure. Additionally, the carbon trading pilot scheme—a market-based effort to combat climate change and reduce carbon emissions—plays a crucial role in guiding corporate green strategies. We examine this scheme's effect on the relationship between OPU and green innovation disclosure. Firms operating in carbon trading pilot regions are subject to stricter environmental regulations and are incentivised to adopt more sustainable practices to meet carbon reduction targets (Ren et al., 2024). Our findings show that firms in these pilot regions are more proactive in disclosing their green innovations when facing higher OPU.

The remainder of the study is organised as follows. Section 3.2 presents the literature review and hypothesis development. Section 3.3 reports the data, variable construction, and the regression model. Section 3.4 presents the empirical results and robustness tests. Section 3.5 concludes the study.

3.2. Literature review and hypothesis development

3.2.1. The economic impacts of oil price uncertainty

Previous literature has revealed the effects of oil prices and their uncertainty on macroeconomic and financial outcomes. Firstly, oil price volatility directly influences production costs and consumer spending (Koirala & Ma, 2020). As crude oil is an indispensable input in the production of most goods and services, an increase in its price raises the marginal cost of production while reducing consumers' spending capacity, thereby leading to a decrease in demand for corporate products (Pindyck, 1990). Moreover, fluctuations in oil prices are often linked to inflation or deflation, prompting central banks to adjust interest rates, which affects future firm cash flows and discount rates (Ferderer, 1996; Sadorsky, 1999).

Further research also demonstrates specific impacts of oil price uncertainty on macroeconomic factors, such as employment, income, consumption, labour flow, and output. Studies by Koirala & Ma (2020) reveal the impact of oil price uncertainty on the U.S. unemployment rate, providing evidence of asymmetric effects of positive and negative oil price uncertainty shocks on rising unemployment rates. Supply-side effects induced by rising oil prices drive up production costs, slow economic growth, and reduce productivity (Brown & Yücel, 2002). Additionally, Maghyereh et al. (2019) show that oil market uncertainty negatively affected industrial output and document the asymmetric effects of oil price volatility on industrial production. Bashar et al. (2013) find that higher oil price uncertainty significantly reduced output and price levels. Ahmed and Wadud (2011) note that a positive shock to oil price uncertainty led to a decline in the consumer price index due to decreased purchasing power and disposable income. Herrera et al. (2019) argue that increased oil price uncertainty had a greater negative impact on employment flows in manufacturing than monetary policy uncertainty.

Existing research indicates that the impact of oil price fluctuations on firms is multifaceted, influencing profitability, investment decisions, financing conditions, and overall financial health. Bugshan et al. (2021) highlight that oil price volatility has a significant and negative impact on firm profitability, suggesting that future oil price uncertainty could profoundly influence corporate policies. At the investment level, Phan et al. (2019) observe that high oil price uncertainty increases the real option value of waiting, causing firms to delay investments until uncertainty resolves. This phenomenon is further supported by the adverse effects of oil price volatility on banks' lending capacities, as examined by Al-Khazali and Mirzaei (2017) and Lee and Lee (2019) in inefficient capital markets.

The broader impact of oil price uncertainty on firms' financial conditions has also drawn widespread attention. Fan et al. (2021), in studying the effects of market-oriented refined oil pricing reform on firm leverage, find a nonlinear relationship between oil price uncertainty and firm leverage, with trade credit and exacerbated financial distress risk as potential impact channels. Hasan et al. (2022a) also find that oil price uncertainty significantly affects short-term debt financing. Zhang et al. (2020) observe that oil price uncertainty increases firms' cash holdings, particularly when firm value increases, though this effect is mitigated for state-owned enterprises.

In the stock market, Park and Ratti (2008), Luo and Qin (2017), and Cunado and de Gracia (2014) all document the negative impact of oil price uncertainty on stock returns. Cunado and de Gracia (2014) suggest that the asymmetric impact of oil price uncertainty on stock returns can be explained by identifying the fundamental causes of oil price changes, whether demand- or supply-side. Additionally, Song and Yang (2022) demonstrate a negative correlation between oil price uncertainty and company performance, while Wong and Hasan (2021) find that oil demand shocks lead to increased stock repurchases, whereas oil supply shocks reduce dividends paid through stock repurchases, primarily driven by non-oil-producing companies. This implies that oil supply shocks create heightened uncertainty regarding companies' future growth potential.

3.2.2. The disclosure of green innovation under oil price uncertainty

Oil price uncertainty may exacerbate information asymmetry between firms and external stakeholders. Such uncertainty leads to delayed or altered investment decisions, especially in industries such as oil and gas, where companies with deeper market insights can manage risks more effectively than outside investors, widening the perceived risk gap (Maghyereh & Abdoh, 2020). Additionally, oil price volatility represents a source of uncertainty affecting the cost of a key input, oil, which creates further uncertainty regarding firm profitability, valuations, and investment decisions (Henriques & Sadorsky, 2011). This uncertainty makes it challenging for stakeholders to gauge a company's true health.

During periods of uncertainty, firms have incentives to provide insurance to the market about their stability by issuing new information (Assaf et al., 2023). Voluntary corporate disclosure serves as a key mechanism for reducing information asymmetry between firms and investors, and there is extensive research showing its effectiveness in managing risk and conveying information. For instance, signalling theory suggests that managers are motivated to send high-quality signals regarding performance and risk management system effectiveness to external investors, enabling them to adjust their valuation and risk perceptions accordingly (Lu et al., 2024). Research by Francis et al. (2008) demonstrates that voluntary disclosure significantly lowers the cost of capital, particularly for firms with higher earnings quality. Similarly, Jo and Kim (2007) show that increased disclosure frequency reduces incentives for earnings management by attracting investor attention, thereby improving earnings quality and enhancing liquidity.

Companies engage in voluntary disclosure not only to reduce information asymmetry between shareholders and management but also to lower the cost of capital (De Villiers & Van Staden, 2011). The uncertainty surrounding oil prices stems not only from market price fluctuations and raw material costs but also from changes in policy, competitive dynamics, and public opinion (Hasan et al., 2022b). Thus, voluntary disclosure becomes an effective tool for companies to signal transparency, align insider and outsider interests, and ultimately lower their cost of capital through increased transparency (Lu et al., 2024).

Oil price fluctuations also raise investor concerns regarding firms' exposure to energy-related risks (Maghyereh & Abdoh, 2020). According to information asymmetry and signalling theories, firms can signal their activities to external stakeholders through information disclosure, which mitigates information asymmetry, helping them gain trust and understanding (Pan et al., 2020). In response to higher expectations, firms with stronger reputations have greater incentives to voluntarily disclose information, signalling their commitment to transparency and adherence to higher social standards (Cao et al., 2012; Zeng et al., 2012). Moreover, companies can proactively disclose measures to address uncertainty rather than relying on reactive disclosure. Jog and McConomy (2003) argue that disclosing prospects through voluntary mechanisms can add value during periods of uncertainty. This proactive approach is particularly crucial during periods of market volatility, as it helps mitigate investor panic and fosters stakeholder trust (Lu et al., 2024). Proactive disclosures reach investors and other stakeholders quickly, emphasising a company's ongoing efforts, even at the planning stage. In green innovation, these disclosures may encompass not only innovation outcomes but also ongoing projects such as green technology development and energy efficiency improvements (Ho et al., 2023).

In markets such as China, where green innovation disclosure is not mandated, companies have the flexibility to decide the scope and nature of their disclosures (Xiang et al., 2020). This autonomy enables firms to control their narrative by reporting both ongoing and completed projects. Furthermore, China's policy environment, characterised by frequent changes and a focus on green development, increases the pressure on firms to engage in proactive disclosure. By doing so, companies can align with national sustainability policies, secure government support, and enhance social recognition (Xiang et al., 2020). Given the volatility of policy shifts, timely and transparent disclosures also help mitigate adverse market reactions (Hu et al., 2023b). Based on this analysis, we propose the following first hypothesis:

Hypothesis 1: Oil price uncertainty increases firm green innovation disclosure.

In contrast, heightened OPU may reduce the disclosure of green innovation. During periods of oil price fluctuation, disclosing green innovation may pose risks to stakeholders. While stakeholder theory suggests that firms use environmental disclosures to meet stakeholder demands, improve transparency, and demonstrate sustainability efforts (Phan et al., 2021), conflicting interests among stakeholders may compel firms to weigh the advantages of transparency against potential downsides. For instance, although investors may value insight into a company's strategies, disclosing green innovations could highlight high costs and long-term risks (Zhao et al., 2023). Rising oil prices reduce purchasing power and discretionary income, curbing consumption and reducing revenue (Baumeister et al., 2018). This uncertainty regarding future growth may trigger investor short-termism, leading to negative reactions to costly innovation activities. Furthermore, oil price fluctuations directly impact firms' operational costs and profitability, prompting them to be more cautious in these periods (Hamilton, 2009). Under such conditions, environmental initiatives may be considered less effective or beneficial in the short term, causing hesitation among both customers and suppliers (Murfield et al., 2017).

Moreover, proprietary cost theory suggests that disclosing sensitive innovation-related information can expose a firm's strategies to competitors, enabling them to counteract these strategies and thus eroding the firm's market position (Verrecchia, 1983). Green innovations often involve new, highly proprietary technologies and business models that are strategically significant. During periods of oil price uncertainty, competitors might actively seek new advantages, and disclosing green innovation strategies could inadvertently provide them with critical insights that allow them to imitate or counteract these innovations. Consequently, firms may opt to keep their information confidential, particularly in an uncertain oil price environment, to safeguard their competitive edge and maintain market share (Badia et al., 2020).

Furthermore, innovation projects often involve complex technical and market risks (Nanda & Rhodes-Kropf, 2017). For example, during periods of low oil prices, the cost advantage of traditional energy may overshadow the appeal of green energy projects, causing investors to question their economic viability. In such cases, disclosing green innovation information could lead to investor scepticism and increase the firm's financing and operational pressures. We expect that during periods of high OPU, disclosing green innovation information may heighten market concerns regarding the uncertainties associated with green innovation, particularly when these projects involve significant upfront investments and long-term technological development, both of which carry considerable uncertainty. Based on the above analysis, we propose the following hypothesis:

Hypothesis 2: Oil price uncertainty reduces firm green innovation disclosure.

3.3. Data and methodology

3.3.1. Sample

In this study, our sample initially consists of all non-financial A-share listed firms on the Shanghai Stock Exchange (SHSE) and Shenzhen Stock Exchange (SZSE) from 2008 to 2023. The starting year of 2008 was selected because China implemented the new accounting standards in 2007. We exclude firm-year observations with missing values, followed by firms listed on the stock exchange for less than 3 years. All continuous variables are winsorised at the top and bottom 1% to control for the possible disturbance of outliers. Our final sample includes 30,829 firm-year observations for 4,532 firms. We collect firm-specific data from the China Stock Market & Accounting Research Platform (CSMAR) database and oil price data from the U.S. Energy Information Administration.

3.3.2. Variable description

3.3.2.1. Oil price uncertainty

The daily crude oil futures price of Brent is selected as a proxy for international crude oil prices, and we employ two measures to obtain metrics for OPU. The first measurement of OPU in our study is the standard deviation of daily oil price returns over 1 year, following Henriques and Sadorsky (2011):

$$OILVOL_t = \sqrt{\frac{1}{N-1}\sum_{d=1}^{N}(r_d - E(r_d))^2 * \sqrt{N}}$$

where r_d represents daily oil price returns for trading day d, and N represents the number of trading days in year *t*.

The second measurement of OPU in our study is the average of the daily conditional variance generated from a GARCH (1,1) model over 1 year, following Alaali (2020):

$$OILVAR_t = GARCH_t = \frac{1}{N}\sum_{d=1}^{N}\widehat{h_d}^2 * \sqrt{N}$$

where $\widehat{h_d}$ represents the fitted value of the conditional variance of trading day d from the GARCH (1,1) model, estimated using daily oil price returns r_d.

3.3.2.2. Firm green innovation disclosure

We employ the method of content analysis to analyse the textual information in corporate annual reports and social responsibility reports, aiming to construct a measure for corporate green innovation disclosure. Content analysis is a technical tool used for investigating published information (Tao et al., 2024; Yu & Jin, 2022; Xie et al., 2019). According to Xie et al. (2019), we quantify the level of corporate green innovation disclosure by constructing a composite index that includes five specific indicators (refer to Appendix A), designed to capture different dimensions of corporate green innovation.

Our analysis focuses on corporate CSR reports and annual reports, with particular attention to sections on environmental protection, sustainable development, and technological innovation. These sections typically contain voluntarily disclosed information regarding companies' environmental innovation initiatives. To ensure the accuracy and comprehensiveness of keyword selection, we refer to the coding methods of Xiang et al. (2020) and Mallin et al. (2013) and compile a set of keywords related to green innovation. This enables us to identify the extent of corporate disclosure on specific environmental innovation activities in the text analysis. The keywords for each indicator were carefully selected and calibrated to ensure they accurately reflect the company's innovation efforts in the respective areas. For instance, for the indicator 'Reducing resource and energy consumption and improving efficiency' (PROC1) in Appendix A, we selected the following 15 keywords: 'energy-saving technology', 'process optimisation', 'renewable energy', 'low-energy consumption', 'energy efficiency', 'resource optimisation', 'energy management system', 'green energy', 'carbon footprint reduction', 'waste heat recovery', 'energy conservation', 'smart grid', 'clean energy', 'cogeneration', and 'energy audit' (translated from Chinese). We first constructed a training sample to ensure these keywords are widely used terms that cover the key green innovation activities in this domain.

In the text analysis process, we combine coding with manual verification to conduct a quantitative analysis of the frequency of keyword occurrences in each report. Python is used to preprocess the text data related to environmental innovation. Specifically, we calculate the frequency of each keyword in the text and score each indicator according to the following rules: if the total frequency of keywords listed for a given indicator is 0 (i.e., there is no relevant description in the report), the score is 0; if the keywords appear 1–5 times, indicating only basic descriptions without detailed implementation information, the score is 1; if the keywords appear more than 5 times or there is a detailed description of specific implementation measures, effects, or technical applications, the score is 2. This scoring system is designed to differentiate the depth of corporate disclosure regarding green innovation, thus providing a more accurate reflection of the company's true extent of environmental innovation efforts.

3.3.2.3. Control variables

Following the approach of previous studies on firm disclosure, such as Flammer et al. (2021), we include a set of firm and CEO characteristics as control variables, which are recognised as significant determinants of firm disclosure. These variables include the market-to-book ratio (*MTB*), sales growth (*Growth*), return on assets (*ROA*), firm size (*Size*), leverage ratio (*Lev*), liquidity (*Cash*), R&D intensity (*RDSales*), board size (*Board*), board independence (*Indep*), auditor prestige (*Big410*), major shareholder ownership (*Top1*), state ownership (*SOE*), and market risk exposure (*Marketbeta*). Additionally, we include industry fixed effects to control unobservable industry-level and macroeconomic factors. Appendix B presents these variable definitions.

3.3.3. Summary statistics

Table 3.1 provides the descriptive statistics for the main variables, detailing means, standard deviations, and distribution data. The mean value of *GInoDis* is 0.327, with a minimum value of 0 and a maximum value of 2. Approximately 25% of the sample firms engage in voluntary green innovation disclosure. For *OILVOL*, the minimum, maximum, mean, and standard deviation values are 0.169, 0.551, 0.296, and 0.076, respectively, while for *OILVAR*, they are 0.008, 0.013, 0.008, and 0.002, respectively. These figures demonstrate that oil price returns exhibit significant fluctuations throughout the sample period.

Table 3.1. Descriptive statistics

	N	mean	sd	min	p25	p50	p75	max
OILVOL	30,829	0.296	0.076	0.169	0.240	0.303	0.310	0.551
OILVAR	30,829	0.008	0.002	0.005	0.006	0.007	0.009	0.013
GInoDis	30,829	0.327	0.413	0.000	0.000	0.000	0.667	2.000
MTB	30,829	1.924	1.259	0.866	1.197	1.515	2.122	8.631
Growth	30,829	0.116	0.296	-0.937	-0.043	0.091	0.232	1.527
ROA	30,829	0.047	0.097	-0.406	0.016	0.049	0.092	0.291
Size	30,829	22.240	1.264	20.040	21.320	22.030	22.940	26.060
Lev	30,829	0.413	0.200	0.057	0.254	0.405	0.558	0.896
Cash	30,829	0.159	0.120	0.011	0.072	0.126	0.210	0.595
RDSales	30,829	0.050	0.051	0.000	0.020	0.038	0.058	0.309
Board	30,829	2.107	0.194	1.609	1.946	2.197	2.197	2.639
Indep	30,829	0.378	0.054	0.333	0.333	0.364	0.429	0.571
Big410	30,829	0.514	0.500	0.000	0.000	1.000	1.000	1.000
Top1	30,829	0.332	0.144	0.087	0.221	0.309	0.426	0.721
SOE	30,829	0.292	0.455	0.000	0.000	0.000	1.000	1.000
Marketbeta	30,829	1.003	0.086	0.793	1.000	1.000	1.008	1.276

This table reports the descriptive statistics of the main variables used in the study. The sample consists of firms listed on the SHSE and SZSE from 2008 to 2023 (30,829 observations). Detailed definitions of variables are presented in Appendix B.

The correlation coefficients of the key variables are reported in Appendix D. The absolute values of the correlation coefficients between the other variables are relatively low, indicating multicollinearity is not a significant issue in our study.

3.4. Empirical results

3.4.1. Baseline regression result

In this study, our primary objective is to explore the impact of OPU on firms' innovation disclosure. Table 3.2 presents the estimated results from our analysis of OPU's effects on firm innovation disclosure. The coefficients of OPU in Columns (1) and (2) are positive and significant at the 1% level, demonstrating that OPU positively influences firm innovation disclosure. In terms of economic significance, for example, in Column (1) of Table 3.2, a 1 standard deviation increase in *OILVOL* leads to a decrease of 4.39% in the green innovation disclosure index (i.e., $(0.189 \times 0.076)/0.327 = 4.39\%$). This supports our positive association conjecture mentioned in Section 3.2. In times of uncertainty, firms have incentives to provide insurance to the market about their stability by issuing new information (Assaf et al., 2023). During periods of uncertainty, firms are incentivised to assure the market regarding their stability by issuing new information (Assaf et al., 2023). Oil price volatility heightens investor concerns regarding firms' exposure to energy-related risks (Maghyereh & Abdoh, 2020). By disclosing sustainability information, firms not only reduce information asymmetry but also signal their commitment to long-term environmental sustainability and risk management (López-Santamaría et al., 2021; Morellec & Schürhoff, 2011).

Table 3.2. OPU and firm green innovation disclosure

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.189***	
	(5.360)	
OILVAR		12.146***
		(4.291)
MTB	0.001	0.001
	(0.023)	(0.315)
Growth	-0.034***	-0.035***
	(-3.856)	(-3.758)
ROA	0.091*	0.093**
	(2.086)	(2.165)
Size	0.103***	0.102***
	(7.080)	(7.042)
Lev	-0.064***	-0.059***
	(-5.081)	(-5.914)

Cash	-0.006**	-0.004**
	(-2.143)	(-2.082)
RDSales	0.173*	0.169*
	(1.981)	(1.978)
Board	0.025**	0.026**
	(2.258)	(2.012)
Indep	0.093**	0.094**
	(2.076)	(2.095)
Big410	0.018***	0.018***
	(4.127)	(4.079)
Top1	0.075**	0.076**
	(2.663)	(2.714)
SOE	0.068***	0.068***
	(4.579)	(4.592)
Marketbeta	-0.177***	-0.162***
	(-3.811)	(-3.332)
Constant	-1.963***	-2.006***
	(-4.827)	(-5.498)
Industry FE	Yes	Yes
Observations	30,829	30,829
Adjusted R-squared	0.196	0.198

This table presents the impact of OPU on firm green innovation disclosure. Columns (1) and (2) respectively show the regression results with *OILVOL* and *OILVAR* as independent variables and *GInoDis* as the dependent variable, controlling for industry fixed effects. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.4.2. Robustness tests

In this section, we present several robustness tests to validate our main results. Specifically, we investigate whether the documented positive effect of OPU on firm innovation disclosure is robust to (1) controlling for multiple fixed effects, (2) controlling for other macroeconomic uncertainties, and (3) using an alternative proxy for oil price uncertainty.

In the baseline regression, we control for industry fixed effects, and following the research of Nguyen and Phan (2017) on economic policy uncertainty, the standard errors are clustered at the firm-year level. To further examine the robustness of our baseline regression results, this study employs a series of fixed effects controls to address potential confounders within the dataset. Specifically, Table 3.3 presents the outcomes of the baseline regression model, incorporating firm fixed effects. This adjustment aims to mitigate the influence of unobserved, firm-specific characteristics that could potentially bias the results. Table 3.4 extends the analysis by incorporating both industry-province and firm-province fixed effects, effectively controlling for systematic differences across firms, sectors, and regions that could influence the dependent variables. The results in Tables 3.3 and 3.4 show that OPU remains significantly and positively associated with firm green innovation disclosure after controlling for multiple fixed effects.

Table 3.3. Robustness test: Controlling for firm fixed effects

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.091**	
	(2.190)	
OILVAR		6.878***
		(3.761)
MTB	-0.002***	-0.003
	(-3.691)	(-1.032)
Growth	-0.029**	-0.028**
	(-2.739)	(-2.300)
ROA	0.013	0.013
	(0.290)	(0.289)
Size	0.063***	0.062***
	(4.922)	(5.135)
Lev	-0.064	-0.072
	(-1.548)	(-1.263)
Cash	-0.025	-0.028
	(-0.570)	(-0.629)
RDSales	-0.108	-0.115
	(-1.091)	(-1.163)
Board	-0.072**	-0.071*
	(-2.168)	(-2.129)
Indep	-0.065	-0.064
	(-0.638)	(-0.628)
Big410	0.030***	0.034***
	(3.268)	(3.211)
Top1	-0.084*	-0.083*
	(-1.826)	(-1.792)
SOE	0.074***	0.073***
	(4.492)	(4.435)
Marketbeta	-0.253**	-0.242**
	(-2.344)	(-2.244)
Constant	-0.675**	-0.692**
	(-2.171)	(-2.731)
Firm FE	Yes	Yes
Observations	30,546	30,546
Adjusted R-squared	0.433	0.434

This table presents the robustness test, controlling for firm fixed effects. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.4. Robustness test: Additional control for firm and province fixed effects

	(1)	(2)	(3)	(4)
	GInoDis	*GInoDis*	*GInoDis*	*GInoDis*
OILVOL	0.179***		0.090**	
	(5.316)		(2.189)	
OILVAR		11.796***		6.878***
		(4.257)		(3.760)
MTB	0.001	-0.001	-0.002	-0.003
	(0.163)	(-0.195)	(-0.690)	(-1.031)
Growth	-0.035***	-0.035***	-0.029**	-0.028**
	(-6.870)	(-6.766)	(-2.738)	(-2.299)
ROA	0.093**	0.094**	0.013	0.013
	(2.187)	(2.265)	(1.290)	(1.289)
Size	0.102***	0.101***	0.063***	0.062***
	(7.028)	(6.989)	(4.920)	(5.133)
Lev	-0.061***	-0.057***	0.064***	0.072***
	(-5.960)	(-5.791)	(3.847)	(3.862)
Cash	-0.086**	-0.093**	-0.025	-0.028
	(-2.131)	(-2.072)	(-1.570)	(-1.629)
RDSales	-0.145	-0.142	-0.108	-0.115
	(-1.558)	(-1.559)	(-1.090)	(-1.163)
Board	0.026**	0.027**	0.072**	0.071*
	(2.416)	(2.470)	(2.167)	(2.128)
Indep	0.218**	0.219**	0.065**	0.064**
	(2.371)	(2.389)	(2.038)	(2.027)
Big410	0.044***	0.044***	0.033**	0.032**
	(4.911)	(4.868)	(2.268)	(2.211)
Top1	0.076**	0.077**	0.084*	0.083*
	(2.686)	(2.738)	(1.825)	(1.791)
SOE	0.074***	0.074***	0.074***	0.073***
	(5.031)	(5.027)	(4.490)	(4.433)
Marketbeta	-0.185***	-0.169***	-0.253**	-0.242**
	(-3.561)	(-3.381)	(-2.343)	(-2.243)
Constant	-1.942***	-1.986***	-0.675**	-0.692**
	(-4.783)	(-5.455)	(-2.170)	(-2.730)
Industry FE	Yes	Yes	No	No
Firm FE	No	No	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	30,829	30,829	30,546	30,546
Adjusted R-squared	0.204	0.206	0.433	0.433

This table presents the robustness test, controlling for industry and province fixed effects in Columns (1) and (2), and firm and province fixed effects in Columns (3) and (4). *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Existing studies have documented that several macroeconomic uncertainties can affect firm innovation disclosure. Therefore, one potential concern regarding our main results is that it may be other macroeconomic uncertainties, rather than OPU, that induce the increase in firm innovation disclosure. To address this concern, we check whether our main results are robust to including other macroeconomic uncertainties. Specifically, following Phan et al. (2021), we control for firm exposure to the China Economic Policy Uncertainty Index (EPU), as constructed by Baker et al. (2013). We calculate firm risk exposure by incorporating the natural logarithm of the EPU Index into the Fama-French Three-Factor Model, and we take the absolute value of EPU beta. The regression results controlling for EPU beta are shown in Table 3.5 (we exclude market beta due to collinearity concerns). The coefficients of OPU in Columns (1) and (2) are positive and significant at the 1% level, suggesting that OPU positively affects firm innovation disclosure. The results are consistent with the baseline, indicating that our main results are robust after controlling for other macroeconomic uncertainties.

Table 3.5. Robustness test: Controlling for *EPUbeta*

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.192***	
	(9.211)	
OILVAR		12.406***
		(8.168)
MTB	-0.001	-0.001
	(-0.093)	(-0.258)
Growth	-0.034***	-0.034***
	(-6.809)	(-6.715)
ROA	0.083*	0.085*
	(1.825)	(1.917)
Size	0.104***	0.104***
	(7.282)	(7.220)
Lev	-0.170***	-0.164***
	(-5.241)	(-5.062)
Cash	-0.072**	-0.079**
	(-2.058)	(-2.208)
RDSales	-0.185	-0.180
	(-1.139)	(-1.112)
Board	0.051**	0.052**
	(2.386)	(2.250)
Indep	0.088**	0.090**
	(2.023)	(2.044)
Big410	0.018	0.018
	(1.099)	(1.062)
Top1	0.074	0.074
	(0.591)	(0.653)
SOE	0.067***	0.067***
	(4.468)	(4.496)
EPUbeta	0.421***	0.366***
	(3.750)	(3.729)
Constant	-2.168***	-2.195***
	(-6.176)	(-6.854)

Industry FE	Yes	Yes
Observations	30,829	30,829
Adjusted R-squared	0.196	0.197

This table presents the robustness test, controlling for the absolute value of *EPUbeta*. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

To assess the robustness of our findings and address potential concerns regarding the measurement of oil price uncertainty, we examine whether our main results hold when employing an alternative proxy for this key variable. Specifically, we utilise the OPU calculated through the EGARCH model, enabling us to capture the dynamic nature of oil price volatility and its potential impact on the economic indicators under study. The results of this analysis, presented in Appendix C, complement our primary findings by providing an alternative measure of oil price uncertainty. Our findings, which remain significant across the alternative specifications, reinforce the robustness of our main results.

3.4.3. Analysis of endogeneity issue

To address potential concerns of reverse causality or contemporaneous relationships between OPU and voluntary green innovation disclosure, this study applies a lagged approach to both the independent and control variables. By incorporating a 1-year lag, we aim to capture the effects that oil price volatility may have on firm green innovation disclosure. This method helps mitigate endogeneity issues, providing a more reliable understanding of the causal impact of oil price uncertainty on firms' voluntary green innovation disclosures. Table 3.6 presents the results using a 1-year lag for both the independent and control variables. The results show that the association between the two OPU measurements and *GInoDis* remains significant, confirming the robustness of the baseline results.

Table 3.6. Robustness check: Baseline regression with lagged independent variables

	(1) *GInoDis*	(2) *GInoDis*
L.OILVOL	0.023***	
	(4.157)	

L.OILVAR		3.151***
		(4.431)
L.MTB	0.006**	0.006**
	(2.476)	(2.306)
L.Growth	-0.018	-0.017
	(-1.068)	(-0.957)
L.ROA	0.108**	0.108**
	(2.791)	(2.781)
L.Size	0.103***	0.103***
	(7.285)	(7.249)
L.Lev	-0.093**	-0.091**
	(-2.901)	(-2.755)
L.Cash	0.009	0.008
	(0.218)	(0.205)
L.RDSales	0.119	0.118
	(1.217)	(1.222)
L.Board	0.026	0.026
	(0.986)	(0.998)
L.Indep	0.059	0.059
	(0.740)	(0.746)
L.Big410	0.031**	0.031***
	(2.945)	(3.022)
L.Top1	0.067**	0.067**
	(2.258)	(2.268)
L.SOE	0.059***	0.059***
	(3.878)	(3.876)
L.Marketbeta	-0.290***	-0.282***
	(-3.201)	(-3.168)
Constant	-1.803***	-1.825***
	(-4.726)	(-5.189)
Firm FE	Yes	Yes
Observations	25,076	25,076
Adjusted R-squared	0.189	0.180

This table presents the results of robustness checks for the baseline regression model, where all independent variables are lagged by 1 year. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

To further address the endogeneity concern arising from causality, we employ instrumental variable 2SLS estimation. Following the approach of Hasan et al. (2022a), we employ the geopolitical risks index (*GPR4c*) as the instrumental variable for oil price uncertainty. Geopolitical risks indirectly influence firm investment through their impact on oil price uncertainty, and prior studies have confirmed its significant role in influencing oil price uncertainty (Noguera-Santaella, 2016). However, the geopolitical risks index is not found to influence corporate green innovation disclosure. Therefore, it can be deemed as a strong instrument for OPU.

In the first stage, we regress the instrumental variables on each independent variable: *OILVOL* and *OILVAR*, respectively. The results are shown in Columns (1) and (2) of Table 8. *GPR4c* is positively related to *OILVOL* and *OILVAR* (with both coefficients statistically significant at the 1% level). The Cragg–Donald Wald F statistics for each test are 595.915 and 1,989.649, which exceed the critical value, indicating that we can safely reject the weak instrumental variable hypothesis. The Kleibergen–Paap Wald rk LM statistics are significant at the 1% level, suggesting that the model is not under-identified. The fitted value of the first-stage regression is then collected and used as the main independent variable in the second-stage analysis. The results of the second-stage analysis are reported in Columns (3) and (4) of Table 3.7. The coefficients of fitted values are positive and statistically significant in both columns. Overall, our baseline results remain robust after addressing endogeneity employing the instrumental variable 2SLS estimation.

Table 3.7. Endogeneity test: IV test

	First stage		Second stage	
	OILVOL	*OILVAR*	*GInoDis* (1)	*GInoDis* (2)
GPR4c	0.198*** (21.131)	0.001*** (32.967)		
Fitted_ OILVOL			0.308*** (3.181)	
Fitted_ OILVAR				9.414** (2.194)
Constant	–0.001 (–0.004)	–0.022 (–1.493)	–0.458*** (–8.103)	–0.458*** (–8.004)
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	30,829	30,829	30,829	30,829
Adjusted R^2	0.680	0.664	0.713	0.714
Cragg-Donald Wald F statistic	595.915	1989.649		
Kleibergen-Paap Wald rk LM statistic	443.176***	1224.285***		

This table presents the endogeneity test using instrumental variable estimation, following Deng and Hao (2024). The average geopolitical risk index of the two largest consumers (the USA and China) and the two largest producers (Saudi Arabia and Russia) of crude oil in the world, namely GPR4c, is employed as the instrumental variable. Controls are the same as in Table 3.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.4.4. Factors shaping the influence of OPU on green innovation disclosures

Firms may have unique motivations for disclosing green innovations under external environmental pressures, which can be explained by various theories. In this section, we examine the factors influencing the impact of oil price uncertainty on green innovation disclosures.

3.4.4.1. Analysis of impact factors on OPU and green innovation disclosures

There is an ongoing academic debate regarding whether companies with good reputations are more inclined to disclose information compared to those with poor reputations. Some studies, such as by Clarkson et al. (2008), argue that firms with superior reputations are motivated to disclose positive information to distinguish themselves from firms with negative news, thus avoiding adverse selection. Stakeholder theory, as advocated by scholars such as Bhandari and Javakhadze (2017) and Goss and Roberts (2011), emphasises the importance of aligning firm strategies with the interests of all stakeholders, beyond solely profit maximisation. This theory suggests that firms with stronger reputations, driven by societal and governmental demands for sustainability, may be more inclined to disclose green innovation efforts to meet stakeholder expectations. However, contrasting views, such as from De Villiers and Van Staden (2011), propose that firms with poorer reputations may disclose more information to address stakeholder concerns. Given this conflicting evidence, further research is required to clarify which types of firms are more likely to disclose.

To identify firms with stronger reputations in environmental initiatives, we refer to Liu et al. (2024) and Tu et al. (2024) and utilise the environmental sub-index from the Huazheng ESG Index to measure firm environmental performance. According to Bhandari and Javakhadze (2017), firms that prioritise stakeholder interests are expected to place greater emphasis on their

CSR objectives. We introduce an interaction term between the two OPU measurements and a dummy variable, *HighCEP*. which takes the value of 1 if the firm's environmental performance score is above the industry-level median for the year, and 0 otherwise. The regression results, as shown in Table 3.8, indicate that both the *HighCEP* variable and the interaction term between OPU and *HighCEP* are positively associated with green innovation disclosures at the 1% significance level. This suggests that firms with higher environmental engagement are more likely to disclose green innovations under conditions of oil price uncertainty, supporting the notion that firms that prioritise stakeholder interests are more responsive to external environmental pressures in the form of green innovation disclosures.

Table 3.8. The impact of firm green performance

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.060**	
	(2.374)	
OILVAR		5.239***
		(3.010)
HighCEP	0.088***	0.040***
	(5.245)	(2.725)
OILVOL HighCEP*	0.523***	
	(7.023)	
OILVAR HighCEP*		0.333***
		(5.314)
Constant	-2.009***	-2.005***
	(-12.828)	(-13.424)
Controls	Yes	Yes
Industry FE	Yes	Yes
Observations	30,829	30,829
Adjusted R2	0.243	0.244

This table reports the results of the regression as follows:

$$GInoDis_{i,t} = \beta_0 + \beta_1 OPU + \beta_2 OPU_t * HighCEP_{i,t} + \beta_2 HighCEP_{i,t} + \sum_k \beta_k Controls_{k,i,t} + \epsilon_{i,t}$$

$HighCEP_{i,t}$ is a dummy variable that takes the value of 1 if the firm's environmental performance score is above the industry-level median for the year, and 0 otherwise. The measurement of the environmental performance score is collected from the environmental sub-index in the Huazheng ESG index. Controls are the same as in Table 3.2. Appendix B presents the detailed variable definitions. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.4.4.2. High legitimacy demand vs. low legitimacy demand

Legitimacy theory posits that organisations seek to manage public perception to avoid the risks associated with negative views of their actions, as highlighted by Dowling and Pfeffer (1975) and Lindblom (1994). To align with societal expectations or values and reduce legitimacy risks, organisations often adopt strategies that include disclosures. Oil price volatility may lead to heightened environmental regulation, as both governments and societies become more aware of the environmental impacts of energy consumption (Kang et al., 2019). This, in turn, encourages firms to enhance their green innovation disclosures to remain aligned with these evolving standards.

To understand the implications of legitimacy pressure for our baseline regression, we introduce an interaction term between the two OPU measurements and a dummy variable, *ISO14001*, which represents the possession of ISO14001 certification—a globally recognised marker of a firm's adherence to rigorous environmental management standards. The regression results, shown in Table 3.9, reveal that both the *ISO14001* and the interaction terms between OPU measurements and *ISO14001* are positively associated with green innovation disclosures at the 1% significance level. This suggests that firms with higher legitimacy demands, as indicated by the possession of ISO14001 certification, are more likely to disclose green innovations under conditions of oil price uncertainty. This finding supports our conjecture that firms facing higher expectations for legitimacy are more proactive in disclosing their green innovations in response to OPU.

Table 3.9. Heterogeneity test: The impact of ISO environmental certification

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.112***	
	(3.912)	
OILVAR		4.706***
		(3.935)
ISO14001	0.233***	0.171***
	(10.498)	(7.243)
OILVOL ISO14001*	0.301***	
	(3.780)	
OILVAR ISO14001*		19.787***
		(6.133)
Constant	-1.973***	-1.973***

	(-18.511)	(-18.550)
Controls	Yes	Yes
Industry FE	Yes	Yes
Observations	30,829	30,829
Adjusted R2	0.277	0.279

This table reports the results of the regression as follows:

$$GInoDis_{i,t} = \beta_0 + \beta_1 OPU + \beta_2 OPU_t * ISO14001_{i,t} + \beta_2 ISO14001_{i,t} + \sum_k \beta_k Controls_{k,i,t} + \epsilon_{i,t}$$

$ISO14001_{i,t}$ is a dummy variable that takes the value of 1 if the firm holds an ISO14001 certificate, and 0 otherwise. Controls are the same as in Table 3.2. Appendix B presents the detailed variable definitions. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.4.4.3. The impact of policy connections

Given China's unique institutional framework—characterised by state control over resources, a high degree of government ownership, and the prevalence of political ties among senior managers—political connections play a significant role in shaping business strategies (Li et al., 2015). For Chinese firms, obtaining political legitimacy is crucial, as political interference is a common feature of the Chinese business environment (Li & Zhang, 2010). These connections help firms negotiate and enforce contracts more effectively, allowing them to align closely with government expectations. This alignment helps safeguard their interests and bolsters their executives' political standing (Zhang et al., 2016). This dynamic is particularly relevant in the area of green innovation, where companies can enhance their corporate image and respond proactively to governmental expectations (Wang & Jiang, 2021). Thus, we conjecture that political connections may positively amplify firms' green innovation disclosure in times of uncertainty, as they allow firms to more adeptly navigate regulatory landscapes and demonstrate alignment with national goals.

Following Li et al. (2015), we introduce an interaction term between the two OPU measurements and a dummy variable, *PC*, which indicates whether a firm's board chairperson or CEO currently holds or has previously held a position in the central government, local government, National People's Congress, local people's congress, Chinese People's Political Consultative Conference, or local people's political consultative conference. The results, presented in Table 3.10, show that both the *PC* and its interaction terms with OPU are positively associated with green innovation disclosures at the 1% significance level. This finding supports our conjecture that political connections enhance firms' responsiveness to oil price uncertainty, encouraging them to more transparently disclose green innovation initiatives.

Table 3.10. The impact of political connection

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.115***	
	(3.413)	
OILVAR		11.064***
		(7.729)
PC	0.201***	0.139***
	(7.060)	(5.322)
OILVOL PC*	0.023***	
	(3.370)	
OILVAR PC*		2.491***
		(3.664)
Constant	-1.835***	-1.838***
	(-15.228)	(-15.426)
Controls	Yes	Yes
Industry FE	Yes	Yes
Observations	30,829	30,829
Adjusted R2	0.200	0.202

This table reports the results of the regression as follows:

$$GInoDis_{i,t} = \beta_0 + \beta_1 OPU + \beta_2 OPU_t * PC_{i,t} + \beta_2 PC_{i,t} + \sum_k \beta_k Controls_{k,i,t} + \epsilon_{i,t}$$

$PC_{i,t}$ is a dummy variable that takes the value of 1 if the firm's board chairperson or CEO is currently holding, or previously held a government position, and 0 otherwise. Controls are the same as in Table 3.2. Appendix B presents the detailed variable definitions. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.4.4.4. The impact of regional environmental regulation intensity

Social and institutional theories have long recognised that a country's institutional environment—including factors such as national culture, legal frameworks, and demographic diversity—plays a significant role in shaping managerial decision-making (Campbell, 2007). In the context of China, regional policy orientation plays a pivotal role in shaping firms' behaviours, which is closely linked to the country's unique economic policy framework (Shen et al., 2020). Previous research indicates that regional environmental preferences are transmitted to firms through policy mechanisms (Lei et al., 2017), and stronger environmental policy intensity can exert pressure on firms to enhance their green and sustainable development practices (Lai et al., 2024). Cheng and Mao (2024) find that stringent administrative policies effectively stimulate firms to engage in environmental disclosure, reducing compliance risks while simultaneously enhancing their environmental reputation in the market. Similarly, Sun and Yang (2024) suggest that government-imposed environmental targets can be a significant driver of firms' green innovation. Based on this, we conjecture that the intensity of regional environmental regulations amplifies the relationship between OPU and firms' green innovation disclosures.

We introduce an interaction term between the two OPU measurements and a dummy variable, *HighRERI*, which indicates whether the environmental regulation intensity in the firm's province is above the median for the year. The intensity of environmental regulation is measured by the ratio of completed industrial pollution control investment to the value added of the secondary industry in the province. The results, presented in Table 3.11, show that both *HighRERI* and its interaction terms with OPU are positively associated with green innovation disclosures at the 1% significance level. This suggests that firms operating in regions with stronger environmental regulations are more likely to disclose green innovations when faced with oil price uncertainty, highlighting the role of regulatory pressure in shaping firms' voluntary strategies.

Table 3.11. The impact of regional environmental regulations

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.157***	
	(3.946)	
OILVAR		9.340***
		(5.716)
HighRERI	0.024***	0.049***
	(4.428)	(2.692)
OILVOL HighRERI*	0.068***	
	(3.102)	
OILVAR HighRERI*		5.967**
		(2.322)
Constant	-1.952***	-1.983***
	(-16.460)	(-16.784)

Controls	Yes	Yes
Industry FE	Yes	Yes
Observations	30,829	30,829
Adjusted R2	0.156	0.158

This table reports the results of the regression as follows:

$$GInoDis_{i,t} = \beta_0 + \beta_1 OPU + \beta_2 OPU_t * HighRERI_{i,t} + \beta_2 HighRERI_{i,t} + \sum_k \beta_k Controls_{k,i,t} + \epsilon_{i,t}$$

$HighRERI_{i,t}$ is a dummy variable that takes the value of 1 if the environmental regulation intensity in the firm's province is above the median for the year, and 0 otherwise. The intensity of environmental regulation is measured by the ratio of completed industrial pollution control investment to the value added of the secondary industry in that province. Controls are the same as in Table 3.2. Appendix B presents the detailed variable definitions. t-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.4.4.5 The impact of **carbon trading pilots**

China's carbon trading pilot scheme, launched as part of its efforts to combat climate change and reduce carbon emissions, plays a crucial role in shaping corporate environmental strategies. After approval by the National Development and Reform Commission in 2011, the pilot scheme was introduced in 2013 across several major regions, including Beijing, Shanghai, Tianjin, Guangdong, and Shenzhen, with Chongqing and Hubei joining in 2014. These pilot regions serve as testing grounds for the national emissions trading system, where firms receive emission allowances and can trade them on the carbon market (Liu & Zhang. 2019). Firms operating in pilot regions are subject to stricter environmental regulations and are incentivised to adopt more sustainable practices to meet carbon reduction targets (Ren et al., 2024). As a result, firms in these regions may be more proactive in disclosing their green innovations to align with regulatory requirements and gain competitive advantages in the low-carbon economy.

We introduce an interaction term between the two OPU measurements and a dummy variable, *Pilot*, which takes the value of 1 if the firm is located in a region included in the carbon trading pilot scheme in a given year, and 0 otherwise. The regression results, presented in Table 3.12, show that *Pilot* is positively associated with green innovation disclosures at the 1% significance level, indicating that firms in pilot regions are more likely to disclose green innovations. Furthermore, the interaction terms between OPU measurements and *Pilot* are positively associated with green innovation disclosures at the 5% significance level. This result aligns with our conjecture and highlights the driving influence of market-based green initiatives on firms' green innovation disclosure.

Table 3.12. The impact of carbon trading pilots

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.215***	
	(5.929)	
OILVAR		13.282***
		(8.693)
Pilot	0.037***	0.035***
	(5.875)	(5.795)
OILVOL Pilot*	0.101**	
	(2.445)	
OILVAR Pilot*		3.707**
		(2.384)
Constant	-1.974***	-2.018***
	(-16.708)	(-17.106)
Controls	Yes	Yes
Industry FE	Yes	Yes
Observations	30,829	30,829
Adjusted R2	0.156	0.158

This table reports the results of the regression as follows:

$$GInoDis_{i,t} = \beta_0 + \beta_1 OPU + \beta_2 OPU_t * Pilot_{i,t} + \beta_2 Pilot_{i,t} + \sum_k \beta_k Controls_{k,i,t} + \epsilon_{i,t}$$

$Pilot_{i,t}$ is a dummy variable that takes the value of 1 if firm i is located in a region that has implemented a pilot carbon trading scheme in year t, and 0 otherwise. The pilot cities include Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen. Chongqing and Hubei joined the carbon trading pilot in 2014, while the other regions joined in 2013. Controls are the same as in Table 3.2. Appendix B presents the detailed variable definitions. t-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.5. Conclusion

The study highlights how firms adapt their voluntary disclosures on green innovation in response to energy uncertainties, specifically examining the impact of oil price uncertainty on corporate green innovation disclosures. We find a significantly positive relationship between these two variables of interest. By employing robust analysis techniques, including controlling for firm, industry, and province fixed effects, as well as addressing endogeneity using instrumental variable and lagged variable approaches, the results validate the robustness and reliability of the findings.

Additionally, this study finds that firms with higher environmental performance and greater legitimacy demands are more inclined to enhance their green innovation disclosures in the face of oil price uncertainty. The findings also show that corporate political connections strengthen this relationship. Furthermore, our results indicate that China's carbon trading pilot scheme and the stringency of regional environmental regulations positively amplify the relationship between OPU and green innovation disclosure, highlighting how regulatory frameworks can drive firms to align their strategies with broader environmental goals.

Overall, this research enriches the discourse on how firms navigate the dual challenges of oil price volatility and environmental sustainability, while also highlighting the nuanced role of internal governance mechanisms and external societal pressures in shaping corporate sustainability practices.

3.6. Appendix

Appendix A: The composition of indicators for corporate green innovation disclosure

Variables	Measurements	Data sources	Sources
GInoDis	PROC1. Aiming to reduce the consumption of resources and energy and improve resource and energy efficiency PROC2. Using recycled materials, recycling techniques, and environmental technologies PROC3. Applying environmental campaigns PROC4. Using pollution-control equipment PROC5. Adopting pollution-control projects and technologies	Firms' annual reports and corporate social responsibility reports	Frondel et al. (2007); Klassen & Whybark (1999); del Río González (2005); Zeng et al. (2010)

Appendix B: Variable description

Variable	Description
OILVOL	According to Yang and Song (2023), *OILVOL* is measured by the standard deviation of daily oil price returns for 1 year.
OILVAR	According to Yang and Song (2023), *OILVAR* is measured by the average of the daily conditional variance from the GARCH (1,1) model for 1 year.
OILVARE	*OILVARE* is measured by the average of the daily conditional variance from the EGARCH (1,1) model for 1 year.
GInoDis	According to Xie et al. (2019), the firm green innovation disclosure index is calculated from five sub-indicators. These sub-indicators are derived from text analysis of firm annual reports and social responsibility reports.
MTB	The ratio of market value to its book value of equity.
Growth	Change in sales between years *t* and *t*-1.
ROA	Return on assets, calculated as net profit after tax/total assets.
Size	The natural logarithm of total assets.
Lev	Total liabilities scaled by total assets.
Cash	Cash and cash equivalents scaled by total assets.
RDSales	R&D expenses scaled by total sales.
Board	The natural logarithm of the total number of directors on the board.
Indep	The proportion of independent directors to the total number of directors on the board.
Big410	A dummy variable equals one if the auditor of the firm is one of international 'Big4' or 'Domestic 10' audit firms, and 0 otherwise.
Top1	The largest shareholding ratio.
SOE	A dummy variable equals 1 if the ultimate controller of a firm is a government agency or a state-owned enterprise, and 0 otherwise.
Marketbeta	Based on monthly data, the annual market risk exposure of a firm is calculated through the FAMA three-factor model.
EPUbeta	According to Peng et al. (2023), the annual firm exposure to EPU is calculated based on monthly data through the FAMA three-factor model. We take its absolute value.
GPR4c	According to Deng and Hao (2024), the average geopolitical risk index of the two largest consumers (the USA and China) and the two largest producers (Saudi Arabia and Russia) of crude oil in the world. GPR4c is calculated using monthly geopolitical risk data constructed by Caldara and Iacoviello (2022) based on 10 newspapers beginning in 1985.
HighCEP	*HighCEP* is a dummy variable, which takes the value of 1 if the firm's environmental performance score is above the industry-level median for the year, and 0 otherwise. The environmental sub-index from the Huazheng ESG Index is used to measure firm environmental performance.
ISO14001	*ISO14001* is a dummy variable, which takes the value of 1 if the firm holds an ISO14001 certificate, and 0 otherwise.

PC	*PC* is a dummy variable that takes the value of 1 if the firm's board chairperson or CEO is currently holding, or previously held a government position, and 0 otherwise.
HighRERI	*HighRERI* is a dummy variable that takes the value of 1 if the environmental regulation intensity in the firm's province is above the median for the year, and 0 otherwise. The intensity of environmental regulation is measured by the ratio of completed industrial pollution control investment to the value added of the secondary industry in that province.
Pilot	*Pilot* is a dummy variable that takes the value of 1 if firm i is located in a region that has implemented a pilot carbon trading scheme in year t, and 0 otherwise. The pilot cities include Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen. Chongqing and Hubei joined the carbon trading pilot in 2014, while the other regions joined in 2013.

Appendix C: Redo baseline using alternative measure of OPU

	GInoDis
OILVARE	5.360***
	(7.213)
Constant	-1.931***
	(-4.943)
Controls	Yes
Industry FE	Yes
Observations	30,829
Adjusted R-squared	0.196

We recalculated our main independent variable of *OILVAR*, denoted as *OILVARE*. *OILVARE* is measured by the average of the daily conditional variance from the EGARCH (1,1) model for 1 year. Controls are the same as in Table 3.2. Appendix B presents the detailed variable definitions. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm-year level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Appendix D. Pairwise Pearson correlation coefficients

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) *OILVOL*	1														
(2) *OILVAR*	0.784***	1													
(3) *MTB*	0.085***	0.098***	1												
(4) *Growth*	-0.087***	-0.048***	0.075***	1											
(5) *ROA*	-0.031***	-0.011***	-0.096***	0.335***	1										
(6) *Size*	-0.017***	-0.016***	-0.047***	0.050***	0.066***	1									
(7) *Lev*	0.048***	0.022***	0.401***	0.014**	-0.252***	0.489***	1								
(8) *Cash*	-0.033***	-0.009**	-0.084***	0.025***	0.196***	-0.213***	-0.416***	1							
(9) *RDSales*	-0.029***	0.013**	0.054***	-0.071***	-0.121***	-0.221***	-0.282***	0.189***	1						
(10) *Board*	0.023***	0.011**	-0.020***	0.018***	0.058***	0.249***	0.132***	-0.034***	-0.117***	1					
(11) *Indep*	-0.022***	-0.003***	0.022***	-0.016***	-0.035***	-0.004	-0.005	0.005	0.047***	-0.567***	1				
(12) *Big410*	-0.034***	-0.079***	-0.003	0.066***	0.097***	0.080***	0.002	0.010*	-0.025***	0.034***	0.002	1			
(13) *Top1*	-0.006	-0.012**	-0.082***	0.012**	0.162***	0.162***	0.015***	0.048***	-0.173***	0.013**	0.041***	0.088***	1		
(14) *SOE*	0.063***	0.031***	0.034***	-0.059***	-0.043***	0.363***	0.267***	-0.059***	-0.194***	0.265***	-0.057***	0.011*	0.214***	1	
(15) *Marketbeta*	-0.206***	-0.199***	0.011*	-0.019***	0.051***	-0.149***	-0.024***	0.094***	-0.021***	0.045***	-0.027***	-0.036***	0.048***	0.017***	1

This table reports the Pearson correlation coefficient. *t*-statistics are given in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

CHAPTER FOUR

ESSAY THREE

Weathering the storm: The impact of firm oil price uncertainty exposure (OPU exposure) on green innovation in times of geopolitical tensions

Abstract

This study examines the impact of firm-level oil price uncertainty sensitivity (OPU exposure) on corporate green innovation, in times of geopolitical tensions. By utilizing manually collected import and export data at the destination country-firm level from the China Customs Dataset, we construct a unique measure of geopolitical tensions faced by Chinese listed companies from their foreign supply chain partners. Our findings indicate that firms with greater OPU exposure are more inclined to pursue green innovation. Notably, geopolitical tensions significantly and positively amplify the relationship between corporate OPU exposure and green innovation performance, with this effect being particularly strong when tensions originate from supplier countries. Further analysis shows that domestic supply chain alliances and supply chain efficiency reduce the urgency for green innovation. Lastly, we observe that the interacted impacts of OPU exposure and geopolitical tensions on green innovation are more pronounced in firms with higher international exposure, lower government subsidies, and greater competitive pressures.

Keywords: Green innovation; Oil price uncertainty; Geopolitical tensions; Supply chain alliances; Supply chain efficiency

4.1. Introduction

In the context of growing demands for environmental sustainability, green innovation has emerged as a crucial strategy for firms to navigate uncertain environments. Green innovation involves not only technological advancements aimed at reducing carbon emissions and pollution but also the adoption of renewable energy sources to decrease reliance on unsustainable resources (Xu et al., 2021; Shao et al., 2021). This study examines the impact of firms' sensitivity to oil price uncertainty (OPU exposure), particularly during periods of geopolitical tension, on green innovation, guided by three primary motivations.

Firstly, frequent fluctuations in international crude oil prices have prompted investigations into how oil price uncertainty (OPU) impacts economic activities and financial market development (Amin et al., 2023; Maghyereh & Abdoh, 2020; Elder & Serletis, 2009; Koirala & Ma, 2020). While existing studies have investigated various strategies that firms use to manage OPU, there is limited research on firms' strategic commitment to green innovation as a response to firm-level exposure to OPU. Oil price uncertainty exacerbates uncertainty in energy supply and demand. For example, Dutta et al. (2020) indicate that as oil price volatility intensifies, green investment plays an increasingly critical role in promoting corporate sustainability, as firms seek green alternatives to mitigate their reliance on oil. Alternatively, Amin et al. (2023) and Yang and Song (2023) find that oil price volatility increases firms' uncertainty-related costs, leading to reduced innovation investments to maintain financial flexibility and cope with rising costs. The impact of firm-level exposure to OPU on corporate green innovation remains an open question.

Secondly, geopolitical tensions have increasingly triggered reactions through global supply chains, significantly affecting corporate decisions (Zhang et al., 2024). Geopolitical tensions have significantly disrupted corporate supply chains, prompting strategies for ensuring supply chain resilience and mitigating the adverse effects of geopolitical risks. Existing research indicates that when facing geopolitical tensions, firms typically adopt strategies such as reducing long-term investments, exiting markets, or restructuring supply chains to mitigate risk exposure (Khoo, 2021; Lee et al., 2023; Moradlou et al., 2024). While Lee et al. (2021) reveal that geopolitical uncertainty often boosts demand for green investments, as firms view green assets as effective tools to hedge against oil market volatility (Lee et al., 2021).

Thirdly and importantly, firms must navigate various risks in an increasingly uncertain global environment, which creates more complex challenges. Examining the influence of OPU exposure during geopolitical tensions on green innovation provides valuable insights into how firms manage multiple sources of uncertainty to maintain sustainability. The influence of OPU exposure, particularly in time of geopolitical tensions, on corporate green innovation remains unexplored. Geopolitical risks may reduce corporate investment willingness by undermining market confidence, as highlighted by Le and Tran (2021) and Wang et al. (2019b), and this effect could be particularly true for firms with greater OPU exposure. Conversely, uncertain environments can encourage long-term investments in areas like innovation (Hassani et al., 2017), and the effect can be stronger during periods of heightened geopolitical tensions.

China's status as the world's largest net oil importer and second-largest oil consumer positions it uniquely at the nexus of oil market dynamics (Yang & Song, 2023). The National Bureau of Statistics of China highlights that the nation's dependency on oil imports has been escalating, surpassing 70% in 2018, thereby making Chinese firms particularly susceptible to oil price shocks (National Bureau of Statistics, 2018). Additionally, China is one of the largest exporters in the world. As of 2022, China accounted for approximately 14.42% of global exports, making it the world's largest exporter (WTO, 2023). Given their extensive involvement in global trade and supply chains, Chinese firms face a complex and transnational set of geopolitical risks, making the Chinese market an ideal case for studying the influence of geopolitical risks transmitted through supply chains on corporate behaviour. Furthermore, China's recent vigorous promotion of green development, with substantial investments in green innovation by both the government and enterprises, provides a rich empirical foundation for examining the role of green innovation in responding to external uncertainties.

Using data from Chinese listed firms from 2006 to 2016[6], our empirical analysis demonstrates that firms with higher sensitivity to OPU significantly increase both the quantity and quality of their green innovation during periods of heightened geopolitical tensions. This finding indicates that, when confronted with oil price volatility and geopolitical risks, firms strategically leverage green innovation to mitigate operational uncertainties and ensure sustainability. Robustness checks, including the use of alternative measures and multiple fixed effects, validate the reliability of these results. Furthermore, our analysis highlights that the positive impact of OPU on green innovation is particularly pronounced in the context of geopolitical tensions originating from supplier countries.

We find an amplifying effect of domestic supply chain alliance and supply chain efficiency on our baseline results. While supply chain alliances provide stability and operational resilience (Philsoophian et al., 2021), they may also be associated with a reduced urgency for green innovation which may be associated with high risk and long investment horizon. This result highlights the stabilizing role of supply chain factors, enabling firms to sustain operational stability when facing extreme high uncertainties arising from both oil price fluctuations and geopolitical tensions. Similarly, supply chain efficiency, achieved by optimizing resource utilization and streamlining operations, enhances firms' ability to withstand disruptions and minimize costs (Kamalahmadi et al., 2022). Our result indicate that higher supply chain efficiency may address the urgency for long-term green innovation initiatives, which is

[6] Our sample period ends in 2016 because the data on imports and exports of Chinese firms, published by Chinese Customs, is only available up to 2016.

extremely risky for firms during periods of heightened oil price volatility and geopolitical tensions.

Additionally, our study finds that the interacted impact of OPU exposure and geopolitical risks on green innovation is more pronounced in firms with a higher proportion of international business, fewer government subsidies, or greater competitive pressures. Firms with a higher proportion of international business are more exposed to global market volatility (Minetti et al., 2019), making them more sensitive to disruptions caused by geopolitical risks and oil price fluctuations. We also observe that the interacted impact on green innovation is stronger in firms with lower government subsidies. Finally, Finally, firms facing intense competitive pressures are often more motivated to innovate, potentially driven by the need to differentiate themselves and seize market opportunities (Di Dio & Correani, 2020). Overall, our results illustrate how firm-level characteristics interact with external shocks to influence corporate green innovation.

The contributions of this paper are fourfold. First, existing studies primarily focus on the impact of oil price fluctuations on firm behaviour, such as Amin et al. (2023) and Yang and Song (2023), which indicate that oil price uncertainty reduces innovation investment. While our study examines how varying degrees of firm-level sensitivity to oil price volatility affects green innovation. In addition, we examine the interacted impact of OPU exposure and the weighted geopolitical risk of firm suppliers' and customers' countries on corporate green innovation. This adds new evidence to the findings of Lee et al. (2023), who investigate the impact of global geopolitical tensions on innovation of Chinese firms. Our study provides new insights into the motivations behind corporate green innovation in uncertain environments, indicating that firms navigate multiple risks through green innovation to improve sustainability.

Second, this study contributes to ongoing debates on corporate investment behaviour under uncertainty. While traditional real options theory posits that firms often delay or reduce investments in uncertain environments to preserve strategic flexibility for the future (Cooper

& Priestley, 2011), Strategic growth theory offers a contrasting view. According to Kulatilaka and Perotti (1998), uncertainty, when coupled with competitive pressures, can incentivize firms to invest proactively in growth opportunities to secure first-mover advantages and deter competitors. Our findings provide empirical support for this perspective, demonstrating that firms facing both oil price volatility and geopolitical risks increase green innovation investments. These results extend the applicability of strategic growth theory, highlighting how firms strategically leverage innovation as a means of responding to external uncertainties while positioning themselves for long-term growth.

Third, this research advances the understanding of the role of supply chain dynamics in amplifying the relationship between external uncertainties and green innovation. Specifically, we reveal that domestic supply chain alliances and supply chain efficiency act as critical impact factors. While external pressures such as OPU and geopolitical risks typically drive firms to enhance green innovation, the stability and resources provided by domestic supply chain alliances reduce firms' dependency on vulnerable international supply chains, thereby diminishing the urgency for green innovation. Similarly, supply chain efficiency fosters operational stability and resource optimization, also tempering the need for green innovation. Our findings expand Hsieh et al. (2018), which highlight the importance of domestic supply chain collaboration in securing resources, and Kamalahmadi et al. (2022), which emphasize the dual role of supply chain efficiency in enhancing stability and constraining flexibility. By integrating these insights, our study provides a nuanced understanding of how supply chain dynamics shape corporate innovation strategies.

Lastly, this paper advances the understanding of firm-level heterogeneity in green innovation responses to OPU and geopolitical risks, expanding on prior studies (e.g., Lee et al., 2023; Zhu et al., 2023) which highlight the factors shaping innovation investments. By integrating factors such as international business exposure, financial constraints, competition intensity, and government subsidies, this paper provides nuanced insights into how firm characteristics interact with external uncertainties to influence green innovation.

4.2. Literature and hypothesis development

4.2.1. Impact of oil price uncertainty

Under the highly energy-dependent global economy, the impact of oil price volatility on corporate decision-making has attracted significant attention. Existing studies have explored how oil price volatility shapes corporate investment and profitability decisions under uncertainty. The influence of oil price volatility on corporate investment decisions is particularly pronounced. Henriques and Sadorsky (2011) demonstrate a U-shaped relationship between OPU and corporate investment, indicating that firms are more inclined to invest under either extremely low or extremely high oil price volatility. Similarly, Alaali (2020), in a study of investment behaviours of UK firms, finds that oil price volatility introduces uncertainty, resulting in a nonlinear relationship between OPU and investment spending. Specifically, firms display a U-shaped investment response, adjusting their strategies to diversify risks (Alaali, 2020).

Beyond investment decisions, oil price volatility significantly impacts corporate profitability, especially in energy-intensive sectors like oil and gas. Lyócsa and Todorova (2021) find that oil price volatility is a key determinant of stock price fluctuations in the oil and gas exploration and production industry, directly influencing profitability expectations. This insight aids firms in developing risk management strategies to navigate market instability. Narayan and Sharma (2014) further reveal that oil price volatility serves as a predictor of stock return volatility, enabling investors to devise trading strategies and achieve higher returns during periods of heightened oil price volatility.

With growing global attention to sustainability, the effect of oil price volatility on green innovation has garnered increasing interest. Fazlollahi and Ebrahimijam (2017) indicate that oil price volatility enhances the market appeal of clean energy firms, driving more investment into the sector. Although the short-term impact of oil price volatility on the clean energy market is limited, its long-term effects are significant (Fazlollahi & Ebrahimijam, 2017). Additionally, Ji and Fan (2012) highlight the strengthened spillover effects of oil price volatility on non-energy commodity markets following the financial crisis, intensifying the linkages between clean energy and traditional energy markets. This relationship suggests that oil price volatility not only influences firms' financial conditions but also encourages them to pursue long-term green investment and risk mitigation strategies.

One of the primary drivers of green innovation prompted by oil price volatility is the threat it poses to the stability of future energy supplies, which compels firms to increase investment in energy technologies and innovation to reduce reliance on traditional fossil fuels. Ebrahim et al. (2014) argue that oil price uncertainty drives firms to focus more on the sustainability of energy supplies, especially during periods of high oil prices, demonstrating a potential causal link between OPU and green innovation. Similarly, Alhassan's (2019) study, based on data from the Gulf Cooperation Council (GCC) markets, indicates that oil price volatility not only impacts short-term financial decisions but may also encourage companies to adopt more strategic investment approaches, including exploring long-term green technology solutions. These findings highlight how oil price volatility exerts financial pressures while simultaneously incentivizing firms to seek innovative energy solutions and drive green innovation.

4.2.2. Geopolitical risks and their disruptive effects on supply chain relationships

Geopolitical crises profoundly affect supply chains, presenting both significant challenges and opportunities for firms. Schotter and Thi My (2013) highlight that suppliers in underdeveloped regions are particularly vulnerable to geopolitical uncertainties due to their limited resources and technical capabilities, often becoming the weakest links in supply chains.

Such vulnerabilities frequently lead to supply interruptions and financial strain, hampering firms' ability to maintain consistent operations. Similarly, Liu and Ning (2023) reveal that global supply chain tensions exacerbate material shortages and increase import costs, forcing firms to bear higher expenses to secure essential raw materials. This diminishes their competitiveness in international markets, further intensifying the adverse effects of geopolitical risks.

However, these disruptions also compel firms to reassess their operational strategies and leverage innovation to mitigate vulnerabilities. Sabahi and Parast (2020) argue that innovation enhances firms' resilience to supply chain disruptions by fostering capabilities such as agility, knowledge sharing, and flexibility, which are particularly valuable in uncertain environments. Roscoe et al. (2022) further demonstrate that firms redesigning their supply chains in response to geopolitical disruptions often adopt strategies that promote sustainability and resilience, such as diversifying supplier bases and investing in green technologies. These approaches not only reduce dependency on high-risk suppliers but also align with broader environmental objectives. Additionally, Jabbarzadeh et al. (2018) highlight that integrating resilience strategies with green practices enable firms to address both operational risks and environmental challenges, positioning crises as potential catalysts for innovative solutions. Together, these findings underscore the transformative potential of geopolitical crises, driving firms toward long-term innovation strategies that enhance their resilience, competitiveness, and sustainability.

4.2.3. Hypothesis development

Strategic growth theory posits that under high uncertainty, firms may choose to invest proactively to secure competitive advantages, particularly in industries characterized by intense competition and rapid change (Kulatilaka & Perotti, 1998). This perspective highlights that uncertainty can reduce the value of waiting and incentivize firms to invest early to pre-empt competitors. For example, Vo and Le (2017) demonstrate that firms in competitive industries are more likely to increase R&D investments during uncertain periods, recognizing the potential to establish first-mover advantages and mitigate risks associated with delayed action. Kulatilaka and Perotti (1998) argue that uncertainty encourage proactive investments, as firms aim to capture larger market shares and deter rivals by leveraging growth opportunities. Chen et al. (2005) illustrate how firms in dynamic and uncertain markets, succeed by adopting adaptive investment strategies that align with both external market shifts and internal growth objectives.

Green innovation requires significant initial investment but provides firms with opportunities to reduce reliance on traditional energy sources and secure long-term operational sustainability. Ebrahim et al. (2014) find that firms adopt innovative, energy-independent technologies to reduce dependence on unstable fossil fuel markets and mitigate resource-related risks. Fazlollahi and Ebrahimijam (2017) show that oil price uncertainty also drives market interest in clean energy, as firms seek sustainable alternatives to maintain operational stability. Green innovation serves as a strategic response, enabling firms to reduce dependence on traditional energy sources and enhance operational sustainability. High OPU exposure may push firms to invest in renewable energy technologies and adaptive strategies to stabilize operations and future-proof their business. Based on the above, we propose the following hypothesis:

Hypothesis 1a: OPU exposure positively influences firms' green innovation.

In contrast, real options theory posits that uncertainty often deters investment, as firms delay committing resources to irreversible projects to maintain strategic flexibility (Cooper & Priestley, 2011). Under oil price volatility, this dynamic may cause firms to hesitate in pursuing green innovation, which typically involves long-term commitments and substantial upfront costs. Alaali (2020) provides evidence that heightened oil price uncertainty reduces capital expenditure as firms prioritize financial flexibility over long-term innovation.

Moreover, Narayan and Sharma (2014) show that oil price uncertainty increases costs for firms by disrupting financial planning and cash flow predictability, further discouraging investment in innovation. Hasan et al. (2022b) find that under volatile energy markets, firms focus on cost control and risk mitigation rather than committing to high-risk initiatives like green innovation. This view aligns with the premise that in uncertain environments, firms with higher OPU exposure might forgo potentially transformative projects to preserve resources for immediate operational needs.

Hypothesis 1b: OPU exposure negatively influences firms' green innovation.

The interplay between OPU and geopolitical risk (GPR) introduces compounded external pressures that significantly shape firms' strategic decisions regarding green innovation. While OPU reflects volatility in energy input costs that can disrupt firms' budgeting and operational planning (Alaali, 2020; Hasan et al., 2022), GPR contributes an additional layer of uncertainty by threatening global supply chain continuity, access to critical resources, and policy stability (Roscoe et al., 2022; Lee et al., 2023). When these two sources of uncertainty coexist, firms may perceive heightened strategic vulnerability. GPR may amplify the effect of OPU exposure by intensifying firms' concerns about long-term access to stable energy and material supplies, thereby reinforcing the urgency to invest in green technologies.

Existing studies suggest that GPR does not merely increase background uncertainty but has a direct influence on global energy volatility, especially in oil markets. Qin et al. (2020) show that geopolitical risks exert asymmetric effects on oil, gas, and heating oil prices under different market conditions, thereby making energy costs more unpredictable for firms. Similarly, Liu et al. (2021) find that GPR induces long-term energy price volatility, exacerbating planning uncertainty for energy-dependent firms. GPR has also been shown to influence oil prices and shipping costs simultaneously, disrupting both input markets and global logistics networks (Khan et al., 2021). Therefore, for firms facing both high firm-level GPR and greater OPU exposure, green innovation becomes a proactive hedge that enables firms to manage the overlapping challenges of energy volatility and geopolitical disruption.

Hypothesis 2: Geopolitical risk positively moderates the relationship between oil price uncertainty and corporate green innovation.

4.3. Research design

4.3.1. Data and sample

Our initial sample comprises all Chinese companies listed on the Shanghai and Shenzhen Stock Exchanges from 2006 to 2016. The financial data are sourced from the China Stock Market and Accounting Research (CSMAR) database. Patent data are obtained from the website of the Chinese National Intellectual Property Administration. Data on firms' overseas customers and suppliers are manually collected from China Customs Database. Oil price data are gathered from the U.S. Energy Information Administration, while data related to global geopolitical risk and country-specific geopolitical risk are extracted from the Economic Policy Uncertainty website. We exclude: (1) financial firms, (2) special treatment (ST) firms, and (3) observations with missing information required for variable construction. Our final sample consists of 3,284 listed firms, amounting to 28,095 firm-year observations. To mitigate the impact of outliers, all continuous variables are winsorized at the 1% and 99% levels.

4.3.2. Firm's OPU exposure

To measure a firm's exposure to oil price uncertainty, we employ a two-step approach. First, following Sadorsky (2008), we measure month-level oil price uncertainty as the standard deviation of daily West Texas Intermediate (WTI) oil price returns over a given month. This approach captures the volatility of oil prices, which reflects market uncertainty. The formula for calculating OPU is expressed as follows:

$$OPU_t = \sqrt{\frac{1}{N-1}\sum_{d=1}^{N}(r_d - E(r_d))^2 * \sqrt{N}} \quad (1)$$

where r_d represents the daily oil price returns of trading day d and N represents the number of trading days in month t. This measure of OPU has been widely adopted in recent studies, including those by Amin et al. (2023), Hasan et al. (2021), and Maghyereh and Abdoh (2020).

Second, to assess a firm's exposure to OPU, we draw on the methodology outlined by Peng et al. (2023). Specifically, we compute a firm's OPU-beta (*OPUbeta*) using an augmented Fama-French three-factor model. The model estimates the sensitivity of a firm's stock returns to changes in oil price uncertainty, as follows:

$$r_{i,t}=\alpha+\beta_{OPU}*OPU_t+\beta_M*MKT_t+\beta_S*SMB_t+\beta_H*HML_t+\epsilon_t \quad (2)$$

where $r_{i,t}$ is the return of firm i at time t; MKT_t, SMB_t, and HML_t are the market, size, and value factors from the Fama-French three-factor model, respectively; β_{OPU} is the firm's sensitivity to oil price uncertainty, referred to as the OPU-beta; ϵ_t is the error term. We compute β_{OPU} using a 60-month rolling window regression approach. The absolute value of β_{OPU} is used as the firm's OPU exposure (*OPUbeta*), capturing the extent to which a firm is affected by oil price uncertainty.

4.3.3. Aggregated geopolitical tensions

The country-specific Geopolitical Risk (GPR) Index, developed by Caldara and Iacoviello (2022), measures the intensity of geopolitical risks on a country-specific basis using automated text-search results from major global newspapers. The GPR index is constructed from articles published in 11 newspapers: the Chicago Tribune, the Daily Telegraph, Financial Times, The Globe and Mail, The Guardian, the Los Angeles Times, The New York Times, USA Today, The Wall Street Journal, and The Washington Post. The index is calculated by counting the number of articles related to adverse geopolitical events each month, expressed as a share of the total number of news articles. The automated search covers eight categories: War Threats, Peace Threats, Military Buildups, Nuclear Threats, Terror Threats, Beginning of War, Escalation of War, and Terror Acts. For 44 advanced and emerging countries, the country-specific GPR index is calculated by counting the monthly share of newspaper articles from 1985 to 2022 that both meet the criterion for inclusion in the global GPR index and mention the name of the country or its major cities.

To assess the impact of geopolitical risk from the countries where a company's overseas clients or suppliers are located, we adjust this metric by weighting it, according to the proportion of business conducted with these clients or suppliers. Specifically, in Equation (3), we calculate the proportion of trade value (import and export) from each client *k* in country *j* relative to the firm *i*'s total trade value with all clients ($p_{ijk,t}$). We then multiply this proportion by the geopolitical risk of the respective client's country *j*. Next, we aggregate the geopolitical risk from all client countries for each firm-year, resulting in the firm's Client Geopolitical Risk (*GPRC*). Similarly, based on Equation (4), we calculate the Supplier Geopolitical Risk (*GPRS*) from the countries where the suppliers are located.

$$GPRC_{i,t} = \sum p_{ijk,t} * GPR_{j,t} \quad (3)$$

$$GPRS_{i,t} = \sum p_{ijk,t} * GPR_{j,t} \quad (4)$$

4.3.4. Green innovation

To evaluate a firm's green innovativeness, we adopt the methodology outlined by Amin et al. (2023) and construct two primary measures of firm innovation. The first measure is the natural logarithm of the total number of green patent applications filed by a firm in a given year that were eventually granted. In line with Amin et al. (2023), we use the application year of a patent instead of its grant year, as the application year more accurately reflects the actual time of the firm's innovation activities.

The number of green patents per firm-year is commonly used in innovation studies, while this measure does not necessarily capture the significance of new inventions. For example, it treats all patents equally, regardless of whether they are revolutionary or incremental. To address this issue, we follow Bradley et al. (2017) to assess the significance of patents by employing a second proxy for innovation productivity. This second measure is the patent's influence, quantified by the natural logarithm of the number of non-self-citations each green patent receives in subsequent years. Green patents are specified based on the green inventory patent classification scheme published by the World Intellectual Property Organization (WIPO).

4.3.5. Control variables

Following the approach of previous studies on firm green innovation, such as Hu et al. (2023) and He et al. (2022), we control for the variables that may influence green innovation, including market to book value (*MTB*) , annual growth rate of sales revenue ($Growth$), return on assets (ROA), firm size ($Size$), leverage ratio ($Leverage$), ratio of net cash flows from operating activities to total assets ($Cash$), research and development investment to total sales (*RDSales*), board size ($Board$), board independence ($Independence$), auditing quality ($Big4/10$), state control (SOE), and ownership of the largest shareholder ($Top1$). The variable definitions are presented in Appendix A.

4.3.6. Model specification

To examine impact of firms' sensitivity to oil price uncertainty, and supply chain geopolitical risk spillover on firm green innovation, we use the following regression model:

$$GreenInno_{i,t+1} = \beta_0 + \beta_1 OPUbeta_{i,t} + \beta_2 OPUbeta_{i,t} * GPR_{i,t} + \sum_k \beta_k Controls_{k,i,t} + \epsilon_{i,t} \quad (5)$$

where $GreenInno_{i,t+1}$ represents one-year forward of the two green innovation measures *Patent* and *Citation*. $GPR_{i,t}$ are the two measures of geopolitical tensions from customer countries (*GPRC*) and supplier countries (*GPRS*), respectively. $OPUbeta_{i,t}$ represents the OPU exposure measure of firm in year t. We include industry fixed effects to control for unobservable industry-level and macroeconomic factors. Year fixed effects are also included in all regressions to account for variations and trends across different years, helping to mitigate the influence of time-related factors on green innovation. Appendix A presents the variable definitions.

4.4. Empirical results

4.4.1. Descriptive statistics and correlation matrix

Table 4.1 presents the descriptive statistics of the key variables. The minimum and maximum values of the *Patent* variable are 0 and 6.608, respectively, with a standard deviation of 0.764. For the *Citation* variable, the minimum and maximum values are 0 and 6.489, with a standard deviation of 0.302. These statistics indicate a significant variation in the number of patent applications and citations among firms in our sample. The mean value of *OPUbeta* is 0.043, with a minimum of 0.001, a maximum of 0.171, and a standard deviation of 0.043. This suggests that while most firms exhibit low sensitivity of returns to oil price uncertainty, there is substantial variation across firms. The mean values of *GPRC* and *GPRS* are 0.035 and 0.026, respectively, with standard deviations of 0.123 and 0.109. This indicates considerable variation in the geopolitical risk, weighted by overseas business volume, from the countries of both clients and suppliers across firms, with the risk from customer countries being greater than that from supplier countries.

Table 4.1. Descriptive statistics

	(1) N	(2) Mean	(3) Standard deviation	(4) Minimum	(5) Maximum
OPUbeta	28,605	0.040	0.043	0.000	0.171
GPRC	28,605	0.035	0.123	0.000	1.172
GPRS	28,605	0.026	0.109	0.000	1.166
Patent	28,605	0.396	0.764	0.000	6.608
Invention	28,605	0.135	0.425	0.000	5.602
Utility	28,605	0.329	0.690	0.000	6.155
Citation	28,605	0.040	0.302	0.000	6.489
CInvention	28,605	0.033	0.259	0.000	5.485
CUtility	28,605	0.026	0.216	0.000	6.163
F.Patent	26,901	0.456	0.811	0.000	6.609

F.Invention	26,901	0.150	0.447	0.000	5.545
F.Utility	26,901	0.383	0.738	0.000	6.188
F.Citation	26,901	0.054	0.355	0.000	6.295
F.CInvention	26,901	0.043	0.300	0.000	5.981
F.CUtility	26,901	0.032	0.243	0.000	5.765
MTB	28,605	0.629	0.246	0.001	1.463
Growth	28,605	0.118	0.280	-0.557	0.989
ROA	28,605	0.065	0.128	-0.495	0.360
Size	28,605	22.030	1.241	19.860	25.620
Lev	28,605	0.453	0.207	0.053	0.878
Cash	28,605	0.152	0.121	0.013	0.631
RDSales	28,605	0.003	0.011	0.000	0.076
Board	28,605	2.151	0.200	1.609	2.708
Indep	28,605	0.372	0.052	0.333	0.571
Big4/10	28,605	0.480	0.500	0.000	1.000
Top1	28,605	0.353	0.149	0.096	0.742
SOE	28,605	0.439	0.496	0.000	1.000

This table reports the descriptive statistics of the main variables used in the study. The sample consists of firms listed on the SHSE and SZSE from 2006 to 2016. The total sample includes 28,605 observations. Detailed definitions of variables are presented in Appendix A.

Appendix D provides the correlation matrix for the main variables used in our analysis. The correlation coefficients between the independent variables are relatively small, suggesting that multicollinearity is not a serious issue in this study.

4.4.2. Firm OPU exposure, geopolitical tensions and firm green innovation

4.4.2.1. Baseline results

Table 4.2 presents the baseline results of the impact of OPU sensitivity on green innovation output and quality during times of geopolitical tensions, based on Equation (5). The coefficients of *OPUbeta* in Columns (1) and (2) are both positive and statistically significant at the 1% level. This indicates that a firm's sensitivity to oil price uncertainty positively influences both its green innovation output and quality. The economic significance of the coefficients for *OPUbeta* in Columns (1) and (2) indicates that a one standard deviation increase in a firm's OPU exposure is associated with an 8.699% increase in green innovation output and a 34.728% improvement in green innovation quality.

In Columns (3) through (6), the coefficients of *OPUbeta* remain significantly positive at the 5% level. The interaction terms *OPUbeta*GPRC* and *OPUbeta*GPRS* are significantly positive at the 1% level, indicating that during geopolitical tensions, firms sensitive to OPU tend to adopt strategies that enhance green innovation. This finding is consistent with the strategic growth theory, suggesting that firms increase investments to seek alternatives when facing risks.

Geopolitical crises transmitted through supply chains may have different impacts depending on whether they originate from suppliers or customers. Comparing the results in Columns (3) and (4) with those in Columns (5) and (6) of Table 4.2 reveals that the coefficients of *GPRC*OPUbeta* are smaller than those of *GPRS*OPUbeta*. This indicates that firms sensitive to oil price uncertainty are more inclined to enhance their innovation levels when geopolitical risks affect their supplier countries, compared to when such risks impact their customer countries. This finding is consistent with the results of Brutschin and Fleig (2018), which show that conflicts involving major supplier nations may drive import-dependent economies to invest more in new technologies, such as increasing research and development expenditures on biofuels, to mitigate the risks of supply disruptions.

Table 4.2. Impact of OPUBeta on firm green innovation in times of geopolitical tensions

	(1)	(2)	(3)	(4)	(5)	(6)
	F. Patent	*F.Citation*	*F. Patent*	*F. Citation*	*F. Patent*	*F.Citation*
OPUbeta	1.794***	0.469***	1.689***	0.187**	1.691***	0.306***
	(7.517)	(4.146)	(7.006)	(1.942)	(7.059)	(2.677)
GPRC			-0.153***	-0.108***		
			(-3.557)	(-3.751)		
*OPUbeta*GPRC*			3.045***	7.728***		
			(2.647)	(6.847)		
GPRS					-0.314***	-0.176***
					(-5.995)	(-4.788)
*OPUbeta*GPRS*					4.759***	9.350***
					(2.798)	(5.501)
MTB	-0.005	0.002	-0.004	-0.004	-0.004	0.000
	(-0.119)	(0.136)	(-0.091)	(-0.232)	(-0.093)	(0.010)
Growth	0.013	0.007	0.013	0.006	0.013	0.005
	(0.829)	(0.907)	(0.799)	(0.771)	(0.816)	(0.664)
ROA	0.132***	0.039**	0.131***	0.035**	0.133***	0.039**
	(2.884)	(2.223)	(2.852)	(2.021)	(2.894)	(2.238)
Size	0.227***	0.028***	0.227***	0.030***	0.227***	0.028***
	(19.409)	(6.617)	(19.424)	(7.219)	(19.468)	(6.741)
Lev	0.095**	0.023	0.094**	0.030	0.092**	0.027
	(2.040)	(1.225)	(2.026)	(1.597)	(1.993)	(1.449)
Cash	0.008	0.006	0.008	0.009	0.010	0.008

	(0.142)	(0.247)	(0.143)	(0.371)	(0.179)	(0.337)
RDSales	2.960***	0.678*	2.955***	0.709*	2.979***	0.655*
	(3.556)	(1.760)	(3.552)	(1.858)	(3.582)	(1.739)
Board	0.070	0.034	0.070	0.030	0.071	0.033
	(1.357)	(1.578)	(1.367)	(1.440)	(1.390)	(1.574)
Indep	0.200	0.085	0.200	0.078	0.202	0.084
	(1.096)	(1.086)	(1.099)	(1.002)	(1.111)	(1.082)
Big4/10	0.004	0.002	0.004	0.001	0.003	0.001
	(0.233)	(0.260)	(0.241)	(0.149)	(0.226)	(0.244)
Top1	-0.100*	0.026	-0.100*	0.018	-0.100*	0.022
	(-1.669)	(0.985)	(-1.673)	(0.683)	(-1.680)	(0.844)
SOE	0.027	-0.004	0.027	-0.001	0.026	-0.002
	(1.292)	(-0.557)	(1.309)	(-0.158)	(1.279)	(-0.225)
Constant	-4.870***	-0.706***	-4.868***	-0.744***	-4.873***	-0.712***
	(-18.125)	(-6.592)	(-18.133)	(-6.964)	(-18.157)	(-6.713)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,901	26,901	26,901	26,901	26,901	26,901
Adjusted R^2	0.313	0.074	0.313	0.083	0.314	0.081

This table presents the impact of *OPUbeta* on firm green innovation productivity and quality, and the effect of geopolitical tensions. Column (1) and (2) reports the regression result between *OPUbeta* and one-year forward *Patent* and *Citation*, respectively. Columns (3) and (4) show the amplifyting effects of geopolitical tensions from customer countries, while Columns (5) and (6) display the amplifying effects of s geopolitical tensions from supplier countries, both on one-year forward *Patent* and *Citation*. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

To ensure the robustness of our baseline regression results, we incorporate firm and year fixed effects to account for potential confounding factors within the dataset. Specifically, Table 4.3 presents the results of the baseline regression model with the inclusion of firm and year fixed effects. This adjustment addresses unobserved firm-specific and time-varying characteristics that might otherwise introduce bias into the analysis, enhancing the reliability of the findings.

Table 4.3. Robustness test: Controlling for firm-year fixed effects

	(1)	(2)	(3)	(4)	(5)	(6)
	F. Patent	*F.Citation*	*F. Patent*	*F. Citation*	*F. Patent*	*F.Citation*
OPUbeta	0.345*	0.469***	1.689***	0.187*	1.691***	0.306***
	(1.680)	(4.146)	(7.006)	(1.728)	(7.059)	(2.677)
GPRC			-0.153***	-0.108***		
			(-3.557)	(-3.751)		
*OPUbeta*GPRC*			3.045***	7.728***		
			(2.647)	(6.847)		
GPRS					-0.314***	-0.176***
					(-5.995)	(-4.788)

*OPUbeta*GPRS*					4.759***	9.350***
					(2.798)	(5.501)
MTB	0.063	0.002	-0.004	-0.004	-0.004	0.000
	(1.619)	(0.136)	(-0.091)	(-0.232)	(-0.093)	(0.010)
Growth	-0.011	0.007	0.013	0.006	0.013	0.005
	(-0.822)	(0.907)	(0.799)	(0.771)	(0.816)	(0.664)
ROA	0.063*	0.039**	0.131***	0.035**	0.133***	0.039**
	(1.661)	(2.223)	(2.852)	(2.021)	(2.894)	(2.238)
Size	0.183***	0.028***	0.227***	0.030***	0.227***	0.028***
	(11.351)	(6.617)	(19.424)	(7.219)	(19.468)	(6.741)
Lev	-0.029	0.023	0.094**	0.030	0.092**	0.027
	(-0.562)	(1.225)	(2.026)	(1.597)	(1.993)	(1.449)
Cash	-0.060	0.006	0.008	0.009	0.010	0.008
	(-1.149)	(0.247)	(0.143)	(0.371)	(0.179)	(0.337)
RDSales	1.658*	0.678*	2.955***	0.709*	2.979***	0.655*
	(1.808)	(1.760)	(3.552)	(1.858)	(3.582)	(1.739)
Board	-0.038	0.034	0.070	0.030	0.071	0.033
	(-0.741)	(1.578)	(1.367)	(1.440)	(1.390)	(1.574)
Indep	0.004	0.085	0.200	0.078	0.202	0.084
	(0.025)	(1.086)	(1.099)	(1.002)	(1.111)	(1.082)
Big4/10	-0.008	0.002	0.004	0.001	0.003	0.001
	(-0.600)	(0.260)	(0.241)	(0.149)	(0.226)	(0.244)
Top1	-0.257***	0.026	-0.100*	0.018	-0.100*	0.022
	(-2.730)	(0.985)	(-1.673)	(0.683)	(-1.680)	(0.844)
SOE	0.081**	-0.004	0.027	-0.001	0.026	-0.002
	(2.179)	(-0.557)	(1.309)	(-0.158)	(1.279)	(-0.225)
Constant	-3.482***	-0.706***	-4.868***	-0.744***	-4.873***	-0.712***
	(-9.690)	(-6.592)	(-18.133)	(-6.964)	(-18.157)	(-6.713)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,901	26,901	26,901	26,901	26,901	26,901
Adjusted R^2	0.606	0.074	0.313	0.083	0.314	0.081

This table replicates the baseline regression from Table 4.2, substituting firm-year fixed effects for the original fixed effects model. The key outcome variables and control variables remain consistent with those in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

In our baseline regression, we initially included both firms with and without foreign customers or suppliers in the sample. However, to eliminate potential bias or noise introduced by firms without any foreign trade activities, we restricted the sample to firms engaged in foreign trade (i.e., those with foreign customers or suppliers). The regression results for this subsample are presented in Table 4.4. As shown, the baseline regression results remain consistent and statistically significant within the subsample, indicating the robustness of our findings.

Table 4.4. Robustness test: Sample of foreign trade firms

	(1)	(2)	(3)	(4)	(5)	(6)
	F. Patent	*F.Citation*	*F. Patent*	*F. Citation*	*F. Patent*	*F.Citation*
OPUbeta	1.557***	1.795***	1.179***	2.038***	1.212***	1.755***
	(4.370)	(6.143)	(3.077)	(6.194)	(3.291)	(5.578)
GPRC			-0.234***	-0.083**		
			(-5.340)	(-2.121)		
*OPUbeta*GPRC*			3.125**	2.245**		
			(2.507)	(1.955)		
GPRS					-0.361***	-0.107**
					(-6.559)	(-2.383)
*OPUbeta*GPRS*					4.310**	0.197**
					(2.383)	(1.914)
MTB	0.046	0.061	0.049	0.061	0.041	0.059
	(0.671)	(1.031)	(0.708)	(1.043)	(0.595)	(0.998)
Growth	0.115***	-0.016	0.114***	-0.016	0.116***	-0.014
	(2.728)	(-0.412)	(2.710)	(-0.406)	(2.752)	(-0.367)
ROA	0.202**	0.157*	0.196*	0.160*	0.212**	0.159*
	(1.993)	(1.847)	(1.943)	(1.879)	(2.103)	(1.866)
Size	0.237***	0.157***	0.235***	0.156***	0.238***	0.158***
	(10.244)	(9.215)	(10.141)	(9.175)	(10.428)	(9.279)
Lev	0.167*	0.188**	0.164*	0.189**	0.163*	0.186**
	(1.918)	(2.495)	(1.879)	(2.505)	(1.887)	(2.467)
Cash	0.044	0.099	0.037	0.099	0.046	0.099
	(0.430)	(1.186)	(0.364)	(1.191)	(0.457)	(1.187)
RDSales	3.650***	3.311***	3.600***	3.315***	3.771***	3.385***
	(2.854)	(2.828)	(2.808)	(2.831)	(2.957)	(2.884)
Board	0.182**	0.136*	0.182**	0.137*	0.182**	0.136*
	(2.107)	(1.923)	(2.105)	(1.940)	(2.126)	(1.932)
Indep	0.348	0.343	0.358	0.345	0.362	0.350
	(1.153)	(1.347)	(1.185)	(1.353)	(1.206)	(1.377)
Big4/10	0.022	-0.004	0.024	-0.004	0.022	-0.004
	(0.888)	(-0.168)	(0.957)	(-0.178)	(0.868)	(-0.188)
Top1	0.006	0.014	0.005	0.016	-0.001	0.012
	(0.056)	(0.157)	(0.055)	(0.177)	(-0.009)	(0.138)
SOE	-0.005	0.024	-0.006	0.024	-0.006	0.023
	(-0.145)	(0.870)	(-0.164)	(0.880)	(-0.175)	(0.829)
Constant	-5.455***	-3.866***	-5.379***	-3.864***	-5.452***	-3.869***
	(-10.403)	(-9.366)	(-10.283)	(-9.360)	(-10.491)	(-9.393)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,274	7,274	7,274	7,274	7,274	7,274
Adjusted R^2	0.271	0.198	0.272	0.198	0.275	0.199

This table presents the baseline regression using only the sample of firms with foreign customers or suppliers. Variables are the same as in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Furthermore, we explore the impact of OPU exposure and geopolitical tensions on the output and quality of different types of patents produced by firms. The results are presented in

Table 4.5. Panel A of Table 4.5 displays the effects of *OPUbeta*, *GPRC*, and *GPRS* on green invention patents and utility model patents, while Panel B highlights the impact of *OPUbeta* on the quality of these patents, e.g., citation of the patents.

The results reveal that the effects of *OPUbeta*GPRC* and *OPUbeta*GPRS* on invention patents are lower than their effects on utility model patents. However, the influence on the quality of invention patents is significantly higher than that of utility model patents. This suggests that while geopolitical tensions and OPU exposure may stimulate a greater quantity of utility model patents due to their relatively lower development costs and shorter innovation cycles, firms prioritize the development of higher-quality invention patents when addressing long-term strategic goals and uncertainties.

Table 4.5. Impact of OPU exposure and geopolitical tensions on green invention and utility patents

Panel A. Impact on green innovation productivity

	(1)	(2)	(3)	(4)	(5)	(6)
	F.Invention	*F.Utility*	*F.Invention*	*F.Utility*	*F.Invention*	*F.Utility*
OPUbeta	0.734***	1.602***	0.683***	1.529***	0.682***	1.518***
	(5.409)	(7.471)	(5.017)	(7.037)	(4.938)	(7.073)
GPRC			-0.059***	-0.115***		
			(-2.588)	(-2.952)		
*OPUbeta*GPRC*			1.465**	2.126**		
			(2.075)	(2.014)		
GPRS					-0.162***	-0.237***
					(-5.856)	(-4.989)
*OPUbeta*GPRS*					2.395**	4.021***
					(2.127)	(2.596)
MTB	-0.040*	0.031	-0.040*	0.032	-0.039*	0.032
	(-1.856)	(0.831)	(-1.853)	(0.858)	(-1.832)	(0.848)
Growth	-0.018*	0.018	-0.018*	0.018	-0.018*	0.018
	(-1.858)	(1.203)	(-1.882)	(1.181)	(-1.871)	(1.184)
ROA	0.004	0.163***	0.004	0.162***	0.004	0.163***
	(0.158)	(3.897)	(0.132)	(3.872)	(0.166)	(3.906)
Size	0.108***	0.188***	0.108***	0.188***	0.108***	0.188***
	(15.395)	(17.695)	(15.429)	(17.694)	(15.434)	(17.737)
Lev	0.017	0.113***	0.017	0.112***	0.016	0.111***
	(0.670)	(2.726)	(0.675)	(2.708)	(0.622)	(2.696)
Cash	0.077**	-0.012	0.077**	-0.012	0.078**	-0.011
	(2.312)	(-0.242)	(2.318)	(-0.243)	(2.347)	(-0.209)
RDSales	2.672***	1.621**	2.672***	1.616**	2.683***	1.633**
	(4.622)	(2.269)	(4.623)	(2.265)	(4.640)	(2.287)
Board	0.069**	0.044	0.069**	0.044	0.069**	0.045
	(2.314)	(0.951)	(2.314)	(0.961)	(2.345)	(0.977)
Indep	0.331***	0.115	0.331***	0.115	0.332***	0.117
	(3.270)	(0.682)	(3.268)	(0.685)	(3.286)	(0.692)

Big4/10	0.012	-0.004	0.012	-0.004	0.011	-0.004
	(1.369)	(-0.276)	(1.370)	(-0.268)	(1.363)	(-0.282)
Top1	-0.048	-0.080	-0.048	-0.080	-0.048	-0.081
	(-1.413)	(-1.492)	(-1.427)	(-1.490)	(-1.422)	(-1.505)
SOE	0.024**	0.018	0.024**	0.018	0.024**	0.018
	(2.064)	(0.987)	(2.089)	(0.997)	(2.046)	(0.987)
Constant	-2.530***	-4.018***	-2.531***	-4.016***	-2.532***	-4.021***
	(-14.590)	(-16.559)	(-14.612)	(-16.562)	(-14.611)	(-16.582)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,901	26,901	26,901	26,901	26,901	26,901
Adjusted R^2	0.178	0.283	0.178	0.283	0.179	0.283

Panel B Impact on green innovation quality

	(1) *F.CInvention*	(2) *F.CUtility*	(3) *F.CInvention*	(4) *F.CUtility*	(5) *F.CInvention*	(6) *F.CUtility*
OPUbeta	0.375***	0.324***	0.180*	0.139**	0.248**	0.234***
	(3.438)	(4.442)	(1.776)	(1.972)	(2.246)	(3.163)
GPRC			-0.041	-0.060***		
			(-1.255)	(-3.097)		
*OPUbeta*GPRC*			5.328***	5.059***		
			(5.613)	(6.870)		
GPRS					-0.130***	-0.119***
					(-4.170)	(-4.885)
OPUbeta GPRS					7.371***	5.064***
					(5.191)	(4.369)
MTB	0.009	0.003	0.004	-0.001	0.008	0.003
	(0.753)	(0.323)	(0.364)	(-0.055)	(0.624)	(0.245)
Growth	0.009	0.000	0.009	-0.000	0.008	-0.001
	(1.419)	(0.072)	(1.311)	(-0.064)	(1.194)	(-0.109)
ROA	0.027**	0.036***	0.024*	0.033***	0.027**	0.035***
	(1.965)	(2.981)	(1.783)	(2.799)	(1.979)	(2.992)
Size	0.019***	0.016***	0.021***	0.018***	0.020***	0.016***
	(5.833)	(5.153)	(6.411)	(5.731)	(5.953)	(5.228)
Lev	0.010	0.031**	0.016	0.036***	0.014	0.033***
	(0.643)	(2.470)	(1.018)	(2.848)	(0.865)	(2.611)
Cash	0.018	0.012	0.021	0.014	0.020	0.013
	(0.763)	(0.725)	(0.869)	(0.860)	(0.836)	(0.807)
RDSales	0.794**	0.256	0.821**	0.278	0.774**	0.247
	(2.392)	(1.094)	(2.492)	(1.201)	(2.386)	(1.058)
Board	0.031*	0.024	0.028*	0.021	0.030*	0.024
	(1.836)	(1.590)	(1.685)	(1.450)	(1.834)	(1.594)
Indep	0.044	0.055	0.038	0.050	0.043	0.055
	(0.736)	(0.968)	(0.639)	(0.884)	(0.727)	(0.969)
Big4/10	0.002	0.004	0.002	0.004	0.002	0.004
	(0.405)	(1.049)	(0.293)	(0.935)	(0.392)	(1.037)
Top1	0.020	0.025	0.014	0.020	0.017	0.023
	(0.910)	(1.460)	(0.629)	(1.147)	(0.774)	(1.357)
SOE	-0.004	-0.004	-0.002	-0.002	-0.002	-0.003
	(-0.610)	(-0.822)	(-0.253)	(-0.432)	(-0.296)	(-0.590)
Constant	-0.506***	-0.437***	-0.537***	-0.463***	-0.511***	-0.440***
	(-6.136)	(-5.480)	(-6.525)	(-5.833)	(-6.257)	(-5.551)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Observations	26,901	26,901	26,901	26,901	26,901	26,901
Adjusted R^2	0.061	0.059	0.069	0.068	0.068	0.064

This table presents the impact of *OPUbeta* and geopolitical risks from suppliers/customers on the quantity and quality of different types of green innovation. In Panel A, the primary outcome variables are the forward one-period natural logarithm of the number of invention patents and utility model patents. Panel B displays the forward one-period natural logarithm of citations for invention patents and the count of utility model patents. The independent and control variables align with those in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

This study initially assumes a linear relationship between OPU exposure and corporate green innovation. However, the effect may be nonlinear. For instance, Henriques and Sadorsky (2011) find that at low levels of OPU, firms tend to be cautious and may postpone green investments due to heightened risk aversion and uncertainty. In contrast, at higher levels of OPU, firms may actively engage in green innovation as a strategic response to mitigate future risks and improve long-term resilience. To explore this possibility, we introduce a squared term of OPU exposure (OPUbeta2) into the baseline regression to capture potential nonlinear effects. The results, reported in Appendix E (columns 1 and 2), show that the coefficient on OPUbeta2 is statistically insignificant. This indicates that the relationship between OPU exposure and green innovation does not exhibit a clear nonlinear pattern in our sample.

4.4.3. Impacts of supply chain perspectives

While we find that external shocks such as OPU exposure and geopolitical risks directly influence firms' innovation strategies, the role of supply chain structures in mediating these effects remains underexplored. Supply chain dynamics, particularly their ability to absorb or amplify external uncertainties, may critically shape firms' green innovation responses. Investigating this perspective provides a foundation for understanding the mechanisms through which firms navigate complex external pressures and adjust their innovation strategies accordingly.

4.4.3.1. Domestic supply chain strategic alliances

Our findings suggest that oil price volatility and geopolitical conflicts create substantial external challenges for firms, which in turn appear to encourage increased investments in green innovation. These external dynamics likely prompt firms to explore alternative energy sources and sustainable development strategies as a means of mitigating risks associated with volatile market conditions. The enhancement of domestic supply chain alliances and supply chain efficiency may act as an effective risk-buffering mechanism in the context of such external pressures. Strategic alliances can improve supply chain resilience and collaboration between suppliers and customers, enhancing organizational entrepreneurship and shaping strategic collaboration networks (Philsoophian et al., 2021). Highly integrated supply chain alliances enhance firms' operational stability and bargaining power. (Monczka et al., 1998). Hsieh et al. (2018) emphasize that domestic supply chain collaborations not only support resource acquisition in domestic markets but also facilitate cooperation with international supply chains, expanding firms' potential for innovation. Based on this, we conjecture that domestic supply chain alliances can provide flexibility for innovation investments and mitigate the impact of geopolitical risks and oil price uncertainty.

To examine the role of domestic supply chain alliances in our baseline regression, we introduce a new variable, *Alliance*, which represents the natural logarithm of the number of domestic supply chain strategic partnerships established by a firm. This variable is incorporated into the baseline regression model along with interaction terms *OPUbeta* GPRC*Alliance* and *OPUbeta*GPRS*Alliance*. The regression results, presented in Table 4.6, indicate that the interaction terms among oil price volatility, geopolitical risks, and domestic supply chain alliances are negatively associated with green innovation at the 1% significance level. This suggests that while domestic supply chain alliances provide firms with stability and risk mitigation, they may simultaneously reduce the urgency for green innovation by alleviating external pressures. Firms relying on domestic alliances may perceive less immediate need to invest in innovation as a strategic response to supply chain disruptions, instead opting to capitalize on the stability provided by these partnerships. This finding highlights the complex interplay between external shocks, supply chain structures, and corporate innovation strategies, underscoring the need for balanced approaches that leverage supply chain stability without undermining innovation momentum.

Table 4.6. The impact of domestic supply chain alliances

	(1)	(2)	(3)	(4)
	F. Patent	*F. Citation*	*F. Patent*	*F.Citation*
OPUbeta	1.685***	0.188*	1.687***	0.306***
	(6.990)	(1.732)	(7.043)	(2.677)
GPRC	-0.154***	-0.108***		
	(-3.571)	(-3.750)		
*OPUbeta*GPRC*	3.063***	7.729***		
	(2.663)	(6.847)		
*OPUbeta*GPRC*Alliance*	-2.845***	-1.083**		
	(-5.404)	(-1.976)		
GPRS			-0.317***	-0.178***
			(-6.039)	(-4.813)
*OPUbeta*GPRS*			4.870***	9.411***
			(2.859)	(5.523)
*OPUbeta*GPRS*Alliance*			-2.051***	-1.104***
			(-7.199)	(-7.455)
Alliance	0.009**	-0.001**	0.010**	-0.001*
	(2.226)	(-1.991)	(2.279)	(-1.833)
Constant	-4.862***	-0.744***	-4.866***	-0.712***
	(-18.097)	(-6.966)	(-18.116)	(-6.710)
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	26,901	26,901	26,901	26,901
Adjusted R^2	0.313	0.083	0.314	0.081

This table examines the moderating effect of firms' domestic supply chain alliances on the impact of *OPUbeta* and geopolitical factors on green innovation. *Alliance* represents the natural logarithm of the number of suppliers/customers with whom the firm has established strategic partnerships domestically. Control variables are consistent with those in Table 4.2. Control variables are consistent with those used in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

4.4.3.2. Supply chain efficiency

While the primary goal of supply chain efficiency is often to enhance the utilization of existing resources, it also enables firms to adapt flexibly to external challenges in highly uncertain environments. Kamalahmadi et al. (2022) emphasizes that supply chain efficiency, by optimizing resource utilization and streamlining operations, enhances firms' ability to withstand disruptions and minimize costs. Although such resource integration may reduce the immediacy of innovation pressures, it concurrently provides stable financial and resource support for long-term innovation investments during crises. This stability allows firms to allocate resources more rationally, focusing their innovation efforts on strategic, long-term projects such as green innovation. Wiengarten et al. (2016) further demonstrate that higher supply chain integration and efficiency can incline firms toward maintaining their existing operational models.

To explore the moderating effect of supply chain efficiency on our baseline regression, following Kwak (2019), we introduce *Efficiency*, measured as the natural logarithm of 365 divided by a firm's inventory turnover ratio. We include the interaction terms *OPUbeta*GPRC *Efficiency* and *OPUbeta*GPRS*Efficiency* in the baseline regression model. The results, presented in Table 4.7, reveal that supply chain efficiency negatively moderates the combined effects of oil price uncertainty and geopolitical risks on green innovation. These findings suggest that while high supply chain efficiency provides firms with operational stability and cost advantages, it may reduce their incentive to pursue green innovation as an immediate response to external pressures. This could be attributed to the fact that highly efficient supply chains focus on short-term cost optimization and resource utilization, which may divert attention from long-term strategic innovation investments. However, this stability can still offer firms the flexibility to invest in green innovation initiatives, underscoring the complex interplay between operational efficiency and corporate innovation under external uncertainty.

Table 4.7. The impact of supply chain efficiency

	(1)	(2)	(3)	(4)
	F. Patent	*F. Citation*	*F. Patent*	*F.Citation*
OPUbeta	1.690***	0.190*	1.684***	0.295***
	(6.998)	(1.751)	(7.018)	(2.580)
GPRC	-0.148***	-0.101***		
	(-3.464)	(-3.560)		
*OPUbeta*GPRC*	12.077**	23.356***		
	(2.214)	(3.983)		

*OPUbeta*GPRC*Efficiency*	-1.925*	-3.341***		
	(-1.772)	(-2.899)		
GPRS			-0.318***	-0.183***
			(-6.050)	(-4.936)
*OPUbeta*GPRS*			16.532***	27.128***
			(2.729)	(4.796)
*OPUbeta*GPRS*Efficiency*			-2.487**	-3.759***
			(-2.127)	(-3.599)
Efficiency	-0.020***	-0.003**	-0.020***	-0.003*
	(-3.236)	(-2.010)	(-3.223)	(-1.890)
Constant	-4.754***	-0.721***	-4.761***	-0.693***
	(-17.619)	(-6.800)	(-17.632)	(-6.557)
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	26,901	26,901	26,901	26,901
Adjusted R^2	0.314	0.085	0.315	0.083

This table investigates the moderating effect of firms' supply chain efficiency on the impact of *OPUbeta* and geopolitical factors on green innovation. *Efficiency* is defined as the natural logarithm of 365/firm's inventory turnover ratio. Control variables are consistent with those used in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

4.4.4. Motivation behind firms' adoption of green innovation strategies

4.4.4.1. The dependence on international markets

We then analyze the motivations behind firms' adoption of green innovation strategies. Geopolitical risks differ from other macroeconomic uncertainties caused by government policies and domestic business environments, as it focuses more on international conflicts and political tensions. Existing research (e.g., Roberts et al., 2019) indicates that such risks often have a significant impact on international trade. Compared to the relatively stable domestic market, international markets are particularly vulnerable to geopolitical tensions, leading to increased fragility in global supply chains and market demand. Therefore, for firms with a higher proportion of international business, facing high OPU and geopolitical risks from supply chain countries, they are more likely to adopt green innovation as a strategy to mitigate these external shocks. Firms with a higher proportion of international business are more dependent on global markets and international supply chains, which significantly increases their risk exposure when dealing with oil price fluctuations and geopolitical risks (Minetti et al., 2019). Particularly for firms highly sensitive to OPU, geopolitical tensions can further exacerbate cost uncertainty, transmitting through global supply chains to impact firm operations. This dual uncertainty makes firms with higher international business exposure more reliant on innovation strategies, especially green innovation, to reduce dependence on fossil fuels and mitigate the impact of energy cost volatility on their global operations.

To test this conjecture, we divide the sample firms into two groups based on the median of their international business proportion: firms with a higher proportion of international business than the median and those with a lower proportion. The estimation results in Table 4.8 show that the impact of *OPUbeta* and geopolitical tensions is more pronounced for firms with a higher proportion of international business. This result suggests that, when faced with high OPU and geopolitical risk, firms with significant international business are more likely to increase their investment in green innovation to reduce uncertainty in their global operations and maintain competitiveness.

Table 4.8. Reliance on overseas business

	High international business				Low international business			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	F. Patent	*F.Patent*	*F.Citation*	*F.Citation*	*F.Patent*	*F.Patent*	*F.Citation*	*F.Citation*
*OPUbeta*GPRC*	2.226**		6.481***		1.521		4.619	
	(1.943)		(5.222)		(0.611)		(1.372)	
*OPUbeta*GPRS*		2.365**		7.248***		8.101		10.846
		(2.134)		(3.493)		(0.871)		(0.729)
Constant	-6.141***	-6.133***	-1.101***	-1.048***	-3.386***	-3.393***	-0.253***	-0.247***
	(-15.734)	(-15.697)	(-6.136)	(-5.831)	(-10.930)	(-10.960)	(-3.010)	(-2.978)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,816	13,816	13,816	13,816	13,085	13,085	13,085	13,085
Adjusted R^2	0.338	0.338	0.107	0.105	0.284	0.285	0.033	0.046

This table shows the analysis with the sample split into two groups based on the median percentage of overseas revenue in total revenue. The control variables are the same as in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

4.4.4.2. Government subsidies

The amount of government subsidies a firm receives is often closely related to its political connections (Tao et al., 2017). Firms with strong political ties tend to secure more government support, including financial subsidies and tax incentives (Jiang et al., 2018). Such subsidies might reduce the pressure on firms to innovate, as financial support allows them to sustain their existing operations without needing to engage in risky innovative ventures (Li et al., 2021). In contrast, firms that receive fewer government subsidies may lack this political backing and protection, and therefore do not have the additional resources to maintain the status quo. Faced with the pressures of both high OPU beta and geopolitical tensions, these low-subsidized firms often have a greater need to enhance their competitiveness and market adaptability through green innovation. For these firms, innovation is not only a crucial tool for responding to external uncertainties but also a strategic choice to strengthen long-term competitiveness.

To test this conjecture, we group the sample firms based on the level of government subsidies they receive and analyze the green innovation of high- and low-subsidized firms. The results, presented in Table 4.9, show that the low-subsidized subgroup significantly promote green innovation when having high OPU beta and geopolitical risks. This finding suggests that for firms with less government support, external environmental uncertainty is more likely to enhance their innovation capabilities to cope with challenges and changes.

Table 4.9. Government subsidies

	Low subsidies				High subsidies			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	F. Patent	*F.Patent*	*F.Citation*	*F.Citation*	*F.Patent*	*F.Patent*	*F.Citation*	*F.Citation*
*OPUbeta*GPRC*	0.264***		1.060***		4.393		10.446	
	(3.132)		(2.908)		(0.167)		(0.230)	
*OPUbeta*GPRS*		0.270***		1.555***		5.284		10.663
		(3.717)		(3.220)		(0.117)		(1.501)
Constant	-2.933***	-2.953***	-0.366***	-0.355***	-5.050***	-5.051***	-0.747***	-0.713***
	(-7.137)	(-7.191)	(-2.883)	(-2.784)	(-17.451)	(-17.457)	(-6.265)	(-5.990)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,349	5,349	5,349	5,349	21,552	21,552	21,552	21,552
Adjusted R^2	0.197	0.198	0.035	0.035	0.331	0.331	0.095	0.090

This table divides the sample into high government subsidies and low subsidies sub-samples based on the median value of log total government subsidies. The control variables are the same as in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

4.4.4.3. Competitive pressure

Competitive pressure typically arises from intense competition among firms, especially in resource-constrained industries and highly saturated markets (Giachetti, 2016). When facing strong competition, firms often need to continuously improve product quality, reduce costs, and enhance operational efficiency to maintain their market position (Di Dio & Correani, 2020). However, in the context of increasing OPU exposure and geopolitical risks, the external environment becomes more complex and unpredictable. This uncertainty not only impacts a firm's operating costs and market demand but can also influences its overall strategic layout through the supply chain (Cao et al., 2020; Roscoe et al., 2020). In such a scenario, firms facing higher competitive pressure may be more inclined to pursue green innovation as a means of gaining a new competitive edge. Green innovation can help firms reduce their dependence on fossil fuels, mitigate the negative effects of energy cost volatility on production and operations, and enhance their sustainable development image, meeting the growing demand from consumers and investors for environmentally friendly products and services (Wurlod & Noailly, 2018). Thus, we hypothesize that in highly competitive environments, firms with a high OPU beta and exposure to geopolitical risks will be more incentivized to engage in green innovation.

To test this conjecture, we group the sample firms based on the median of the Herfindahl Index to distinguish between high and low competitive pressure environments. We then analyze the impact of OPU beta and geopolitical risks on green innovation under these conditions. The results, presented in Table 4.10, show that in highly competitive environments, the interaction of OPU beta and geopolitical risks significantly promote green innovation.

Table 4.10. Impact of competitive pressure

	High competition				Low competition			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	F. Patent	*F.Patent*	*F.Citation*	*F.Citation*	*F.Patent*	*F.Patent*	*F.Citation*	*F.Citation*
*OPUbeta*GPRC*	1.993		4.999***		3.615		9.826	
	(1.309)		(3.600)		(1.207)		(0.709)	
*OPUbeta*GPRS*		2.298***		8.917***		4.180		10.744
		(2.871)		(3.618)		(1.008)		(1.218)
Constant	-5.508***	-5.529***	-0.743***	-0.730***	-4.362***	-4.359***	-0.740***	-0.693***
	(-14.133)	(-14.185)	(-5.067)	(-5.031)	(-13.417)	(-13.406)	(-4.867)	(-4.528)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,584	13,584	13,584	13,584	13,317	13,317	13,317	13,317
Adjusted R^2	0.338	0.339	0.067	0.071	0.310	0.310	0.098	0.091

This table divides the sample into high competition and low competition sub-samples based on the median value of Herfindahl-Hirschman Index (HHI). The control variables are the same as in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

4.5. Additional robustness tests

In the original baseline regression, we analyze the impact of OPU and geopolitical risks on firms' green innovation using panel data. While this approach captures key characteristics at the firm level, it may introduce sample selection bias or omitted variable issues in the statistical analysis. For instance, the differences arising from customers or suppliers from difference countries may not be fully accounted for in the baseline sample.

To address this concern and enhance the robustness of our results, we re-estimate Equation (5) using paired samples including supplier country-firm pairs and customer country-firm pairs. We control for pair fixed effects between firms and countries, as well as industry and year fixed effects. We construct firm-customer and firm-supplier country pair-level geopolitical risk indices, *GPRCustomer* and *GPRSupplier*, based on the countries where firms' suppliers and customers come from. The results, presented in Appendix B, are consistent with those of the baseline regression. This finding indicates that the positive impact of OPU and geopolitical risks on firms' green innovation remains significant, whether considering the supplier or customer country samples. This strengthens the robustness of our findings.

Additionally, following the methodology of Li (2017), we use a 36-month rolling window to compute *OPUbeta2* as an alternative measure of OPU exposure. The regression results are presented in Appendix C. In columns (1) and (2), the coefficients of *OPUbeta2* are positive and statistically significant at conventional levels, indicating a robust relationship. Furthermore, in columns (4) through (6), the interaction terms *OPUbeta2* × *GPRC* and *OPUbeta2* × *GPRS* also exhibit positive and statistically significant coefficients at conventional levels, underscoring the amplifying effects of geopolitical risk on OPU exposure.

4.5. Conclusion

This study examines the impact of OPU exposure, geopolitical risks, and their interaction on corporate green innovation, providing novel insights into how firms respond strategically to external uncertainties. Our findings demonstrate that firms with greater sensitivity to oil price uncertainty are more likely to increase investments in green innovation, particularly during periods of intensified geopolitical tensions. The amplifying effect of geopolitical risk is more pronounced when tensions originate from supplier countries, highlighting the role of supply chain vulnerabilities in shaping corporate innovation strategies.

Additionally, we observe a negative moderating effect of domestic supply chain alliances and supply chain efficiency on our baseline results. While domestic supply chain alliances and supply chain efficiency provide stability and operational resilience (Philsoophian et al., 2021), they may also reduce the urgency for green innovation when facing heightened uncertainties. This effect likely reflects the stabilizing role these factors play, enabling firms to prioritize maintaining operations under extreme uncertain environment. Similarly, supply chain efficiency enhances firms' resilience by optimizing resource utilization and streamlining operations, allowing them to withstand disruptions and minimize costs (Kamalahmadi et al., 2022), which enable firms maintain operational stability when facing extreme high uncertainties arising from both OPU exposure and geopolitical tensions. Furthermore, heterogeneity analysis reveals that firms with higher international exposure, fewer financial constraints, lower government subsidies, and greater competitive pressures are more likely to leverage green innovation as a strategic response to external shocks.

These findings offer significant implications for both corporate strategy and policymaking. For firms, the results emphasize the importance of promotion green innovation to achieve sustainability in uncertain environments. For policymakers, on the other hand, should recognize the role of supply chain dynamics in mitigating the effects of external uncertainties. Efforts to enhance domestic supply chain alliances and efficiency should be accompanied by incentives that encourage firms to maintain innovation intensity. Moreover, targeted policies that promote green innovation in energy-sensitive and firms heavily depend on international supply chain are essential. These insights provide a comprehensive framework for navigating the complexities of geopolitical and oil price uncertainty to achieve sustainability goals.

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4.6. Appendix

Appendix A: Variable description

Variable	Description
Patent	Natural logarithm of the total number of green patent applications filed by a firm in the given year that were eventually granted.
Invention	Natural logarithm of the total number of green invention patent applications filed by a firm in the given year that were eventually granted.
Utility	Natural logarithm of the total number of green utility patent applications filed by a firm in the given year that were eventually granted.
Citation	Natural logarithm of the number of non-self-citations each green patent receives in the given year.
CInvention	Natural logarithm of the number of non-self-citations each green invention patent receives in the given year.
CUtility	Natural logarithm of the number of non-self-citations each green utility patent receives in the given year.
OPUbeta	According to Peng et al. (2023), the annual firm exposure to OPU is calculated based on monthly data through the FAMA three-factor model. We take its absolute value.
GPRC	This variable represents the cumulative geopolitical risk faced by the countries of firm *i*'s customers during year *t*. The annual geopolitical risk index for each country is obtained from the work of Caldara and Iacoviello (2022).
GPRS	This variable represents the cumulative geopolitical risk faced by the countries of firm *i*'s suppliers during year *t*. The annual geopolitical risk index for each country is obtained from the work of Caldara and Iacoviello (2022).
GPRCustomer	This variable represents the firm-customer country paired geopolitical risk faced by the country *j* of firm *i*'s customers during year *t*. The annual geopolitical risk index for each country is obtained from the work of Caldara and Iacoviello (2022).
GPRSupplier	This variable represents the firm-supplier country paired geopolitical risk faced by the country *j* of firm *i*'s suppliers during year *t*. The annual geopolitical risk index for each country is obtained from the work of Caldara and Iacoviello (2022).
MTB	The ratio of market value to its book value of equity.
Growth	Change in sales between years *t* and *t-1*.
ROA	Return on assets, calculated as net profit after tax/total assets.
Size	The natural logarithm of total assets.
Lev	Total liabilities scaled by total assets.
Cash	Cash and cash equivalents scaled by total assets.
RDSales	R&D expenses scaled by total sales.
Board	The natural logarithm of the total number of directors on the board.
Indep	The proportion of independent directors to the total number of directors on the board.
Big4/10	A dummy variable equals one if the auditor of the firm is one of international "Big4" or "Domestic 10" audit firms, and zero otherwise.
Top1	The largest shareholding ratio.
SOE	A dummy variable equals one if the ultimate controller of a firm is a government agency or a state-owned enterprise, and zero otherwise.

Alliance	*Alliance* represents the natural logarithm of the number of suppliers/customers with whom the firm has established strategic partnerships domestically.
Efficiency	*Efficiency* is defined as the natural logarithm of 365/firm's inventory turnover ratio.
FC	*WW* Index. $WW = -0.091\ Cash - 0.062\ DivPos + 0.021\ Lev - 0.044\ Size + 0.102\ ISG - 0.035\ Growth$. Note: *DivPos*: Dummy variable of Cash dividend payment; *Lev*: Total liabilities divided by total assets; *ISG*: Industry average sales Growth rate
HHI	The variable Herfindahl-Hirschman Index (*HHI*) represents the degree of industry competition. It is calculated as the sum of the squares of the market shares of all firms within the industry, with higher values indicating lower competition and greater market concentration.

Appendix B. Baseline regression using firm-country paired sample

	(1)	(2)	(3)	(4)
	F.Patent	*F.Patent*	*F.Citation*	*F.Citation*
OPUbeta	0.251**	0.321*	1.086***	1.010***
	(2.304)	(1.712)	(11.474)	(6.313)
GPRCustomer	-0.171***		-0.108**	
	(-3.978)		(-2.323)	
*OPUbeta * GPRCustomer*	2.162***		3.198**	
	(2.819)		(2.216)	
GPRSupplier		-0.148***		-0.122***
		(-4.062)		(-2.768)
*OPUbeta * GPRSupplier*		3.246***		6.289***
		(4.212)		(4.026)
MTB	-0.022***	-0.011***	-0.038***	-0.022***
	(-11.337)	(-3.576)	(-17.122)	(-6.704)
Growth	-0.050***	-0.021	-0.213***	-0.160***
	(-4.328)	(-1.391)	(-18.421)	(-9.791)
ROA	0.171***	0.062	0.277***	0.227***
	(6.071)	(1.643)	(9.043)	(5.903)
Size	0.319***	0.298***	0.209***	0.177***
	(30.810)	(20.373)	(16.708)	(10.889)
Lev	0.114***	0.054	0.669***	0.279***
	(3.424)	(1.050)	(18.793)	(5.507)
Cash	0.006	0.041	0.129***	0.147***
	(0.184)	(0.886)	(3.294)	(3.133)
RDSales	3.288***	2.685***	2.970***	3.866***
	(6.443)	(3.494)	(4.579)	(3.744)
Board	0.064**	0.104***	0.066**	0.043
	(2.507)	(2.890)	(2.061)	(0.967)
Indep	-0.001	-0.391***	-0.462***	-0.536***
	(-0.011)	(-3.214)	(-4.359)	(-3.618)
Big4/10	-0.052***	0.031***	-0.025***	0.028**
	(-7.479)	(3.130)	(-2.700)	(2.303)
Top1	-0.242***	-0.003	-0.012	-0.126
	(-4.333)	(-0.038)	(-0.189)	(-1.381)
SOE	-0.085***	-0.005	-0.132***	-0.037
	(-3.313)	(-0.167)	(-4.889)	(-1.121)
Constant	-6.436***	-6.221***	-4.395***	-3.650***
	(-27.650)	(-18.887)	(-15.656)	(-9.824)
Industry FE	Yes	Yes	Yes	Yes
Paired FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	85,645	35,581	83,310	32,876
Adjusted R^2	0.659	0.647	0.638	0.574

This table presents the impact of *OPUBeta* on firm green innovation productivity and the amplifying effect of geopolitical tensions using firm-customer country and firm-supplier country matched data, respectively. Columns (1) and (3) present the regression analysis of *OPUbeta* and geopolitical tensions form customer countries on one-year forward *Patent* and *Citation*, respectively, using data matched at the firm and customer country level. Columns (2) and (4) present the regression analysis of *OPUbeta* and geopolitical tensions form supplier countries on one-year forward *Patent* and *Citation*, respectively, using data matched at the firm and supplier country level. All the regressions control for Industry and firm-country paired fixed effect. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm*country level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Appendix C. Robustness test: Alternative measure for OPU beta

	(1)	(2)	(3)	(4)	(5)	(6)
	F. Patent	*F.Citation*	*F. Patent*	*F. Citation*	*F. Patent*	*F.Citation*
OPUbeta2	1.602***	0.532***	1.453***	0.255*	1.444***	0.346**
	(5.957)	(3.908)	(5.297)	(1.859)	(5.385)	(2.558)
GPRC			-0.151***	-0.057**		
			(-3.659)	(-2.080)		
*OPUbeta2*GPRC*			3.199***	6.343***		
			(2.991)	(5.963)		
GPRS					-0.326***	-0.142***
					(-6.463)	(-4.492)
*OPUbeta2*GPRS*					5.075***	8.127***
					(3.147)	(5.318)
MTB	-0.015	-0.001	-0.012	-0.004	-0.013	-0.002
	(-0.358)	(-0.049)	(-0.305)	(-0.246)	(-0.314)	(-0.103)
Growth	0.013	0.007	0.013	0.006	0.013	0.005
	(0.794)	(0.854)	(0.776)	(0.786)	(0.799)	(0.693)
ROA	0.111**	0.034**	0.111**	0.034**	0.112**	0.034**
	(2.436)	(1.990)	(2.433)	(2.002)	(2.449)	(2.006)
Size	0.232***	0.029***	0.232***	0.030***	0.232***	0.029***
	(19.842)	(6.905)	(19.833)	(7.271)	(19.885)	(6.949)
Lev	0.090*	0.023	0.089*	0.029	0.087*	0.026
	(1.937)	(1.191)	(1.923)	(1.533)	(1.884)	(1.377)
Cash	0.010	0.005	0.011	0.009	0.013	0.007
	(0.183)	(0.221)	(0.199)	(0.383)	(0.226)	(0.296)
RDSales	3.004***	0.688*	3.002***	0.719*	3.010***	0.644*
	(3.600)	(1.786)	(3.600)	(1.883)	(3.608)	(1.705)
Board	0.066	0.033	0.066	0.029	0.068	0.033
	(1.283)	(1.539)	(1.284)	(1.379)	(1.322)	(1.552)
Indep	0.193	0.084	0.192	0.074	0.196	0.084
	(1.060)	(1.068)	(1.053)	(0.953)	(1.078)	(1.074)
Big4/10	0.002	0.001	0.002	0.001	0.002	0.001
	(0.112)	(0.178)	(0.124)	(0.103)	(0.113)	(0.194)
Top1	-0.114*	0.022	-0.113*	0.018	-0.114*	0.020
	(-1.908)	(0.859)	(-1.893)	(0.691)	(-1.903)	(0.786)
SOE	0.029	-0.004	0.029	-0.002	0.028	-0.002
	(1.400)	(-0.466)	(1.403)	(-0.202)	(1.363)	(-0.267)
Constant	-4.941***	-0.726***	-4.931***	-0.745***	-4.938***	-0.725***
	(-18.303)	(-6.723)	(-18.280)	(-6.934)	(-18.321)	(-6.786)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,901	26,901	26,901	26,901	26,901	26,901
Adjusted R^2	0.312	0.074	0.312	0.081	0.313	0.080

This table presents the baseline regression using alternative measurement of OPU beta. We compute *OPUbeta2* using a 36-month rolling window regression approach. Dependent variables and control variables are the same as in Table 4.2. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Appendix D. Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) *OPUbeta*	1																
(2) *GPRC*	-0.004	1															
(3) *GPRS*	-0.029***	-0.068***	1														
(4) *Patent*	0.154***	-0.050***	-0.040***	1													
(5) *Citation*	0.144***	0.072***	0.053***	0.261***	1												
(6) *MTB*	-0.197***	-0.056***	-0.019***	0.147***	-0.012**	1											
(7) *Growth*	0.019***	-0.006	0.011*	0.037***	0.011*	-0.025***	1										
(8) *ROA*	-0.038***	0.004	0.015**	0.031***	0.017***	-0.072***	0.336***	1									
(9) *Size*	0.115***	-0.124***	-0.053***	0.339***	0.082***	0.534***	0.061***	0.131***	1								
(10) *Lev*	-0.052***	-0.082***	-0.036***	0.116***	0.023***	0.323***	0.021***	-0.172***	0.422***	1							
(11) *Cash*	0.003	0.042***	0.027***	-0.070***	-0.001	-0.186***	0.030***	0.183***	-0.195***	-0.392***	1						
(12) *RDSales*	0.037***	-0.004	0.015**	0.077***	0.036***	-0.092***	-0.005	-0.035***	-0.012*	-0.089***	0.038***	1					
(13) *Board*	-0.046***	0.004	0.020***	0.034***	0.016***	0.154***	0.012**	0.052***	0.232***	0.152***	-0.036***	-0.049***	1				
(14) *Indep*	0.027***	-0.012*	-0.010*	0.043***	0.013**	-0.024***	-0.004	-0.027***	0.022***	-0.017***	0.006	0.029***	-0.492***	1			
(15) *Big4/10*	0.095***	-0.009	-0.018***	0.105***	0.040***	0.029***	-0.008	0.031***	0.176***	-0.036***	0.001	0.042***	-0.010*	0.030***	1		
(16) *Top1*	-0.051***	0.011*	0.012*	0.016***	0.016***	0.155***	0.037***	0.152***	0.217***	0.036***	0.034***	-0.074***	0.025***	0.033***	0.060***	1	
(17) *SOE*	-0.051***	-0.050***	-0.019***	0.013**	-0.007	0.191***	-0.048***	-0.025***	0.278***	0.264***	-0.065***	-0.070***	0.272***	-0.076***	-0.049***	0.210***	1

This table reports the Pearson correlation coefficient. *t*-statistics are given in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Appenidx E. Test the nonlinear relationship between OPU Beta and green innovation

	(1)	(2)
	F. Patent	*F.Citation*
OPUbeta	2.883***	0.286***
	(5.621)	(4.100)
OPUbeta2	1.505	1.428
	(0.591)	(0.736)
Constant	-4.868***	-0.707***
	(-18.126)	(-6.592)
Controls	Yes	Yes
Industry FE	Yes	Yes
Year FE	Yes	Yes
Observations	26,901	26,901
Adjusted R^2	0.313	0.074

This table presents the impact of *OPUbeta* on firm green innovation productivity and quality. *OPUbeta2* represents the squared term of *OPUbeta*. *t*-statistics are reported in parentheses. Standard errors are robust and clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

CHAPTER FIVE

CONCLUSION

5.1. Main findings and implications

This thesis explores key factors influencing corporate disclosure and innovation behaviors under external uncertainties and socio-political pressures, contributing to the understanding of corporate strategies in dynamic and complex environments.

The first essay demonstrates a negative association between bad news timeliness and corporate environmental disclosure, emphasizing the moderating role of socio-political pressures. Firms may have already promptly reflected negative news in their earnings to meet stakeholder expectations, those with CEO or chairman holding government-nominated positions are associated with increased environmental disclosure due to heightened socio-political demands. Additionally, the negative relationship between bad news timeliness and environmental disclosure is less pronounced for heavy polluters, who face stricter environmental regulations. These findings suggest that top management strategically adjusts the nature and scope of information disclosed to the public. This study underscores the need for policymakers to develop strategies that promote corporate information transparency and enhance stakeholder trust.

The second essay investigates the relationship between oil price uncertainty and corporate green innovation disclosure behavior. Utilizing textual analysis of annual and social responsibility reports from Chinese listed firms, the study manually constructs the measure of corporate green innovation disclosure intensity. The findings reveal a significantly positive relationship between oil price volatility and green innovation disclosure, which remains robust after accounting for endogeneity and conducting extensive robustness checks. This relationship is further found to be affected by firm-level factors such as environmental performance, legitimacy demands, and political connections, with a stronger effect observed in firms operating under stricter regional environmental regulations and market-based green initiatives. These results offer valuable insights into corporate sustainable development, illustrating how energy uncertainty drives firms to enhance information transparency regarding green innovation.

The third essay provides notable evidence on the impact of OPU sensitivity on corporate green innovation in the context of geopolitical tensions. By using hand collected data at the country-firm level from the China Customs Dataset, the study develops a unique measure of firm-level geopolitical tensions experienced through foreign supply chain partners. The findings indicate that firms with higher exposure to OPU are more likely to engage in green innovation, with geopolitical tensions significantly amplifying this relationship. The effect is particularly pronounced when tensions arise from supplier countries, highlighting the strategic importance of supply chain vulnerabilities. Further analysis shows that domestic supply chain alliances and supply chain efficiency reduce the urgency for green innovation by providing operational stability. Finally, the effects of OPU and geopolitical tensions on green innovation are amplified in firms with higher international exposure, lower government subsidies, and greater competitive pressures. These insights contribute to the understanding of how firms navigate external shocks and align innovation strategies with global uncertainties.

5.2. Limitation and future research

The essays in this thesis have limitations that open avenues for further research. The first essay examines the relationship between bad news timeliness and corporate environmental disclosure, emphasizing socio-political pressures and regulatory dynamics. However, it is possible that industry-specific factors or variations in political implementation might shape environmental disclosure practices. Although industry-level variations are not our focus, future studies could examine how characteristics such as regulatory intensity or enforcement mechanisms influence the interplay between financial reporting policies and environmental disclosures. Additionally, while this essay highlights the role of top management in disclosure decisions, the potential influence of other stakeholders, such as institutional investors, and/or individual shareholder activism, in shaping disclosure strategies warrant further investigation.

The second essay investigates the impact of oil price uncertainty on green innovation disclosure, and we rely primarily on textual analysis of corporate reports to measure the intensity of green innovation disclosure. Future research could integrate whether and how third-party evaluation on green performance can influence corporate disclose on green innovation.

The third essay explores the relationship between oil price uncertainty, geopolitical risks, and corporate green innovation, emphasizing the moderating effects of supply chain alliances and efficiency. However, it is a limitable that the China Customs Dataset is only available to 2016. The research question is worth of further estimation when the data on firm import and export are variable for more recent years. Additionally, although the essay accounts for firm-level heterogeneity, including factors like international exposure and financial constraints, it does not focus on the potential effects of managerial characteristics, such as risk tolerance or innovation orientation, which could shape firms’ responses to external pressures. Investigating these aspects would provide other insights into corporate reactions to oil price uncertainty and geopolitical risks.

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MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Kai Huang
Name and title of main supervisor:	Associate Professor Jing Liao
In which chapter is the manuscript/published work?	Chapter Two

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

All authors contributed to the study conception and design. Data collection and analysis were performed by Kai Huang. The manuscript was written by Kai Huang and all authors commented on the manuscript. All authors read and approved the manuscript. No conflict of interest exits in the submission of this manuscript.

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Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

All authors contributed to the study conception and design. Data collection and analysis were performed by Kai Huang. The manuscript was written by Kai Huang and all authors commented on the manuscript. All authors read and approved the manuscript. No conflict of interest exits in the submission of this manuscript.

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Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

All authors contributed to the study conception and design. Data collection and analysis were performed by Kai Huang. The manuscript was written by Kai Huang and all authors commented on the manuscript. All authors read and approved the manuscript. No conflict of interest exits in the submission of this manuscript.

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