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 the behavior of corporate green innovation disclosure. Based on textual analysis of the annual reports and social responsibility reports of Chinese listed companies, we construct an indicator for corporate green innovation disclosure. Our results indicate a significant positive relationship between oil price volatility and the level of green innovation disclosure. This relationship remains robust after conducting stringent tests for robustness and addressing potential endogeneity issues. Further analysis reveals that this positive association is more pronounced in firms with high levels of CSR performance; firms with strong political connections; and those with heightened legitimacy demands. Our findings contribute new evidence to corporate sustainable development, demonstrating that energy uncertainty significantly influences information transparency in green innovation.

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

1. Introduction

In the contemporary business landscape, the increasing volatility of oil prices has heightened the focus on sustainability. This growing emphasis on green initiatives is not merely a reaction to regulatory pressures but also a strategic adaptation to economic challenges. The heightened interest in sustainability, especially oil price uncertainty (OPU), has become a central topic in both academic and industrial discourse (Hu et al., 2023). Existing literature underscores the profound impacts of oil price fluctuations on businesses, including higher operational costs, supply chain disruptions, exchange rate volatility, and uncertainty in energy policy (Smith & Jones, 2021; Hu et al., 2023). Such heightened uncertainty may increase stakeholders' concerns, necessitating that companies demonstrate their efforts in addressing these uncertainties through disclosures (Orij, 2010). While existing studies explore the impact of OPU on innovation practices (Amin et al., 2023; Yang & Song, 2023), a gap remains in understanding whether and how uncertainties due to oil price fluctuations influence the disclosure of green innovation. This paper aims to explore how OPU influences the behavior of corporate green innovation disclosure, shedding light on the motivations, challenges, and implications of green innovation disclosures in the pursuit for sustainable development.

Firm green innovations disclosure is crucial in shaping stakeholder perceptions, boosting investor confidence, and ensuring regulatory compliance (Patten, 2002; Clarkson et al., 2008). In China, companies have the discretion to voluntarily disclose their green innovation initiatives and plans in their annual reports. On one hand, this voluntary disclosure can showcase a company's effort in green innovation to the public. On the other hand, compared to patents, such voluntary disclosures are likely to expose the company's research and development information to competitors. Therefore, firms need to address the dilemma of whether they should voluntarily disclose green innovation information. This dilemma becomes even more strategic in the face of OPU.

According to proprietary cost theory, when deciding whether and when to disclose innovation information, companies weigh the benefits of disclosure, such as gaining investor trust and improving reputation, against the need to protect their competitive advantage. Disclosure might allow competitors to obtain key information, enabling them to take actions that could weaken the company's market position and competitiveness (Ellis, Fee & Thomas, 2012). Additionally, innovation projects often involve high levels of uncertainty, and disclosing innovation information may lead to excessive market expectations about the company's future performance. If the innovation projects ultimately fail, this could result in a decline in investor confidence (Greve, 2011).

However, when facing heightened OPU, stakeholders may be affected, and these impacted stakeholders can become a source of social pressure on enterprises (Patten, 2002), compelling them to disclose more innovative information. Firstly, OPU may lead to a decline in corporate profitability, thereby affecting shareholder returns (Thi et al., 2024). Fluctuations in oil prices increase the uncertainty of corporate operations, causing investors to worry about the company's future financial performance (Song & Yang, 2022). An increase in oil prices may lead to higher prices for products or services, thereby increasing the financial burden on customers (Hu & Su, 2018). The impact of OPU on business operations can also cause concern among employees (Aye et al., 2014). Stakeholder theory posits that managers should embrace social responsibility as an ethical obligation, suggesting a departure from the strict objective of shareholder-wealth maximization in favor of societal benefits (Bhandari & Javakhadze, 2017). As a result, companies may face greater social pressure to demonstrate their efforts in green innovation. By increasing green innovation disclosure, companies can showcase their capabilities and determination in addressing environmental risks, thereby boosting stakeholder confidence (Orij, 2010). This beneficial effect is particularly valuable when firms face heightened OPU.

Additionally, according to legitimacy theory, the existence and operation of enterprises require social recognition and legitimacy (Dowling & Pfeffer, 1975). Corporate behaviors and decisions must align with social norms, values, and expectations to maintain their legitimacy and social license to operate (Lindblom, 1994). OPU may prompt heightened environmental regulation as governments and societies become more attuned to the environmental impacts of energy consumption (Kang et al., 2018), compelling firms to increase green innovation disclosures to align with these evolving regulatory expectations.

Selecting China as the research backdrop for examining the impact of OPU on firm green innovation disclosure is underpinned by several reasons. Foremost, 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 and firm behavior. 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, lack of information transparency is one of the major concerns on the development Chinese financial markets. Information asymmetry, coupled with less mature regulatory and investor protection mechanisms, suggest that Chinese firms might exhibit distinct responses to oil price volatility compared to firms in more developed markets (Hu et al., 2022; Ma, 2012). Furthermore, there is a burgeoning interest in exploring the relationship between oil prices and market dynamics within the Chinese context (Cong et al., 2008; Zhu et al., 2016). Although previous research has explored the link between oil price shocks and stock market fluctuations in China (Wei et al., 2019; Cong et al., 2008), the dynamic interaction between oil market shocks and firm disclosure behavior 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.

Utilizing data from China's A-share market from 2008 to 2019, this study explores the relationship between OPU and firm green innovation disclosure. Based on textual analysis of the annual reports and social responsibility reports of Chinese listed companies, we construct an indicator for corporate green innovation disclosure, following the method of Xie et al. (2019). The regression analysis indicates a significant positive relationship between OPU and the level of green innovation disclosures. To ensure robustness, additional tests are conducted by controlling for EPU beta, addressing firm fixed effects, as well as industry and province fixed effects. Furthermore, to ascertain the reliability of our findings, alternative measurements of OPU are examined. Additionally, the study employs the IV-GMM approach to rigorously address potential endogeneity issues, thereby strengthening the validity of our results.

We further examine the cross-sectional variation of the impact of OPU on firm green innovation disclosure. According to Bhandari & Javakhadze (2017), stakeholder theory advocates that firms prioritize the interests of stakeholders over their own economic benefits. Consequently, we constructed sub-samples of high- and low-CSR firms, and the results demonstrate that the positive correlation between OPU and firm green innovation disclosure is significantly pronounced in the high-CSR subsample, but not the high-CSR subsample. Drawing on legitimacy theory, firms with higher demands for legitimacy are more inclined to enhance their legitimacy through disclosure mechanisms (Deegan et al., 2000). We divide the sample into firms with higher and lower demands for legitimacy, and the results confirm our expectation that the impact of OPU is more salient in firms with heightened legitimacy demands. This comprehensive analysis highlights the complex dynamics of firm responses to macroeconomic challenges and the pivotal role of regulatory environments in guiding these responses.

The contributions of this paper are fourfold. First, leveraging the context of OPU, our research provides new evidence to 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 & Han (2007), firms should protect their innovation information and avoid proactive disclosure to prevent the risk of leaking confidential information and increasing competition. Conversely, socio-political theory posits that uncertainty increases socio-political forces, which compel firms to disclose more information (Puroila & Mäkelä, 2019). Our study fills a gap in the existing literature by supporting socio-political 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 are distinct. First, patents are mandatory disclosures and are legally protected, whereas corporate innovation disclosures are voluntary and do not receive protection because they are disclosed voluntarily. Second, patents represent the output of innovation, whereas disclosures might include plans and progress of innovation. Interestingly, both Amin et al. (2023) and Yang & Song (2023) find that OPU reduces the number of patents and citations, but we discover that OPU increases firms' voluntary disclosure of information related to green innovation. This finding not only provides new perspectives for theory but also offers significant insights for corporate disclosure practices.

The second contribution of this study lies in its exploration of firm responses to energy uncertainties, particularly in the context of oil price fluctuations and their impact on disclosure practices. This finding adds a new dimension to the existing literature on firm behavior under energy uncertainties, especially regarding environmental sustainability (You et al., 2017; Zhang et al., 2020). By demonstrating the discrepancy between firm communication and action, the study enhances our understanding of how firms navigate the challenges posed by energy uncertainties, thereby contributing to the broader discourse on firm strategy and sustainability.

The third contribution of this study lies in its exploration of how firm green innovation disclosure is influenced by social and litigation pressures, specifically highlighting the role of

CSR and legitimacy demands. Our findings reveal that firms with higher levels of CSR engagement, as well as those facing greater legitimacy demands, are more likely to intensify their green innovation disclosures in response to oil price volatility. By delineating the cross-sectional variation of the impact of OPU on firm green innovation disclosure, this research offers profound insights for policymakers and firm executives. It suggests that the development of effective regulatory policies and disclosure standards should consider the heterogeneity among firms in terms of their CSR commitments and legitimacy demands. Consequently, this study enriches the existing literature by providing a better understanding of the conditions under which firms choose to enhance their sustainability disclosures, thereby aiding in the formulation of more targeted and effective sustainability initiatives.

The final contribution of this study lies in its extension and application of stakeholder theory and legitimacy theory, within the realm of firm responses to OPU. The application of stakeholder theory in this study reveals that firms increasingly recognize and prioritize the diverse interests and expectations of their stakeholders, not merely as a strategic maneuver but as a fundamental component of their firm ethos (Freeman, 1984; Mitchell, Agle, & Wood, 1997). This perspective suggests that in facing OPU, firms with intensive stakeholder engagement strategy are more inclined to navigate the complexities of environmental sustainability disclosures, as they seek to align their actions with stakeholder expectations. On the other hand, legitimacy theory offers insights into another dimension of firm behavior, emphasizing that firms are motivated to undertake sustainability disclosures as a means to ensure their legitimacy within the broader social framework (Suchman, 1995; Dowling & Pfeffer, 1975). This theory posits that firms engage in green innovation disclosures to mitigate the risks of legitimacy threats and align themselves with societal norms and values. This contrast in theoretical application not only underscores the complexity of firm responses to environmental challenges and economic volatility but also enriches the understanding of the interplay between firm strategy and societal expectations. The integration of stakeholder and legitimacy theories provides a comprehensive view of the multifaceted motivations behind firm sustainability strategies, contributing to the literature on corporate environmental disclosure.

The remainder of the study is organized as follows: Section 2 presents literature review and hypothesis development. Section 3 reports the data, variable construction, and the regression model. Section 4 presents the empirical results and robustness tests. Section 5 concludes the study.

2. Literature review and hypothesis development

2.1 The economic impacts of oil price uncertainty

Previous literatures have revealed the effects of oil prices and their uncertainty on macroeconomic and financial outcomes. Firstly, the volatility of oil prices 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 elevates the marginal cost of production while reducing consumers' spending capacity, thereby leading to a decrease in demand for corporate products (Pindyck, 1990). Moreover, fluctuation in oil prices is usually considered inflation or deflation, which will cause central banks to respond by adjusting interest rates, affecting future firm cash flows and discount rates (Ferderer, 1996; Sadorsky, 1999). Further research also demonstrates the specific impacts of oil price uncertainty on macroeconomic factors such as employment, income, consumption, labor flow, and output. Studies by Kocaaslan (2019) and Koirala & Ma (2020) reveal the impact of oil price uncertainty on the unemployment rate in the United States, providing evidence of asymmetric effects of positive and negative oil price uncertainty shocks on rising unemployment rates. The supply-side effects induced by rising oil prices force an increase in production costs, slow economic growth, and reduce productivity (Brown & Yücel, 2002). Additionally, Maghyereh et al. (2019) show that the uncertainty in the oil market negatively affected industrial output, while documenting 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 after a positive shock to oil price uncertainty, due to decreases in purchasing power and disposable income, there was a decline in the consumer price index. Herrera et al. (2019) argue that the rise in oil price uncertainty had a more significant negative impact on employment flows in manufacturing than the uncertainty of monetary policy.

Existing research indicates that the impact of oil price fluctuations on firms is multifaceted, including profitability, investment decisions, and financing conditions to the overall financial health of a firm. Regarding profitability, Bugshan et al. (2021) highlight that oil price volatility has a significant negative impact on firm profitability, suggesting that the uncertainty of future oil price levels could have a major influence on corporate policies. At the investment level, Phan et al. (2019) observe that high oil price uncertainty increases the real option value of waiting for firms, leading them to pause investments until uncertainty resolves. This phenomenon is further supported by the adverse effects of oil price volatility on banks' lending capacities, with Al-Khazali and Mirzaei (2017) and Lee and Lee (2019) arguing that this results in inefficient capital markets, thereby increasing market imperfections. Furthermore, the comprehensive impact of oil price uncertainty on firms' financial conditions has garnered widespread attention. Fan et al. (2021), through studying the effects of market-oriented refined oil pricing reform on firm leverage, find a nonlinear relationship between oil price uncertainty and firm leverage, indicating trade credit and exacerbated financial distress risk as potential channels of impact. Hasan et al. (2021) also discover that oil price uncertainty significantly affects short-term debt financing. Zhang et al. (2020) observe that oil price uncertainty increases firms' cash holdings, especially when the firm value increases and for state-owned enterprises, where this effect is mitigated. 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 (demand-side and supply-side). Additionally, Song and Yang (2022) demonstrate that oil price uncertainty negatively correlates with company performance, while Wong and Hasan (2021) find that oil demand shocks increase stock repurchases, but oil supply shocks reduce dividends paid through stock repurchases, primarily driven by non-oil producing companies. This implies that oil supply shocks lead to increased uncertainty about companies' future growth potential.

2.2 Motivations for firms to voluntarily disclose green innovation

Socio-political theories provide a foundational basis to explain why firms voluntarily disclose environmental information. These theories suggest that social disclosure is a function of social and political pressures facing the firm (Patten, 2002).

The legitimacy theory posits that a company's existence and operations require societal approval and legitimacy. A company's actions and decisions must align with societal norms, values, and expectations to maintain its legitimate status and social license to operate (Patten, 1992). When oil price fluctuations significantly impact society and the economy, companies need to sustain their legitimacy through transparent and responsible behavior (Cho and Patten, 2007), with innovative information disclosure being a crucial strategy. Oil price volatility can lead to rising energy costs and increased production expenses, thereby affecting a company's market competitiveness and profitability (Song & Yang, 2022). In response to these challenges, companies must demonstrate to society their ability to adapt to market changes and uphold sustainable development. By disclosing efforts in energy alternatives, technological innovation, and green development, companies can show their capacity to meet societal expectations and norms, thereby gaining social recognition and legitimacy (Gallego-Álvarez & Quina-Custodio, 2016). Governments and regulatory bodies are crucial judges of corporate legitimacy (Black, 2008). When oil price fluctuations impact the economy and environment, governments may intensify regulations and requirements for companies, particularly concerning energy usage and environmental protection (Kang et al., 2019). By disclosing progress in innovation and technological development, companies can demonstrate their efforts to comply with policies and regulations, thereby reducing regulatory risks and gaining policy support (Li et al., 2018). Additionally, the media and the public act as watchdogs of corporate legitimacy (Castelló et al., 2016). Social attention and discussions triggered by oil price fluctuations may increase public and media scrutiny of companies. By proactively disclosing innovative information, companies can show their transparency and responsible attitude, alleviating social doubts and criticisms, and enhancing their credibility and image among the public.

According to stakeholder theory, a company's operations should not only consider the interests of shareholders but also balance and meet the needs of all related stakeholders (Goss & Roberts, 2011; Bhandari & Javakhadze, 2017). When oil prices fluctuate, the needs and expectations of various stakeholders change, which may compel companies to take actions to maintain their reputation and trust. For example, investors focus on a company's financial performance and future prospects. Oil price fluctuations can lead to increased costs and reduced profits, impacting stock prices and investor confidence (Thi et al., 2024; Song & Yang, 2022). In such circumstances, companies need to demonstrate to investors their ability to adapt to market changes, making the disclosure of innovative information a crucial means to showcase their strategy and resilience. By revealing their innovations in technology development, energy alternatives, and cost control, companies can boost investor confidence, stabilize stock prices, and avoid market panic.

Customers are also important stakeholders, especially when facing oil price fluctuations, which may affect the prices of products and services (Hu & Su, 2018). Customers expect companies to maintain stable prices and service quality through innovation. By disclosing initiatives in renewable energy application, improving energy efficiency, and reducing production costs, companies can signal their proactive response to oil price fluctuations, thereby enhancing customer loyalty and satisfaction (Delmas & Burbano, 2011). Furthermore, employees, as key internal stakeholders, are concerned about job stability and the company's long-term prospects. Operational pressures from oil price fluctuations may lead to layoffs or salary cuts, causing anxiety and dissatisfaction among employees (Aye et al., 2014). By publicizing innovation projects and future development plans, companies can demonstrate their capacity to cope with market changes and future prospects, thereby boosting employee confidence and motivation (Carmeli & Spreitzer, 2009).

Moreover, external stakeholders such as suppliers also exert pressure on companies (Charoenwong et al., 2023). Suppliers expect companies to maintain stable orders and payments, while oil price fluctuations can lead to supply chain instability and increased environmental concerns from the community (Orij, 2010). Through the disclosure of innovative information, companies can show suppliers their stable production and payment capabilities, and demonstrate to the community their efforts in environmental protection and sustainable development.

Therefore, companies are motivated to use environmental information disclosure to inform the public about their compliance with environmental laws and regulations.

Hypothesis 1: Oil price uncertainty has a positive impact on firm green innovation disclosure.

2.3 Oil price volatility and proprietary cost theory

According to the proprietary cost theory, companies typically weigh the benefits of disclosing innovation information (such as gaining investor trust and increasing market transparency) against the necessity of protecting their competitive advantage (Verrecchia, 1983). Disclosure can reveal critical information to competitors, enabling them to take counteractions that weaken the company's market position and competitiveness. Green innovations often involve new technologies and business models, which are highly proprietary and strategically important to the company. The uncertainty of oil prices may drive competitors to actively seek new competitive advantages. If a company discloses its green innovation strategy in such an environment, competitors might use this information to imitate or implement targeted competitive measures, thereby undermining the company's market position and competitiveness. Therefore, under oil price uncertainty, companies tend to keep their green innovation information confidential to protect their technological edge and market share (Healy & Palepu, 2001).

Oil price fluctuations directly impact a company's operating costs and profitability, making companies more cautious (Hamilton, 2009). In such circumstances, disclosing green innovation information might exacerbate market volatility. Green innovation projects often require substantial upfront investment and long-term technological development, which are inherently highly uncertain (Roper & Tapinos, 2016). Disclosing this information during oil price volatility may lead to overly high market expectations for the company’s future performance. If these projects do not succeed as anticipated, it could result in significant stock price fluctuations and damage investor confidence. Additionally, green innovation projects usually involve complex technical and market risks (Nanda & Rhodes-Kropf, 2017). Oil price fluctuations can affect the economic feasibility of these projects. For example, when oil prices are low, the cost advantage of traditional energy may diminish the relative attractiveness of green energy projects, potentially weakening investor and market support for these initiatives (Borenstein, 2012). In such cases, disclosing green innovation information might lead to investor skepticism about the feasibility and economic returns of the projects, increasing the company's financing and operational pressures.

In conclusion, the reasons companies are reluctant to disclose green innovation information under oil price uncertainty include increased market instability, threats from competitors, and the inherent uncertainty of the projects themselves. By keeping their green innovation information confidential, companies can more effectively protect their competitive advantage and mitigate the negative impacts of external uncertainty on their strategic implementation.

Hypothesis 2: Oil price uncertainty has a negative impact on firm green innovation disclosure.

3. Data and methodology

3.1 Sample

In this study, our sample initially includes all non-financial A-share listed firms on Shanghai stock exchange (SHSE) and Shenzhen stock exchange (SZSE) from 2008 to 2019. We select the year 2008 as the starting point of our study because the new accounting standards in China are implemented in 2007. Our cutoff date was selected up to 2019 because in 2020, international oil prices fell to negative values for the first time, which would impact the overall analysis. The data filtering procedure is as follows. First, firm-year observations with missing values are eliminated. Second, we exclude firms that listed on the stock exchange for less than 3 years. Finally, we winsorize all firm-level variables at the top and bottom 1% to alleviate concerns of possible disturbance of outliers. Our final sample includes 24,792 firm-year observations for 3,261 firms. We collect firm-specific data from the China Stock Market & Accounting Research Platform (CSMAR) database. Oil price data are collected from U.S. Energy Information Administration.

3.2 Variable description

3.2.1 Independent variables: Oil price uncertainty

The daily crude oil futures price of Brent is selected as the proxy for international crude oil prices. In this paper, 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 for one year following (Henriques & 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 the daily oil price returns of trading day d and N represents the number of trading days in year t.

(2) The second measurement of OPU in our study is the average of the daily conditional variance generated from a GARCH (1,1) model for one year following (Alaali, 2020; Wang et al., 2017):

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

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

3.2.2 Dependent variables: Firm green innovation disclosure

Following the methodology of Xie et al (2019), we measure green innovation disclosure using five indexes (refer to the table below). The data for these measures were derived from a textual analysis of firms' social responsibility report and annual report, with each item being scored from 0 to 2: 0 indicates no related description; 1 signifies a basic description without detailed implementation information; and 2 denotes a detailed description including implementation details. Finally, the scores for each item are averaged to obtain the index for 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' Corporate Social Responsibility Reports	Frondel et al. (2007); Klassen and Whybark (1999); del Río González (2005)

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, acknowledged as significant determinants of firm disclosure. These variables comprise 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*). We also include industry fixed effects to control unobservable industry-level and macroeconomic factors. Appendix A presents the variable definitions.

(Insert Appendix A here)

3.3 Summary statistics

Table 1 provides the descriptive statistics for the main variables, detailing means, standard deviations, and distribution data. The mean value of *GInoDis* is 0.281, with a minimum value of 0 and a maximum value of 2. And there’re approximately 25% of sample firms engage in voluntary green innovation disclosure. For *OILVOL*, the minimum, maximum, mean, and standard deviation values are 0.169, 0.551, 0.316, and 0.104, respectively, while for *OILVAR*, they are 0.005, 0.013, 0.008, and 0.002, respectively. This demonstrates that oil price return experiences significant fluctuations throughout the sample period.

(Insert Table 1 here)

The correlation coefficients of the key variables are reported in Table 2. The absolute values of correlation coefficients between other variables are relatively low, indicating that there is no serious multicollinearity problem in our study.

(Insert Table 2 here)

4. Empirical results

4.1 Baseline regression result

In this study, our primary objective is to explore the impact of OPU on firms' innovation disclosure. Table 3 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, with one standard deviation increasing of *OILVOL*, the green innovation disclosure index will decrease by 7.62% $(0.206 \times 0.104)/0.281 = 7.62\%$). This supports our positive association conjecture mentioned in Section 1. Drawing on socio-political theories, social disclosure is viewed as a response to the social and political pressures encountered by firms (Patten, 2002). OPU introduces external pressures to firms (Smith & Jones, 2021; Hu et al., 2023), compelling them to engage in green innovation disclosure as a means to address these pressures. We will further discuss the specific socio-political theories that explain this positive association in Section 3.4.

(Insert Table 3 here)

4.2 Robustness tests

In this section, we present several robustness tests to consolidate our main results. Specifically, we investigate whether the documented positive effect of OPU on firm innovation disclosure in Section 3.1 is robust to (1) controlling for other fixed effect, (2) controlling for other macroeconomic uncertainties, (3) alternative proxy for oil price uncertainty.

To examine the robustness of our baseline regression results, this study employs a series of fixed effects controls, addressing potential confounders within the dataset. Specifically, Table 4 presents the outcomes of the baseline regression model, incorporating firm-level fixed effects. This adjustment aims to mitigate the influence of unobserved, firm-specific characteristics that could potentially bias the results. Table 5 extends the analysis by controlling for both industry and provincial fixed effects, thereby accounting for systematic differences across sectors and regions that might affect the dependent variables. The results in Table 4 and 5 show that OPU is still significantly and positively associated with firm green innovation disclosure after controlling for multiple fixed effects.

(Insert Table 4 here)

(Insert Table 5 here)

Existing studies have documented that several macroeconomic uncertainties other than OPU can affect firm innovation disclosure. Therefore, one potential concern about our main results is that it may be the other macroeconomic uncertainties but not OPU that induce the increase in firm innovation disclosure. To address this concern, we check whether our main results are robust to controlling for other macroeconomic uncertainties. Specifically, following (Phan et al., 2021), we control for firm exposure to China Economic Policy Uncertainty Index (EPU) constructed by (Baker, Bloom, & Davis, 2016) and World Uncertainty Index (WUI) developed by (Ahir, Bloom, & Furceri, 2022). Then we calculate firm risk exposure incorporates the natural logarithm of the EPU Index into the Fama-French Three-Factor Model. The regression results controlling for EPU beta are shown in Table 6 (we remove market beta due to concerns of collinearity). We take the absolute value of EPU beta. The coefficients of OPU in columns (1) and (2) are positive and significant at 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.

(Insert Table 6 here)

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 utilize the OPU calculated through the EGARCH model. This approach allows 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 B, 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.

(Insert Appendix B here)

4.3 Analysis of endogeneity issue

To address this endogeneity concern resulting from the omission of macroeconomic variables and causality, we employ IV-GMM estimation. Following the approach of Hasan et al. (2022), we select 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 their significant role in influencing oil price uncertainty (Noguera-Santaella, 2016). Therefore, they can be deemed as strong instruments.

In the first stage, we regress the instrumental variables on each independent variable: *OILVOL* and *OILVAR*, respectively. The result is shown in Column (1) and (2) of Table 7. *GPR4c* is positively related to *OILVOL* and *OILVAR* (both coefficients are statistically significant at the 1% level). The Cragg-Donald Wald F statistics for each test are 593.875 and

2158.801, which are larger than 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) in Table 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 IV-GMM analysis.

(Insert Table 7 here)

4.4 Heterogeneity analysis

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 heterogeneous factors influencing the impact of oil price uncertainty on green innovation disclosures.

4.4.1 High CSR vs. low CSR

Stakeholder theory, advocated by scholars such as Bhandari & Javakhadze (2017) and Goss & Roberts (2011), posits the importance of aligning firm strategies with the interests of all stakeholders, beyond just profit maximization. This approach suggests a shift towards embracing social responsibility and prioritizing broader societal benefits, as supported by Bozzolan et al. (2015) who highlight the significance of transparency and accountability. Stakeholder-oriented firms are more inclined to openly disclose their green innovation efforts because OPU amplifies societal and governmental demands for sustainable development or clean energy and other green innovations. Consequently, firms are motivated to adopt sustainable practices to meet stakeholder expectations for environmental responsibility.

In the context of stakeholder theory, to identify firms that are more considerate of stakeholder interests amidst oil price volatility, we refer to Tang et al. (2018) and utilize the Hexun Social Responsibility Index. According to Bhandari & Javakhadze (2017), firms that prioritize stakeholder interests are expected to place greater emphasis on their CSR objectives. To account for industry and annual variations, we selected the industry-year adjusted Hexun CSR index as our definitive parameter. Based on the median of the CSR index, our sample was divided into high CSR and low CSR sub-samples, with each undergoing regression analysis relative to the baseline regression. The findings, presented in Table 8, reveal that the positive correlation between OPU and green innovation disclosure predominantly occurs within the high CSR firm sub-sample. This outcome validates our hypothesis that, guided by stakeholder theory, firms, prioritizing the needs of their stakeholders, engage in green innovation disclosures when confronted with OPU.

(Insert Table 8 here)

4.4.2 High Legitimacy demand vs. low legitimacy demand

Legitimacy theory posits that organizations seek to manage public perception to avoid risks associated with negative views of their actions, as highlighted by Dowling and Pfeffer (1975) and Lindblom (1994). These entities may adopt various strategies to align with societal expectations or values, often necessitating disclosures to maintain legitimacy. The volatility of oil prices may lead to increased environmental regulation as governments and societies become more aware of the environmental impacts of energy consumption (Kang et al., 2018), thereby urging firms to enhance their green innovation disclosures to stay in line with these evolving standards.

To understand the implications of legitimacy theory for our baseline regression, we divided our sample into sub-samples with high and low demands for legitimacy. We used the possession of the ISO14001 certification as a criterion to differentiate between high and low legitimacy demands, because this certification is a globally recognized marker of a firm's adherence to rigorous environmental management standards. Firms with the ISO14001 certification were coded as 1, and those without as 0. The results, displayed in Table 9, show that the positive correlation between OPU and green innovation disclosure is significantly pronounced in the sub-sample with high legitimacy demands. This supports our hypothesis that, under the scrutiny of legitimacy theory, firms facing higher expectations for legitimacy are compelled to disclose their green innovations more proactively in response to OPU.

(Insert Table 9 here)

4.4.3 The impact of policy connections

We further examined the moderating effect of resource dependence theory on our baseline regression. Resource dependence theory posits that an organization's external dependence on resources, along with the scarcity and criticality of these resources, shapes its degree of external dependence (Pfeffer & Salancik, 2003). To secure continuous access to key resources and minimize acquisition costs, firms often seek to strengthen relationships with resource providers (Hillman et al., 2009). OPU introduces economic unpredictability, potentially leading to increased costs and operational risks (Smith & Jones, 2021; Hu et al., 2023). The degree of resource dependence may vary between firms with and without political connections. Firms with political connections may have better access to financing, subsidies, early insights into energy regulations, and face fewer sanctions (Cullinan et al., 2012). In contrast, firms without political ties might need to adopt strategies to align with government policies to tap into government resources, such as increasing green innovation disclosures.

Following Li et al. (2015), we used whether a firm's chairman had previously held a government position as a criterion to identify political connections, thus dividing the sample into firms with and without political connections. The results, presented in Table 10, indicate that the positive correlation between OPU and green innovation disclosure is significantly stronger in the sub-sample of firms without political connections. This finding supports the reshaping effect of resource dependence theory on our results, suggesting that firms lacking political ties, and consequently more vulnerable to resource dependence pressures, may leverage green innovation disclosure as a strategic means to mitigate these pressures and secure necessary resources.

(Insert Table 10 here)

5. Conclusion

This study delves into the impact of oil price volatility on firm green innovation disclosure and uncovers a significant positive relationship. Through robustness analysis incorporating firm-specific, industry, and provincial fixed effects, and addressing endogeneity with the GMM IV approach, the research confirms the robustness of its findings. It further explores the interplay of socio-political theories, particularly focusing on how stakeholder and legitimacy theories shape firm responses to economic uncertainties. The research reveals that firms with higher CSR engagement and greater demands for legitimacy are more likely to intensify their green innovation disclosures in response to oil price volatility. This study not only enriches the discourse on how corporations navigate economic volatility and environmental sustainability challenges but also sheds light on the nuanced role of internal governance structures and external societal pressures in influencing firm sustainability practices. By integrating stakeholder and legitimacy theories, the research offers profound insights into the motivations behind firm sustainability strategies and the strategic importance of managing stakeholder relations and societal legitimacy in contemporary business practices.

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Table 1. Descriptive statistics

	N	mean	sd	min	p25	p50	p75	max
OILVOL	24,792	0.316	0.104	0.169	0.240	0.301	0.441	0.551
OILVAR	24,792	0.008	0.002	0.005	0.006	0.007	0.008	0.013
GInoDis	24,792	0.281	0.470	0.000	0.000	0.000	0.667	2.000
MTB	24,792	3.889	2.100	1.504	2.355	3.279	4.751	9.392
Growth	24,792	0.117	0.331	-0.937	-0.027	0.101	0.241	1.572
ROA	24,792	0.059	0.156	-0.870	0.027	0.070	0.122	0.406
Size	24,792	22.100	1.283	19.540	21.190	21.940	22.840	26.060
Lev	24,792	0.449	0.210	0.054	0.283	0.445	0.609	0.914
Cash	24,792	0.154	0.121	0.008	0.068	0.120	0.201	0.618
RDSales	24,792	0.003	0.012	0.000	0.000	0.000	0.000	0.087
Board	24,792	2.142	0.199	1.609	1.946	2.197	2.197	2.708
Indep	24,792	0.374	0.053	0.333	0.333	0.333	0.429	0.571
Big410	24,792	0.513	0.500	0.000	0.000	1.000	1.000	1.000
Top1	24,792	0.351	0.150	0.087	0.232	0.331	0.452	0.748
SOE	24,792	0.412	0.492	0.000	0.000	0.000	1.000	1.000
Marketbeta	24,792	1.050	0.139	0.775	0.939	1.014	1.186	1.305

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 2019 (24,792 observations). Detailed definitions of variables are presented in Appendix A.

Table 2. Pairwise Pearson correlation coefficients

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1)	*OILVOL*	1														
(2)	*OILVAR*	0.825***	1													
(3)	*MTB*	0.113***	0.184***	1												
(4)	*Growth*	-0.046***	-0.037***	0.001	1											
(5)	*ROA*	-0.031***	-0.013**	-0.139***	0.308***	1										
(6)	*Size*	-0.033***	-0.009	-0.103***	0.067***	0.125***	1									
(7)	*Lev*	0.044***	0.022***	0.465***	0.018***	-0.200***	0.451***	1								
(8)	*Cash*	-0.047***	-0.017***	-0.103***	0.028***	0.176***	-0.211***	-0.391***	1							
(9)	*RDSales*	-0.020***	-0.009	0.013**	-0.005	-0.031***	-0.016**	-0.089***	0.035***	1						
(10)	*Board*	0.023***	0.01	-0.026***	0.007	0.050***	0.235***	0.144***	-0.030***	-0.045***	1					
(11)	*Indep*	-0.023***	-0.013**	0.019***	-0.005	-0.031***	0.023***	-0.007	0.001	0.026***	-0.506***	1				
(12)	*Big410*	-0.115***	-0.070***	-0.037***	0.005	0.042***	0.148***	-0.021***	-0.005	0.032***	0.003	0.017***	1			
(13)	*Top1*	-0.009	-0.012*	-0.080***	0.034***	0.145***	0.216***	0.042***	0.036***	-0.078***	0.023***	0.041***	0.069***	1		
(14)	*SOE*	0.066***	0.039***	0.059***	-0.052***	-0.023***	0.295***	0.271***	-0.063***	-0.068***	0.262***	-0.062***	-0.022***	0.210***	1	
(15)	*Marketbeta*	-0.004	-0.056***	0.087***	0.002	0.058***	-0.169***	0.097***	0.064***	-0.068***	0.123***	-0.063***	-0.169***	0.069***	0.165***	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.

Table 3. Baseline regression

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.206***	
	(8.697)	
OILVAR		9.174***
		(8.420)
MTB	0.000	-0.001
	(0.124)	(-0.542)
Growth	-0.048***	-0.048***
	(-6.367)	(-6.398)
ROA	0.028	0.028
	(1.267)	(1.277)
Size	0.142***	0.140***
	(23.831)	(23.659)
Lev	-0.199***	-0.187***
	(-5.931)	(-5.547)
Cash	-0.079**	-0.084**
	(-2.322)	(-2.450)
RDSales	-0.612	-0.610
	(-1.623)	(-1.616)
Board	0.068**	0.069**
	(2.256)	(2.277)
Indep	0.223**	0.224**
	(2.143)	(2.146)
Big410	0.042***	0.041***
	(4.859)	(4.735)
Top1	0.011	0.011
	(0.323)	(0.333)
SOE	0.073***	0.074***
	(5.901)	(5.985)
Marketbeta	-0.087***	-0.082***
	(-3.068)	(-2.914)
Constant	-3.005***	-2.980***
	(-18.848)	(-18.849)
Industry FE	Yes	Yes
Observations	24792	24792
Adjusted R-squared	0.198	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 firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 4. Robustness test: Controlling for firm fixed effects

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.038*	
	(1.826)	
OILVAR		3.341***
		(3.575)
MTB	-0.006***	-0.008***
	(-3.674)	(-4.217)
Growth	-0.033***	-0.033***
	(-5.054)	(-4.998)
ROA	-0.008	-0.007
	(-0.416)	(-0.409)
Size	0.092***	0.092***
	(12.652)	(12.711)
Lev	-0.052	-0.043
	(-1.533)	(-1.260)
Cash	-0.045	-0.046
	(-1.437)	(-1.495)
RDSales	-0.175	-0.174
	(-0.396)	(-0.395)
Board	-0.045	-0.044
	(-1.322)	(-1.320)
Indep	0.039	0.041
	(0.364)	(0.382)
Big410	0.029***	0.029***
	(3.419)	(3.515)
Top1	-0.092*	-0.093*
	(-1.819)	(-1.857)
SOE	0.011	0.010
	(0.547)	(0.531)
Marketbeta	-0.201***	-0.197***
	(-7.287)	(-7.178)
Constant	-1.407***	-1.411***
	(-6.975)	(-7.088)
Firm FE	Yes	Yes
Observations	24627	24627
Adjusted R-squared	0.468	0.468

This table presents the robustness test, controlling for firm fixed effects. *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.

Table 5. Robustness test: Controlling for industry and province fixed effect

	(1)	*(2)*
	GInoDis	*GInoDis*
OILVOL	0.198***	
	(8.408)	
OILVAR		8.875***
		(8.171)
MTB	0.000	-0.001
	(0.198)	(-0.471)
Growth	-0.049***	-0.049***
	(-6.501)	(-6.529)
ROA	0.029	0.029
	(1.353)	(1.366)
Size	0.140***	0.139***
	(23.948)	(23.784)
Lev	-0.194***	-0.182***
	(-5.890)	(-5.503)
Cash	-0.086**	-0.091***
	(-2.521)	(-2.648)
RDSales	-0.714*	-0.714*
	(-1.863)	(-1.859)
Board	0.071**	0.072**
	(2.406)	(2.424)
Indep	0.239**	0.239**
	(2.329)	(2.330)
Big410	0.040***	0.039***
	(4.633)	(4.501)
Top1	0.005	0.006
	(0.156)	(0.166)
SOE	0.076***	0.077***
	(6.071)	(6.151)
Marketbeta	-0.088***	-0.084***
	(-3.140)	(-2.993)
Constant	-2.978***	-2.953***
	(-18.890)	(-18.888)
Industry FE	Yes	Yes
Province FE	Yes	Yes
Observations	24785	24785
Adjusted R-squared	0.209	0.209

This table presents the robustness test, controlling for industry and province fixed effects. *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.

Table 6. Robustness test: Controlling for *EPUbeta*

	(1) *GInoDis*	(2) *GInoDis*
OILVOL	0.215***	
	(9.143)	
OILVAR		9.155***
		(8.404)
MTB	-0.000	-0.001
	(-0.044)	(-0.618)
Growth	-0.049***	-0.049***
	(-6.522)	(-6.525)
ROA	0.029	0.027
	(1.318)	(1.245)
Size	0.141***	0.140***
	(23.201)	(23.107)
Lev	-0.195***	-0.186***
	(-5.782)	(-5.511)
Cash	-0.079**	-0.085**
	(-2.333)	(-2.511)
RDSales	-0.616	-0.611
	(-1.634)	(-1.618)
Board	0.070**	0.069**
	(2.304)	(2.274)
Indep	0.224**	0.223**
	(2.153)	(2.139)
Big410	0.042***	0.041***
	(4.905)	(4.794)
Top1	0.014	0.013
	(0.410)	(0.376)
SOE	0.073***	0.074***
	(5.915)	(5.959)
EPUbeta	0.351***	0.280***
	(3.598)	(2.863)
Constant	-3.078***	-3.058***
	(-20.620)	(-20.583)
Industry FE	Yes	Yes
Observations	24792	24792
Adjusted R-squared	0.198	0.198

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 firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 7. Endogeneity test: IV GMM test

	First stage		Second stage		
	OILVOL	*OILVAR*	*GInoDis* (1)	*GInoDis* (2)	*CEP index* (3)
GPR4c	0.111***	0.004***			
	(24.37)	(46.46)			
Fitted_ OILVOL			0.308**		
			(1.81)		
Fitted_ OILVAR				9.414*	
				(1.82)	
Constant	–0.000	–0.049	–0.622***	–0.624***	–0.623***
	(–0.004)	(–1.513)	(–10.013)	(–10.037)	(–10.026)
Controls	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Observations	24,792	24,792	24,792	24,792	24,792
Adjusted R^2	0.680	0.664	0.713	0.714	0.714
Cragg-Donald Wald F statistic	593.875	2158.801			
Kleibergen-Paap Wald rk LM statistic	579.126***	1557.367***			

This table presents the endogeneity test using IV GMM estimation, following Deng & 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. *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.

Table 8. Heterogeneity test: The moderating effect of CSR

	High CSR		Low CSR	
	(1)	(2)	(3)	(4)
	GInoDis	*GInoDis*	*GInoDis*	*GInoDis*
OILVOL	0.110***		0.035	
	(2.630)		(1.016)	
OILVAR		11.437***		-0.956
		(5.965)		(-0.713)
Constant	-3.329***	-3.343***	-1.797***	-1.784***
	(-16.530)	(-17.370)	(-10.578)	(-10.487)
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	10436	10436	14066	14066
Adjusted R^2	0.262	0.264	0.184	0.184

This table divides the sample into high CSR and low CSR sub-samples based on the median value of CSR scores. The measurement of CSR is the Hexun CSR index adjusted for industry. *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.

Table 9. Heterogeneity test: The moderating effect of ISO environmental certification

	With ISO14001		Without ISO14001	
	(1)	(2)		
	GInoDis	*GInoDis*	*GInoDis*	*GInoDis*
OILVOL	0.579***		0.024	
	(7.119)		(1.195)	
OILVAR		23.706***		1.085
		(6.734)		(1.145)
Constant	-3.692***	-3.650***	-2.660***	-2.656***
	(-10.920)	(-10.842)	(-17.012)	(-17.133)
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	4724	4724	19985	19985
Adjusted R^2	0.221	0.220	0.196	0.196

This table divides the sample into two sub-samples based on whether firms have obtained ISO14001 certification. Firms certified with ISO14001 face greater legitimacy demands because ISO14001 is an international standard that specifies requirements for an effective environmental management system. *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.

Table 10. Heterogeneity test: The moderating effect of political connection

	With connection		Without connection	
	(1)	(2)		
	GInoDis	*GInoDis*	*GInoDis*	*GInoDis*
OILVOL	0.215***		0.098	
	(8.468)		(1.404)	
OILVAR		9.479***		5.280
		(8.123)		(1.629)
Constant	-3.002***	-2.976***	-2.827***	-2.818***
	(-18.053)	(-18.031)	(-6.318)	(-6.390)
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	22400	22400	2390	2390
Adjusted R^2	0.197	0.197	0.210	0.210

This table divides the sample into two sub-samples based on whether the chairman has previously worked in the government sector. *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.

Appendix A: Variable description

Variable	Description
Dependent variables	
OILVOL	According to Yang & Song (2023), OILVOL is measured by the standard deviation of daily oil price returns for one year.
OILVAR	According to Yang & Song (2023), OILVAR is measured by the average of the daily conditional variance from the GARCH (1,1) model for one year.
Independent variable	
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.
Control variables	
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 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.
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.
Marketbeta	Based on monthly data, the annual market risk exposure of a firm is calculated through the FAMA three-factor model.
Instrumental variable	
GPR4c	According to Deng & 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.

Alternative independent variable	
OILVARE	OILVARE is measured by the average of the daily conditional variance from the EGARCH (1,1) model for one year.

Appendix B: Redo baseline using EGARCH

	GInoDis
OILVARE	8.075***
	(7.246)
Constant	-3.011***
	(-18.740)
Controls	Yes
Industry FE	Yes
Observations	24792
Adjusted R-squared	0.197

We recalculated our main independent variable *OPU*, denoted as *OILVARE*, using the EGARCH model. *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.