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Energy transition policy, cash flow uncertainty and R&D expenditures of energy enterprises

Yuyin Ma[1] · Shuai Lu[1] · Shouwei Li[1]

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Abstract
To cope with risks of increasing climate changes and curb carbon emission, various policies have been implemented to facilitate energy transition in China. However, it remains unclear that whether the cash flow of energy enterprises is affected by energy transition policy and whether they invest more on R&D activities to transition. To answer these questions, we utilize a difference-in-differences method to detect the impact of the Peaking-Carbon-Dioxide-Emissions policy on the cash flow uncertainty of the energy enterprises and examine the interaction between it and R&D expenditures by using the sample of listed energy enterprises in China during 2008–2021. We find that the energy transition policy has a positive effect on the cash flow uncertainty of the energy enterprises, and the higher cash flow uncertainty after the policy further decreases the R&D expenditure of the energy enterprises. We also find that this negative role of the cash flow uncertainty is partially conducted by the reduction proportion of the long-term loan. In addition, the over-valued enterprises have stronger incentives to squeeze the expenses of R&D activities. Last, we capture the heterogeneity that the energy enterprises with less political connections and in more developed areas prefer prudent strategy management to maintain their investments in R&D activities.

Keywords Energy transition policy · Cash flow uncertainty · R&D expenditures · Difference in differences approach

✉ Shuai Lu
youwin_lushuai@163.com

Yuyin Ma
3062686534@qq.com

Shouwei Li
lishouwei@seu.edu.cn

1 School of Economics and Management, Southeast University, Nanjing 211189, People's Republic of China

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1 Introduction

The energy industry has been considered as an essential factor in influencing economic growth for decades, and when energy is scarce it imposes a strong constraint on the growth of the economy. However, in China, energy used per unit of economic output has declined, owing to both technological change and a shift from poorer-quality fuels, such as coal, to the use of higher-quality fuels (Stern, 2011). Moreover, the overuse of traditional energy could lead to global warming and environmental pollution (Ren et al., 2020). Therefore, the primary goal of economic development in China is shifting from boosting traditional energy to exploiting various new energies, decreasing carbon emissions and enhancing the transition of traditional energy.[1]

In recent years, two energy transition policies have been implemented, the "Peaking carbon dioxide emissions" policy (PCDEP) and the "Achieving carbon neutrality" policy (ACNP). Compared to the latter policy, the PCDEP was issued earlier and designed to strive for the goal of peaking carbon dioxide emissions before 2030. The PCDEP specifically stipulates the work plan for various sectors. Among them, the energy industry will bear the brunt of provisions[2] in the PCDEP due to its thorough reform of energy use and transition.[3] However, support for the traditional energy sector may be limited because efforts to support climate-aligned financing have primarily focused on "pure green" and near "pure green" activities.[4] Regarding cash flow, it seems that energy enterprises experienced a significant increase of cash flow uncertainty in 2017 following a drop after 2017 compared to non-energy enterprises, as shown inFig. 1.[5] Note that energy enterprises maintain a relatively higher level of cash flow uncertainty after the PCDEP. For energy enterprises, their transition process, which requires a significant amount of innovation, would not be successfully implemented if there is a funding interruption. According to Fig. 2, energy enterprises experienced a significant decrease in cash flow uncertainty in 2017, followed by a slight increase after 2017 compared to non-energy enterprises. Moreover, energy enterprises maintain a relatively lower level of R&D expenditures after the PCDEP. This prompts us to investigate whether the PCDEP has a positive impact on the cash flow uncertainty of energy enterprises. It motivates us to investigate whether the PCDEP has a positive impact on the cash flow uncertainty of energy enterprises and how this effect affects the R&D activities of energy companies.

[1] To cope with increasing catastrophe risks from climate change, governments worldwide have been pushing for various forms of regulations to curb carbon emissions (Bartram et al., 2022). As one of the co-signatories in the Paris Agreement, China is taking responsibility for its commitment to promote low-carbon transition, curb greenhouse gas emissions and improve energy use efficiency (Chang et al., 2019; Lin & Wang, 2020).

[2] The PCDEP highlights the importance of "low-carbon leading the energy revolution" in the first section after the summary section, which can be seen at http://www.gov.cn/zhengce/content/2016-11/04/content_5128619.htm.

[3] Despite some recent studies on the benefits of the peaking carbon dioxide emission policy (Li & Yu, 2019; Tang et al., 2022), there is an increasing number of studies that devote to penetrating the challenges of enterprises under the transition pressure, such as the declines to established business models and technologies (Markard, 2018), the inequity problems in energy transition (Carley & Konisky, 2020), and the inefficiency of energy transition (González & Rendon, 2022).

[4] It is reported by the 2020 G20 Sustainable Finance Report. It is available from https://g20sfwg.org/wp-content/uploads/2022/10/2022-G20-Sustainable-Finance-Report-2.pdf.

[5] Related data and measurement of cash flow uncertainty can be seen in Sect. 2 and Sect. 3.

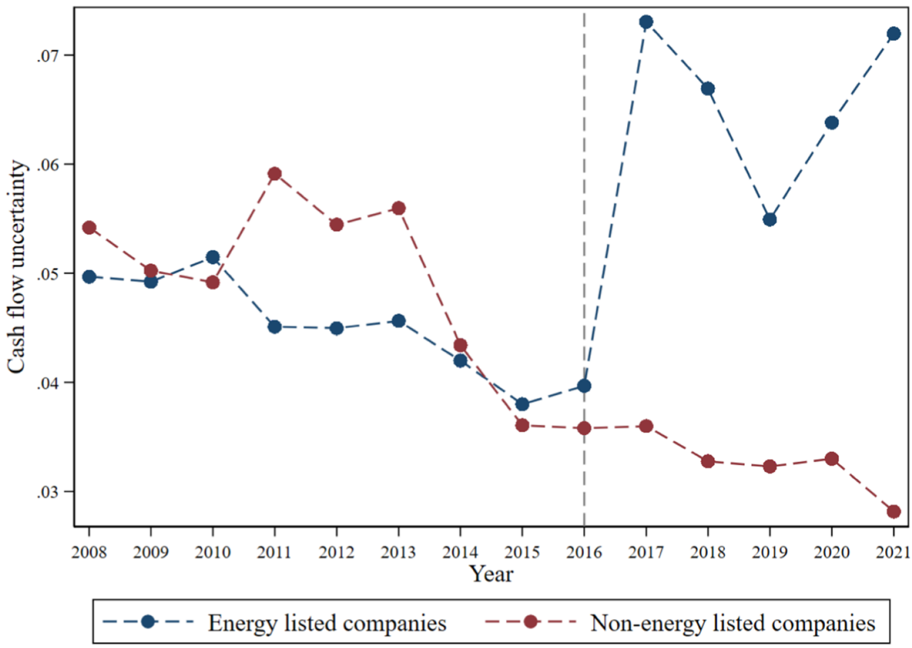

Fig. 1 The cash flow uncertainty of the energy and non-energy enterprises around the PCDEP (As emphasized in previous literature, the treated and control groups should follow the parallel trend before the policy enactment to ensure a reliable comparison between them (Abadie, 2005; Goodman, 2021). Based on our aim to recognize the changes in cash flow uncertainty and R&D expenditures of energy enterprises after the policy, we consider the energy listed enterprises and non-energy listed enterprises as the treated and control groups, respectively, and then compare the changes in their *RDEX* prior to and after the policy.)

The motivation behind this study stems from observing that energy enterprises experienced a significant increase in cash flow uncertainty after the PCDEP, followed by a decrease, yet maintaining a relatively higher level of uncertainty compared to non-energy enterprises. In China's financial market, significant "ownership discrimination" and "scale discrimination" exist (Brandt & Li, 2003), imposing more severe financing constraints on Chinese energy firms compared to those in developed countries. In developing economies, where financial markets are often not fully mature, enterprises frequently face heightened challenges in securing funding, particularly for innovative projects with uncertain returns. These difficulties are further exacerbated by environmental policy shifts, where the demand for investment in sustainable technologies and practices may not align with the available financial resources. This misalignment strains cash flows and necessitates cautious financial management. This motivates us to investigate whether the PCDEP positively affects the cash flow uncertainty of energy enterprises and how this uncertainty affects R&D activities.

This study significantly advances our understanding of the intricate dynamics between energy transition policies and their economic implications for the energy sector, particularly through the lens of China's Peaking-Carbon-Dioxide-Emissions Policy (PCDEP). By delving into the nuanced impacts of this policy on cash flow uncertainty and R&D investment among energy enterprises, the research illuminates several critical areas of interest for a diverse range of stakeholders: first, the research provides invaluable policy

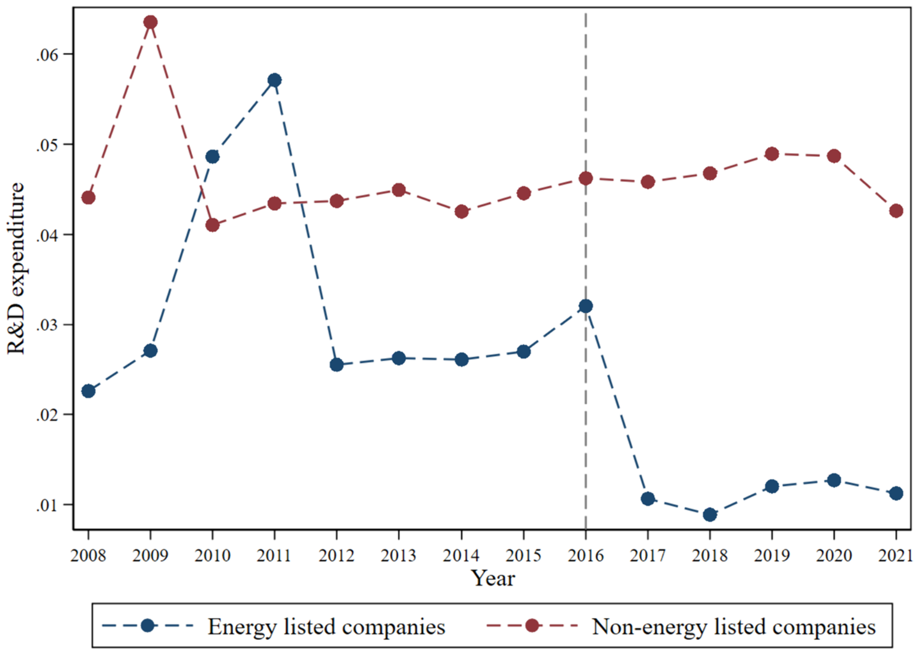

Fig. 2 The R&D expenditures of the energy and non-energy enterprises around the PCDEP

insights, elucidating the direct and indirect effects of the PCDEP on the financial stability and strategic direction of energy companies. Understanding the financial repercussions of the PCDEP enables a more informed approach to future environmental regulation, potentially guiding the development of policies that achieve environmental objectives without undermining financial stability. Second, the findings offer a rich source of information for investors by highlighting the risks and opportunities presented by the evolving policy landscape. In particular, the study draws attention to the heightened cash flow uncertainty faced by energy enterprises in the wake of the PCDEP, a factor of paramount importance for investment decisions. Furthermore, the research serves as a strategic tool for energy companies themselves, equipping them with the knowledge needed to navigate the financial challenges posed by stringent environmental policies. By understanding the relationship between policy-induced financial instability and the allocation of resources to R&D, energy enterprises can make more strategic decisions regarding their innovation efforts and technology development initiatives. This contribution is especially relevant against the backdrop of China's unique financial market characteristics and the global push towards sustainable energy solutions.

In this paper, we explore the PCDEP impact on cash flow uncertainty, and the subsequent effect of this uncertainty on the R&D investments of energy enterprises in China. The PCDEP creates a unique context for examining how energy enterprises react to both the policy shock and alterations in their financial status. It penetrates the possible dilemma between accelerated technical transformation and safe financial status for energy enterprises after the policy. To conduct this empirical analysis, we employ a difference-in-differences model by using the data of all the energy listed enterprises and a control group of non-energy enterprises in China, spanning 2008–2021, from the Wind database and the CSMAR database. The control group covers all the non-energy-industry enterprises in the industries that are not mentioned in the regulatory provisions of the PCDEP. We first investigate the changes in the cash flow uncertainty of the energy enterprises after the policy. Our results exhibit that the enactment of the PCDEP leads to a stubbornly high cash flow uncertainty of the energy enterprises compared to the non-energy enterprises. We then detect how the enterprises respond to the post-policy cash flow changes. Our results indicate a significant retrenchment of the R&D investments of energy firms due to the post-PCDEP cash flow uncertainty effect. This confirms our hypothesis about the dilemma faced by energy enterprises: confronted with a credit crunch and increased cash flow uncertainty post-policy, energy enterprises tend to slow down their investment in energy transition projects, opting instead for more conservative strategies that limit R&D investments.

Next, we look in-depth into the economic mechanisms for our results and find that the post-policy cash flow uncertainty effect is mediated by the more restrictive long-term debt financing of energy enterprises after the policy. We also show that over-valued and bubbled enterprises reduce RDEX to ensure their liquidity more than others due to the negative post-PCDEP cash flow uncertainty effect. In terms of ownership and economic environment, we find that SOE energy enterprises are more likely to obtain financial support from the government and have more confidence in investing in long-term activities such as RDEX. In contrast, the non-SOE ones may adjust their investments by substituting activities with short payback periods for the RDEX. Besides, the post-PCDEP cash flow uncertainty has a negative effect on the RDEX of the energy enterprises both in more developed and less developed areas with a greater impact on that of the less developed areas.

We use a series of robustness checks to examine the sensitivity of our empirical results. The results remain robust when we employ the propensity score matching (PSM) approach to mitigate concerns about the potential endogeneity of sample selection bias. Results also remain similar when we take equity concentration into consideration. We use an alternative measure of RDEX, the ratio of RDEX and capital expenditure, to replace it, and the results remain similar to baseline regressions. We also find similar results by employing the ordinary least square model to replace the fixed effect model. Additionally, we conduct a placebo test by randomly altering the treatment point, and the conclusions remain robust.

The remainder of this paper is arranged as follows. Section 2 introduces the energy-related regulations in the PCDEP policy and the data. Section 3 demonstrates the methodology of the difference-in-difference analysis as well as the variable construction. Section 4 shows the main empirical results, including the impact of the PCDEP on the cash flow uncertainty of the energy enterprises, the interaction effect between the cash flow uncertainty and the policy on R&D expenses of the enterprises, the mechanism analysis, and a series of robustness checks. Section 5 concludes this paper.

2 Literature review, the policy and hypotheses

2.1 Literature review

Energy transition policy is pivotal in shifting from fossil fuel-based systems to sustainable and renewable energy sources. Existing studies mainly focus on the implementation challenges of energy transition policies, financing and investment impacts, socio-economic implications.

Implementing energy transition policies to achieve sustainability goals presents significant challenges. The Dutch energy transition policy exemplifies efforts to balance long-term sustainability with short-term market competitiveness. This balance is often difficult to achieve due to entrenched interests and the substantial investments required for new technologies. The policy emphasizes the need for structural changes in the energy system, driven bccultural, and institutional factors (Jansen, 2020; Kern & Smith, 2008); ; ; ; ; ; ; ; . Similar barriers are noted in other regions, such as Berlin, where grassroots initiatives struggle to influence local energy policy-making against established interests (Becker & Naumann, 2017). In Mexico, efforts to integrate climate and energy policies highlight the complexity of aligning sectoral goals and overcoming institutional fragmentation (Von Lüpke & Well, 2020).

The uncertainty surrounding energy transition policies significantly affects financing decisions and investments in sustainable technologies. The policy-making process has led to hesitant investments in long-term projects due to policy uncertainty (Becker & Naumann, 2017). High initial costs and uncertain returns on investments in renewable technologies pose substantial financial risks. The maturity of financial markets is crucial for supporting these investments, as they can better handle the financial strain of transitioning to sustainable energy systems (Carley & Konisky, 2020). Additionally, the justice and equity implications of the clean energy transition highlight the need for inclusive financing strategies that consider the socio-economic diversity of affected populations (Carley & Konisky, 2020).

The socio-economic implications of energy transition policies are profound, affecting employment and economic stability. The transition to renewable energy in the Netherlands has led to both challenges and opportunities in the labor market, requiring policies that support retraining and job creation in new sectors (Jansen, 2020). The clean energy transition impacts energy prices and accessibility, which can affect both businesses and consumers. Sovacool (2021) discusses the importance of historical, strategic, and economic perspectives on these impacts, indicating that while there are opportunities for economic growth, there are also significant socio-economic disruptions to manage. In Mexico, the reform of the energy sector has highlighted the need for integrated policy approaches to address both economic and environmental goals (Von Lüpke & Well, 2020). Furthermore, Heffron et al. (2020) discuss the broader economic implications of clean energy transitions and the need for strategic policy frameworks (Markard, 2018).

Based on the above review, prior studies present evidence that the pre-eminence of the production and consumption of non-renewable fossil fuels has been waning due to the increasing development of renewable energy, while energy transition policies are exerting more uncertainty and evolving changes to traditional energy markets (Erin Bass & Grøgaard, 2021; Pegels & Lütkenhorst, 2014). The crucial elements of an effective energy transition policy are patience, predictability, credibility, alignment, and documentation of successes. In contrast, an aggressive and steep policy is more likely to give rise to unexpected consequences (Grubler, 2011). Moreover, a series of supporting measures is essential to assist enterprises with a smooth transition when implementing radical reform. Despite the studies regarding various energy transition policies around the world, there is limited research investigating the new energy transition policy that is also climate-related, viz., the PCDEP policy, and the effect of its enactment on the traditional energy industry. Our study contributes to this growing literature that quantifies the effect of energy transition policy on energy industry (Hillman et al., 2018; Pollitt, 2012; Yang et al., 2019). For the energy enterprises stuck in transition problems and the policymakers in China, our investigation of the PCDEP effect on the energy industry timely detects the responses of the energy enterprises and provides practical suggestions for them.

Cash flow uncertainty, a critical factor influencing corporate financial decisions, has been extensively studied in the context of its impact on investment, financing decisions, and capital structure and R&D Innovation (Alessandri et al., 2004; Chay & Suh, 2009; Levitas & McFadyen, 2009; Trigeorgis & Reuer, 2017). It refers to the unpredictability in a firm's cash flow, significantly affecting its strategic financial choices and overall financial health.

Cash flow uncertainty significantly affects corporate financing decisions, including dividend payments and capital raising strategies. Firms with high cash flow uncertainty tend to pay lower dividends due to the fear of future cash shortfalls. Chay & Suh (2009) show that higher cash flow uncertainty negatively impacts both the amount of dividends paid and the likelihood of paying dividends at all. Their findings indicate that firms facing greater uncertainty prefer to conserve cash to avoid financial distress and maintain operational stability (Bates et al., 2009). Additionally, firms might increase their cash holdings to buffer against unexpected shortfalls, affecting their overall capital raising strategies (Brown et al., 2009).

Cash flow uncertainty also profoundly influences a firm's capital structure. Firms facing high cash flow uncertainty tend to reduce their reliance on debt financing due to the increased risk of financial distress and the potential costs of bankruptcy (Jensen, 1986). Instead, these firms might prefer equity financing or retain earnings to maintain financial flexibility (Bates et al., 2009; Brown et al., 2009). Boyle & Guthrie (2003) discuss how liquidity management becomes crucial under conditions of cash flow uncertainty, leading firms to hold more cash reserves to buffer against unexpected shortfalls (Kim & Bettis, 2014).

The relationship between cash flow uncertainty and R&D investment has been debated for a long time. One stream of research supports a positive relationship, arguing that lower current financing costs compared to future costs incentivize firms to invest in R&D now (Gordon & Li, 2003; Maitland & Sammartino, 2015). Conversely, another stream posits that constrained financial conditions lead enterprises to decrease long-term R&D investments due to conservative financial management (Courtney et al., 1997; Kim & Bettis, 2014). Beladi et al. (2021) reveal that higher uncertainty leads to more conservative investment strategies, especially in R&D, which is further exacerbated by financial constraints (Boyle & Guthrie, 2003). Liu et al. (2017) emphasize that cash flow uncertainty can make management more conservative and prudent, highlighting its dual role in influencing corporate R&D activities. However, despite the two streams of studies, few studies focus on the possible interaction effect between an external policy shock and the cash flow uncertainty on corporate strategic management. Our study also contributes to the extensive literature on cash flow uncertainty and investment management (Alessandri et al., 2004; Levitas & McFadyen, 2009; Trigeorgis & Reuer, 2017). Accordingly, we attempt to shed light on the post-policy cash flow uncertainty effect on the changes in R&D expenses of energy listed enterprises in the context of the enactment of the PCDEP.

2.2 The policy

On October 27th, 2016, to achieve the stated ambition of deepening participation in global climate governance, the government of China formulated and enacted the "Notice of The State Council on the issuance of the 13th Five-Year Plan for the Control of Greenhouse Gas Emissions". In this notice, it clearly demonstrates that "This work program is formulated to accelerate the promotion of green and low-carbon development, ensure the completion of the low-carbon development goals and tasks determined by the "13th Five-Year Plan" outline, and promote China's carbon dioxide emissions to peak around 2030 and strive to reach the peak as soon as possible" in the first leading paragraph. According to the requirement of this notice, it could be seen as the China's first Peaking-Carbon-Dioxide-Emissions policy (PCDEP) after the Paris Agreement.[6]

Even though the PCDEP was enacted after the Paris Agreement, which was co-signed in the same year, the PCDEP is a more practical policy to regulate the emission of greenhouse gases from related sectors and to enforce the transition to more efficient energy use. It also proposes an explicit goal of "peaking carbon dioxide emissions before 2030" for the entire nation. In terms of specific provisions, the PCDEP includes numerous regulations on energy consumption and energy transition. For example, it mandates the following requirements:

- By 2030, energy consumption per unit of GDP should decrease by over 15% compared to 2015 levels, and traditional energy consumption should be kept below 75%.
- Carbon dioxide emissions per unit of industrial added value should decrease by 22%.
- Major sectors such as energy, industry, and agriculture must expedite the development and application of low-carbon technologies.
- Increased use of clean and renewable energy is encouraged in transportation and urban–rural construction.

These provisions convey the Chinese government's determination to support energy transition and curb the traditional energy industry. Predictably, the enactment of the PCDEP may exert a significant effect on the future development trends of the energy industry, influencing R&D activities, financing constraints, and cash flow stability. This inspires us to investigate the effect of the PCDEP on the cash flow performance and R&D expenditures of energy enterprises.

2.3 Research hypothesis

In the context of an increasingly volatile global economic landscape, the intersection of environmental policy and corporate finance has emerged as a pivotal area of study. The role of government regulations, particularly in the realm of environmental protection, has become more pronounced, influencing not only the operational aspects of businesses but also their financial health and strategic decisions. This paper seeks to delve into the theoretical underpinnings of how environmental policies, specifically the Peaking-Carbon-Dioxide-Emissions Policy (PCDEP) in China, exert influence on the financial dynamics of energy enterprises.

Extant theoretical frameworks suggest that policy-induced environmental regulations can serve as a double-edged sword for businesses (Herman & Xiang, 2019; Lee et al., 2011). On one hand, they drive the adoption of sustainable practices and technologies, potentially leading to long-term benefits such as operational efficiencies, access to new markets, and improved public image (Ortiz-de-Mandojana & Bansal, 2016). On the other hand, the immediate ramifications of complying with stringent policies often manifest in

[6] The detailed policy can be seen on the China's government website at http://www.gov.cn/zhengce/content/2016-11/04/content_5128619.htm.

the form of increased operational costs, higher capital expenditures for green technology adoption, and a consequent impact on cash flow stability (Qian et al., 2023). The dynamic tension between these short-term challenges and long-term opportunities forms the crux of our analysis. Furthermore, the concept of policy uncertainty adds another layer of complexity to this scenario. The unpredictable nature of policy environments, especially concerning environmental regulations, can significantly amplify cash flow uncertainty. This is particularly pertinent in the energy sector, which is at the forefront of policy-induced transformations due to its substantial environmental footprint. The uncertainty surrounding the enactment and specifics of policies like the PCDEP can lead to hesitant investment in long-term projects, including R&D, due to fears of regulatory non-compliance or shifts in policy direction.

Recent studies have provided empirical evidence of the impact of the external environment and policy uncertainty on cash flow performance (Baum et al., 2010; Beladi et al., 2021; Liao et al., 2021; Nnadi et al., 2022; Wang et al., 2023). Li et al. (2023) identified the relationship between trade policy uncertainty and energy firms' cash flow holdings and financial investments. Lee et al. (2023) explored how the interplay between climate risks and cash flow can affect corporate cash holdings. However, research on the impact of the PCDEP on energy enterprises is relatively scarce. As a significant reform of carbon emission regulations, the PCDEP is expected to intensify the transition pressure and increase the cost of financing for energy enterprises. Requirements for carbon emission disclosure and the development of green technology could pose additional challenges to the production and operation of energy enterprises (Cheng & Feng, 2023), leading to a decline in solvency and a deterioration of the balance sheet. This suggests less stable cash flows for energy enterprises following the policy implementation.

Based on the above analysis, we pose the following research question:

Research question 1 Does the Peaking-Carbon-Dioxide-Emissions policy increase cash flow uncertainty for energy enterprises in China?

Previous empirical studies have shown a strong association between cash flow uncertainty and R&D investment. There are two competing views on the relationship between cash flow uncertainty and R&D investment. The first supports a positive association, suggesting that enterprises are more likely to invest more in advance to save on potentially higher future financing costs (Almeida et al., 2011; Hirth & Viswanatha, 2011). The other argues that enterprises with higher cash flow uncertainties are more inclined to adopt prudent financial management, meaning they tend to limit R&D expenses and other investments with long payback periods (Lee et al., 2023; Li et al., 2023). These studies, however, mainly focus on developed countries and pay less attention to developing countries with less mature financial markets. In developing countries like China, enterprises face higher risks during R&D activities due to an imperfect financial market and are more likely to encounter information asymmetry, moral hazard, and adverse selection. This leads to challenges in obtaining external financing and a higher dependence on cash flow for R&D activities. Enterprise innovation faces strong financial constraints and high uncertainty (Liu et al., 2017). Enterprises need ample and stable funds from the initiation to the completion of research and development activities (Beladi et al., 2021). For energy enterprises, their transition process, which requires a significant amount of innovation, would not be successfully implemented if there is a funding interruption. Based on the theoretical analysis, we pose the following question:

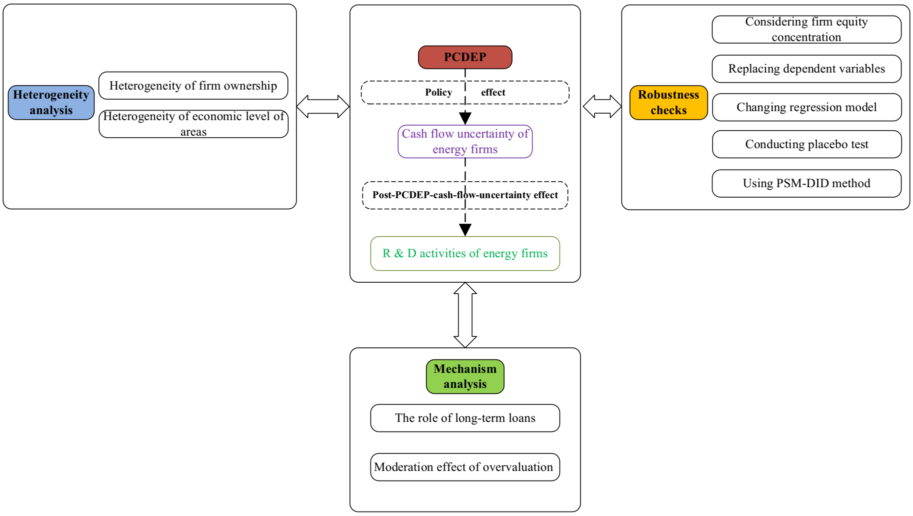

Fig. 3 Mechanisms for the PCDEP effect on the cash flow uncertainty and its effect on R&D activities of energy firms

Research question 2 Do the changes in cash flow uncertainty after the PCDEP further squeeze R&D expenditures of energy enterprises in China?

Based on the above analysis, the PCDEP can theoretically increase the cash flow uncertainty of energy firms and restrain the R&D activities of them. Figure 3 demonstrates the mechanism of PCDEP effect on the cash flow uncertainty of energy firms and the post-PCDEP effect on R&D expenditures of energy firms.

3 Methodology and data

3.1 Difference-in-differences approach

The primary objective of this study is to investigate the impact of the Peaking-Carbon-Dioxide-Emissions Policy (PCDEP) on the cash flow uncertainty and subsequent R&D expenditures (RDEX) of energy enterprises in China. To achieve this, we need a method that can effectively differentiate between the effects of the policy on the treatment group (energy enterprises) and the control group (non-energy enterprises) while controlling for other factors that might influence both groups simultaneously.

Difference-in-differences (DID) is the most prevalent and oldest quasi-experimental research design, with its origins tracing back to the study of Snow (1855) on a cholera outbreak in London. The DID estimate represents the difference in the changes of outcomes before and after the intervention between the treatment group and the control group, which could be described as $(y_{Post\_Treat} - y_{pre\_Treat}) - (y_{Post\_Control} - y_{Pre\_Control})$. This measure is also reflected in the estimated coefficient of the interaction term between a treatment group indicator and a post-treatment period indicator in the following regression model (Goodman-Bacon, 2021):

$$y_{i,t} = \partial_0 + \partial_1 Treat + \partial_2 Post + \partial_3 Treat * Post + u_{it}$$

The DID estimate makes it clear which comparisons generate the estimate and what leads to bias. The formulation using sample means links the regression analysis to potential outcomes, demonstrating that, under the assumption of common trends, an interaction term DID described as $Treat * Post$ identifies the average treatment effect on the treated (Goodman-Bacon, 2021).

The DID approach is tailored for this analysis for the following reasons. First, it can control for omitted trends. The DID method controls for omitted variable bias by accounting for trends that could influence both the treatment and control groups simultaneously, ensuring that the observed effects are attributable to the policy intervention; Second, it allows us to recognize the dynamic adjustment. This method allows us to capture the dynamic adjustments enterprises make in their investment strategies, particularly in key strategic resources like RDEX, before and after the policy enactment; Third, it allows us to analyze exogenous event. By introducing an exogenous policy event, the DID approach helps us understand how external shocks influence corporate financial behavior under unusual conditions, such as forced investment adjustments due to unexpected regulatory changes. Therefore, we adopt a DID approach to examine RDEX changes of the energy enterprises after the PCDEP due to their cash flow uncertainty changes.

3.2 Model specifications

Based on the actual issuing date, henceforth, we consider 2016 as the policy point. Then 2008–2015 are the years before the policy, and 2017–2021 are the years after the policy. The treatment group consists of all the energy enterprises, and the control group consists of all the non-energy enterprises. Specifically, we carry out a series of progressive estimations to examine the effect of the PCDEP, which are shown as follows:

$$\begin{aligned} CFROSD = & \beta_0 + \beta_1 PCDEP + \beta_2 ENERGY + \beta_3 POST\_ENERGY \\ & + \sum Controls + YEARFE + FIRMFE + \varepsilon \end{aligned} \quad (1)$$

$$\begin{aligned} RDEX = & \gamma_0 + \gamma_1 PCDEP + \gamma_2 ENERGY + \gamma_3 POST\_ENERGY + \gamma_4 CFROSD \\ & + \gamma_5 POST\_ENERGY\_CFROSD + \sum Controls + YEARFE + FIRMFE + \varepsilon \end{aligned} \quad (2)$$

where Model (1) further runs a difference-in-differences regression to examine the effect of the PCDEP on cash flow uncertainty *CFROSD* of the energy enterprises compared to the enterprises of the control group; Model (2) estimate the interaction effect of *CFROSD* and the DID estimator on the RDEX of the energy enterprises. *RDEX* denotes the total expenses on R&D activities divided by the total revenue. *CFROSD* denotes the cash flow uncertainty, proxied by the rolling standard deviation of cash flows from operations. *PCDEP* denotes the dummy variable of the policy. It equals to 1 if the year is after 2016, otherwise, it equals to 0. *ENERGY* denotes the dummy variable of the treatment. It equals to 1 if the firm is energy enterprise, otherwise it equals to 0. Then, *POST_ENERGY* denotes the DID estimator, which is the first core independent variable that is equivalent to *ENERGY* times *PCDEP*. *POST_ENERGY_CFROSD* denotes the interaction variable of

CFROSD and *POST_ENERGY*, which is another core independent variable in this study. It is worth noting that the coefficient α_1 and β_3 examine whether the PCDEP has a significant effect on the cash flow uncertainty of the energy enterprises by using the energy enterprise sample and whole sample, respectively. While γ_5 detect whether there was a significant interaction effect between cash flow uncertainty and the policy on the RDEX of the energy enterprises. α_0, $\beta_{0,}$ γ_0 present the intercept terms, and ε denotes the residual.

In terms of the control variables, prior research documents that firms in relatively better financial condition have more stable cash flows, and they are more likely to invest in R&D activities (Brown & Petersen, 2009; Driver & Guedes, 2012; Weng & Söderbom, 2018). Therefore, we include firm size (*SIZE*) proxied by the logarithm of the firm's year-end total assets, fixed assets (*Fixed*) proxied by the ratio of the firm's fixed assets to total assets, book-to-market ratio (*BM*) measured by the ratio of total equity of company owners to firm market value, profitability (*ROA*) proxied by the ratio of the firm's annual return, and return volatility (*VOL*) proxied by the volatility of the firm's annual return as controls, as we expect them to affect *CFROSD* and *RDEX*. Simultaneously, as a firm with idle financial resources indicates more cash flow and has more confidence in affording R&D expenses (Cai & Zhang, 2011), we control for cash flow (*CFO*) proxied by the cash flow from operating activities and leverage ratio (*LEV*) proxied by the firm financial leverage ratio. Regarding costs, we include administration costs (*ADMINISTRATION*) proxied by the administration costs divided by total assets and selling costs (*SELL*) proxied by the selling costs divided by total assets, to control for the squeezing effect of other expenditures (Chen et al., 2019, 2021; Yang et al., 2012). We then include firm age (*AGE*) proxied by the year at the time of the sample examination minus the year of the firm's enterprise, to control for its effect on cash flow management and investment strategy (García-Quevedo et al., 2014). Based on Dickinson (2011), we also add the variable turnover (*TURNOVER*) proxied by the trading volume divided by outstanding share capital, and the institutional ownership (*INST*) calculated as the holding ratio of institutional investors to control for the effect of liquidity of enterprises' stocks and institutional supervision. Besides, in the spirit of Deng et al. (2013), we construct the indicator *CFROSD* to measure cash flow uncertainty, which is obtained by the rolling standard deviation of cash flows from operations (T ≥ 6). Formally, we present it as follows:

$$CFROSD_{i,t} = \sqrt{\frac{1}{T-1}\sum_{t=1}^{T}(OCF_{i,t} - \frac{1}{T}\sum_{t=1}^{T}OCF_{i,t})^2} \tag{3}$$

where *OCF* denotes operational cash flow, the earnings before interest, taxes, depreciation, and amortization to assets (EBITDA/Assets) ratio. While, i and t denote the enterprise and year, respectively, T ≥ 6 presents a time window over 6 years.

3.3 Data

Since the PCDEP was issued on OCT 27, 2016, we collect all energy A-share listed enterprises from January 1st, 2008, to January 1st, 2021, to ensure a sufficient observing period. Based on the classification in the Wind database and the CSMAR database, we obtain our initial sample of energy enterprises. According to our aim, we only focus on traditional energy enterprises. Therefore, we manually collect their financial statement and exclude several enterprises that are ambiguous or wavering in the classification due to their capricious main business.[7] Combining their actual main business and the above classification, we ultimately obtain 691 observations of energy listed enterprises after data filtering.[8]

In addition, to explicitly distinguish the difference in policy effect on the energy enterprises and others, we collect a group of listed enterprises randomly to construct a control group for the treatment group (energy enterprises). To alleviate the endogenous problem, we abandon all enterprises mentioned in the PCDEP policy because they could be highly related to the policy.[9] Besides, we also avoid enterprises in carbon-intensive industries that are more likely to be constrained by the carbon emission limits in the PCDEP. We finally obtain 3526 observations of the control group and 691 observations of the treatment group. Including all industries without potentially-affected industries after the PCDEP allows us to conduct difference-in-differences analysis and the matching result of the subsequent propensity score matching approach.[10] Our final sample consists of 641 enterprises, including 4217 observations. All the financial and corporate governance information is obtained from the Wind database and the CSMAR database.

Even if the global financial crisis influences financial markets of most countries, we tend to include the period from 2008 to 2011 because fierce natural disasters and extreme climate changes, such as freezing disasters suffered by the southern area of China, leading to the long-time supply disruption of coal, oil and other traditional energies, have exposed some drawbacks of abusing non-renewable energy sources. It stimulates the initial progress of the energy transition in China to some extent. Hence, we attempt to investigate the effect of the PCDEP on the RDEX and financial performance of the enterprises over the period of 2008–2021.

4 Main empirical results

4.1 Summarize statistics

Table 1 provides descriptive statistics of the variables used in our analysis. The whole sample is divided into four subsamples that are pre-policy energy, post-policy energy, pre-policy non-energy and post-policy non-energy samples, respectively. The Panels A–D of Table 1 show that, on average, the *RDEX* of the energy enterprise decreases 55.56% after the PCDEP, while the *RDEX* of the non-energy enterprise has a slight increase. Moreover, we find an increase in cash flow uncertainty of the energy enterprise after the PCDEP but a significant drop in that of the non-energy enterprise. The post-policy changes indicate a PCDEP effect on the *RDEX* and cash flow uncertainty of the energy enterprises, which inspires us to detect this effect and the possible interaction

[7] Specifically, several enterprises began to transition from a traditional-energy-leading business to a new-energy-leading one due to the impressive of the increased operate risks in recent years, such as Huayin Electric Power Co., LTD. (SH600744), Jidian Electric Co., LTD. (SZ000875) and Yuedian Electric Co., LTD. (SZ000539).

[8] We also exclude enterprises delisted during the sample period and enterprises receive special treatment which means they have a risk of delisting.

[9] The industries include Construction, Transportation, Agriculture, Paper, Electricity, and Aviation industry based on the specific provisions.

[10] The detailed methodology can be seen in Sect. 3.2 and Sect. 4.3. Note that some control sample may be omitted in the propensity score matching approach, therefore, we collect more control enterprises than the energy enterprises.

Table 1 Summary statistics

Variables	Obs	Mean	SD	Min	Median	Max
Panel A The sample of pre-policy energy enterprises						
RDEX	194	0.027	0.039	0.000	0.012	0.297
CFROSD	408	0.044	0.033	0.001	0.037	0.236
PCDEP	408	0.000	0.000	0.000	0.000	0.000
CFO	408	0.060	0.074	−0.283	0.051	0.337
SIZE	408	23.122	1.724	19.702	23.087	28.509
LEV	408	0.484	0.190	0.021	0.503	0.978
ROA	408	0.035	0.066	−0.277	0.027	0.266
ADMINISTRATION	408	0.093	0.117	0.002	0.074	2.045
SELL	407	0.021	0.024	0.000	0.013	0.153
DIVIDENDS	280	0.185	0.259	0.002	0.100	2.970
VOL	408	0.032	0.026	0.001	0.025	0.149
AGE	408	2.298	0.495	1.099	2.398	3.178
TURNOVER	408	-0.057	0.364	−1.263	-0.032	2.667
LONGDEBT	408	0.226	0.188	0.000	0.192	0.889
Panel B The sample of post-policy energy enterprises						
RDEX	245	0.012	0.017	0.000	0.007	0.109
CFROSD	283	0.066	0.053	0.002	0.053	0.348
PCDEP	283	1.000	0.000	1.000	1.000	1.000
CFO	283	0.067	0.064	−0.257	0.068	0.353
SIZE	283	23.539	1.726	19.634	23.476	28.636
LEV	283	0.468	0.174	0.055	0.471	0.929
ROA	283	0.026	0.093	−1.130	0.031	0.202
ADMINISTRATION	283	0.068	0.065	0.003	0.047	0.509
SELL	274	0.018	0.025	0.000	0.008	0.156
DIVIDENDS	209	0.262	0.348	0.007	0.160	2.540
VOL	283	0.029	0.050	0.000	0.017	0.650
AGE	283	2.577	0.545	1.099	2.708	3.367
TURNOVER	283	−0.002	0.285	−1.442	0.002	1.354
LONGDEBT	283	0.203	0.154	0.000	0.170	0.769
Panel C The sample of pre-policy non-energy enterprises						
RDEX	1174	0.045	0.045	0.000	0.036	0.484
CFROSD	1237	0.038	0.032	−0.001	0.029	0.354
PCDEP	1237	0.000	0.000	0.000	0.000	0.000
CFO	1237	0.065	0.068	−0.225	0.059	0.488
SIZE	1237	22.545	1.284	19.716	22.342	27.962
LEV	1237	0.405	0.199	0.034	0.389	0.957
ROA	1237	0.058	0.051	−0.225	0.049	0.373
ADMINISTRATION	1237	0.102	0.070	0.008	0.091	0.615
SELL	1236	0.046	0.059	0.000	0.026	0.570
DIVIDENDS	1176	0.176	0.344	0.001	0.100	6.787
VOL	1237	0.018	0.023	0.000	0.012	0.352
AGE	1237	2.285	0.546	1.099	2.197	3.296
TURNOVER	1237	−0.011	0.408	−1.536	−0.013	1.376
LONGDEBT	1237	0.124	0.146	0.000	0.060	0.798

Table 1 (continued)

Variables	Obs	Mean	SD	Min	Median	Max
Panel D The sample of post-policy non-energy enterprises						
RDEX	2285	0.047	0.044	0.000	0.038	0.485
CFROSD	2289	0.033	0.027	0.000	0.026	0.344
PCDEP	2289	1.000	0.000	1.000	1.000	1.000
CFO	2289	0.066	0.061	−0.313	0.061	0.375
SIZE	2289	22.945	1.327	19.780	22.743	28.416
LEV	2289	0.411	0.182	0.029	0.409	0.991
ROA	2289	0.060	0.053	−0.198	0.049	0.478
ADMINISTRATION	2289	0.071	0.067	0.005	0.059	1.402
SELL	2279	0.049	0.066	0.000	0.025	0.777
DIVIDENDS	2237	0.236	0.724	0.002	0.110	19.293
VOL	2289	0.017	0.021	0.000	0.011	0.274
AGE	2289	2.568	0.438	1.099	2.485	3.434
TURNOVER	2289	0.011	0.259	−2.479	0.005	1.616
LONGDEBT	2289	0.125	0.140	−0.195	0.065	0.709

The unit of *SIZE* is 10 billion ¥; *RDEX*, *ADMINISTRATION* and *SELL*, *DIVIDENDS* are scaled by firm size; *LONGLOAN* is scaled by the total debt

effect between the RDEX and cash flow uncertainty. The detailed changes in the other variables can be found in Table 1. We also show the correlation analysis result in Table 9 in Appendix.

4.2 The impact of the PCDEP on the cash flow uncertainty of the energy enterprises

Results in Columns (1) and (2) show that the coefficients of PCDEP are negative and statistically significant by using the whole sample, which are estimated by the difference-in-differences regressions. It suggests that the enactment of the PCDEP mitigates the cash flow uncertainty of the sample enterprises to a certain extent. However, the coefficients of the *POST_ENERGY* are positive and statistically significant in Columns (1) and (2), indicating that energy listed enterprises experience weaker mitigation of cash flow uncertainty than the non-energy enterprises after the PCDEP. Therefore, regression results in Table 2 indicate that the cash flow uncertainty of the energy listed enterprises in China still maintains a relatively high level after the policy. In contrast, the non-energy enterprises present a significant decrease in cash flow uncertainty after the policy. In addition, *SIZE* and *FIXED* have a negative effect on the cash flow uncertainty, while *ROA*, *ADMINISTRATION* and *DIVIDENDS* have a positive effect on it. The results indicate that the energy enterprises experience higher cash flow uncertainty than other enterprises after the enactment of the PCDEP. It reflects a external shock from policy changes on financial performance of enterprises, which is consistent with Chay & Suh (2009) and Deng et al. (2013).

Table 2 The PCDEP effect on the cash flow uncertainty of the energy listed enterprises

	(1)	(2)
VARIABLES	*CFROSD*	*CFROSD*
PCDEP	−0.004***	−10.007
	(−3.69)	(−11.38)
ENERGY	0.007***	0.004
	(3.75)	(1.40)
POST_ENERGY	0.026***	0.031***
	(9.60)	(11.79)
SIZE		−0.006***
		(−8.19)
LEV		0.038***
		(8.56)
VOL		0.220***
		(11.97)
ROA		0.043***
		(4.18)
AGE		−0.000
		(−0.05)
TURNOVER		−0.000
		(−0.08)
CFO		0.034***
		(4.12)
FIXED		−0.020***
		(−4.38)
BM		0.000
		(0.10)
INST		0.001
		(0.19)
Constant	0.038***	0.163***
	(41.64)	(10.63)
Observations	4,217	4,217
R-squared	0.064	0.259
Cluster Firm	YES	YES
Firm FE	YES	YES
Year FE	YES	YES

Robust t-statistics in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$. *ENERGY* and *AGE* are omitted because of controlling for the firm-level fixed effect

4.3 The role of cash flow uncertainty in the PCDEP effect on R&D expenditures of energy firms

We further examine the cash flow uncertainty effect in the impact of the PCDEP on the RDEX of the energy enterprises. Table 3 reports the results of regressing model (3). We can find that the coefficients of the PCDEP are positive and statistically significant in Columns (1) and (2), while the coefficients of the *POST_ENERGY* are negative and statistically

Table 3 The interaction effect of cash flow uncertainty on the RDEX of energy enterprises after the PCDEP

	(1)
VARIABLES	*RDEX*
PCDEP	0.011
	(0.98)
POST_ENERGY	−0.009***
	(−3.25)
POST_CFROSD	−0.008
	(−0.56)
ENERGY_CFROSD	0.017
	(0.37)
POST_ENERGY_CFROSD	−0.155***
	(−3.06)
SIZE	0.004***
	(3.38)
LEV	−0.042***
	(−10.40)
VOL	−0.025**
	(−2.01)
ROA	−0.081***
	(−11.79)
AGE	−0.013***
	(−4.31)
TURNOVER	0.002*
	(1.78)
CFO	−0.000
	(−0.09)
FIXED	0.002
	(0.33)
BM	−0.000
	(−1.26)
INST	−0.003
	(−0.99)
Constant	0.014
	(0.57)
Observations	3,898
R-squared	0.127
Cluster Firm	YES
Firm FE	YES
Year FE	YES

Robust t-statistics in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$. *ENERGY* and *AGE* are omitted because of controlling for the firm-level fixed effect significant. It indicates the opposite changes in the RDEX of the energy enterprises after the policy compared to the other enterprises. Besides, we can detect the negative effect of the cash flow uncertainty on the RDEX of the energy enterprises according to its coefficients and t-values in Columns (1) and (2). Further, the coefficients of the interaction variable *POST_ENERGY_CFROSD* are also negative and statistically significant in Columns (1) and (2), indicating that the increased cash flow uncertainty after the PCDEP exacerbates the shrink of RDEX of the energy enterprises. It can be deduced that the energy enterprises are forced to transfer more cash from the R&D activities, expected to pay off in a relatively long circle, to satisfy more urgent financing demands. It is consistent with Coles et al. (2006) and Sasaki (2016).

This discussion about this post-PCDEP-cash-flow-uncertainty effect is pivotal for several reasons. First, it underscores the nuanced challenge that energy enterprises face in balancing long-term innovation goals with short-term financial pressures, especially in the context of stringent environmental policies like the PCDEP. Second, it provides empirical support to the theoretical frameworks posited by Coles et al. (2006) and Sasaki (2016), linking financial constraints with strategic investment decisions in R&D. Understanding this dynamic is crucial for policymakers and industry stakeholders aiming to foster an environment where environmental goals and innovation can coexist without compromising financial stability. This insight could guide the development of supplementary policies or financial instruments aimed at mitigating the adverse effects of cash flow uncertainty on R&D investment in the energy sector, thereby ensuring that environmental policies do not inadvertently stifle innovation essential for achieving long-term sustainability goals. (Table 4).

4.4 Endogeneity: propensity score matching approach

Even if our treated and control groups present parallel trends prior to the PCDEP, there is still an endogenous concern regarding the self-selection of the sample. In the context of this paper, whether the treatment to the enterprises is driven by their enterprise characteristics or not is still unclear. For the purpose of alleviating the endogeneity, we employ a propensity score matching approach to score the tendency of being treated based on their characteristics and match the sample according to the scores (Becerril & Abdulai, 2010; Oh et al., 2009). First, we run a Probit model to estimate the probability of being treated by the policy for each enterprise, viz., the propensity score. Using the closest neighbor matching approach (one-to-one), we obtain the propensity scores and the average treatment effect on the treated (ATT)[11] of all the enterprises, and the relations between the treatment variable and the controls can be seen in Table 10 of Appendix. ATTs in Table 4 of Columns (1) and Column (2) are 8.93 and -8.17, respectively. It indicates that the average treatment effects on *CFROSD* and *RDEX* are positive and negative, and both statistically significant at 1% level. The results support that the *CFROSD* of the energy enterprises increase more than that of the control group under the policy effect and the *RDEX* of the energy enterprises decreases more than that of the control group under the policy effect.[12] Further, we

[11] The average treatment effect is to estimate the difference in mean RDEX between the enterprises after the policy and their PSM-matched pre-policy counterparts, which can be used to measure the actual policy effect (Abadie & Imbens, 2016).

[12] The result of comparing the difference between pre-matching and post-matching for each variable suggests that we have a credible control group for the difference in difference analysis, which is not reported. It will be available from authors.

Table 4 The DID results using the PSM-matching sample

	(1)	(2)
VARIABLES	*CFROSD*	*RDEX*
PCDEP	−0.004	−0.005
	(−1.34)	(−1.40)
ENERGY	0.004	−0.014***
	(1.43)	(−3.01)
POST_ENERGY	0.031***	−0.002
	(8.07)	(−0.35)
POST_CFROSD		0.122
		(1.52)
ENERGY_CFROSD		0.106
		(1.31)
POST_ENERGY_CFROSD		−0.289**
		(−2.37)
Constant	0.193***	0.037***
	(9.78)	(14.99)
ATT	8.93***	−8.17***
Controls	Yes	Yes
Observations	1,274	850
R-squared	0.228	0.109
Cluster Firm	YES	YES
Firm FE	YES	YES
Year FE	YES	YES

Robust t-statistics in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$; *ENERGY* and *AGE* are omitted because of controlling for the firm-level fixed effect. The PSM-matching sample consists of 1351 observations.

also reexamine our results using the matching sample by employing the PSM approach, the coefficients of the *POST_ENERGY* in Column (1) and the *POST_ENERGY_CFROSD* in Column (2) are positive and negative, and statistically significant at the 1% level, indicating that the positive effect of the CPP on *CFROSD* and the negative post-PCDEP cash flow uncertainty effect on the *RDEX* the energy enterprises remain unchanged by using the matching sample.

4.5 Mechanism analysis

4.5.1 The role of long-term loans

Given that high cash flow uncertainty may indicate a more intense financing constraint of the companies after the policy, we attempt to investigate the mechanism of the negative PCDEP effect on the RDEX from a debt financing channel view. Based on Modigliani & Miller (1958), companies are inclined to acquire more long-term loans than short-term loans to reduce the financing cost. However, it is challenging for the energy enterprises to gain sufficient long-term loans during the pre-policy period when they are facing an adverse policy shock. To fill the financing gap, enterprises may decrease the portion of long-term debt financing and increase short-term debt financing. As D'Mello & Miranda (2010), more long-term debt financing can strengthen the stability of cash flow and indicate a positive signal of financing condition of enterprises. Accordingly, to distinctly detect the role of long-term loans in the post-policy cash flow uncertainty effect on the RDEX, we construct a variable named *LONGDEBT* (the long-term debt divided by total debt) to conduct a mediating effect test following Zhou et al. (2022), and construct the following progressive models:

$$RDEX = \beta_0 + \theta_1 PCDEP + \theta_2 * ENERGY + \theta_3 * LONGDEBT + \sum \beta_x Controls + \alpha + \varphi + \varepsilon \tag{4}$$

$$CFROSD\_POST\_ENERGY = \psi_0 + \theta_1' PCDEP + \theta_2' ENERGY + \theta_3' * POST\_ENERGY + \theta_4' * LONGDEBT + \sum \beta_x Controls + \alpha + \varphi + \varepsilon \tag{5}$$

$$RDEX = \rho_0 + \theta_1'' PCDEP + \theta_2'' ENERGY + \theta_3'' * POST\_ENERGY + \theta_4'' * CFROSD\_POST\_ENERGY + \gamma' * LONGDEBT + \sum \beta_x Controls + \alpha + \varphi + \varepsilon \tag{6}$$

where *LONGDEBT* denotes the long-term debt divided by total debt of the enterprises. Model (4) regresses the *RDEX* on the *CFROSD* and the interaction term between it and the estimator *POST_ENERGY_CFROSD*, which is consistent with mode (2). Further, Model (5) regresses *CFROSD_POST_ENERGY* on *LONGDEBT* to specifically detect the post-policy effect of the long-term debt on the cash flow uncertainty of the energy enterprises. Finally, Model (6) runs a mediation model to estimate the mediation effect of the *LONGDEBT* in the effect of *POST_ENERGY_CFROSD* on *RDEX*. Results in Columns (1) and (2) of Table 5 show that the coefficients θ_3 and θ_4' are positive and negative, respectively, while both are statistically significant at 1% level. Moreover, results in Column (3) presents that the coefficients γ' and θ_4'' are positive and negative respectively, while both are statistically significant at 1% level. The results indicate that there is a partially mediation effect of *LONGDEBT* according to the Sobel Z-value reported in Column (3). In addition, we can identify that the ratios of the indirect to direct effect is 7.56%, respectively. Therefore, we confirm the mechanism that the interaction effect between the cash flow uncertainty and the PCDEP on the *RDEX* is partially conducted by the post-PCDEP changes in long-term debt. Specifically, the post-PCDEP reduction of the long-term debt leads to the stubbornly-high cash flow uncertainty of the energy enterprises after the policy compared to the non-energy enterprises, resulting in the squeeze of the *RDEX* of the energy companies. The main reason may be that the enactment of the PCDEP induces the risk aptitude and risk assessment of banks on the energy enterprises in China and then results in the reallocation of credit supply (Chang et al., 2019).

4.5.2 Moderation effect of overvaluation

Whether the energy enterprises are under- or over-valued matters in our study since it reflects the enthusiasm of investors for their stocks and their resistance to uncertainty. Enterprises are over-valued when their stock prices are higher than their underlying value (Jensen, 2005). Specifically, overvalued equities indicate that enterprises will not be capable of delivering—except by pure luck—the performance to justify their values. As Brown et al. (2009), over-valued enterprises are more vulnerable to liquidity shortage and prudent to allocate more capital on risky activities. When they are stuck in cash flow volatilities, they are willing to delay discretionary spending such as R&D costs, advertising

Table 5 The mediating role of long-term debt in the post-PCDEP cash flow uncertainty effect

	(1)	(2)	(3)
VARIABLES	*RDEX*	*POST_ENERGY_CFROSD*	*RDEX*
POST_ENERGY_CFROSD			−0.232***
			(−5.66)
LONGDEBT	0.020***	−0.007**	0.018***
	(2.81)	(−2.47)	(2.62)
PCDEP	0.004***	0.012***	0.006***
	(3.14)	(19.15)	(4.39)
ENERGY	−0.018***	0.029***	−0.009***
	(−7.99)	(35.31)	(−3.57)
Constant	0.129***	0.012*	0.132***
	(8.16)	(1.91)	(8.38)
SOBEL-Z			2.035**
Ratio of indirect to direct effect			7.56%
Controls	YES	YES	YES
Observations	3,898	4,217	3,898
R-squared	0.181	0.302	0.188
Cluster Firm	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES

Robust t-statistics in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$. *ENERGY* and *AGE* are omitted because of controlling for the firm-level fixed effect.

and maintenance. To investigate the relationship between the post-PCDEP cash flow uncertainty effect and corporate valuation, we construct four dummy variables by the extent of how the enterprises are over- or under-valued. According to the values of price-to-earnings ratio[13] (*PE*), we construct a dummy variable *PE1,* which equals to 1 if a firm's PE is higher than the mean of PE, otherwise it equals to 0. Note that we also include the interaction variables between *PE1* and the *POST_ENERGY_CFROSD* to detect possible moderating effect. Results reported in Table 6 show that only the coefficient of the *POST_ENERGY_CFROSD_PE1* is negative and statistically significant at 1% level. It suggests that the overvaluation has intensified the post-PCDEP cash flow uncertainty effect on the *RDEX* of the energy enterprises. The results indicate that the over-valued energy enterprises reduce *RDEX* more to guarantee their liquidity than other enterprises due to the negative post-PCDEP cash flow uncertainty effect, which is consistent with Jensen (2005).

4.6 Effects of different types of ownership and economic level

So far, we have recognized the negative effect of the post-PCDEP cash flow uncertainty on the *RDEX* of the energy enterprises, however, there are still some internal and external factors that might influence the effect, such as the different regional economic levels and ownerships of the enterprises. These determinants may affect the cash flow uncertainty effect on *RDEX* by

[13] As a robustness check, we also replace PE ratio as Price-to-Book Ratio to repeat the regressions and the main conclusions remain unchanged, and the results are not shown for brevity.

Table 6 The moderation effect of firm overvaluation in the post-PCDEP cash flow uncertainty effect

	(1)
VARIABLES	RDEX
PCDEP	0.004
	(0.36)
POST_ENERGY	−0.007**
	(−2.48)
POST_CFROSD	−0.012
	(−0.94)
ENERGY_CFROSD	0.008
	(0.14)
POST_ENERGY_CFROSD	−0.052
	(−0.87)
PE1	0.000***
	(4.73)
POST_ENERGY_CFROSD_PE1	−0.001***
	(−9.05)
Constant	0.040*
	(1.69)
Controls	YES
Observations	3,717
Number of stkcd	634
R-squared	0.150
Cluster Firm	YES
Firm FE	YES
Year FE	YES

Robust t-statistics in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

reinforcing or impairing the confidence in the investment in R&D activities. Following Girma et al. (2009), we first divide our sample into two groups with different ownerships, which are state-owned enterprises (SOE) and non-state-owned enterprises (non-SOE), and repeat our baseline regressions using them. Then we divide our sample into two groups in regions with different economic-level, which are eastern and western enterprises, and repeat our baseline regressions.

Results in Columns (1) and (2) of Table 7 provide different evidence that the SOE energy enterprises present higher resilience to the high cash flow uncertainty after the policy than the non-SOE ones. It is consistent with Wu (2017) that the SOE energy enterprises tend to obtain more financial support from the government due to their political connections, leading to confidence in investing in long-term activities such as *RDEX*. However, the non-SOE ones may adjust their investments in key strategic resources conservatively, for instance, substituting activities with short payback periods for the *RDEX*.

Columns (3) of Table 7 report similar results as that of baseline tests. The coefficient of *POST_ENERGY_CFROSD* is negative and statistically significant. It indicates the negative post-PCDEP cash flow uncertainty effect on the *RDEX* of the energy enterprises is significant in eastern enterprises. However, we can find that the coefficient of *POST_ENERGY_CFROSD* in Column (4) is statistically insignificant, indicating that western energy enterprises present better resilience to the post-PCDEP cash flow uncertainty effect, which could be related to their higher natural endowments for mining of ore

Table 7 The heterogeneous effect of ownership and regional economic level

	(1) SOE	(2) non-SOE	(3) Eastern	(4) Western
VARIABLES	*RDEX*	*RDEX*	*RDEX*	*RDEX*
PCDEP	0.004***	0.002*	0.026*	−0.016
	(4.01)	(1.74)	(1.65)	(−1.01)
POST_ENERGY	−0.006**	−0.031***	−0.016***	−0.003
	(−2.12)	(−6.24)	(−4.11)	(−0.80)
POST_CFROSD	−0.023	−0.006	−0.008	−0.001
	(−1.30)	(−0.31)	(−0.50)	(−0.04)
ENERGY_CFROSD	−0.008	−0.103	0.060	0.008
	(−0.19)	(−1.07)	(0.68)	(0.14)
POST_ENERGY_CFROSD	−0.042	−0.159*	−0.275***	−0.055
	(−0.83)	(−1.70)	(−3.23)	(−0.82)
Constant	0.062***	0.024	0.036	−0.023
	(2.92)	(0.92)	(1.08)	(−0.64)
Controls	YES	YES	YES	YES
Observations	1,571	2,327	2,648	1,250
R-squared	0.170	0.094	0.162	0.126
Number of stkcd	262	399	435	200
Cluster Firm	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Robust t-statistics in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

resources. Our results reveal interesting evidence that the energy enterprises with less political connections and in developed areas conduct more prudent strategy management to maintain their investments in key strategic resources such as *RDEX*.

4.7 Additional robustness tests

To examine the validity of our results further, we then conduct a battery of robustness tests as follows: first, as Wan et al. (2021), the strategic investment may be determined by equity concentration, which reflects the independence of decision-making of enterprises. Accordingly, we divide our sample into two groups, which are high-equity-concentration (high-EC) and low-equity-concentration (low-EC) enterprises, and conduct our regressions separately. The results shown in Columns (1) and (2) of Table 8 indicate that only the high-equity-concentration enterprises' RDEX is significantly affected by the post-PCDEP cash flow uncertainty effect; second, we use the ratio of RDEX and capital expenditure to replace the RDEX, and the empirical results still remain unchanged, which can be seen in Column (3) of Table 8; third, we replace FE model as the ordinary-least-squares model to repeat our baseline regression and the main conclusion keep consistent with that of the baseline regression, although some coefficients have slight changes that are shown in Column (4) of Table 8; fourth, to mitigate the impact of the COVID-19 pandemic, we omit the sample after 2019 and re-run the baseline regression and the main conclusions remain unchanged that are shown in Column (5) of Table 8; Fifth, following Hutton et al. (2014), Le & Kroll (2017) and Jiang & Liu (2020), we control for the board characteristic based on three variables, which are *FinBack* (it equals to 1 if executives have financial background, otherwise it is 0), *OverseaBack* (it equals to 1 if executives have international background; otherwise it is 0) and *Female* (it is calculated by the ratio of female executives to the all executives), and re-run the baseline regression. We find the coefficient of the core variable remain a high statistical significance at 1% level, indicating the validity of our estimation that is shown in Column (6) of Table 8; Sixth, following Lu et al. (2022), we conduct a placebo test by randomly altering the treatment point and re-run our DID estimator. The result in Fig. 4 and Fig. 5 show that the coefficient has no significant difference with zero both in the PCDEP effect on the CFROSD of energy firms and the post-PCDEP-cash-flow-uncertainty effect on the R&D expenditures of energy firms, indicating the validity of our estimation.

5 Conclusion and policy implications

5.1 Conclusions

In this study, we apply a difference-in-differences approach to examine the impact of the Peaking-Carbon-Dioxide-Emissions policy on cash flow uncertainty among energy companies in China, as well as the interaction effect between cash flow uncertainty and R&D expenditure post-policy. Our empirical analysis demonstrates the persistently high cash flow uncertainty of energy firms compared to non-energy firms, utilizing a sample of listed energy and non-energy companies in China from 2008 to 2021. Further empirical investigation reveals the negative impact of cash flow uncertainty on the policy's beneficial effects on R&D expenditure for energy firms versus non-energy firms. To address potential endogeneity concerns, we adopt a Propensity Score Matching (PSM) methodology to mitigate sample selection bias concerns. The regression results from the PSM-matched sample remain consistent.

Additionally, we explore potential mechanisms behind this interaction effect of cash flow uncertainty. The interaction between cash flow uncertainty and the policy's effect on R&D expenditure is partly mediated by the reduction in long-term loans; namely, the post-policy reduction in long-term loans diminishes the policy's impact on reducing cash flow uncertainty, thereby maintaining high cash flow uncertainty for energy firms after the policy, which leads to a reduction in R&D expenditure for these firms. Another mechanism identified involves the moderating effect of firm overvaluation, with over-valued firms having a greater incentive to reduce R&D expenditure to enhance liquidity due to the negative cash flow uncertainty effect post-policy. Moreover, we recognize the heterogeneity where energy firms with fewer political connections and located in more developed areas adopt a cautious strategic management approach to maintain their R&D investment.

5.2 Policy recommendations

Our investigation significantly deepens the understanding of the Peaking-Carbon-Dioxide-Emissions Policy (PCDEP) on the fiscal conditions and investment strategies of energy companies. With the Chinese government's introduction of various carbon peak policies, it's vital

Table 8 Additional robustness checks

	(1) FE model(high-EC)	(2) FE model (low-EC)	(3) FE model	(4) OLS model	(5) FE model	(5) FE model
VARIABLES	*RDEX*	*RDEX*	*RDCPEX*	*RDEX*	*RDEX*	*RDEX*
PCDEP	0.025*	0.043***	0.010	0.004***	0.004***	0.004***
	(1.90)	(2.60)	(0.17)	(4.40)	(4.00)	(4.39)
POST_ENERGY	−0.002	−0.034***	0.003	−0.009***	−0.009***	−0.009***
	(−0.68)	(−7.09)	(0.25)	(−3.32)	(−3.05)	(−3.27)
POST_CFROSD	−0.012	−0.005	0.022	−0.014	−0.017	−0.014
	(−0.51)	(−0.34)	(0.32)	(−1.05)	(−1.07)	(−1.05)
ENERGY_CFROSD	0.090	−0.301***	0.281	0.009	−0.011	0.011
	(1.48)	(−3.30)	(1.18)	(0.20)	(−0.23)	(0.23)
POST_ENERGY_CFROSD	−0.232***	0.122	−0.560**	−0.142***	−0.143***	−0.144***
	(−3.25)	(1.43)	(−2.15)	(−2.80)	(−2.63)	(−2.83)
Constant	0.052	−0.062	0.580***	0.042**	0.053***	0.040**
	(1.40)	(−1.52)	(4.61)	(2.41)	(2.62)	(2.31)
Controls	YES	YES	YES	YES	YES	YES
Board characteristics	NO	NO	NO	NO	NO	YES
Observations	1,888	2,010	3,898	3,898	3,186	3,898
R − squared	0.140	0.167	0.038	0.107	0.332	0.327
Year FE	YES	YES	YES	YES	YES	YES
Cluster Firm	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES

Robust t-statistics in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

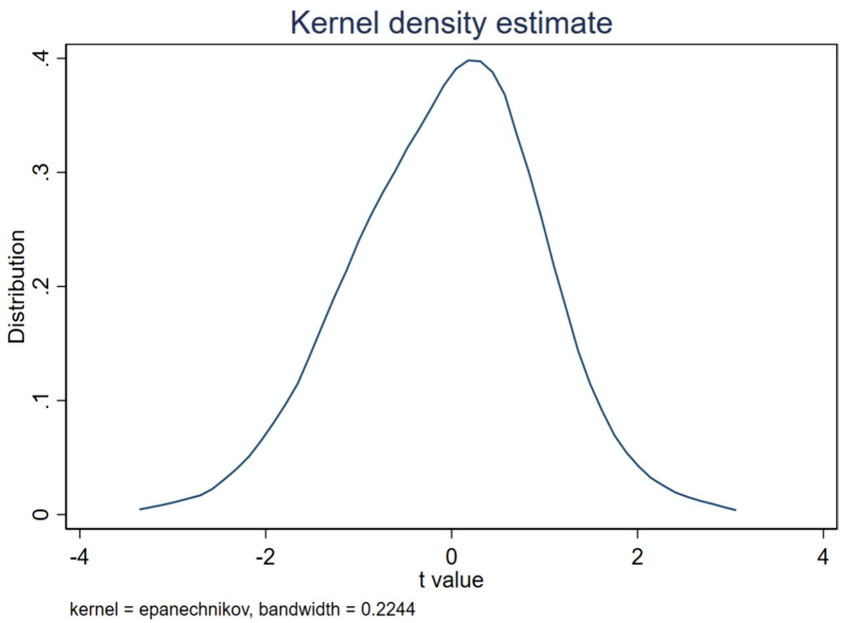

Fig. 4 Placebo test for the PCDEP effect on the CFROSD of energy firms

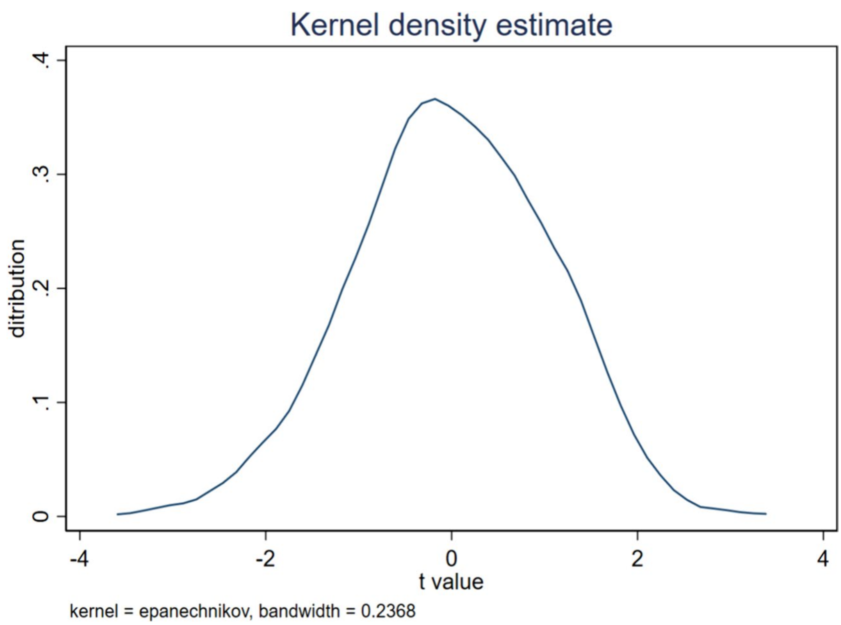

Fig. 5 Placebo test for the post-PCDEP-cash-flow-uncertainty effect on the R&D expenditures of energy firms

to identify how firms adapt their operations, financing, and investments. Energy companies, bearing the brunt of these reforms, face increased financial uncertainty, complicating the policy's effectiveness. These companies must diversify financing sources and maintain strong cash flow to mitigate risks from policy shifts, especially with China aiming for carbon emissions to peak by 2030. Despite financial challenges as capital shifts towards greener industries, the energy sector's role in economic stability and public welfare remains crucial. The government should enhance financial support in alignment with transition goals, ensuring policies accommodate diverse energy company responses for a smooth transition. Our findings highlight the need for further research on policy impacts, including those from the COVID-19 pandemic, and suggest more investigations into various-stage energy transition policies.

Based on our conclusions, we provide several suggestions for energy companies: first, energy firms should broaden their financial sources beyond traditional avenues, exploring green bonds, sustainability-linked loans, and other innovative financing mechanisms that align with global sustainability criteria; second, allocate substantial resources towards R&D in renewable energy technologies, energy efficiency improvements, and carbon capture and storage (CCS) technologies to pivot away from dependency on fossil fuels; third, streamline operations to reduce costs and increase competitiveness in a market that increasingly favors sustainable and efficient energy solutions; fourth, forge alliances with technology firms, research institutions, and other stakeholders to share risks and benefits associated with green innovation and to access new markets; fifth, develop comprehensive risk assessment and management frameworks to navigate the uncertainties and volatility introduced by the transition policies effectively.

Then we provide policy recommendations for policymakers: Policy Recommendations for Policymakers: first, implement subsidies, tax incentives, and financial support programs specifically designed to support energy companies in their transition towards greener operations; second, provide clear, consistent, and long-term regulatory frameworks that give energy companies the confidence to invest in green technologies and infrastructure; third, increase funding for research and development in renewable energy and low-carbon technologies, facilitating the commercialization of innovative solutions; fourth, create mechanisms that enable easier access to green technology markets for energy companies, including through public–private partnerships and international cooperation; fifth, recognize the diversity among energy companies and develop differentiated policies that account for varying capacities and starting points in the transition process.

This investigation has some limitations that could be further analyzed in future research, such as the interaction effect between the energy transition policy effect and the COVID-19 pandemic effect. Further, more energy transition regulations and policies are appearing. Our analysis calls for further investigations of detecting the effect of different-stage energy transition policies (such as the carbon neutral policy) on energy enterprises, which extend to various empirical and theoretical studies navigating new directions in this field.

Appendix

See Tables 9 and 10.

Table 9 Correlation analysis

	CFROSD	PCDEP	ENERGY	POST_ ENERGY	SIZE	LEV	VOL	ROA	AGE	TURNOVER	CFO	FIXED	BM	INST
CFROSD	1													
PCDEP	−0.033**	1												
ENERGY	0.208***	−0.182***	1											
POST_ ENERGY	0.231***	0.214***	0.606***	1										
SIZE	−0.120***	0.111***	0.128***	0.124***	1									
LEV	0.061***	−0.019	0.134***	0.067***	0.544***	1								
VOL	0.252***	−0.051***	0.188***	0.094***	−0.094***	−0.054***	1							
ROA	−0.010	0.036**	−0.178***	−0.131***	−0.016	−0.372***	−0.035**	1						
AGE	−0.030*	0.272***	−0.042***	0.062***	0.311***	0.225***	−0.035**	−0.032**	1					
TURNOVER	−0.022	0.048***	−0.043***	0.000	0.012	0.023	0.025	−0.016	0.068***	1				
CFO	0.068***	0.014	−0.017	0.006	0.070***	−0.177***	0.144***	0.499***	0.026*	0.046***	1			
FIXED	−0.036**	−0.100***	0.222***	0.108***	0.117***	0.120***	0.033**	−0.117***	0.003	0.009	0.192***	1		
BM	−0.054***	0.163***	0.129***	0.164***	0.613***	0.555***	−0.124***	−0.283***	0.224***	−0.020	−0.146***	0.073***	1	
INST	−0.073***	0.007	0.085***	0.075***	0.504***	0.203***	−0.099***	0.121***	0.247***	−0.053***	0.146***	0.081***	0.203***	1

Table 10 Propensity-Score-Matching results

	(1)
VARIABLES	ENERGY
SIZE	0.084***
	(3.19)
LEV	−0.051
	(−0.29)
VOL	12.745***
	(13.02)
ROA	−5.009***
	(−8.31)
AGE	−0.288***
	(−5.62)
TURNOVER	−0.244***
	(−3.13)
CFO	−0.268
	(−0.56)
FIXED	1.722***
	(10.58)
BM	0.054**
	(2.33)
INST	0.453***
	(3.66)
Constant	−2.934***
	(−5.43)
ATT	8.93***
Observations	4,217
R-squared	
Cluster Firm	YES
Firm FE	YES
Year FE	YES

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