UNIVERSITY OF ECONOMICS HO CHI MINH CITY
International School of Business

Nguyen Ha Phuoc Trong

CLIMATE CHANGE AND CASH HOLDINGS ADJUSTMENT SPEEDS: INTERNATIONAL EVIDENCE

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Finally, I extend my thanks to all future readers for this dissertation. I hope that my work can contribute, in some small way, to a deeper understanding of this field and serve as a source for future research.

COMMITTMENT

I hereby declare that this dissertation is my original work and has been conducted in accordance with the guidelines and regulations of UEH University. I affirm that this research has been undertaken in full compliance with the ethical standards and principles of research. It has not been submitted for any other degree or qualification at this or any other institution.

Nguyen Ha Phuoc Trong

CLIMATE CHANGE AND CASH HOLDINGS ADJUSTMENT SPEEDS

Abstract

This article explores the relationship between climate change and the speed of corporate cash holdings adjustments around the world. Using international data from 49 countries between 2002 and 2019, we find evidence that firms tend to adjust their cash holdings more rapidly in response to rising climate change world. Our findings are robust across alternative measures of cash ratios and climate change, with potential endogeneity concerns addressed using system generalised-method-of-moments (GMM) estimations and propensity score matching (PSM) approaches. Furthermore, the effect is more pronounced for firms with cash deficits, facing high financial constraints, or operating in regions with stringent environmental policies. Overall, this research contributes to the existing literature on dynamic partial adjustment models by demonstrating the intensified cash holdings adjustment in response to climate change, especially under financial or regulatory pressures. These valuable insights present significant implications for investors, analysts, corporate stakeholders, academics and policymakers, particularly in understanding corporate financial decision-making and behaviour.

Keywords: *climate change exposure, climate change risk; adjustment speed of cash holdings; environmental policy stringency; financial constraints.*

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1. Introduction

"We are the first generation to feel the effect of climate change and the last generation who can do something about it." – Barack Obama.

Climate change has become as one of the severest pressing global concerns of the 21^{st} century due to its effects on humanity. Climate change-related risks have seen a substantial increase over the past few years (Gounopoulos & Zhang, 2024). Beyond environmental degradation, climate change disrupts global economic systems and poses direct risks to financial markets around the world. Climate change presents itself in various forms, such as more frequent and intense extreme weather, rising global temperatures, increasing carbon dioxide levels, rising sea levels, and shifting climate patterns. Addressing the severe effects of climate change has important and profound implications for business and economies worldwide (IPCC, 2015). Economic costs are skyrocketing due to the dramatic increase in climate change-related disasters. According Kompas, Pham and Che (2018), global economic could face a loss of $23 trillion annually if global temperature rises by 4°C above pre-industrial levels within the next 80 years.

With growing awareness of the significant consequences of climate change, efforts to mitigate its impact have long dominated the agendas of national governments and international policymakers. Notably, in 2021 at the 26^{th} Conference of the Parties (COP26), representative from more than 190 nations renewed the goal of the Paris Agreement and committed to limited the global warming (UNFCCC, 2022). However, limiting total warming to less than 2°C will be challenging, and achieve the more ambitious goal of 1.5°C, regarded as an upper bound to avoid significant risks to the economy, human health and well-being, and Earth's ecosystems (Dietz, Shwom, & Whitley, 2020).

In addressing climate change, as proposed by Carney (2015), risks related to climate change comprise two main categories: (i) physical risks and (ii) transition risks. Regarding physical risk, firms face the destructive effects of climate change, damaging infrastructure, disrupting supply chains, and reducing their production capacity, thereby requiring firms to have flexibility in their financial management. Transition risk arises from regulatory and market shifts towards a low-carbon economy, creating unanticipated and sudden adjustments in asset prices, resulting in financial shocks for asset managers (Battiston, Dafermos, & Monasterolo, 2021). Moreover, firms also face liability risk, which presents the long-term possibility of financial claims, leading to losses or damages due to climate change, as they may be required to compensate those for whom they are held legally accountable (BCBS, 2021; ECB, 2020). Therefore, climate change risks generate future uncertainties and potential financial instability by damaging firms' assets, leading to various costs associated with managing these consequences. While firms around the world experience the risks of climate change, it is widely agreed that developing countries are bearing the most significant impacts. Furthermore, the difficulties caused by climate change extend beyond operational concerns and into firms' financial management. Climate change creates substantial uncertainty and potential financial distress, particularly in how firms manage their liquidity and maintain financial stability in volatile conditions. Therefore, it is essential for firms to fully understand the influence of climate change on their businesses and incorporate climate change-related risks into their financial strategies.

The 2024 Global Risks Report by the World Economic Forum ranks environmental risks, including climate change, among the top global concerns in terms of their likelihood and potential impact (WEF, 2024). Moreover, the report emphasises that extreme environmental events pose the most serious global threats to businesses. This recognition highlights the need for firms to adapt their financial management practices to mitigate uncertainties and challenges arising from climate change. While a considerable amount of literature has explored the consequences of climate change on corporate operations, a gap remains in understanding its effects on corporate financial management. For example, various studies have investigated the correlation between climate change-related risks and firm performance and financial decisions (Huang, Kerstein, & Wang, 2018a; Ozkan, Temiz, & Yildiz, 2023), financial stability (Chabot & Bertrand, 2023; Roncoroni et al., 2021), capital structure (Ginglinger & Moreau, 2023), and firm valuation (Matsumura, Prakash, & Vera-Muñoz, 2014). However, there is a scarcity of empirical research that investigates the association between climate change and corporate financial management, with a specific focus on liquidity management. Prior research has extensively examined corporate cash holdings and the determinants of them (Bates, Kahle, & Stulz, 2009; Gao, Harford, & Li, 2013; Opler et al., 1999), yet the dynamic adjustment of cash holdings in response to external shocks, such as climate change, remains underexplored. Therefore, this study seeks to fill the existing gap by examining the impact of climate change risks on the cash holding adjustment speed of firms, Specifically, it explores whether and how climate change influences the cash holding adjustment speed for publicly traded nonfinancial firms globally, covering the period from 2002 to 2019.

Climate change appears to present new risks and uncertainties for firms, ranging from physical risks to transition risk. Therefore, climate change forces firms to reconsider how they manage their financial resources more effectively due to increased costs. Additionally, it is well-recognised that firms facing climate change-related risks incur higher operational costs (Ozkan, Temiz, & Yildiz, 2023). Brown, Gustafson and Ivanov (2021) found that heavy winter snowfall can cause liquidity shocks for firms by disrupting their distribution channels and elevating operating costs. Moreover, Ozkan, Temiz and Yildiz (2023) state that firms may incur additional costs in their response to climate change, such as costs of adapting new technologies and measures to address society's concerns and expectations. In addition, firms are faced with cost of debt increasing directly and indirectly due to climate change impact on restricting access to financing (Kling et al., 2021). These challenges require firms to have a strong financial management by holding enough liquidity to respond swiftly to unexpected climate change events. Generally, climate change risks introduce complexity for firm in managing their resources to deal with increasing uncertainties, thereby potentially affecting their liquidity management policy. Therefore, we argue that corporate liquidity management holds greater importance under the pressure of climate change context, as it may enhance firms' ability to navigate these risks and preserve firm value. While the association between environmental risks, especially climate change risks and firm performance has been widely examined in contemporary studies. Huang, Kerstein and Wang (2018b) demonstrate that firms located in countries with more intense climate risks experience poor performance and greater earning volatility. Additionally, specific climate risks, such as extreme heat and drought, decrease a firm's operating incomes (Hong, Li, & Xu, 2019; Pankratz, Bauer, & Derwall, 2023). The literature is still limited in focusing on how these risks affect financial decision-making, especially firms' cash holdings. Given the role of liquid assets, especially cash holdings, as protection against forthcoming uncertainties and potential distress, understanding the relationship between firms' cash holdings and climate change risks is more crucial than ever.

Existing studies have explored and found the positive association between climate change and firms' cash holdings. Dessaint and Matray (2017) found that managers tend to hold more cash reserves in the face of natural disasters, treating cash as a defence against liquidity risks caused by climate change. Gounopoulos and Zhang (2024) use temperature trends as a proxy of climate change to observe the positive effect on firms' cash holdings. In these studies, they consistently support evidence that firms tend to maintain liquid assets, especially to meet unexpected contingences as the precautionary purpose. These firms accumulate more cash to secure themselves against likely uncertainties related to climate change.

Moreover, in alignment with the transaction motive propose by Keynes (1937), firm accumulate more cash to deal with the escalation in default risks and borrowing costs in the context of climate change (Wu, Shahbaz, & Kyriakou, 2024). Hoarding more cash from internal financing enable firms to undertake their profitable investment projects without suffering from the high transaction costs of external funds. Additionally, the imperfect capital market creates the relationship between cash holding and firm value which is well-studied in literature (Dittmar & Mahrt-Smith, 2007; Gao, Harford, & Li, 2013; Tong, 2011). However, hoarding more cash from internal financing enable firms to undertake their profitable investment projects without suffering high transaction costs of external funds. Firms hold more cash also lead to opportunity costs, which is inefficient in their financial management (Han & Qiu, 2007; Kim & Bettis, 2014). Firms facing financial frictions decide to incur the opportunity costs of maintaining assets to prevent further disruptions to their corporate policies (Cortes, 2021). Additionally, excess cash can create agency-related tensions between the agent and the principal. In line with the hypothesis of free cash flow proposed by Jensen (1986), holding more cash increase discretion of managers, where they do not maximise the shareholders' wealth and goes against shareholders' interest. Therefore, it is necessary for firms carefully evaluate the benefits and costs of hoarding cash. Martínez-Sola, García-Teruel and Martínez-Solano (2013) found that there is existing the target of cash reserves where firm value is maximised. Moreover, regardless of holding more cash or less cash, they document that it creates a deviation between the actual and target cash levels. Additionally, the authors also document that deviations of cash balances higher or lower their target level of cash holdings are both decrease firm value. Therefore, there has been debatable about the role of firms' cash reserves on financial management. However, existing research has explored the consequences of climate change on both the levels and values of firms' cash holdings, the influence of climate change on the behaviour of adjusting cash holdings, to our knowledge, has been largely ignored. Opler et al. (1999) explore the determinants of corporate cash holding. Bates, Kahle and Stulz (2009) support for extending the analysis of cash reserves determinants while also examining the motive of holdings cash. Cardella, Fairhurst and Klasa (2021) find that firms' decisions about the composition of cash holdings are influenced by other important liquidity management practices, including credit lines, trade credit, and inventory management. There is no study directly investigate the climate change and its consequences on firms' speed of adjustment in cash holdings (SOA-CH).

Graham and Harvey (2001) show that CFOs not only aim to achieve a specific cash holding target but also actively control the speed at which they modify their actual cash reserves to reach the target. Similarly, Bates, Kahle and Stulz (2009) emphasise the importance of the speed of adjusting cash, showing that firms with faster adjustment experience lower financing costs and higher firm value. Therefore, we expect that the speed of cash adjustments plays a critical role, as it has far-reaching implications for firms' liquidity management. Opler et al. (1999) document that managers maintain cash holdings close to the target level avoiding significant deviations, which reflect the firms' adjustment behaviour. This behaviour suggests that firms not only consider their target cash level but also actively work to align actual cash holdings with the target.

To examine the above behaviour, we collect firm-year climate change data as constructed by Sautner et al. (2023), utilising transcripts from earnings conference calls. Using data from 31,766 firm-year observations across 49 countries between 2002 and 2019, we find that firms with higher exposure to climate change risks demonstrate a faster speed of adjustment in cash holdings. The results retain their quantitative consistency when we employ a system GMM estimation to mitigate possible endogeneity. Our study also considers two competing hypotheses on how climate change affects the cash holdings adjustment in the presence of excess cash reserves. Additionally, we implement multiple tests to assess the positive association of climate change on the speed of adjusting cash holdings (SOA-CH). In cross-sectional analysis, we discover that the positive impact of climate change and firms' adjustment speed is stronger for firms facing higher financial constraints or operating in countries with stricter environmental policies. To verify the robustness of our findings, we re-estimate these models applying different measures for climate change and cash ratios, and we also examine the sensitivity of the sample size. The results further validate our main finding that there is a positive correlation between climate change risks and firms' speed of adjusting cash holdings.

Our study offers multiple contributions to the previous literature. First, we extend the growing research by exploring the ways in which climate change and its risks influence corporate decision-making on a global scale (Ding et al., 2021; Ginglinger & Moreau, 2023; Huang, Kerstein, & Wang, 2018a). The precautionary savings motive for maintaining cash reserves is backed by empirical evidence and widely discussed in the literature as a reaction to unforeseen shocks (Bates, Kahle, & Stulz, 2009); aggregate risks (Palazzo, 2012); sensitivity of cash flow (Almeida, Campello, & Weisbach, 2004); external financing restriction (Ahrends, Drobetz, & Puhan, 2018; Marwick, Hasan, & Luo, 2020). In addition, previous studies have investigated how climate change affects cash holdings using the static trade-off theory and the static adjustment model (Gounopoulos & Zhang, 2024; Javadi et al., 2023; Li & Wan, 2024; Zhang, Kanagaretnam, & Gao, 2024). Our study, however, our study contributes by applying the dynamic trade-off theory and dynamic partial adjustment model into the study of firms' cash holdings (El Kalak, Goergen, & Guney, 2024; Han &

Qiu, 2007; Jiang & Lie, 2016; Martínez-Sola, García-Teruel, & Martínez-Solano, 2018; Orlova & Rao, 2018). Moreover, there is currently no evidence linking climate change to cash holdings adjustment speeds. Taken together, we fill these gaps by providing global evidence regarding the influence of climate change on the speed of cash adjustment.

Second, we confirm the findings in the existing literature on corporate cash holdings and the speed of adjusting cash by examining the differential effects of climate change on firms with cash deficits and cash surpluses (Guariglia & Yang, 2018; Venkiteshwaran, 2011). Specifically, we explore how firms with varying cash levels modify their cash balances in reaction to climate change factors. We provide evidence that firms with cash deficits are more vulnerable to external shocks like climate change, forcing them adjust their cash holdings more rapidly. However, firms with cash surpluses tend to use their surplus to finance climate change-related investments, without the immediate need for aggressive cash accumulations. These findings also provide additional evidence for the precautionary motive and the pecking order theory. For firms with cash deficits, the findings support the precautionary motive, whereas the pecking order theory better explains the results for firms with surpluses. Specifically, firms with cash deficit accumulate cash to safeguard against future uncertainties. In contrast, firms may prefer to use internal funds to finance operations and investments with a surplus in cash. This duality enriches the understanding of corporate liquidity management in the context of external uncertainties, such as climate change.

Third, we find that financial constraints are a key moderator in the relationship between climate change and cash policies, especially in the cash holding adjustment speed. Specifically, we introduce the three-way interactions between climate change, the speed of cash holdings adjustment, and financial constraints. This analysis explores how financially constrained firms differ in their cash management behaviour when faced with climate change, providing new insights into corporate liquidity management under external pressures. We find that cross-sectional variations between climate change, cash holdings adjustment speed and financial constraints can potentially influence firms' liquidity management decisions. The study adds depth to understanding how financial constraints intensify the precautionary savings motive for cash holdings, making constrained firms more proactive when managing their liquidity. This contributes to the findings of recent studies (Denis & Sibilkov, 2009; Eskandari & Zamanian, 2022; Zhang, Tong, & Li, 2020).

Finally, our study makes a significant contribution by exploring the moderating effect of environmental policy stringency on the positive relationship between climate change and the speed of cash adjustments. We find that firms in nations with stricter environmental policies adjust their cash holdings more rapidly in response to climate change-related risks, as these regulations impose higher compliance costs and increase operational uncertainties. The findings demonstrate that stringent environmental regulations force firms to prioritise cash management to ensure they can meet compliance obligations, invest in adaptation measures, and address the risks related to climate change. Moreover, our findings further confirm that environmental policies are effective in driving corporate behaviour, highlighting the importance role of governments, policymakers, and their legal issues in effort of mitigate climate change. Therefore, this contribution strengthens our understanding of how regulatory frameworks impact corporate liquidity strategies as part of the effort to combat climate change, offering critical insights for policymakers, corporate managers, and stakeholders aiming to foster resilience in a changing climate. The results contribute to contemporary studies (Duong et al., 2020; Su et al., 2020; Yuan & Gao, 2022).

The organisation of our paper is as described below. Section **2** reviews the literature on climate change, related policies for combating it, and the theory and models of cash holdings, forming the foundation of our hypotheses. Section **3** represent our methodology, including the measures of cash holdings adjustment speed and climate change. In Section **4**, we describe our data and report empirical findings, including our baseline results, cross-sectional analysis, endogeneity and robustness tests, respectively. Section **5** concludes the paper.

2. Background, Literature review and hypothesis development

2.1 Climate change

Climate change is a significant global issue, involving long-term changes of the average weather patterns that determine the climates across local, regional and global scales (NASA, 2024). Human activities – especially burning fossil fuels (e.g. coal, oil and gas) and deforestation – play an essential role in driving climate change. By accelerating the emissions of greenhouse gases (GHG) into the air, these activities have led to acid rain, ozone depletion, global warming (IPCC, 2015). As reported by the Intergovernmental Panel on Climate Change (IPCC), global surface temperature is expected to rise by 1.4°C to 4.5°C compared to preindustrial levels, depending on future emission trends (IPCC, 2023). In particular, carbon dioxide emissions cause anthropogenic climate change and economic damages from increasingly threats to environment, society, and organisations.

On the one hand, climate change causes a several extreme climate event across the globe which affects economic development, resources management, and urbanisation (Alok, Kumar, & Wermers, 2020; Bernstein, Gustafson, & Lewis, 2019; Cattaneo et al., 2019; Dell, Jones, & Olken, 2012; Graff Zivin & Neidell, 2014; Krueger, Sautner, & Starks, 2020). The most obvious effect is the rise in the global temperatures, known as global warming, which is intensifying heatwaves, altering weather patterns and increasing the frequency of droughts, leading to significant losses in GDP and overall welfare across countries (Cruz & Rossi-Hansberg, 2024; Newell, Prest, & Sexton, 2021). Natural disaster and other weather-related disruptions such as hurricanes, floods, and wildfires have become more frequent and intense, causing widespread severely damage to business's production infrastructure and equipment, interrupting supply chains and leading to halt operations (Li et al., 2024). In 2017, $370 billion in economic damage from natural disasters worldwide was record, equivalent to the GDP of Denmark or Egypt (Munich, 2018). Furthermore, both global warming and natural disasters have the negative impacts on long-term economic growth (Kahn et al., 2021; Klomp & Valckx, 2014). Besides, sea-level rise is also putting coastal regions and economic centres at risk, forcing relocations and solutions for financial burdens to both governments and firms (Kahn et al., 2021). Lastly, in Europe, according to IPBES (2018) climate change is considered as the fasters-expanding directly contributing to biodiversity loss which intensify the demand for materials, energy, and food (Paleari, 2024).

In comparison, the economic consequences of climate change are profound and broad, impacting global markets and also the operations of individual firms (Felbermayr & Gröschl, 2014; Huang, Kerstein, & Wang, 2018a; Kling et al., 2021; Li et al., 2024; Vestrelli, Colladon, & Pisello, 2024). Climate change has been consistently ranked by the World Economic Forum has consistently ranked climate change among the top 10 global risks to economic stability, and it is projected to be the top risk over the next decade (WEF, 2024). The rapid increase in climate change-related risk results in massive economics costs. Climate change may influence firms from any industry and size. However, industries that depend heavily on natural resources such as agriculture, energy and insurance are experiencing more operation costs due to the impact of climate change. Moreover, environmental policies are likely to raise the production costs, and those firms with high energy-consuming or polluting may face restrictions or closures(Li et al., 2024). In addition, heat exposure also declines substantially labour productivity, causing the largest economic costs related to climate change (Zhao et al., 2024). Furthermore, supply chain and logistical disruptions due to extreme weather-related events are increasingly becoming a common risk factor for firms' operation in globalised markets. These cause stock shortages, inventory costs and bottlenecks disrupting, affecting procurement, production and logistics operations (Er Kara, Ghadge, & Bititci, 2021).

From a financial perspective, climate change is creating considerable uncertainties, forcing firms to reassess their risk management strategies. They apply a range of approaches, from purely quantitative methods or sophisticated statistical tools to the more recent use scenario analysis and stress testing (Chenet, Ryan-Collins, & Van Lerven, 2021). Financial risk from climate change can be classified into two channels: physical risks and transition risks. Firstly, physical risk is damages to infrastructure or firms' operation from climate change-related extreme events or natural disasters. Along with that, transition risk appears from regulatory of shift towards a low-carbon economy (Ardia et al., 2023). Apart from addressing losses from physical risk, firms are also facing high costs due to compliance with environmental regulations, transitioning their operations to reduce emissions (TCFD, 2017). These increased costs and risks have significant implications for firm's strategic decisions and responsibilities, particularly regarding the need for transparency about climate risk exposure and its impacts. Therefore, the mandatory climate risk disclosure is important for firms to proactive price and manage the financial risks in as part of their financial decisions and risk management strategies (Ilhan et al., 2023; Krueger, Sautner, & Starks, 2020; Litterman, 2021).

In response to the urgent need for global actions, governments around the world have established various climate-related policies in response to mitigate the severe effects of climate change, especially global warming. The adoption of the Paris Agreement in 2015 marks a key milestone in global climate policy. Under this agreement, nations committed to limiting the rise in global warming at less than 2°C above preindustrial levels, while also working to keep the increase within 1.5°C to prevent the harmful effects of climate change (UNFCCC, 2015). Moreover, the agreement requires nations to submit the Nationally Determined Contributions (NDCs), which represent their "pursue efforts" to lower greenhouse gas (GHG) emissions, but only cover 50% of the needed reductions. Therefore, without further policies, these measures will not be sufficient to meet the above global climate goals (Rogelj et al., 2016). Before the Paris Agreement, the Kyoto Protocol of 1998 – the first global treaty – set legally binding emission reduction targets for participating nations (Orazalin, Ntim, & Malagila, 2024). Although it initiated a foundation for global cooperation on climate change, its scope was limited to developed nations (37 nations without China and United States). Furthermore, the absence of United States (U.S.), the largest contributor to greenhouse gases (GHG) emissions globally, generating 25% of all global emissions, significantly weakened its overall effectiveness (Bang et al., 2007; UNFCCC, 1998). In 2017, the Financial Stability Board issued the Task Force on Climate-related Financial Disclosures (TCFD) which provides a framework and guidelines for reporting the potential. This guidance covers four main operational fields: governance, strategy, risk management, and metrics/targets (Chiu et al., 2023; TCFD, 2017). The TCFD promotes transparency, allowing investors, insurers, and lenders in making informed decisions, thereby strengthening the financial system's resilience to climate-related related risks (TCFD, 2024). More recently, at the 26th Conference of the Parties (COP26), the Glasgow Climate Pact renewed the global commitment of combating climate change by emphasising the Paris Agreement's aim of restricting global temperature rise to 1.5°C (UNFCCC, 2022). In particular, over 120 nations, representing more than 70% of global emissions, upgraded their 2030 emissions reduction targets and pledged to achieve net-zero emissions by 2050-2070 (van de Ven et al., 2023). Besides, at the regional level, several notable policies include the European Union's Green Deal in Europe (Fetting, 2020), the Inflation Reduction Act in the United States (Bistline et al., 2023), and China's Dual Carbon Goals or Carbon Neutrality Policy (Huang, Zhang, & Wang, 2022). In conclusion, while the significant progress made through global consensuses, they remain insufficient in fully mitigating the severe effects of climate change. The increasing number of political agreements being issued reflects this ongoing challenge. To completely cope with the effects of climate change, continuous advancements in policy and further adaptive measures will still need to be taken (Abbass et al., 2022).

2.2 Determinants of cash holdings

Cash holdings have been examined through several theories in finance, such as the trade-off theory, the pecking order theory (the financing hierarchy theory), and the market timing theory. The trade-off theory, which was initially developed for capital structure, has been applied to understand corporate liquidity (Fischer, Heinkel, & Zechner, 1989; Kim, Mauer, & Sherman, 1998; Leland & Toft, 1996). Recently, it also helps to explain the firm's cash holdings in research (Flannery & Rangan, 2006; Opler et al., 1999; Orlova & Rao, 2018). Under the static trade-off theory, firms balance between the costs and benefits of holding cash by numerous motivations, setting a target cash level and gradually adjusting to reach it. In line with the trade-off theory, Opler et al. (1999) found that specific determinants of corporate liquidity, such as size, leverage, net working capital, dividend payment status are negatively correlated with cash holdings, whereas cash flow, capital expenditures, industry volatility, and R&D are positively associated with cash levels. Dittmar, Mahrt-Smith and Servaes (2003) supported these findings using the data from a multinational sample. Riddick and Whited (2009) further extended the research by noting the negative relationship between Tobin's Q and cash holdings. Bates, Kahle and Stulz (2009) observed that average cash holdings have grown significantly in recent decades, resulting in increased firms' cash flows risk, decreased inventories and capital expenditures, but increased in R&D expenses. Additionally, they also found acquisition activity also has a negative impact on cash holdings levels.

In addition to the trade-off theory, earlier studies on cash holdings also consider the presence of other factors in determining cash reserves. There is no doubt that managers and shareholders weight the costs and benefits of liquid assets holdings, particular cash, in different ways (Opler et al., 1999). Therefore, the conflict between these parties also has a critical influence on corporate financial policy decisions (Nikolov & Whited, 2014). The agency conflicts, in particular, shape firm's motivation for accumulating and utilise liquid assets. Within the agency theory framework, it is suggested that firms aim for a target cash holdings that balances the benefits between managers – who may prefer to hold excess cash to increase their discretion, and shareholder – who seek to maximise their wealth. Meckling and Jensen (1976) along with Jensen (1986) introduced the agency theory framework, which was explored through free cash flow hypothesis grounded in the principle of agency costs, explaining why firms may not reserve cash to maximise the shareholder wealth. Additionally, this theory indicates that firms with excess cash holdings may arise risks. Holding excess cash allows managerial opportunism, as managers may pursue their personal interests by inefficiently using free cash flow, even investing in unprofitable projects with negative net present value (NPV) (Alipour & Yaprak, 2024; Dittmar, Mahrt-Smith, & Servaes, 2003; Harford, Mansi, & Maxwell, 2008). Thus, without shareholder protection, managers tend to hoard cash rather than increasing dividends, aiming to avoid costs of external capital, taxes and policy discipline (Dong et al., 2021; Kalcheva & Lins, 2007; Pinkowitz, Stulz, & Williamson, 2006; Smith Jr, 1986). Managerial risk aversion, as indicated by proxies such as firm size, R&D intensity, and industry volatility, is also an important determinant of cash holdings within the agency theory framework (Dittmar & Duchin, 2016; Feng & Rao, 2018; Sah, 2021).

In contrast, under the assumption that managers prioritise shareholder wealth by maximising firm value, they would always hold a target cash balance as long as it were costless. However, the process of adjusting cash reserves incurs non-trivial costs due to capital market imperfections. As a result, firms do not pursue a particular level of cash reserves, according to Opler et al. (1999), financing hierarchy theory of corporate liquidity. Instead, when facing with financial deficits, firms typically tend to use their cash reserves, while they accumulate additional cash holdings during the periods of cash flow surplus. This theory is based on the capital structure hierarchy model suggested by Donaldson (1961), which was later extended by Myers and Majluf (1984) and Shyam-Sunder and Myers (1999) who suggested that information asymmetry and the costs of adverse selection are also the main determinants of firm's financial decision. Moreover, hierarchy theory of corporate liquidity views debt and cash simply as to sides of the same coin. Particularly, Opler et al. (1999) argued that a corporate's financial position remains unchanged if an additional dollar of cash is acquired by increasing debt by an equivalent amount. Thus, the cash holdings are simply the result of the investment and financing decisions of firms in response to the pecking order theory. In addition, several variables from this theory that correlate with cash flows was employed as proxies within the trade-off theory (Dittmar & Duchin, 2016).

DeAngelo, DeAngelo and Stulz (2010) identified that cash balances as a key motive behind seasoned equity offerings (SEOs). In line with the market timing theory framework, firms take advantages of favourable conditions to strategically raise funds as cash reserves, which serve as a hedge against unfavourable market conditions (Bolton, Chen, & Wang, 2013; McLean, 2011). This behaviour is particularly evident when shares are overvalued, as noted by (Spiess & Affleck-Graves, 1995) and Baker and Wurgler (2000). Consequently, existing studies imply a strong association between cash holdings and the market timing decisions of issuing securities, although the impact of the market timing variables tends to weaken as firms age (Alti, 2006; Baker & Wurgler, 2002).

Overall, in line with the capital structure literature, studies on cash holdings suggests that firms' cash management behaviours are shaped by various determinants (Bates, Kahle, & Stulz, 2009; Jiang & Lie, 2016; Opler et al., 1999). Opler et al. (1999) found evidence supporting the trade-off theory, showing that firms set a target cash level and progressively adjust their cash reserves toward it. They also observed that firms with cash balances exceeding their target level present a higher absolute value of coefficient of the flow of funds deficit (financial deficit). Therefore, the financial hierarchy model is more effective at predicting cash changes in such firms due to an agency consideration. Moreover, combining the pecking order model (or financial hierarchy model) with the target adjustment variable from the static trade-off model also significantly explains cash level changes, with the target cash level defined by the static trade-off theory.

2.3 Cash holdings adjustment speeds

Under a setting where capital market are perfect and financial frictions are insignificant, Opler et al. (1999) documented that cash holdings are irrelevant, consistent with the theorem of Modigliani and Miller (1958). If a target cash level exists and managers aim to maximise the firm value, they would maintain this optimal level, as doing so is costless. Moreover, external funds for investments or to cover temporary cash flow shortfalls can always be obtained at a fair price, there is no compelling reason for firms to hold a significant amounts of excess liquid assets. Thus, the implications are that firms should optimally maintain zero excess cash (Kim, Mauer, & Sherman, 1998).

However, according to research on leverage rebalancing, adjustment costs or imperfect capital markets prevent firms from continuously rebalancing their leverage (Leary & Roberts, 2005; Strebulaev, 2007; Titman & Tsyplakov, 2007). Under conditions of financing and investment frictions, firms also face non-trivial costs associated with adjusting their cash levels (Orlova & Rao, 2018). Moreover, firms often experience difficulties in immediately adapting to changes in industry and market conditions, causing deviations of their actual cash reserves from target cash levels (Venkiteshwaran, 2011). To mitigate these uncertainties, firms hold excess cash reserves as the precautionary motive to protect against unexpected contingencies, such as cash flows shortages or costly external financing for future production and operational needs (Opler et al., 1999). In addition, due to high cost of adjusting cash holdings, firms have a tendency to balance the marginal cost and benefit of maintaining liquidity, rebalancing their cash levels through security issuance or investment cuts.

Overall, several studies have been conducted to identify the key determinants of corporate cash balances and the behaviour of cash management over time. For this purpose, some studies including the work of Kim and Bettis (2014); Opler et al. (1999); and Han and Qiu (2007) examined the cross-sectional dispersion of cash reserves based on the static trade-off theory. However, this approach has faced criticism for ignoring investment and financing frictions that impact the adjustment speed to target cash levels. Moreover, the assumption that firms have the ability to instantly adjust to target cash levels is unrealistic under market imperfections. Therefore, numerous studies have recognised the need to incorporate dynamic models of cash holdings based on the dynamic trade-off theory, which takes market frictions and adjustment costs into account (El Kalak, Goergen, & Guney, 2024; Flannery & Rangan, 2006; Guariglia & Yang, 2018; Huang & Ritter, 2009; Jiang & Lie, 2016; Ozkan & Ozkan, 2004; Venkiteshwaran, 2011). These dynamic models are more suitable than static models, because they allow firms to adjust their cash holdings gradually to the target level in the presence of market imperfections and adjustment costs (Ozkan & Ozkan, 2004).

According to Orlova and Rao (2018), a high speed of adjustment (SOA) indicates a firm's capacity to quickly align its actual cash level with the target, which is in line with the trade-off theory. This suggests that firms possess a clear target cash policy and make regular adjustments to reach this target. A speed of adjustment (SOA) of 1 is consistent with the static approach in the model of trade-off theory, implying that firms adjust immediately to maintain target cash holdings. In contrast, when the speed of adjustments (SOA) is close to 0, the trade-off theory fails to adequately explain firms' cash management behaviour, as they are not actively adjusting toward their target. In such cases, other factors, such as market conditions, risk, and investment opportunities, become more important in determining cash holdings (Bates, Kahle, & Stulz, 2009). Additionally, if the speed of adjustment is shown to be systematically related to adjustment costs, even when below 1, it would support the dynamic trade-off theory.

The dynamic partial adjustment models have been widely employed in the literature on the leverage adjustment speed (or capital structure) to identify various antecedents that affect the adjustment toward the target level. These studies include Fischer, Heinkel and Zechner (1989), who was among the first to develop a dynamic model for firms' capital structure considering recapitalisation costs; Leland and Toft (1996), who investigated debt maturity; Zhou et al. (2016) on the cost of equity; Warr et al. (2012) on equity mispricing; Faulkender et al. (2012) on cash flows; DeMarzo and He (2021) on absent commitment; and Hackbarth and Sun (2024) on corporate investment. There has been a lot of research done on leverage adjustment, but not as much on the adjustment of cash. Opler et al. (1999) provided initial evidence in supporting for the trade-off theory in identifying the determinants of cash holdings, finding that firms with significant growth opportunities and riskier cash flows tend to accumulate more cash, while larger firms with greater access to capital markets tend to hold less. Bates, Kahle and Stulz (2009) observed that average cash holdings more than twofold between 1980 and 2006 due to increased cash flow risk, reduced inventories and receivables, and increased R&D intensity. Specially, the findings provided no evidence supporting the agency theory. Consistent with these findings, Venkiteshwaran (2011) also demonstrated inconsistencies with agency theory, noting that smaller firms hoard more cash and adjust more swiftly than larger ones, taking an average of two years to close deviations from the target cash level. Jiang and Lie (2016) found that firms revert about 31% of their deviations from the target annually, with faster adjustment occurring when cash holdings exceed the target, as accumulating cash is cheaper than raising it externally. Bates, Kahle and Stulz (2009) emphasised investment opportunities and cash flow volatility are important factors driving increased cash holdings, while market frictions slow the speed of adjustment. In conclusion, assuming homogeneous and immediate adjustment across all firms is unrealistic, as differences in adjustment costs largely depend on firm characteristics. Furthermore, the adjustment speed of cash holdings is greatly impacted by both internal and external frictions.

2.4 Climate change and cash holdings adjustment speeds

Scholars have made substantial efforts into examining the potential impact of climate change on earnings management (Ding et al., 2021; Velte, 2021); cost of capital (Kling et al., 2021); financial stability (Battiston, Dafermos, & Monasterolo, 2021; Chabot & Bertrand, 2023; Roncoroni et al., 2021); bank stability (Le, Tran, & Mishra, 2023); firm performance (Ozkan, Temiz, & Yildiz, 2023) capital structure (Ginglinger & Moreau, 2023); and payout flexibility (Chang, He, & Mi, 2024a). Several preceding studies have provided evidence supporting the effect of climate change on macro-level economic efficiency, however, the association between risks from climate change and corporate financial decision-making, especially liquidity management, has yet to be sufficiently examined. This study aims to develop hypotheses to understand how firms respond to the effect of climate change-related risks by adjusting their cash holdings.

The firms' behaviour in adjusting cash holdings can be affected by various motives, as defined by financial theories discussed previously. The precautionary savings motive indicates that firms accumulate greater cash reserves for precautionary and speculative purposes to address costs from unexpected shocks. In a seminal work, Bates, Kahle and Stulz (2009) support this motive by finding that firms maintain higher cash balances to be better positioned to cope with future uncertainties and potential financial distress. Ozkan, Temiz and Yildiz (2023) indicate that firms with high exposure to climate change-related risks face significant costs. In particular, physical risks (e.g., infrastructure damage from natural disasters) and transition risks (e.g., investment in new technologies to meet society's concern and expectation) substantially increase costs. Climate change-related risks lead to an increase in financial costs, pushing business into financial distress (Naseer et al., 2024). Moreover, Kabir et al. (2021) stress that firms with reputational risks related to high emissions can face financial distress due to revenue loss and market share decline. Therefore, firms facing greater exposure to climate change-related risks have a stronger incentive to raise their cash holdings. As a result, they are more likely to adjust their cash position more swiftly to reach the target level that can buffer against these financial uncertainties and distress.

In addition, prior studies demonstrated that climate change-related risks substantially increase the cost of external financing for both equity and debt channels (Cepni, Şensoy, & Yılmaz, 2024; Chava, 2014; Jung, Herbohn, & Clarkson, 2018). Indeed, analysing an international dataset from 71 countries, Kling et al. (2021) find that investors and lenders become more cautious about financing firms with high climate risk exposure, leading to higher capital costs or reduced access to funding. This finding aligns with the pecking order theory, where firms prioritise internal financing rather than external financing because of asymmetric information and transaction costs. As a consequence, maintaining a target cash level becomes even more critical, prompting firms to accumulate more cash by adjusting faster their cash reserves.

Furthermore, in addition to damaging the capital of firms, Dafermos, Nikolaidi and Galanis (2018) observe that climate change-related risks are likely to reduce their profitability, which in turn deteriorates firms' liquidity. In specific climate change events, such as extreme heat and drought, Hong, Li and Xu (2019) and Pankratz, Bauer and Derwall (2023) present evidence of a negative association between climate change-related risks and firm's operating. Similarly, Huang, Kerstein and Wang (2018a) used a large multinational dataset of 353,906 firm-year observations across 54 countries and found that firms in countries facing significant climate change risks tend to perform poorly and have more volatile earnings. The authors further indicate that these firms are inclined to hold more cash and long-term debt to build resilience to climatic threats. The implication is firms have a tendency to adjust their actual cash holdings toward the target balance faster as part of risk mitigation.

Overall, firms appear to be conscious of their exposure to climate change-related risks and recognise the importance of financial resources to make necessary adjustments in their infrastructure and operations to counter these risks. These findings indicate that firms respond by accumulating additional cash as a cushion to buffer increased costs from external capital, unfavourable cash flow volatility, and the stranded assets risks(Javadi et al., 2023). Thus, exposure to increased climate change-related risks drives firms to adjust their cash holdings more rapidly to accumulate the necessary cash reserves to navigate market friction effectively. Taken together, we predict that increased climate change-related risks and exposure lead to a faster adjustment speed in cash holdings to maintain adequate cash buffers. We formulate the hypothesis as follows:

*Hypothesis **1**: Climate change is positively associated with cash holdings adjustment speeds.*

2.5 Excess cash, climate change, and cash holdings adjustment speeds

This study argues that the speed of adjustment (SOA) among firms with high level of exposing climate change-related risks may be affect differently between firms with below-target cash levels (a cash deficit) and above-target cash level (a cash surplus). We develop two competing hypotheses to analyse whether and how these effects vary:

On the one hand, we argue that climate change exerts a more pronounced positive influence on cash holdings adjustment speed when cash balances are below their target level rather than above it. In a seminal work, Schumpeter (1936) introduced the precautionary savings motives for holding cash behaviour, positing that firms maintain liquid assets to safeguard against future and unforeseen contingencies. The author also argue that the unpredictability of the economic environment necessitates a buffer stock of cash to ensure operational flexibility and solvency. This concept has been a foundation in understanding corporate liquidity management. Bates, Kahle and Stulz (2009) empirically examined U.S. industrial firms and found that increase in business risks and uncertainties lead to higher cash holdings. They attributed this to firm's desire to hedge against potential adverse shocks, reinforcing the precautionary motive. Their study indicates that firms facing greater risks adjust their cash reserves more proactively to maintain financial stability. Climate change represents a profound source of uncertainty and risk for firms globally. Several studies highlight the impact of climate risks on disrupting supply chains, alter resource availability, and necessitate significant capital investment for adaptation (Hepburn et al., 2020; Lash & Wellington, 2007; Pankratz & Schiller, 2024; Smith, Knapp, & Collins, 2009). When firms' actual cash holdings are below their optimal targets (or a cash deficit), the urgency to rebuild liquidity intensifies. Indeed, Almeida, Campello and Weisbach (2004) demonstrate that firms facing financial constraints are more sensitive to internal cash flows when adjusting their cash positions. They argue that such firms face higher external financing costs, making internal liquidity important for investments and operations. Hence, in this situation of climate change, firms with cash deficits exposed to climate risk find external financing both more costly and less accessible due to heightened risk perceptions among investors (Graham, Leary, & Roberts, 2015). As a result, these firms have a stronger motivation to adjust their cash holdings more quickly to mitigate liquidity constraints and ensure they can respond effectively, such as to climate-induced challenges (Campello, Graham, & Harvey, 2010). Palazzo (2012) supports the evidence by showing that firms facing higher aggregate risk factors exhibit increased cash adjustment speeds, aligning with the precautionary purpose. Moreover, Baum et al. (2006) also report that firms adjust their cash holdings more swiftly in light of macroeconomic uncertainties. Consequently, we predict that increased climate change leads to a faster adjustment of corporate cash level, which is more pronounced for firms experiencing cash deficits. The first hypothesis is defined as follows:

Hypothesis ***2a****: The positive association between climate change and cash holdings adjustment speed is more pronounced when cash holdings are below their target level compared to when they are above the target level.*

On the other hand, we contend that climate change has a stronger positive effect on the adjustment speed of cash holdings when they are above the target compared to when they are below. As introduced by Jensen (1986), the agency theory proposes that excess cash holding can lead to managerial discretion problems, where managers invest in projects that do not maximise shareholder value. This free cash flow hypothesis documents that surplus cash enables overinvestment and can exacerbate agency disputes between managers and shareholders. Stulz (1990) extends this argument by indicating that managers with access to excess liquidity may pursue personal objectives, such as empire-building, rather than value-enhancing investments. Harford (1999) investigates empirical evidence that firms with surplus cash have a higher likelihood of making acquisitions that reduce shareholder wealth, noting the risks associated with surplus cash holdings. With in the context of climate change, firms with cash surpluses face increase pressure from stakeholders to utilise their resources effectively in addressing environmental risks (Eccles, Ioannou, & Serafeim, 2014). Shareholders and institutional investors demand that excess cash be invested in sustainable initiatives or returned to shareholders if not efficiently deployed (Dyck et al., 2019). Moreover, Bansal and Clelland (2004) documents that firms with higher visibility and reputational concerns are more responsive to environmental pressure. Firms with surplus cash might adjust their cash holdings more rapidly to fund credible climate-resilient projects, enhancing their legitimacy and competitive advantage (Porter & Linde, 1995). Additionally, the opportunity cost of holding excess cash increases under severe climate change. Firms recognise that investing in adaptive technologies or sustainability initiatives can earn long-term benefits and mitigate future risks (Delmas & Toffel, 2008). As a result, Bénabou and Tirole (2010) argue that corporate social responsibility actions can align with shareholder interests, suggesting that surplus cash can be accumulated faster towards value-enhancing environmental investments.Taken together, we anticipate that cash surplus firms will adjust their cash reserves more rapidly. We proposed the following hypothesis:

*Hypothesis **2b**: The positive association between climate change and cash holdings adjustment speed is more pronounced when cash holdings are above their target level compared to when they are below the target level.*

In the climate change-related issues, Krueger, Sautner and Starks (2020) report that institutional investors are increasingly concerned about climate risks and expect firms to manage these risks proactively. This external pressure can affect managerial decisions regarding cash adjustments, potentially supporting Hypothesis **2b**. However, the urgency associated with liquidity shortages emphasise the evidence for Hypothesis **2a**. Indeed, Campello, Graham and Harvey (2010) show that during financial crises, firms with constrained access capital markets adjustment their policies more intensely to preserve liquidity. Where climate change can be perceived as a persistent, systemic risk that requires firms to maintain adequate cash reserves, especially when internal funds are scarce. Given to both hypotheses from theoretical considerations, we seek empirical test whether which hypothesis holds true.

2.6 Moderating impact of environmental policy stringency

We identify a positive relationship between climate change and the adjustment speeds of cash holdings, which aligns with the precautionary savings motive. In our second set of hypotheses, we explore the role of government in implementing stringent environmental and climate change policies. The association between climate change and firms' cash holdings adjustment speed (SOA) possibly influenced by the environment policy stringency of their operating nations. We build hypotheses to examine whether the presence of environmental policy stringency, as a moderator on the association of climate change and speed of adjustment in cash holdings:

With increasing awareness of the climate change and its consequences, efforts to slow down climate change have dominated the agenda of policymakers across the world (Ozkan, Temiz, & Yildiz, 2023). As first defined by Botta and Koźluk (2014), environmental policy stringency is the strictness and enforcement intensity of environmental regulations imposed by governments. Such stringent policies often lead to increased compliance costs, operational adjustments, and necessitate investments in cleaner technologies (Ambec et al., 2013). Consequently, firms operating under such harsh conditions face greater regulatory pressures, which significantly impact their financial and strategic decisions (Berrone et al., 2013).

From the perspective of the Resource-Based View (RBV), Barney (1991) suggests that firms with strong financial flexibility invest better in sustainable technologies and practices to gain a competitive advantage. In the scene of stringent environmental policies, Hart and Dowell (2011) support the evidence by finding that financial flexibility enables firms to adapt swiftly to regulatory changes and mitigate climate change-related risks, thereby enhancing their competitiveness. Financial flexibility helps firms to adapt swifty to regulatory changes and mitigate climate change-related risks, enhancing their competitiveness. Therefore, efficiently managing cash holdings becomes a strategic asset, helps firms take the opportunities arising from those environmental regulations, such as investing in green technologies. This suggests for a more pronounced relationship between climate change and cash holdings adjustment speed, in which environmental policy work as the moderator.

Moreover, these views also align with Institutional theory which introduced by DiMaggio and Powell (1983). This theory show that firms tend to comply to their institutional environment's norms and rules can gain legitimacy and access resources. In addition, Ou and Jiang (2023) show evidence that special emission limit (SEL) reduces firm performance, in particular, less production scale, profitability, and market size, leads firms face financial distresses and constraints. Therefore, firms tend to accelerate cash holdings adjustment not only fund environment-relates projects but also cope with its adverse caused.

As proposed by Teece, Pisano and Shuen (1997), the Dynamic capabilities framework refers firm's ability to integrate, build, and reconfigures competencies to address rapidly changing environments, which are also relevant. Li et al. (2018) supports the evidence by showing that in the climate change and stringent policy of disclosure, firms with active financial management can response better to environmental uncertainties and regulatory pressure. This implies for those firms to actively adjust their cash faster to deal with such adverse. Thus, the policy may accelerate the speed of cash holdings adjustment under intense climate change circumstances.

Overall, we expect that firms in nations with higher environmental policy stringency face greater regulatory pressures, expectations, and risk associated with non-compliance, forcing them be more likely to have active and flexible in liquidity management by adjusting their cash holdings toward the target more rapidly. By applying this strategy, firms tend to have sufficient liquidity for compliance, innovation, and strategic investments related to climate change adaptation and mitigation. Taken together, we developed the hypothesis as follows:

Hypothesis ***3****: The positive relation between climate change and cash holdings adjustment speeds is more pronounced for firms in nations with higher environmental policy stringency.*

2.7 Moderating impact of financial constraints

Up to this point, we have documented the positive association between climate change-related risks and the speed of firms' cash holdings adjustment. This finding supports the precautionary savings motives for cash reserves. In this section, we explore how financial constraints moderate the correlation between climate change-related risks and cash holdings adjustment speed. Specifically, we argue that the effect of climate change related risks on the speed of cash holdings adjustment is more pronounced in financially constrained companies. Thus, financial constraints serve as a moderator in this relationship.

As previously discussed, climate change leads to significant operational and financial uncertainties for firms. These uncertainties force firms to reassess their liquidity management strategies. For financially constrained firms, these challenges even more pronounced. Financial constraints could be defined as a firm with limited ability to access external financing due to factors such as high cost of external capital, lack of collateral, or underdeveloped financial markets (Fazzari, Hubbard, & Petersen, 1987). Consequently, financially constrained firms are more reliant on internal funds to finance their investments and operations, especially when they face substantial risks like climate change.

Accordingly, the precautionary savings motive suggests that firms are more likely to hold more cash reserves to minimise loss from future uncertainties and potential financial distress (Bates, Kahle, & Stulz, 2009). The motive is even stronger for financially constrained firms because their restricted access to external capital results in critical internal liquidity. In other words, climate change-related risks lead to a more pronounced adjustment in cash holdings for these firms. Using the U.S. firms' sample of 29,954 observations, Almeida, Campello and Weisbach (2004) find that firms facing financial constraints have a greater cash flow sensitivity of cash. This indicates that firms adjust more aggressively cash holdings to deal with internal cash flow changes. Similarly, Li (2019) also demonstrates that firms under more severe financial constraints accumulate considerably more cash when faced with higher levels of economic policy uncertainty, such as those due to climate change. These findings indicate how financial constraints strengthen the association between climate change risks and the speed of adjusting cash holdings.

On balance, the pecking order theory further supports this perspective. In the seminal work, Myers and Majluf (1984) document that firms appear to favour internal financing rather than external financing due to information asymmetries and more costly of external funds. When firms have high exposure to climate change risks, firms under constraints are more likely to face even greater challenges in securing external financing. As a consequence, they rely heavily on internal funds for necessary investments in adaptation and mitigation strategies. This option requires firms to have a faster adjustment in cash holdings. Gao, Harford and Li (2013) reinforce the evidence by showing that constrained private firms have a tendency to adjust their cash holdings more quickly because they cannot easily finance in external capital markets. Using data of Chinese enterprises from 2012 to 2017, Zhang, Xing and Wang (2020) show evidence that financially constrained firms depend more significantly on internal cash reserves to develop environmental innovation. This implies that it is necessary for firms to faster cash adjustments under environmental pressures. In summary, these arguments predict that higher financial constraints lead to the faster adjustment in cash holdings in response to climate change.

Moreover, existing empirical evidence also supports the argument that financial constraints increase the need for adjusting faster cash level in the face of uncertainties. Using an extensive survey sample from over 1,000 CFOs across 39 countries during the 2008 financial crisis, Campello, Graham and Harvey (2010) show that financially constrained firms hoarded cash more aggressively. This behaviour indicates that firms rapidly adjust in order to preserve liquidity. Lins, Servaes and Tamayo (2017) also show that corporate governance and financial stress influence cash policies during financial crises. Therefore, constrained firms are more prone to significantly raise their cash holdings compared to unconstrained firms. Climate change-related risks can similarly disrupt financial markets and increase uncertainty. We expect that firms under financial constraints will adjust their cash holdings to the target more rapidly compared to unconstrained firms, due to higher exposure to climate change risks. In contrast, such firms with low financial constraints have better access to external financing. Therefore, they finance external funds to address climate change challenges without heavily relying on internal liquidity. Thus, they reflect that the impact is more substantial for firms experiencing financially constraints. In summary, we integrate these insights and develop the following hypothesis:

*Hypothesis **4**: The positive relation between climate change and cash holdings adjustment speeds is more pronounced for firms with a higher degree of financial constraints.*

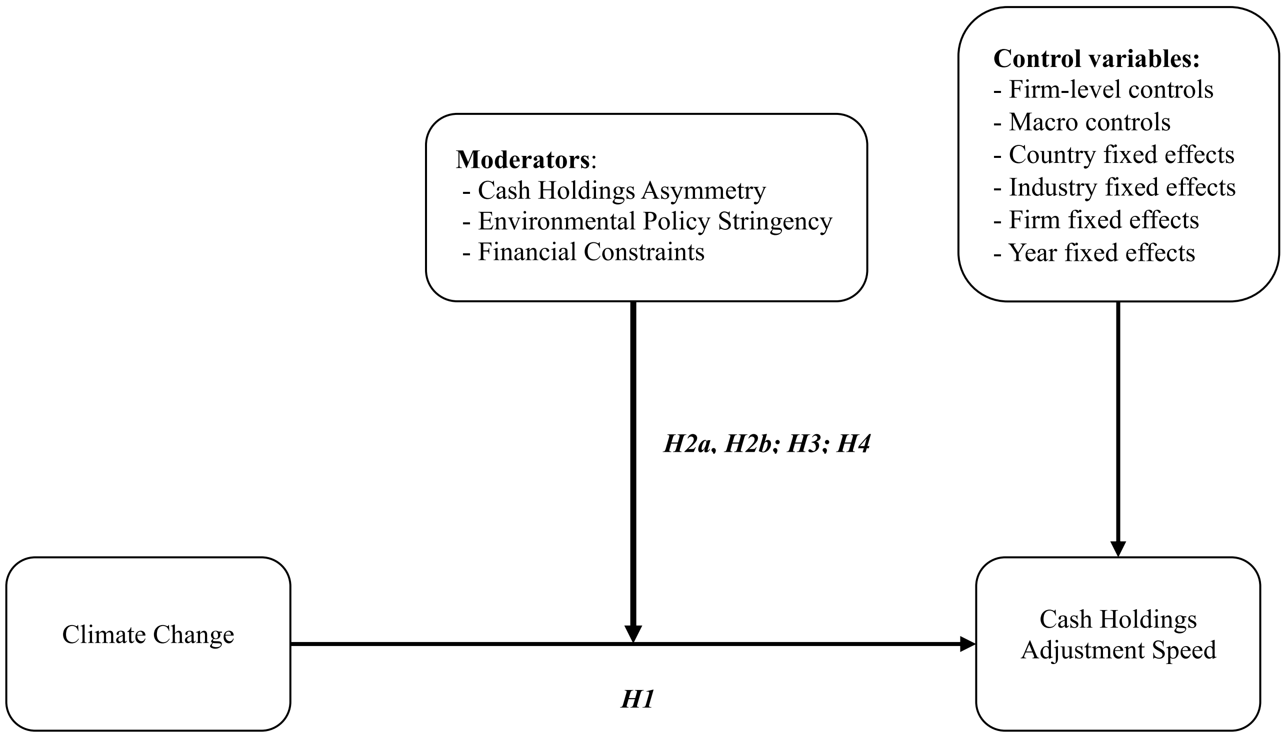

Figure 1: Theoretical model

3. Methodology

3.1 Data selection

To construct the sample, the data on our study were compiled from several sources. We first obtained firm-level accounting data of all firms from Compustat US and Compustat Global. Following that, data on firm-year climate change were collected, as developed by Sautner et al. (2023).[1] Data at the country level are gathered from the World Bank's World Development Indicators, World Bank Worldwide Governance Indicators database, and OECD Data Explorer.

Following prior studies, we excluded: (1) firms in the financial sector (SIC codes 6000-6999) and utilities industries (SIC codes 4900-4999) because of the heavy regulatory environment in these sectors and significant differences in their operating decisions compares to other firms, (2) nations with fewer than 10 observations, (3) any firm-years

[1] The details of climate change data can be found at https://doi.org/10.17605/OSF.IO/FD6JQ. We thank Professor Zacharias Sautner for sharing the data.

observations with missing value for the main variables of our interest. To minimise the impact of outliers, we applied winsorisation to all continuous financial variables at the 1st and 99th percentiles of their distributions. Finally, the proprietary database contains 31,766 firm-year observations targeting 4,787 unique firms worldwide across 49 nations, covering the period between 2002 and 2019. We started our sample in 2002 due to it was the first available data of firm-level climate change exposure (CCE) and climate change risk (CCR), ended in 2019 to mitigate the COVID-19 pandemic bias results.

3.2 Variable measurements

3.2.1 Dependent variable: cash holdings adjustment speeds.

We estimate the adjustment speed of cash holdings follows an approach similar to the dynamic partial adjustment model proposed in leverage adjustment speed by Myers (1984), Fischer, Heinkel and Zechner (1989) and widely used in capital structure research (Byoun, 2008; Faulkender et al., 2012; Warr et al., 2012; Zhou et al., 2016). In the essence of Ozkan and Ozkan (2004), Bates, Kahle and Stulz (2009) and Jiang and Lie (2016), we applied standard partial adjustment model to measure the speed of adjustment of cash holdings (CH-SOA), which is determined by the trade-off between the benefits and costs of cash reserves. In particular, the adjustment speed of cash holdings refers to the difference between a firm's current cash level and the targeted optimal cash holdings. When the absolute value of the speed of adjusting cash holdings is greater, it reflects a larger deviation in actual cash holdings from the target level, resulting in inefficiency.

Following previous studies, we adopt a two-step estimation procedure. In this approach, we calculate the actual cash holdings ratio by applying cash and equivalents relative to total assets. We first estimated the target cash holdings level by employing the static model proposed by Opler et al. (1999) as shown below:

$$
\begin{aligned}
Cash/TA_{i,t} = {} & \beta_0 Size_{i,t-1} + \beta_1 Tobin's\ Q_{i,t-1} + \ \beta_2 Industry\ CF\ risk_{i,t-1} + \beta_3 CFO_{i,t-1} \\
& + \beta_4 NWC_{i,t-1} + \ \beta_5 CapEx_{,t-1} + \ \beta_6 Leverage_{i,t-1} + \beta_7 R\&D_{i,t-1} \\
& + \ \beta_8 Dividend_{i,t-1} + \ \beta_9 Acquisition_{i,t-1} + \ \beta_{10} Age_{i,t-1} \\
& + Fixed\ Effects + \varepsilon_{i,t}
\end{aligned}
\tag{1}
$$

where $Cash/TA_{i,t}$ is the cash and equivalents as a proportion of total assets from year $t-1$ to year t for firm i; $Size_{i,t-1}$ is the natural logarithm of total assets scaled by total assets of firm i during the year $t-1$; $Tobin's\ Q_{i,t-1}$ is determined by subtracting the book value of equity from total assets, adding the market value of equity, all scaled the total assets in firm i for year $t-1$; $Industry\ CF\ risk_{i,t-1}$ is the cash flow-to-total-assets ratios across a 4-year period for firms within the similar industry, classified by two-digit Standard Industrial Classification (SIC) code of firm i in year $t-1$; $CFO_{i,t-1}$ refers to earnings after interests, dividends, and taxes, but excluding depreciation, scaled by the total assets for firm i during the year $t-1$; $NWC_{i,t-1}$ represents net working capital, excluding cash and equivalents scaled, and dividing it by total assets in firm i for year $t-1$; $CapEx_{i,t-1}$ is calculated by scaling capital expenditures by the total assets of firm i at time $t-1$; $Leverage_{i,t-1}$ is the ratio of total debt to the total assets relating to firm i for year $t-1$; $R\&D_{i,t-1}$ is the research and development expenditures expressed as a proportion of the total assets for firm i in year $t-1$; $Dividend_{i,t-1}$ is a dummy variable that set to 1 if the firm paid a common dividend in that year, and 0 otherwise; $Acquisition_{i,t-1}$ is set to 1 if the firm made an acquisition that year, and equals 0 otherwise; $Age_{i,t-1}$ is the durations, in years, since the firms started its operations. In addition, we also controlled the country, firm, year, and industry fixed effects employ the 48-industry classification codes by Fama and French (1997) to define for industry fixed effects.

In previous studies, a firm's target cash holdings ratio was derived from the basic method on pooled ordinary least squares (OLS) regression, where the firm's cash holdings ratio was regressed on specific firm-level variables (Anderson & Hamadi, 2016; Martínez-

Sola, García-Teruel, & Martínez-Solano, 2018). To isolate for the possible influences of time-varying, firm-level unobserved or industry-invariant heterogeneity at firm-level of the target cash holdings ratio, we also ran the regression for year fixed effects with each of the years 2002-2019; for industry fixed effects, firm fixed effects as Standard Industrial Classification (SIC) code. The estimation of this regression resulted in a variety of annual regressions for each industry and firm. Nevertheless, as noted by El Kalak, Goergen and Guney (2024), this method may still produce biased coefficients, affecting the heterogeneity of cash holdings ratio targets across firms. As a result, firm-year Fama-MacBeth cross-sectional regression was employed with to allow for those variations as mentioned.

The coefficients resulting from predicting Equation ***(1)*** denotes the target level of cash holdings ($Cash/TA^{*}$). In the second step, we use the estimated target cash holdings ratio from Equation ***(1)*** to apply the subsequent partial adjustment model:

$$Cash/TA_{\ i,t} - Cash/TA_{\ i,t-1} = \gamma_0 + \gamma_1(Cash/TA^{*}_{\ i,t} - Cash/TA_{\ i,t-1}) + \sum \gamma_n Controls + \varepsilon_{i,t} \quad \textbf{\textit{(2)}}$$

where $Cash/TA_{\ i,t} - Cash/TA_{\ i,t-1}$ represents the change in the actual cash holdings ratio between year t and the previous year $t-1$ for firm i; Similarly, $Cash/TA^{*}_{\ i,t} - Cash/TA_{\ i,t-1}$ denotes the difference between the target cash ratio for the current year and the actual ratio for the previous year; $Controls$ consist of a range of firm-level control variables: $Size_{i,t-1}$, $Tobin's\ Q_{i,t-1}$, $Industry\ CF\ risk_{i,t-1}$, $CFO_{i,t-1}$, $CapEx_{i,t-1}$, $Leverage_{i,t-1}$, $R\&D_{i,t-1}$, $Age_{i,t-1}$; dummy variables: $Dividend_{i,t-1}$, $Acquisition_{i,t-1}$ as a result of critical determinants of cash holdings ratio (Bates, Kahle, & Stulz, 2009); and country-level control variables: $Inflation_{i,t-1}$, $GDP\ Growth_{i,t-1}$, $Corruption_{i,t-1}$ (Chang, He, & Mi, 2024b; Orlova & Rao, 2018). Importantly, the coefficient for the deviation between actual cash holdings and the target, γ_1, represents the average speed of cash holdings adjustment to its target (CH-SOA), expected to range from 0 to 1. A coefficient, γ_1, value of 1 means that firm immediately move their actual cash holdings level towards their target; while value of 0 indicates that the adjustments costs are too high for the firm to modify their liquid asset investments (Martínez-Sola, García-Teruel, & Martínez-Solano, 2018). Note that higher values of the adjustment speed of cash holdings indicates a faster movement from the actual cash holdings towards their target.

3.2.2 Main independent variables: climate change.

We obtained both the climate change exposure (CCE) and climate change risk (CCR) measures relying on a language-based methodology, developed by Sautner et al. (2023). They constructed the measures using transcripts of quarterly earnings conference calls from publicly listed firms, collected from the Refinitiv Eikon database. What makes their measures distinctive is that those approaches capture the climate change exposure (CCE) and climate change risk (CCR) both within and across firm level. They derived the firm-level climate change exposure (CCE) and climate change risk (CCR) measures as in the following step. In the first step, they chose a small group of "initial bigrams" which relate explicitly to climate change. In the next step, they used machine learning (ML) algorithm that determines a specific set of "new bigrams" from the initial group and best distinguish climate-change-related sentences from others.

They then generated an overall climate change exposure by assessing the frequency with specified bigrams appear in a transcript. The procedure involves counting the frequency of bigrams which in the set of climate bigrams $\boldsymbol{C}$ (including the initial bigrams and the newly discovered bigrams) in the transcript for firm i in quarter t:

$$CCE_{i,t} = \frac{1}{B_{i,t}} \sum_{b}^{B_{i,t}} (1[b \in \boldsymbol{C}])$$

where $b = 0, 1, \ldots$; $B_{i,t}$ are bigrams extracted from the transcripts of quarterly earnings conference calls for firm i in quarter t; $1[b \in C]$ denotes the indicator function.

With the same refinement, they constructed a risk measure by counting the occurrence of the climate change-related bigrams appearing in sentences containing the words "risk", "uncertainty", or equivalent terms:

$$CCR_{i,t} = \frac{1}{B_{i,t}} \sum_{b}^{B_{i,t}} (1[b \in C] \times 1[b, r \in \boldsymbol{S}\,])$$

where r includes terms such as "risk", "uncertainty", or equivalent terms in the disclosures of firms.

Sautner et al. (2023) takes the average of the quarterly measures to create an annual measure for each firm. The climate change exposure ($CCE_{i,t}$) captures the degree to which a firm is expected to exposure severe climate-related events. Meanwhile, the climate change risk ($CCR_{i,t}$) measures the climate change risks at the firm level that a firm is anticipated to face. Both climate change exposure (CCE) and climate change risk (CCR) data are obtained and scaled by a factor of 10^3 to improve the interpretability of the coefficients in our regressions (Ginglinger & Moreau, 2023; Sautner et al., 2023).

3.2.3 Control variables.

Following prior studies, we also include a comprehensive group of microeconomic variables that affect the speed of adjustment for corporate cash holdings in our regression as follows (Bates, Chang, & Chi, 2018; Bates, Kahle, & Stulz, 2009; El Kalak, Goergen, & Guney, 2024; Nikolov & Whited, 2014; Opler et al., 1999; Venkiteshwaran, 2011).

One such variable is firm size ($Size_{i,t}$), measured as the natural logarithm of the book value of total assets. We expect the negative relationship between firm size and their cash holdings. The classic work of Miller and Orr (1966), supported by Mulligan (1997), states that larger firms benefit from economies of scale, which reduce the transaction costs incurred in converting noncash financial assets into cash. Furthermore, larger firms are typically better positioned to access bank lines of credit, thus reducing the necessity to hoard cash. In accordance with the precautionary motive, Almeida, Campello and Weisbach

(2004) provide evidence that larger firms face reduced financial distress and information asymmetries, enhancing their ability to access external and thereby lessens the need for cash reserves.

In a similar vein, we expect a negative relationship between firm age and cash reserves. Following Cheung (2016), we account for the impact of firms' lifecycle stage on their cash policies by employing $Age_{i,t}$, represented as the natural logarithm of the firm's age. This variable accounts for the fact that younger firms face greater information asymmetries, which restricts their access to external financing and compels them to retain more cash due to precautionary purposes (Ahrends, Drobetz, & Puhan, 2018; Marwick, Hasan, & Luo, 2020).

To capture the effect of growth opportunities, we include Tobin's Q ($Tobin's\ Q_{i,t}$), which is computed by summing total assets and the market value of equity, then subtracting the book value of equity and scaling the result by total assets. According to the precautionary motive, firms with significant growth opportunities tend to keep higher cash balances. Opler et al. (1999) and Bates, Kahle and Stulz (2009) argue that firms with substantial growth prospects face greater costs related to financial distress, which may lead them to retain more cash. Due to high information asymmetry, these firms may otherwise be forced to give up positive net-present-value (NPV) projects because of cash shortages or costly external financing. Conversely, firms experiencing limited growth opportunities are inclined to maintain less cash in order to avoid agency problems, as proposed by Jensen (1986) with the free cash flow hypothesis. Thus, firms possessing greater growth opportunities are expected to accumulate higher cash reserves.

In our analysis, we include research and development ($R\&D_{i,t}$) expenses, measured as the ratio of R&D expenditure to total assets, to capture the impact of innovation intensity on cash holdings. While some studies, such as Bates, Kahle and Stulz (2009), suggest that R&D spending might reduce cash holding due to its cash-consuming nature, we align with Opler et al. (1999) in arguing that firms with significant R&D expenditure tend to maintain higher cash reserves. Opler and Titman (1994) show evidence that the costs of financial distress are greater for firms with significant R&D expenditures due to increased information asymmetry. As R&D-intensive firms hold substantial proprietary information that cannot be disclosed to external investors, we follow D'Mello, Krishnaswami and Larkin (2008) to consider that higher R&D intensity indicates greater information asymmetry, which leads to increased cash holdings.

To assess the effects of operating and financial risk on the speed of cash adjustments, we also include industry cash flow risks ($Industry\ CF\ risk_{i,t}$) in our regression. This variable captures the volatility of cash flows within an industry, calculated using the standard deviation of cash flow ratios across a four-year period for firms in that industry, as classified by the two-digit SIC code (Bates, Chang, & Chi, 2018; Bates, Kahle, & Stulz, 2009; Opler et al., 1999). By using industry-level volatility, we mitigate potential endogeneity between cash holdings and cash flows at the firm level. As demonstrated by Opler et al. (1999), firms facing greater industry-average cash flow volatility tend to hold more liquid assets, particularly cash, as a precaution against increased financial distress, thereby limiting their ability to access external funds from capital markets.

We include cash flow from operating activities ($CFO_{i,t}$) in our analysis, which is calculated as income from operations before depreciation, less interest expenses, income taxes, and dividends, and then scaled by total assets. We predict a negative association between cash flow and cash holdings, consistent with recent studies (El Kalak, Goergen, & Guney, 2024; Jiang & Lie, 2016; Orlova & Rao, 2018)). Firms with stronger cash flows have greater operational capacity and liquidity, which reducing the requirement to hold large cash balances, thereby limiting both opportunities costs and adjustment costs. This behaviour is in line with the precautionary savings motive. Kim, Mauer and Sherman (1998) find that firms with superior internal fund generation capacity can substitute cash holdings with other liquid resources. Byoun (2008) adds that smaller firms, which typically have lower cash flow from operations, tend to accumulate more cash in order to ensure financial flexibility, as they are less able to generate sufficient internal funds.

Following Dittmar, Mahrt-Smith and Servaes (2003), we also examine the association between net working capital ($NWC_{i,t}$) and cash holdings. Net working capital is calculated as current assets subtract current liabilities, excluding cash and cash equivalents, and then scaled by total assets. Since net working capital can easily be converted into cash, it serves as an alternative to cash holdings. Therefore, we expect a negative association between net working capital and cash holdings, as firms with higher net working capital need to hold less cash to maintain their liquidity position.

According to the pecking order theory, Riddick and Whited (2009) suggest that firms undertaking substantial investments in assets may temporarily reduce their cash holdings, as increased capital expenditures serve as collateral, reducing the need for cash hoarding. This implies a negative correlation between capital expenditure and cash holdings. Conversely, the trade-off theory posits that firms engaging in significant capital expenditures, such as investment in fixed assets, indicate greater growth opportunities. To support these opportunities, firms tend to maintain higher cash, which aligns with existing findings by Orlova and Rao (2018) and Martínez-Sola, García-Teruel and Martínez-Solano (2018). Therefore, we include capital expenditure ($CapEx_{i,t}$) in our analysis to investigate this relationship.

We also include leverage ($Leverage_{i,t}$), measured as the debt-to-assets ratio, as a key factor affecting cash reserves. Studies consistently show a positive relationship between leverage and cash holdings. Firms with higher leverage accumulate more cash due to the lower adjustment cost associated with maintaining liquidity, which facilitates a higher speed of cash adjustment. Gao, Harford and Li (2013) argue that increased leverage requires greater cash accumulation to decrease net debt and ensure sufficient liquidity to meet interest obligations. Furthermore, Ozkan and Ozkan (2004) highlight that firms with higher leverage maintain greater cash levels to mitigate default risk. Martínez-Sola, García-Teruel and Martínez-Solano (2018) further support this view, demonstrating that highly leveraged SMEs retain more cash as a strategy to cope with potential financial distress. Given this relationship, leverage is employed into our regression model to assess its impact on firms' cash balances.

Following prior research, we include dummy variable in our regression models to represent specific corporate decisions. In this study, we consider two dummy variables: one for dividend payouts and one for acquisition activities. As proposed by Opler et al. (1999), we use a dividend dummy variable ($Dividend_{i,t}$), which is assigned a value of 1 if a firm pays a common dividend during the year, and o otherwise. According to Fazzari, Hubbard and Petersen (1987), firms without financial constraints and are potentially cash-rich tend to pay dividends compare to constrained firms. Acharya, Almeida and Campello (2007) and Bates, Kahle and Stulz (2009) further argue that dividend-paying firms maintain lower cash levels because they are perceived as carrying less risk, leading to improved access to external capital markets, as confirmed by Xie et al. (2017). We also include an acquisition dummy variable ($Acquisition_{i,t}$) to represent acquisition activities, set to 1 if a firm undertakes an acquisition during the year and 0 otherwise. Acquisitions typically require substantial liquid assets, primarily cash. Riddick and Whited (2009) show that firms with high cash reserves often coincide with periods of increased mergers and acquisitions. As a result, these firms tend to adjust their cash holdings more rapidly to facilitate acquisitions, thereby managing excess cash effectively (Harford, Mansi, & Maxwell, 2008).

Following other literatures, they found that macroeconomic factors such as inflation, GDP growth, corruption are essential determinants of firm's cash holdings and adjustment speed of cash holdings (CH-SOA) at country-level. Consistent with the existing studies (Batuman, Yildiz, & Karan, 2022; Opler et al., 2001; Orlova, 2020; Pinkowitz, Stulz, & Williamson, 2006), we include a range of country-level control variables into the regression model. To control for erosion of purchasing power, we included inflation ($Inflation_{j,t}$) defined by the consumer price index (CPI). Within the above studies, they suggested that firms in nations facing a higher level of inflation, tend to potentially slower the adjustment speed of cash holdings (CH-SOA) (Orlova, 2020). Specifically, in nations under high level of inflationary conditions, cash holdings are valued considerably lower compared to nations with low inflation (Orlova & Sun, 2018; Pinkowitz, Stulz, & Williamson, 2006). Therefore, firms potentially slower the adjustment speed. To examine the influence of governance on cash holdings value, we included corruption, ($Corruption_{j,t}$), which indicates the extent of public power being exploited for private gain. In nation with strong investor protection and low levels of corruptions, value of cash is greater compared to nations with high corruption (Pinkowitz, Stulz, & Williamson, 2006). In environments with higher corruption and less transparency, to lower liquidity risk, firms are expected to reserves less cash holdings (Caprio, Faccio, & McConnell, 2013). Firms are more likely to adjust their cash holdings (CH-SOA) at a slower speed to mitigate the risk of political extraction, as government officials frequently target cash-rich firms through corruption. To capture economic growth, we also include GDP growth ($GDP\ Growth_{j,t}$) defined by the GDP per capita. We followed Orlova and Sun (2018) measuring GDP growth by the natural logarithm of the gross domestic product per capita for each country. Following Pinkowitz, Stulz and Williamson (2006), cash holdings are more highly valued in nation with high economic growth and financial development. Therefore, higher GDP growth implies higher volatility in corporate cash holdings, but the extent of deviation from target cash holdings is lower, resulting in a slower adjustment speed of cash holdings (CH-SOA) (Orlova, 2020).

In summary, this study employs two groups of control variables: microeconomic factors, which determine firm-level characteristics affecting cash holdings, and macroeconomic factors, which represent external financial frictions. The microeconomic variables consist of firm size, Tobin's Q, industry cash flow risk, cash flow from operations, net working capital, capital expenditure, leverage, R&D expenses, dividend payouts, acquisition activity, and firm age, with most of these factors being scaled by the total assets. The macroeconomic factors, namely inflation rate, corruption and GDP growth, are intended to account for financial frictions experienced by firms at the national level.

Based on prior research, we anticipate that these control variables will impact cash holdings, thereby affecting the adjustment speed of cash reserves. Specifically, smaller and younger firms, those with significant growth opportunities (Tobin's Q and R&D expenses), and those facing high industry cash flow risk are more likely to hold substantial cash reserves. In contrast, firms with high net working capital, leverage, strong cash flows from operations, and high capital expenditure are likely to hold less cash. Regarding dividend payouts and acquisitions, dividend-paying firms generally retain less cash because of easier access to external finance, while firms undertaking acquisitions often hold more cash to support such activities. In terms of macroeconomic influences, firms in high-inflation environments adjust their cash holdings more rapidly, whereas those in nations with high corruption or fast GPD growth tend to adjust more slowly. Appendix **A** presents detailed definitions and sources for all variables.

3.3 Model

3.3.1 Baseline regression model

In line with Ozkan and Ozkan (2004); Bates, Kahle and Stulz (2009); and Jiang and Lie (2016) , we first investigated the consequences of climate change exposure (CCE) on the cash holdings adjustment speed (CH-SOA) by estimating the regression model presented below:

$$\begin{aligned} Cash/TA_{i,t} - Cash/TA_{i,t-1} = \ & \gamma_0 + \gamma_1(Cash/TA^*_{i,t} - Cash/TA_{i,t-1}) \\ & + \gamma_2(Cash/TA^*_{i,t} - Cash/TA_{i,t-1}) \times CCE_{i,t-1} \\ & + \gamma_3 CCE_{i,t-1} + \sum \gamma_n Controls \\ & + Fixed\ Effects + \varepsilon_{i,t} \end{aligned} \quad (3)$$

We subsequently estimated a similar regression model to investigate the influence of climate change risk (CCR) on the cash holdings adjustment speed (CH-SOA):

$$\begin{aligned} Cash/TA_{i,t} - Cash/TA_{i,t-1} = \ & \gamma_0 + \gamma_1(Cash/TA^*_{i,t} - Cash/TA_{i,t-1}) \\ & + \gamma_2(Cash/TA^*_{i,t} - Cash/TA_{i,t-1}) \times CCR_{i,t-1} \\ & + \gamma_3 CCR_{i,t-1} + \sum \gamma_n Controls \\ & + Fixed\ Effects + \varepsilon_{i,t} \end{aligned} \quad (4)$$

where i and t denotes firm and year, respectively. $CCE_{i,t-1}$ represents the climate change exposure (CCE) for firm i in year $t-1$, while $CCR_{i,t-1}$ refers the climate change risk (CCR) for firm i in year $t-1$. Other variables are defined as above. Our primary interest is the interaction term $(Cash/TA^{*}{}_{i,t} - Cash/TA_{i,t-1}) \times CCE_{i,t-1}$ in the Equation **(3)** and $(Cash/TA^{*}{}_{i,t} - Cash/TA_{i,t-1}) \times CCR_{i,t-1}$ in the Equation **(4)**. The interaction term coefficients in both Equation **(3)** and **(4)** are our main focus (i.e. γ_2). In the Equation **(3)**, if firms with greater exposure to climate change risks adjust their cash balances more rapidly towards the target level, we would expect to find a significantly positive coefficient on the interaction between deviation from target cash and the climate change exposure, denoted as γ_2. Conversely, the coefficient on γ_2 would indicate a significant negative value if climate change exposure is inversely correlated with the speed of cash balances adjustment in reaching the target. Similarly, in Equation **(4)**, the positive (negative) of the coefficient suggests that climate change risk (CCR) increases (decreases) the cash holdings adjustment speed (CH-SOA). Furthermore, the cash holdings adjustment speed at firms with low climate change exposure (or climate change risk) can be interpreted as $\delta = \gamma_1$, whereas those with high climate change exposure (or climate change risk) adjust at $\delta = \gamma_1 + \gamma_2$.

3.3.2 Interaction-term regression model

3.3.2.1 The subsample of deviation from target cash above and below zero

Following Jiang and Lie (2016), we estimated Equation **(3)** and Equation **(4)** separately for the subsample of firm-year observations with a negative deviation from target cash, and the subsample of firm-year observations with deviation from target cash equal to or greater than zero:

$$\begin{aligned} Cash/TA_{i,t} - Cash/TA_{i,t-1} = \gamma_0 + \gamma_1(Cash/TA^{*}{}_{i,t} - Cash/TA_{i,t-1}) \\ + \gamma_2(Cash/TA^{*}{}_{i,t} - Cash/TA_{i,t-1}) \times CCE_{i,t-1} \times Dev_{i,t-1} \\ + \gamma_3 CCE_{i,t-1} + \sum \gamma_n Controls \\ + Industry\ Dummies + Year\ Dummies \end{aligned}$$

$$+ Firm\ Dummies + \varepsilon_{i,t}$$

(5)

$$\begin{aligned} Cash/TA_{\ i,t} - Cash/TA_{\ i,t-1} = \ & \gamma_0 + \gamma_1 (Cash/TA^*_{\ i,t} - Cash/TA_{\ i,t-1}) \\ & + \gamma_2 (Cash/TA^*_{\ i,t} - ash/TA_{\ i,t-1}) \times CCR_{i,t-1} \times Dev_{i,t-1} \\ & + \gamma_3 CCR_{i,t-1} + \sum \gamma_n Controls \\ & + Industry\ Dummies + Year\ Dummies \\ & + Firm\ Dummies + \varepsilon_{i,t} \end{aligned}$$

(6)

where i and t denotes firm and year, respectively. Other variables are defined in the baseline regression. We created a dummy variable, $Dev_{i,t-1}$, to identify firm-year where cash holdings exceed the target compared to those below. By estimating them, we can investigate whether the influence of climate change exposure (climate change risk) on the speed of cash holdings adjustment is asymmetric, based on the cash holdings level relative to the target.

3.3.2.2 The role of environmental policy stringency

The adjustment speed of cash holdings might also be impacted by the environmental policy stringency (EPS). Environmental policy stringency, a country-year level environmental policy stringency index proposed by Botta and Koźluk (2014) to indicates policies and regulations aimed at mitigating climate change, air pollution, and other harmful environmental behaviour. They comprised three equally weighted sub-indices including for market-based (taxes, permits, and certificates) non-market-based (upstream R&D measures and downstream feed-in tariffs) environmental policies and regulations. They then derived this country-level index by scoring nations between zero and six, with higher scores attributes higher stringent policies and regulations. Alexander, De Vito and Menicacci (2024) documented that a one-standard-deviation rise in the environmental policy stringency (EPS) index results in a roughly 4% (equivalent to $6.5 million) decrease in cash holdings. However, they also found that operating costs of firms increase, while profitability decrease since environmental regulations have become stricter. This implies that under high climate change exposure and stringent environmental policies, firms tend to quickly adjust their cash holdings due to increasing operating costs and decreasing profitability. Firms' adjustments were taken as a precautionary measure, allowing them to maintain liquidity to isolate risks associated with high environmental policy stringency under high climate change exposure (climate change risk).

To examine this situation, we use the following regression model:

$$
\begin{aligned}
Cash/TA_{\,i,t} - Cash/TA_{\,i,t-1} = \gamma_0 &+ \gamma_1(Cash/TA^{*}_{\,i,t} - Cash/TA_{\,i,t-1}) \\
&+ \gamma_2(Cash/TA^{*}_{\,i,t} - Cash/TA_{\,i,t-1}) \times CC_{i,t-1} \times EPS_{i,t-1} \\
&+ \gamma_3(Cash/TA^{*}_{\,i,t} - Cash/TA_{\,i,t-1}) \times CC_{i,t-1} \\
&+ \gamma_4(Cash/TA^{*}_{\,i,t} - Cash/TA_{\,i,t-1}) \times EPS_{j,t-1} \\
&+ \gamma_5 CC_{i,t-1} \times EPS_{i,t-1} \\
&+ \gamma_6 CC_{i,t-1} + \sum \gamma_n Controls \\
&+ Industry\ Dummies + Year\ Dummies \\
&+ Firm\ Dummies + \varepsilon_{i,t}
\end{aligned}
\tag{7}
$$

where i and t denotes firm and year, respectively. $CC_{i,t-1}$ represents the climate change exposure (climate change risk) of firm i during year $t-1$; $EPS_{j,t-1}$ is the indicator variable, set to a value of 1 (classified as high stringency) for firms in the top tercile of environmental policy stringency (EPS) index, and is 0 for firms in the bottom; Other variables are defined in the baseline regression. We also account for the country, industry, year fixed effects.

3.3.2.3 The role of financial constraint

Another factor, financial constraints, influence how quickly firms can adjust their cash holdings to reach their target levels over time (Bates, Chang, & Chi, 2018). As proposed by Whited and Wu (2006), we measure financial constraints by Whited-Wu (WW) index as below:

$$WWI_{i,t} = -0.091CF_{i,t} - 0.062DIVPOS_{i,t} + 0.021TLTD_{i,t} - 0.044LNTA_{i,t} - 0.102ISG_{i,t} - 0.035SG_{i,t}$$

where $WWI_{i,t}$ is the Whited-Wu (WW) index for firm i in year t; $CF_{i,t}$ is the cash flow scaled by the total assets for firm i in year t; $DIVPOS_{i,t}$ is an dummy variable that set to 1 if the firms pays cash dividends and 0 otherwise for firm i in year t; $TLTD_{i,t}$ is the long-term debt scaled by the book value of total assets of firm i during year t; $LNTA_{i,t}$ is the natural logarithm of the book value of total assets for firm i in year t; $ISG_{i,t}$ is the industry sales growth for firms within the same industry, as classified by three-digit Standard Industrial Classification (SIC) for firm i in year t; and $SG_{i,t}$ is the firm's sales growth for firm i in year t.

Following existing literature, firms with financially constrained adjust their cash holdings level more rapidly than non-constrained firms (Diaw, 2021; Martínez-Sola, García-Teruel, & Martínez-Solano, 2018). Climate change exposure (climate change risk) is likely to generate future financial risk and encourages firms to implement more adaptable measure and flexible investment strategies. Meanwhile, constrained firms have the limited ability of funding for their investment, higher external cost of financing, or even normal operations (Almeida, Campello, & Weisbach, 2004). Therefore, those firms with financially constrained have tendency to adjust substantially their cash holdings level following uncertainty shocks for precautionary purposes (Denis & Sibilkov, 2009; Hadlock & Pierce, 2010; Kaplan & Zingales, 1997). This implies that under high climate change exposure and high financial constraints, firms are likely to quickly adjust their cash holdings due to precautionary motive.

To investigate the influence of financial constraints on the association of climate change exposure (climate change risk) and the adjustment speed of cash holdings, we regress the model as follows:

$$
\begin{aligned}
Cash/TA_{\ i,t} - \ Cash/TA_{\ i,t-1} \ = \ \gamma_0 + \ & \gamma_1(Cash/TA^*_{\ i,t} \ - Cash/TA_{\ i,t-1}) \\
& + \gamma_2(Cash/TA^*_{\ i,t} \ - Cash/TA_{\ i,t-1}) \times CC_{i,t-1} \times \ WI_{i,t-1} \\
& + \gamma_3(Cash/TA^*_{\ i,t} \ - Cash/TA_{\ i,t-1}) \times CC_{i,t-1} \\
& + \gamma_4(Cash/TA^*_{\ i,t} \ - Cash/TA_{\ i,t-1}) \times \ WWI_{i,t-1} \\
& + \gamma_5 CC_{i,t-1} \times \ WWI_{i,t-1} \\
& + \gamma_6 CC_{i,t-1} + \sum \gamma_n Controls \\
& + Industry\ Dummies + Year\ Dummies \\
& + Firm\ Dummies + \varepsilon_{i,t}
\end{aligned}
\qquad (8)
$$

where i and t denotes firm and year, respectively. $CC_{i,t-1}$ represents the climate change exposure (climate change risk) for firm i in year $t-1$; $WWI_{i,t-1}$ is the indicator variable, which takes the value of 1 (or classified as high financial constraints) for firms in the top tercile of Whited-Wu (WW) index, and is 0 for firms in the bottom; Other variables are defined in the baseline regression. We also control for the country, industry, year fixed effects.

4. Empirical Result

4.1 Sample distribution

The Panel A of Table **1** shows the sample distribution and summary statistics for each country. There are notable differences across 49 nations in terms of the number of observations, cash holdings adjustment speeds, climate change. Aligned with existing studies, the United States, Canada and United Kingdom account for the largest proportions of the sample with 2,696, 1,950, and 1,402 firm-years, respectively. China has the highest climate change exposure (2.412), followed by Spain (1.988) and Cayman Islands (1.675). The highest cash ratios scaled by total assets are found in Cayman Island (0.291), Israel (0.289), and United States (0.200). Meanwhile, firms in Spain have the highest climate change risk (0.126) and firms in Brazil shows the highest cash ratios scaled by net assets (0.626).

The Panel B of Table **1** display the distribution of the sample along with summary statistics across the observed time period. The number of observations increased significantly, rising from 166 in 2002 to 1,219 in 2018, indicating broader Compustat coverage. However, a slight drop to 1,165 observations in 2019 is due to missing accounting data in some regions. Over the sample period, the climate change exposure also saw a rise from 0.455 in 2002 to 1.169 in 2019, and from 0.019 in 2002 to 0.041 in 2019 of the climate change risk. This overall upward trend reflects the increasing integration of climate change considerations into business activities, underlining the importance of continued research on climate-related risks.

The sample distribution and summary statistics are reported in Panel C of Table **1** across different industries. The business services and electrical equipment sectors contribute the most to the sample, with 4,173 and 2,243 observations, respectively. Note that, electrical equipment (5.119); coal (2.442); and shipbuilding, railroad equipment (2.349) has the highest climate change exposure. These sectors with high climate change exposure (such as coal) are more likely to adopt climate-related risks mitigation strategies, not only to manage their environmental footprint but also to meet growing societal and regulatory demands for "greener" and more sustainable practices.

Table 1 Sample Distribution

Panel **A** – Sample distribution and statistics by country

Country	# of firms	N	%	CCE	CCR	Cash/TA	Cash/NA
Argentina	4	27	0.08	1.008	0.070	0.101	0.308
Australia	191	799	2.52	0.806	0.030	0.093	0.232
Austria	17	100	0.31	1.084	0.047	0.120	0.303
Belgium	18	123	0.39	0.972	0.036	0.117	0.489
Bermuda	36	193	0.61	0.689	0.026	0.129	0.301
Brazil	63	342	1.08	0.799	0.037	0.161	0.626
Canada	441	1,950	6.14	0.759	0.028	0.197	0.531
Cayman Islands	36	121	0.38	1.675	0.116	0.291	0.507
Chile	8	48	0.15	0.811	0.035	0.081	0.199
China	9	52	0.16	2.412	0.120	0.135	0.269
Colombia	4	20	0.06	1.085	0.071	0.081	0.187
Czech Republic	2	12	0.04	0.239	0.017	0.072	0.142
Denmark	29	197	0.62	0.997	0.040	0.154	0.319
Egypt	3	15	0.05	0.595	0.059	0.157	0.070
Finland	35	263	0.83	1.334	0.093	0.096	0.237
France	88	854	2.69	1.099	0.039	0.132	0.384
Germany	102	817	2.57	1.230	0.059	0.135	0.397
Greece	8	57	0.18	0.380	0.019	0.188	0.541
Hong Kong	17	103	0.32	1.280	0.014	0.158	0.275
India	122	434	1.37	0.955	0.040	0.177	0.331
Indonesia	8	33	0.10	1.086	0.060	0.087	0.188
Ireland	6	45	0.14	0.263	0.009	0.195	0.376
Israel	14	242	0.76	0.390	0.011	0.289	0.565
Italy	29	202	0.64	1.110	0.050	0.104	0.330
Japan	118	609	1.92	1.125	0.027	0.158	0.347
Luxembourg	6	37	0.12	0.731	0.085	0.149	0.330
Malaysia	11	37	0.12	0.284	0.022	0.146	0.438
Mexico	32	187	0.59	0.985	0.046	0.097	0.248
Netherlands	33	292	0.92	0.624	0.026	0.133	0.320
New Zealand	14	53	0.17	0.351	0.000	0.073	0.168
Norway	49	289	0.91	1.117	0.030	0.119	0.245
Panama	2	13	0.04	0.275	0.000	0.137	0.390
Papua New Guinea	2	11	0.03	1.462	0.069	0.059	0.125
Peru	3	12	0.04	0.662	0.025	0.062	0.146
Philippines	6	24	0.08	0.807	0.02	0.091	0.397
Poland	9	29	0.09	0.996	0.031	0.063	0.154
Portugal	6	54	0.17	0.375	0.026	0.092	0.386
Singapore	18	101	0.32	1.264	0.032	0.099	0.595
South Africa	45	232	0.73	0.935	0.03	0.095	0.222
South Korea	14	77	0.24	1.179	0.082	0.182	0.319
Spain	35	241	0.76	1.988	0.126	0.125	0.461
Sweden	89	449	1.41	0.704	0.028	0.111	0.265
Switzerland	55	427	1.34	0.654	0.027	0.182	0.408
Taiwan	2	13	0.04	0.311	0.000	0.194	0.280
Thailand	4	11	0.03	0.466	0.017	0.075	0.145
Turkey	16	73	0.23	0.664	0.020	0.179	0.529
United Arab Emirates	4	17	0.05	0.420	0.057	0.093	0.209
United Kingdom	228	1,402	4.41	0.808	0.026	0.107	0.392
United States	2,696	20,027	63.05	0.759	0.025	0.200	0.412
Overall	4,787	31,766	100.00	0.820	0.030	0.179	0.402

Panel **B** – Sample distribution and statistics by year

Year	# of firms	N	%	CCE	CCR	Cash/TA	Cash/NA
2002	166	166	0.52	0.455	0.019	0.151	0.283
2003	1,040	1,205	3.79	0.475	0.017	0.182	0.244
2004	465	1,629	5.13	0.512	0.020	0.192	0.817
2005	294	1,829	5.76	0.535	0.021	0.201	0.394
2006	340	2,027	6.38	0.646	0.021	0.211	0.396
2007	230	2,110	6.64	0.673	0.022	0.202	0.408
2008	222	2,226	7.01	0.725	0.027	0.185	0.422
2009	180	2,248	7.08	0.867	0.032	0.167	0.393
2010	193	2,304	7.25	0.948	0.034	0.196	0.311
2011	211	2,411	7.59	0.960	0.034	0.191	0.331
2012	232	2,492	7.84	0.986	0.037	0.182	0.431
2013	289	2,417	7.61	0.907	0.033	0.175	0.406
2014	171	2,477	7.80	0.836	0.028	0.177	0.356
2015	123	2,129	6.70	0.857	0.032	0.168	0.467
2016	73	756	2.38	0.866	0.033	0.130	0.394
2017	110	956	3.01	0.927	0.038	0.131	0.346
2018	288	1,219	3.84	1.108	0.040	0.135	0.358
2019	160	1,165	3.67	1.169	0.041	0.140	0.324
Overall	4,787	31,766	100.00	0.820	0.030	0.179	0.402

Panel **C** – Sample distribution and statistics by industry

Industry	**# of firms**	**N**	**%**	**CCE**	**CCR**	**Cash/TA**	**Cash/NA**
Agriculture	9	54	0.17	0.434	0.016	0.065	0.125
Food Products	118	745	2.35	0.468	0.019	0.082	0.257
Candy & Soda	17	120	0.38	0.614	0.017	0.098	-0.442
Beer & Liquor	28	224	0.71	0.281	0.012	0.074	0.147
Tobacco Products	12	106	0.33	0.253	0.020	0.151	-0.293
Recreation	22	164	0.52	0.382	0.016	0.209	0.352
Entertainment	65	391	1.23	0.284	0.016	0.115	1.120
Printing and Publishing	46	304	0.96	0.191	0.006	0.075	0.187
Consumer Goods	77	571	1.80	0.520	0.017	0.131	0.181
Apparel	73	542	1.71	0.255	0.011	0.173	0.263
Healthcare	100	524	1.65	0.326	0.010	0.138	0.390
Medical Equipment	162	1,095	3.45	0.330	0.010	0.233	0.368
Pharmaceutical Products	343	2,064	6.50	0.207	0.007	0.412	0.840
Chemicals	131	994	3.13	1.315	0.048	0.103	0.262
Rubber and Plastic Products	34	192	0.60	0.798	0.023	0.074	0.174
Textiles	11	91	0.29	0.310	0.012	0.060	0.139
Construction Materials	101	723	2.28	1.043	0.036	0.104	0.252
Construction	80	535	1.68	1.885	0.084	0.131	0.432
Steel Works Etc	81	538	1.69	1.487	0.054	0.087	0.230
Fabricated Products	7	40	0.13	2.173	0.076	0.153	0.258
Machinery	186	1,411	4.44	1.861	0.072	0.159	0.845
Electrical Equipment	81	603	1.90	5.119	0.140	0.163	0.298
Automobiles and Trucks	96	628	1.98	1.620	0.059	0.122	-0.133
Aircraft	28	261	0.82	0.957	0.026	0.084	0.305
Shipbuilding, Railroad Equipment	9	70	0.22	2.349	0.111	0.175	0.531
Defence	7	56	0.18	0.944	0.037	0.180	1.245
Precious Metals	36	219	0.69	0.733	0.026	0.117	0.180
Non-Metallic and Industrial Metal Mining	50	321	1.01	1.674	0.064	0.114	0.243
Coal	17	88	0.28	2.442	0.111	0.067	0.176
Petroleum and Natural Gas	240	1,619	5.10	0.888	0.042	0.081	0.182
Communication	245	1,690	5.32	0.302	0.010	0.105	0.309
Personal Services	67	412	1.30	0.400	0.010	0.176	0.546
Business Services	719	4,173	13.14	0.536	0.020	0.257	0.433
Computers	164	1,165	3.67	0.455	0.013	0.287	0.495
Electronic Equipment	315	2,243	7.06	1.202	0.040	0.301	0.603
Measuring and Control Equipment	88	695	2.19	1.003	0.045	0.250	0.394
Business Supplies	61	451	1.42	0.754	0.034	0.068	0.333
Shipping Containers	18	145	0.46	0.667	0.017	0.058	0.563
Transportation	221	1,326	4.17	0.593	0.023	0.118	0.457
Wholesale	156	1,081	3.40	0.750	0.030	0.087	0.222
Retail	305	2,065	6.50	0.384	0.010	0.125	0.257
Restaurants, Hotels, Motels	93	636	2.00	0.236	0.007	0.085	0.252
Almost Nothing	68	391	1.23	0.995	0.033	0.187	0.518
Overall	4,787	31,766	100.00	0.820	0.030	0.179	0.402

Note: *This table displays the sample distribution by country in Panel **A**, by year in Panel **B**, and by industry in Panel **C**. The sample consists of 31,766 firm-year observations of 4,787 unique firms in 49 nations over the 2002–2019 period. Industries in Panel C are classified based on the Fama–French 48 industry codes. All of the variables are defined in Appendix **A**.*

4.2 Descriptive statistics

In Panel A of Table **2**, the descriptive statistics for the main variables used in the empirical analysis are presented. Following Bates, Chang and Chi (2018); Orlova and Rao (2018); and El Kalak, Goergen and Guney (2024), we winsorised all continuous financial variables at the 1st and 99th percentiles of their distributions. The mean values for climate change exposure at 0.820 while the medians are 0.310. The overall of climate change risk is 0.030 and 0.000 of the medians. On average, firms report a cash ratio of 17.60% of total assets and 35.90% of net assets. In our sample, firms exhibit higher sensitivity to climate change exposure than to climate change risk. According to the descriptive statistic of control variables, the average firm size in our sample is 7.495 with the Tobin's Q value of 2.619. Industry cash flow risk make up 0.073, while cash flow from operating. The average net working capital (NWC) is -0.142, and capital expenditures (CapEx) are 4.80% of total assets. Firm, on average, have a leverage ratio of 21.40%, research and development (R&D) expenditures of 4.10%. A 19.70% paid common dividend and a 46.50% undertook acquisition over the research period. In terms of macroeconomic control variables, the inflation is 2.1$, GDP growth averages 2.00%, and the corruption index of studied nations has mean value of 1.463, with a median of 1.411.

Panel B of Table 2 presents the Pearson correlation matrix for the variables discussed in the preceding section. We observe significant correlations between climate change (both climate change exposure and climate change risk) and several control variables, suggesting that these variables are reliable determinants of cash holdings adjustment speeds. Importantly, all correlation coefficients are below 0.6, indicating no significant linear correlation between the independent variables. Additionally, the variance inflation factor (VIF) values for all variables are below 10, with a mean VIF of 2.243, confirming that perfect collinearity is absent in our model.

The correlation between climate change exposure (CCE) and climate change risk (CCR) is positive and statistically significant at the 1% level, indicating that firms exposed to greater climate change are also more vulnerable to climate-related risks. This highlights the importance of adaptive strategies to mitigate these risks, especially for firms in more climate-sensitive regions or industries. Further, climate change exposure and risk both show a significant positive correlation with firm size, implying that larger firms are better equipped to manage climate change-related risks due to their greater resources and resilience capabilities. Significant positive correlations are also observed between climate change and net working capital, as well as dividend payouts, both at the 1% level. This suggests that firms experiencing higher climate change-related risks tend to maintain higher levels of net working capital as a precaution against unexpected costs while continuing dividend payouts to projects stability and maintain investor confidence. In contrast, we find significant negative correlations between climate change and Tobin's Q, along with cash flow from operations, both at the 1% level. This suggests that higher exposure to climate change may reduce firms' growth opportunities and make it more difficult for them to generate sufficient cash flows due to increased costs and disruptions. Similarly, research and development (R&D) spending and acquisition activities show significant negative correlations with climate change at the 1% level, implying that firms facing greater climate risks may reduce their investment in R&D and limit acquisition activities. Additionally, leverage is negatively correlated with climate change, significant at the 5% level, suggesting that firms exposed to higher climate risks are less inclined to take on additional debt as a precautionary measure. Regarding macro-level variables, the correlation between inflation and climate change is positive, though weakly significant at the 10% level, suggesting a minor but notable relationship. Meanwhile, GDP growth and control of corruption exhibit significant negative correlations with climate change at the 1% level, implying that firms in nations with stronger economic growth and better corruption control are better positioned to mitigate climate change-related risks.

Panel C of Table **2** provides a comparative analysis of firms with cash deficits and those with cash surpluses. We compared firms with deviations from target cash below zero (a cash deficit) to firms with deviations at or above zero (a cash surplus). The results indicate that firms with a cash deficit adjust their cash holdings faster than those with a cash surplus.

Specifically, the mean difference in the speed of adjustment between these two groups is approximately 16%, which is statistically significant at the 1% level. In addition to the speed of adjustment, several other variables show significant differences between cash deficit and cash surplus firms, suggesting substantial cross-sectional variation in cash deviation among firms. The mean deviation from target cash (DevCash) for cash deficit firms is significantly lower than that for cash surplus firms. This finding implies that while cash deficit firms adjust their cash holdings faster, they are less efficient in reaching their target cash levels compared to cash surplus firms, thereby lending support to Hypothesis **2a**. Panel C of Table **2** provides preliminary results that suggest a more pronounced effect of excess cash on the relationship between climate change and the speed of cash holdings adjustments.

Table 2 Summary statistics

Panel **A** - Descriptive statistics

	N	Mean	SD	P25	Median	P75	P95
Climate change exposure	31,766	0.820	1.885	0.109	0.310	0.759	3.169
Climate change risk	31,766	0.030	0.132	0.000	0.000	0.000	0.167
Cash/TA	31,766	0.176	0.181	0.047	0.112	0.242	0.583
Cash/NA	31,766	0.359	0.457	0.100	0.248	0.485	1.117
Size	31,766	7.495	2.342	5.892	7.330	8.851	11.372
Tobin's Q	31,766	2.619	2.115	1.597	2.129	2.918	7.270
Industry CF risk	31,766	0.073	0.083	0.045	0.062	0.079	0.113
CFO	31,766	0.060	0.151	0.041	0.083	0.126	0.215
NWC	31,766	-0.142	0.204	-0.220	-0.086	-0.019	0.111
CapEx	31,766	0.048	0.049	0.017	0.033	0.061	0.145
Leverage	31,766	0.214	0.188	0.042	0.191	0.322	0.569
R&D	31,766	0.041	0.077	0.000	0.003	0.049	0.190
Dividend	31,766	0.197	0.398	0.000	0.000	0.000	1.000
Acquisition	31,766	0.465	0.499	0.000	0.000	0.100	1.000
Age	31,766	2.330	0.864	1.792	2.565	3.045	3.332
Inflation	31,766	0.021	0.017	0.014	0.019	0.027	0.038
GDP Growth	31,766	0.020	0.020	0.016	0.022	0.029	0.041
Corruption	31,766	1.463	0.514	1.313	1.411	1.833	2.073

Panel **B** - Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Climate change exposure	1.000							
(2) Climate change risk	0.538***	1.000						
(3) Size	0.019***	0.027***	1.000					
(4) Tobin's Q	-0.034***	-0.030***	-0.072***	1.000				
(5) Industry CF risk	0.002	0.002	-0.007	0.008	1.000			
(6) CFO	-0.074***	-0.030***	0.265***	0.052***	-0.037***	1.000		
(7) NWC	0.024***	0.024***	0.410***	-0.215***	-0.021***	0.290***	1.000	
(8) CapEx	0.009	0.024***	0.100***	0.029***	0.090***	0.179***	0.139***	1.000
(9) Leverage	-0.013**	0.007	0.242***	-0.077***	-0.017***	-0.067***	0.243***	0.115***
(10) R&D	-0.015***	-0.021***	-0.337***	0.174***	0.061***	-0.523***	-0.494***	-0.175***
(11) Dividend	0.035***	0.032***	0.432***	-0.104***	0.001	0.145***	0.339***	0.003
(12) Acquisition	-0.015***	-0.006	0.127***	-0.010*	-0.056***	0.118***	0.160***	-0.122***
(13) Age	0.036***	0.011**	0.325***	-0.063***	-0.012**	0.153***	0.249***	-0.046***
(14) Inflation	-0.011*	-0.004	0.044***	0.044***	-0.016***	0.024***	0.005	0.070***
(15) GDP Growth	-0.033***	-0.016***	0.049***	0.053***	0.021***	0.063***	0.000	0.055***
(16) Corruption	-0.029***	-0.023***	-0.184***	0.021***	0.011*	-0.033***	-0.022***	-0.034***
Mean VIF								

Panel **B** - Pairwise correlations *(continued)*

Variables	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	VIF
(1) Climate change exposure									1.032
(2) Climate change risk									1.019
(3) Size									2.522
(4) Tobin's Q									1.141
(5) Industry CF risk									1.070
(6) CFO									1.618
(7) NWC									2.610
(8) CapEx									1.156
(9) Leverage	1.000								1.346
(10) R&D	-0.193***	1.000							1.936
(11) Dividend	0.039***	-0.141***	1.000						2.644
(12) Acquisition	0.060***	-0.142***	0.063***	1.000					1.161
(13) Age	0.032***	-0.168***	0.136***	0.074***	1.000				1.287
(14) Inflation	0.027***	-0.036***	-0.002	0.004	-0.057***	1.000			2.502
(15) GDP Growth	-0.023***	-0.010*	0.036***	-0.001	-0.082***	0.231***	1.000		4.421
(16) Corruption	-0.039***	0.055***	-0.005	0.053***	-0.043***	-0.383***	-0.043***	1.000	8.424
Mean VIF									2.243

Panel **C** - Means by cash ratio characteristics (the t-statistics in italics are for the differences in means)

	CCE	CCR	Cash/TA	Cash/NTA	DevCashTA	DevCashNTA
Deviation from target Cash < 0	0.839	0.031	0.303	0.666	-0.091	0.121
Deviation from target Cash ≥ 0	0.808	0.029	0.100	0.232	0.070	0.244
Difference	0.030***	0.003***	0.204***	0.434***	-0.161***	-0.122***
P-value	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000

Note: *This table reports the summary statistics in Panel* ***A*** *and correlation coefficient matrix in Panel* ***B*** *for the key variables used in the main regression analyses. Panel* ***C*** *shows the results of the tests of the difference in means between the subsamples of Deviation from target Cash < 0 and Deviation from target Cash ≥ 0, while ***, **, and * indicates statistical significance at the 1%, 5%, and 10% level. All of the variables are defined in Appendix* ***A****.*

4.3 Climate change and cash holdings adjustment speeds

In this section, we investigated the relationship between climate change and cash holdings adjustment speeds in a multivariate analysis, considering a range of firm and country characteristics. Table **3** presents the results of the Fama-MacBeth (FM) cross-sectional regression, pooled ordinary least squares (OLS), and generalized method of moments (GMM) analyses, which examine the primary determinants of cash holdings, following Equation (1). We used these regressions models to determine the target cash holdings ratios for every firm in the sample. For clarity in tabulation, we show the Fama-MacBeth (FM) regression results in Column (1) of Table **3**. Using an alternative estimation approach, Columns (2)-(8) present the results from pooled ordinary least squares (OLS) in Column (2)-(8). Moreover, we also show the results of generalised method of moments (GMM) in Column (9) as one solution to the dynamic endogeneity problems. We include country, industry, firm and year fixed effects in Column (2)-(5); country, industry, firm fixed effects with year fixed effects in Column (6)-(8); country, industry and year fixed effects in Column (9). Lastly, we also account for unobservable firm characteristics by incorporating firm-year fixed effects in Column (1) and (9). The industries are identified using two-digit Standard Industrial Classification (SIC) codes. Test statistics and significance levels are reported with standard errors adjusted by a two-dimensional clustering at the firm level, following Petersen (2008).

The coefficient of the determinants of cash holdings across various estimation models are mostly consistent and statistically significant at the 1% level, with their signs aligning with findings from previous literature (El Kalak, Goergen, & Guney, 2024; Jiang & Lie, 2016; Orlova & Rao, 2018). Specially, in line with our prior expectations, as well as the precaution motive and trade-off theory, a firm's cash holdings are positively related to growth opportunities, as reflected in Tobin's Q, and R&D expenses. The positive coefficients for both Tobin's Q and R&D expenses, statistically significant at the 1% level, indicate that firms with substantial growth prospects or higher R&D intensity are likely to hold more cash to mitigate the risks associated with information asymmetries and financial distress. This finding is consistent with previous studies (Bates, Kahle, & Stulz, 2009; D'Mello, Krishnaswami, & Larkin, 2008; Jensen, 1986; Opler et al., 1999; Opler & Titman, 1994).

Moreover, industry cash flow volatility has a positive and significant effect on cash holdings, indicating that firms exposed to greater industry volatility are likely to accumulate more cash as a precaution. This finding supports the argument of Opler et al. (1999) and Bates, Kahle and Stulz (2009), who also found that the importance of liquidity for firms in volatile industries with limited access to external funds. The analysis further shows that larger firms tend to hold less cash, which is consistent with the transaction cost theory, precautionary savings motive, and credit line argument. Economies of scale, better access to credit (Miller & Orr, 1966; Mulligan, 1997); fewer financial distress and information asymmetries (Almeida, Campello, & Weisbach, 2004) contribute to a reduced for cash hoarding among larger firms. Meanwhile, our findings indicate that mature firms tend to hold less cash, demonstrating a negative relationship between firm age and cash holdings. In other words, younger firms are more likely to hold higher cash reserves, primarily to address information asymmetries and as a precaution propose by Ahrends, Drobetz and Puhan (2018) and Marwick, Hasan and Luo (2020). We also find that firms that pay dividends have tendency to hold more cash, whereas those undertaking acquisitions hold less. This aligns with the findings of Fazzari, Hubbard and Petersen (1987), who argue that firms with fewer financial constraints (possibly cash-rich) are more prone to pay dividends in contrast to financially constrained firms. In contrast, acquisition activities often require significant cash reserves, thereby reducing cash holdings, as suggested by Riddick and Whited (2009). Finally, out results show that capital expenditures, net working capital, cash flow from operations, and leverage all have a significant negative impact on cash holdings. This supports existing findings that substantial assets investments lead to a temporary decrease in cash reserves, and net working capital serves as a close substitute for cash due to its liquidity (Bates, Kahle, & Stulz, 2009; Riddick & Whited, 2009). Since net working capital can be readily converted into cash, it can act as a replacement for cash holdings. As a result, firms with higher net working capital tend to hold less cash to maintain their liquidity positions, which aligns with our first prediction and the findings of Dittmar, Mahrt-Smith and Servaes (2003). Firms with stronger cash flows are also likely to hold less cash, minimising both opportunity and adjustment costs, in accordance with the precautionary savings motive (Byoun, 2008; Jiang & Lie, 2016; Kim, Mauer, & Sherman, 1998; Orlova & Rao, 2018), while firms with high leverage acquire less cash due to ability of accessing external financing markets.

Table **4** reports the estimation results for the dynamic partial adjustment model, as detailed by Equation (2). These results provide strong support for the dynamic trade-off theory of corporate cash holdings, indicating that an asymmetry exists between firms' actual cash holdings and their target level. The deviation coefficient from the target cash holdings ratio represents the average annual speed at which firms adjust their cash holdings. In addition, we introduce additional variables in the second stage, such as inflation, GDP growth, and control of corruption as proxies of financial friction. We include these macroeconomic factors to assess the effect of economic and financial development alongside the government deficit. We show present the relationship of microeconomic factors in Column (1)-(4), while Column (5)-(8) report both the influence of microeconomic and macroeconomic factors. In each column, we also include different country, industry, firm, and year fixed effects; two-way fixed effects; three-way fixed effects. Column (5)-(8) comprises macroeconomic control variables, including: Inflation, GDP growth, and Corruption. For example, in Column (8), the deviation from the target cash holdings ratio has a coefficient of 0.230, suggesting that firms, on average, adjust their cash holdings at a rate of 23% in each year. Furthermore, the estimated coefficient for the adjustment speed in Table **4** is not very different from fixed effects model estimate which according to Bond (2002) produces downward biased estimates. All the other variables carry coefficient mainly similar to those presented earlier in Table **3**. These findings are similar to those reported in prior studies. The coefficient on the deviation from the regression (8) (i.e. SOA) is in line with the findings of Dittmar and Duchin (2010), who report an SOA of 0.220; and El Kalak, Goergen and Guney (2024), who find an SOA of 0.157. Generally, we find that firms in environments with higher corruption which is less transparency, firms tend to hold less cash holdings to lower the liquidity risk, aligns with the findings of Caprio, Faccio and McConnell (2013). The evidence also shows that firms tend to slow down the speed at which they adjust their cash holdings to mitigate the risk of political extraction. This occurs because government officials frequently target cash-rich firms for assets extraction, taking advantage of the liquidity and ease of transaction (Le & Tran, 2022; Myers & Rajan, 1998; Xu et al., 2016). In line with Pinkowitz, Stulz and Williamson (2006), Orlova and Sun (2018), and Orlova (2020), we support the evidence that firms in nations with higher GDP growth indicate higher volatility in cash reserves, thereby lower deviation from target cash and slower the adjustment speed. In contrast, we include inflation and find that in nations facing higher level of inflation, firms tend to adjust slowly their actual cash holdings toward the target, therefore, have slower speed of adjustment in cash holdings which is consistent with work of Pinkowitz, Stulz and Williamson (2006) and Orlova and Sun (2018). The implication is that firms make significant progress in closing actual cash holdings and target ratios annually, reflecting that managers continuously take target cash ratios over time. In particular, Column (8) estimates Equation (2), showing that the adjustment coefficient of 0.230 is statically significant. This suggests that firms, on average, cover around 23% of the gap between their actual and target cash holdings. These findings suggest that firms move toward their optimal cash holdings, reaching half the adjustment within a period of less than three years. After 3 years, the remaining gap is 45.65%, indicating firms still have a significant gap to reach their cash targets.[2] Overall, the results in this section provide a robust estimate of the speed of adjustment for a typical firm.

In Table **5**, Columns (1)-(4) investigate the impact of climate change exposure (CCE) on cash holdings adjustment speeds (CH-SOA) according to Equation (3), while Columns (5)-(8) report the influence of climate change risk (CCR) on the adjustment speed of cash

[2] The difference in years is computed as $t = \frac{\ln(\alpha)}{\ln(1-\gamma_1)}$, where α is the fraction of adjustment, and $\gamma_1 = 0.230$ as reported in Column (8) of Table **4**. Additionally, the remaining gap after T years is computed as $R_T = (1 - \gamma_1)^T \times R_0$.

holdings (CH-SOA). The deviations from target cash are calculated using the target cash holdings ratio, which is derived from the regression of Fama-Macbeth (FM) method from Column (1) of Table **3**, based on the Equation (1). Whereas Column (1) controls for unobservable firm characteristics, consisting of firm and year fixed effects. We also include macro-level control variables that affect firms' cash holdings adjustment speed including inflation, GDP growth, control of corruption. The coefficient for Deviation from target cash is consistently positive and statistically significant across all models, presented in Column (1)-(8). These results suggest that firms with greater deviations from their target cash holdings typically exhibit a faster adjustment speed. This aligns with the dynamic trade-off theory, indicating that firms gradually adjust to align their actual cash reserves with the target level, stressing their intention to achieve optimal cash management. Our findings are also consistent with a widely range of studies in cash holdings adjustment speed including Orlova and Rao (2018), Ozkan and Ozkan (2004), Venkiteshwaran (2011), Jiang and Lie (2016), Guariglia and Yang (2018), and recently El Kalak, Goergen and Guney (2024), who support evidence for the dynamic partial adjustment model. These authors also document that firms maintain a target cash level and gradually move their actual cash holdings towards that target. Moreover, firms with a larger discrepancy between their actual and target cash reserves tend to make faster adjustments than those with a smaller gap, which is also in line with our first expectations and existing studies. Regarding to climate change, the coefficient for both Climate change exposure and Climate change risk appears to be statistically insignificant across all 8 models. This indicates that the exposure to climate change or climate risk of firms, as used in this study, does not have a direct significant impact on cash holdings adjustment behaviour. The main variable of interest is the interaction term between the deviation form target cash ($Cash/TA^{*}{}_{i,t} - Cash/TA_{\,i,t-1}$) and the climate change ($CCE_{i,t-1}$and $CCR_{i,t-1}$). In Columns (1)-(4) the interaction term ($Cash/TA^{*}{}_{i,t} - Cash/TA_{\,i,t-1}$) $\times$ $CCE_{i,t-1}$ has a positive sign with statistically significant (at the 1% level) coefficient, suggesting that the adjustment behaviour is heightened in the presence of Climate change exposure. This suggests that an increase in climate change exposure is positively related to firms adjusting their cash holdings more quickly. In other words, firms more exposed to climate change, on average, tend to adjust their actual cash holdings level more quickly, reducing the deviation between their current and target cash holdings levels, which is consistent with the precautionary motive. For example, in Column (4), the interaction term coefficient of 0.009 (t-value$=4.333$) implies that firms with higher climate change exposure adjust their cash holdings faster, allowing them to revert more quickly to their target levels. Similarly, in Columns (5)-(8), the interaction term $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\ i,t-1}) \times CCR_{i,t-1}$ also has a positive sign with a statistically significant (at the 1% level) coefficient, suggesting that the adjustment behaviour is intensified in the presence of Climate change risk. This shows that firms facing higher climate change risk are also faster in adjusting their actual cash holdings with the target level, forcing them to take more proactive actions in adjusting their liquidity, especially cash holdings. For instance, in Column (8), the interaction term coefficient of 0.197 (t-value$=6.168$) shows that firms with greater climate change risk experience a faster cash holdings adjustment speed, helping them to revert more quickly to their target cash holdings. Regarding Columns (4) and (8), high climate change exposure increases cash holdings adjustment speed by 4.46% $(=0.009/0.202)$, while high climate change risk leads to a 96.57% $(=0.197/0.204)$ faster adjustment. In our models, we also consider a range of control variables including micro-level and macro-level, and fixed effects for country, industry, firm, and year to control for unobservable variables and factors potentially affecting cash holdings adjustment behaviour. Therefore, firms with higher climate change exposure, on average, take approximately 35.4 months less to close half of the gap between their actual and target cash holdings compared to those with lower exposure. Likewise, firms facing greater climate change risk take about 35.3 months less, on average, to adjust half of the difference between their actual and target cash holdings compared to those with lower risk.[3] In summary, in line with prior studies, these results show that firms tend to adjust their actual cash holdings toward the target level, and firms are likely

[3] The difference in months is computed as $t = \frac{\ln(\alpha)}{\ln(1-(\gamma_1+\gamma_2 \times CC))} \times 12$. In particular, the average adjustment time in months is $t_{mean} = \frac{\ln(\alpha)}{\ln(1-(\gamma_1+\gamma_2 \times CC_{mean}))} \times 12$; in which α is the fraction of adjustment, CC represents the climate change exposure (climate change risk). $CCE_{mean} = 0.820$ and $CCR_{mean} = 0.030$ are reported in Panel A of Table **2**.

to faster the speed of adjustment if firms have larger deviation between their actual balance and the target level. Moreover, firms seem to faster in their adjustment effort of cash holdings in response to climate change-related uncertainties, indicating a precautionary approach in their liquidity management strategy in the face of climate change. The implications are highly consistent with existing studies, which finds that due to the precautionary purposes, firms have more effort to hoard more cash, leading to adjust faster their actual cash balance toward the target in order to maintain adequate cash buffers cope with future uncertainties and potential financial distress, especially due to climate change issues (Bates, Kahle, & Stulz, 2009; Huang, Kerstein, & Wang, 2018a; Javadi et al., 2023; Naseer et al., 2024; Ozkan, Temiz, & Yildiz, 2023). When viewed collectively, our findings provide strong evidence for Hypothesis **1**, regarding climate change increasing the speed of cash level adjustment, in line with the precautionary savings motives for holding cash.

Table 3 Stage 1 – Cash holdings determinants

	Cash/TA									
	FM	OLS								GMM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Size	-0.002***	-0.002***	-0.007***	-0.001***	-0.012***	-0.007***	-0.002***	-0.013***	-0.007***	-0.056*
	(-4.126)	(-10.022)	(-26.231)	(-3.156)	(-17.547)	(-26.711)	(-9.58)	(-18.459)	(-24.257)	(-1.814)
Tobin's Q	0.004***	0.004***	0.005***	0.004***	0.001**	0.005***	0.004***	0.001***	0.004***	-0.001
	(6.514)	(16.198)	(18.401)	(14.185)	(2.572)	(18.650)	(15.037)	(3.196)	(17.283)	(-1.148)
Industry CF risk	0.246***	0.050***	0.050***	0.023***	0.016***	0.048***	-0.003	0.013***	0.004	-0.083
	(5.934)	(10.762)	(11.086)	(4.190)	(3.747)	(10.471)	(-0.505)	(3.121)	(.831)	(-0.762)
CFO	-0.041***	-0.039***	-0.022***	-0.055***	-0.016***	-0.020***	-0.040***	-0.013***	-0.022***	-0.090***
	(-4.748)	(-12.509)	(-7.106)	(-17.622)	(-5.427)	(-6.463)	(-12.936)	(-4.343)	(-7.066)	(-4.974)
NWC	-0.365***	-0.337***	-0.364***	-0.326***	-0.220***	-0.364***	-0.338***	-0.219***	-0.365***	-0.175***
	(-10.372)	(-135.682)	(-140.452)	(-129.79)	(-65.541)	(-139.81)	(-134.111)	(-64.866)	(-137.597)	(-3.794)
CapEx	-0.270***	-0.296***	-0.289***	-0.328***	-0.202***	-0.288***	-0.301***	-0.199***	-0.294***	-0.275***
	(-13.798)	(-32.188)	(-31.827)	(-32.382)	(-20.367)	(-31.556)	(-29.806)	(-19.948)	(-29.467)	(-3.288)
Leverage	-0.224***	-0.253***	-0.246***	-0.254***	-0.114***	-0.245***	-0.249***	-0.112***	-0.242***	-0.637***
	(-17.702)	(-95.77)	(-93.034)	(-92.709)	(-33.26)	(-92.673)	(-91.257)	(-32.549)	(-89.296)	(-5.430)
R&D	0.553***	0.621***	0.618***	0.545***	0.064***	0.617***	0.546***	0.061***	0.550***	0.196***
	(19.303)	(84.602)	(84.346)	(67.726)	(5.899)	(84.309)	(68.401)	(5.627)	(69.695)	(3.572)
Dividend	0.032***	0.023***	0.002	0.031***	0.006***	0.002*	0.025***	0.006***	0.004***	0.015*
	(6.465)	(19.943)	(1.144)	(26.815)	(4.185)	(1.695)	(21.223)	(4.532)	(3.253)	(1.793)
Acquisition	-0.034***	-0.037***	-0.029***	-0.038***	-0.014***	-0.029***	-0.036***	-0.014***	-0.029***	-0.023***
	(-15.519)	(-37.046)	(-28.075)	(-37.523)	(-15.738)	(-28.449)	(-35.604)	(-15.931)	(-27.675)	(-2.622)
Age	-0.015***	-0.017***	-0.010***	-0.013***	-0.007***	-0.011***	-0.016***	-0.012***	-0.011***	0.004
	(-17.915)	(-28.755)	(-17.017)	(-22.023)	(-9.193)	(-18.071)	(-27.821)	(-10.139)	(-17.88)	(0.407)
Cash/TA (t-1)										0.410***
										(9.580)
Constant	0.204***	0.236***	0.252***	0.225***	0.285***	0.255***	0.241***	0.302***	0.258***	0.674***
	(15.835)	(118.69)	(118.402)	(112.409)	(64.426)	(118.094)	(117.774)	(56.158)	(115.343)	(2.872)
Observations	81,300	81,300	81,300	81,220	80,024	81,300	81,220	80,024	81,220	68,825
R-squared	0.503	0.479	0.499	0.482	0.802	0.500	0.490	0.803	0.510	.z
Country FEs	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO
Industry FEs	NO	NO	NO	YES	NO	NO	YES	NO	YES	NO
Firm FEs	YES	NO	NO	NO	YES	NO	NO	YES	NO	YES
Year FEs	YES	YES	NO	NO	NO	YES	YES	YES	YES	YES
p-value for AR (2) test										0.281
p-value for Hansen J test										0.177

Note: *This table presents determinants for optimal Cash Holdings estimated by FM, OLS, and GMM. All of the variables are defined in Appendix A. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

Table 4 Stage 2 – Cash holdings adjustment speed.

	Deviation from actual Cash							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Deviation from target Cash	0.227***	0.224***	0.579***	0.230***	0.228***	0.224***	0.580***	0.230***
	(90.374)	(90.373)	(145.289)	(90.407)	(89.762)	(90.016)	(144.329)	(89.820)
Size	-0.001***	0.000*	-0.008***	-0.001***	-0.001***	0.000	-0.008***	-0.001***
	(-5.429)	(1.657)	(-12.149)	(-4.908)	(-5.262)	(-0.090)	(-12.333)	(-4.785)
Tobin's Q	-0.001***	-0.001***	-0.003***	-0.001***	-0.001***	-0.001***	-0.003***	-0.001***
	(-4.920)	(-5.623)	(-12.488)	(-5.207)	(-4.767)	(-5.368)	(-12.413)	(-5.056)
Industry CF risk	0.010***	0.000	-0.014***	0.001	0.010***	0.000	-0.014***	0.000
	(3.201)	(0.110)	(-3.540)	(0.314)	(3.100)	(-0.067)	(-3.489)	(0.082)
CFO	-0.009***	-0.012***	0.001	-0.010***	-0.009***	-0.011***	0.001	-0.010***
	(-4.329)	(-5.445)	(0.312)	(-4.608)	(-4.093)	(-5.354)	(0.190)	(-4.366)
NWC	0.052***	0.053***	0.171***	0.055***	0.052***	0.054***	0.171***	0.055***
	(28.732)	(30.883)	(53.089)	(29.199)	(28.634)	(31.082)	(52.777)	(29.088)
CapEx	0.000	0.001	0.059***	-0.001	0.001	0.000	0.060***	-0.001
	(0.024)	(0.110)	(6.301)	(-0.130)	(0.098)	(-0.032)	(6.306)	(-0.118)
Leverage	0.018***	0.017***	0.115***	0.019***	0.018***	0.017***	0.115***	0.018***
	(9.816)	(9.338)	(35.319)	(9.809)	(9.655)	(9.282)	(34.961)	(9.621)
R&D	0.052***	0.038***	-0.269***	0.039***	0.053***	0.039***	-0.270***	0.040***
	(10.322)	(6.954)	(-25.330)	(7.143)	(10.341)	(7.054)	(-25.304)	(7.165)
Dividend	-0.006***	-0.005***	-0.013***	-0.006***	-0.006***	-0.005***	-0.013***	-0.006***
	(-6.209)	(-6.626)	(-10.025)	(-5.851)	(-6.343)	(-5.986)	(-9.988)	(-5.970)
Acquisition	0.001*	-0.001	0.013***	0.001	0.001*	0.000	0.013***	0.001
	(1.733)	(-0.789)	(16.178)	(1.378)	(1.668)	(-0.294)	(16.164)	(1.322)
Age	0.003***	0.002***	0.004***	0.003***	0.003***	0.003***	0.004***	0.003***
	(7.431)	(6.159)	(3.955)	(7.753)	(7.427)	(6.571)	(3.904)	(7.759)
Inflation					0.002	-0.016	0.042*	0.005
					(0.099)	(-0.826)	(1.752)	(0.191)
GDP Growth					-0.094***	-0.001	-0.032	-0.091***
					(-3.332)	(-0.063)	(-1.165)	(-3.22)
Corruption					-0.002	-0.002***	-0.006***	-0.002
					(-1.127)	(-3.785)	(-2.642)	(-1.032)
Constant	0.001	-0.004***	0.049***	0.002	0.006*	0.001	0.058***	0.006*
	(0.564)	(-2.797)	(9.583)	(0.965)	(1.708)	(0.427)	(9.217)	(1.802)
Observations	81,300	81,220	80,024	81,220	80,486	80,417	79,296	80,417
R-squared	0.120	0.118	0.347	0.121	0.120	0.119	0.347	0.121
Country FEs	YES	NO	NO	YES	YES	NO	NO	YES
Industry FEs	NO	YES	NO	YES	NO	YES	NO	YES
Firm FEs	NO	NO	YES	NO	NO	NO	YES	NO
Year FEs	YES	YES	YES	YES	YES	YES	YES	YES

Note: *This table capturers average adjustment speed of cash holdings towards the target by the deviation of actual cash holdings from the target estimated by OLS. All of the variables are defined in Appendix A. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

Table 5 Stage 3 – Climate change and Cash holdings adjustment speed.

	Deviation from actual Cash							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Deviation from target Cash	0.197***	0.197***	0.559***	0.202***	0.198***	0.199***	0.559***	0.204***
	(36.378)	(37.744)	(58.300)	(36.633)	(37.712)	(39.215)	(59.414)	(37.906)
Climate change exposure	0.000	0.000	0.000	0.000				
	(-1.010)	(-1.094)	(-0.582)	(-1.141)				
Deviation from target Cash*	0.01***	0.009***	0.008***	0.009***				
Climate change exposure	(4.545)	(4.238)	(2.787)	(4.333)				
Climate change risk					-0.001	-0.001	-0.005	-0.001
					(-0.383)	(-0.288)	(-1.157)	(-0.397)
Deviation from target Cash*					0.198***	0.191***	0.172***	0.197***
Climate change risk					(6.197)	(5.993)	(4.815)	(6.168)
Constant	0.004	0.006*	0.060***	0.003	0.004	0.005*	0.06***	0.003
	(0.774)	(1.683)	(5.608)	(0.620)	(0.752)	(1.657)	(5.604)	(0.572)
Observations	31,766	31,762	31,188	31,762	31,766	31,762	31,188	31,762
R-squared	0.121	0.123	0.361	0.125	0.122	0.124	0.361	0.125
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Country FEs	YES	NO	NO	YES	YES	NO	NO	YES
Industry FEs	NO	YES	NO	YES	NO	YES	NO	YES
Firm FEs	NO	NO	YES	NO	NO	NO	YES	NO
Year FEs	YES	YES	YES	YES	YES	YES	YES	YES

Note: *This table presents an analysis of the effect of climate change risk and climate change exposure on cash adjustment speeds, estimated by OLS. All of the variables are defined in* ***Appendix A****. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

4.4 Endogeneity

4.4.1 System generalised method of moments (GMM) approach

To mitigate any possible endogeneity issues arising from fixed effects techniques, we employ a dynamic panel generalised-method-of-moments (GMM) model introduced by Blundell and Bond (1998), a widely recognised econometric approach that relies on instrumental variables based on Arellano and Bond (1991) and Arellano and Bover (1995), using all the variables lagged $t-3$ as instruments for the equations in levels and all the variables lagged $t-4$ as instruments for the equation in differences. By using this approach, we can control for potential bias from omitted variables while addressing both simultaneous and dynamic endogeneity (Abdallah, Goergen, & O'Sullivan, 2015; Wintoki, Linck, & Netter, 2012). Existing studies on cash holdings adjustment speed also apply similar methods (Jiang & Lie, 2016; Orlova & Rao, 2018; Venkiteshwaran, 2011).

In this method, all explanatory variables are instrumented using their lagged values. Furthermore, we also employ a two-step system generalised method of moments (GMM) with robust errors and collapsed instruments, which provide more asymptotically efficient estimates compared to the one-step approach. We applied this method for both for Stage 1 representing in Equation (1) and for Stage 3 which is in Equation (3) and Equation (4) and (5). Dynamic generalised method of moments (GMM) regressions results is reported for Stage1 in Column (10) of Table **3** and for Stage 3 in Columns (1) and (2) of Table **6**. We find a significantly positive impact of climate change exposure and climate change risk on the cash holdings adjustment speeds. In Column (1), the interaction term coefficient between cash holdings adjustment speeds and climate change exposure is 0.772, with statistically significant at the 1% level (t-statistic = 2.683). Meanwhile, the coefficient of interaction term between cash holdings adjustment speeds and climate change risk is 8.255 and statistically significant at 1% level (t-statistics = 2.634) in Column (2).

To verify this estimation's validity, we primarily consider the $p-value$ of the Hansen J test and second-order autocorrelation AR (2) test. Particularly, we conduct the AR

(2) test for serial correlation in the first-differenced residuals along with the Hansen test for over-identifying restrictions to evaluate the model's validity. Since we fail to reject the null hypotheses, it confirms that the instrument set is valid, and there is no second-order autocorrelation in the residuals. Consequently, we can verify that our results on the relationship between climate change exposure (climate change risk) and cash holdings adjustment speeds are significant and not affected by endogenous concerns. The results suggest that climate change is statistically positively correlated with firms' cash holdings adjustment speeds. We confirm that the positive impact of climate change on the speed of cash holdings adjustment, even controlling for potential endogeneity problems.

4.4.2 Propensity score matching (PSM) approach

In our baseline analysis, we initially account for several firm characteristics. To further mitigate the possible omitted variable bias, we apply a propensity score matching method, as suggested by Dehejia and Wahba (2002). This method allows us to generate comparable groups of treated and control firms, matched based on observable covariates. Adopting the approaches of Abid, Schneider and Scheffran (2016) and Gebre, Amekawa and Fikadu (2023), treated firms are classified as those above the median in terms of climate change exposure or risk, while the control group includes those below the median level for each year. A logit regression model is used to regress the treated group dummy variable against a range of control variables, as shown in Equation (3) and (4), in order to estimate the propensity scores. The results of this model are reported in Panel **A** of Table **7**. Specifically, in Column (1), the coefficient for climate change exposure is 0.545, statistically significant at 1% level, which suggest that firms more exposed to climate risk are more likely to be part of the treated group. With the calculated propensity scores, we matched the treated group observations to those of the control group, using the nearest neighbour criterion with a caliper of 0.05, without replacement. Control firms were constrained to be in the same industry and year as the treated firms. Consequently, the matched sample includes around 28,336 observations related to climate change exposure and 7,726 for climate change risk.

Panel **B** of Table **7** presents the balance check results, indicating that most firm characteristic do not significant differ between the matched high and low climate change exposure or risk groups. We specifically evaluated the balance between the treated and control groups and found minimal differences, such as a 0.013 (or 0.066) difference in Size for climate change exposure (or risk), which supports that the groups are well-matched. The average treatment effect for the treated firms is reported in Panel **C**. We find that the mean Deviation from actual Cash for treated firms is significantly higher than that of control firms under both climate change exposure and risk conditions, supporting our previous findings. In other words, firms that are more exposed to climate change adjust their cash holdings more swiftly than those in the control group. With the matched sample, we re-estimate the baseline regressions and present the results in Panel **D** of Table 7. After including a different set of control variables and fixed effects, we still find consistent results. Particularly, we found that the interaction term coefficients of Deviation from target Cash*Climate change exposure and Deviation from target Cash*Climate change risk remain positive and statistically significant at the 1% level. For example, in Column (2), the coefficient for climate change exposure and the speed adjustment of cash holdings is 0.01, with a t-statistic of 4.662 , indicates a positive correlation. Similarly, the interaction term for climate change risk shows a coefficient of 0.127, statistically significant at the 1% level, with a t-statistic of 3.321. In conclusion, the empirical results indicates that climate change intensifies the speed of firms' cash holdings adjustment. This effect is robustly validated through propensity score matching (PSM), which helps to mitigate endogeneity concerns in our study.

Table 6 System Generalised Method of Moments (GMM) approach

	Deviation from actual Cash	
	(1)	(2)
Deviation from target Cash	0.390	0.734***
	(1.195)	(2.973)
Climate change exposure	-0.002	
	(-0.293)	
Deviation from target Cash* Climate change exposure	0.772***	
	(2.683)	
Climate change risk		0.321
		(1.146)
Deviation from target Cash* Climate change risk		8.255***
		(2.634)
Size	0.018**	0.010*
	(2.319)	(1.714)
Tobin's Q	0.003	0.003
	(0.571)	(0.653)
Industry CF risk	0.089	0.045
	(1.450)	(0.613)
CFO	-0.282	-0.133
	(-1.158)	(-0.894)
NWC	-0.289***	-0.277***
	(-2.767)	(-2.978)
CapEx	0.175**	0.118**
	(2.407)	(2.371)
Leverage	0.089**	0.116***
	(2.400)	(3.338)
R&D	-0.467**	-0.329**
	(-1.969)	(-2.316)
Dividend	0.004	0.011
	(0.408)	(1.220)
Acquisition	0.020	0.021*
	(1.245)	(1.772)
Age	-0.007	-0.002
	(-1.197)	(-0.338)
Inflation	-0.072	-0.070
	(-0.591)	(-0.601)
GDP Growth	-0.015	0.098
	(-0.077)	(0.585)
Corruption	-0.013*	-0.019***
	(-1.669)	(-2.770)
Constant	-0.166***	-0.126***
	(-2.915)	(-2.800)
Observations	18,004	18,004
Pseudo R^2	.z	.z
Firm FEs	YES	YES
Year FEs	YES	YES
p-value for AR (2) test	0.763	0.378
p-value for Hansen J test	0.853	0.139

Note: *This table presents the generalised method of moments (GMM) used for solving endogeneity problems. All of the variables are defined in* ***Appendix A****. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

Table 7 Propensity Score Matching (PSM) approach

Note: *This table reports the results of the propensity score matching in addressing the endogenous problems. We presented the logit model results in Panel* ***A****, which consider the probability that a given firms be a part of the treated group. We ensure control firms appear in the same industry and year as the treated firms. Next, we check the covariates between the treated group and the control group of the matched sample in Panel* ***B****. We measure the causal impact of treated group on the results by estimating the average treatment effect (ATE). Finally, we addressed the endogeneity by showing the estimation results of Equation (3) and (4) in our matched sample. All of the variables are defined in* [***Appendix A***]*. The t-statistical from robust standard errors clustered at the country level are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

Panel **A** – Logit Model Estimation		
	High Climate change	
	(1)	(2)
Deviation from target Cash	-0.461***	-1.070**
	(0.151)	(-2.190)
Climate change exposure	0.545***	
	(0.015)	
Deviation from target Cash* Climate change exposure	1.115***	
	(0.123)	
Climate change risk		44.922***
		(67.200)
Deviation from target Cash* Climate change risk		42.595***
		(7.750)
Size	0.019***	0.147***
	(0.007)	(7.640)
Tobin's Q	0.002	0.020
	(0.006)	(1.220)
Industry CF risk	0.042	0.428
	(0.166)	(1.030)
CFO	0.432***	0.920***
	(0.102)	(3.090)
NWC	-0.181**	-0.566**
	(0.089)	(-2.080)
CapEx	-0.710**	-1.291
	(0.304)	(-1.490)
Leverage	-0.083	0.091
	(0.075)	(0.420)
R&D	1.372***	0.849
	(0.229)	(1.210)
Dividend	-0.107***	-0.545***
	(0.037)	(-5.110)
Acquisition	0.104***	0.194***
	(0.025)	(2.830)
Age	0.113***	0.171***
	(0.015)	(3.910)
Inflation	1.050	-4.140*
	(0.830)	(-1.880)
GDP Growth	-1.597*	-4.461*
	(0.966)	(-1.660)
Corruption	0.031	-0.030
	(0.029)	(-0.360)
Constant	-1.015***	-8.418***
	(0.384)	(-3.860)
Observations	31,762	31,760
Pseudo R^2	0.060	0.648
Country FEs	NO	NO
Industry FEs	YES	YES
Firm FEs	NO	NO
Year FEs	YES	YES

Panel **B** – Balance Checking

	Climate change exposure				Climate change risk			
	Treated group	Control group	Difference	t-statistic	Treated group	Control group	Difference	t-statistic
Size	7.562	7.575	0.013	-0.450	8.039	8.105	0.066	-1.240
Tobin's Q	2.615	2.576	-0.039	1.590	2.507	2.531	0.024	-0.560
Industry CF risk	0.073	0.073	0.000	-0.480	0.076	0.076	0.000	-0.280
CFO	0.061	0.060	-0.001	0.810	0.062	0.060	-0.002	0.550
NWC	-0.141	-0.143	-0.002	0.710	-0.117	-0.119	-0.002	0.480
CapEx	0.048	0.048	0.000	0.340	0.052	0.052	0.000	-0.420
Leverage	0.213	0.214	0.001	-0.330	0.224	0.227	0.003	-0.560
R&D	0.041	0.039	-0.002	1.190	0.032	0.033	0.001	-0.840
Dividend	0.197	0.188	-0.009	1.850	0.216	0.221	0.005	-0.500
Acquisition	0.480	0.487	0.007	-1.310	0.508	0.511	0.003	-0.200
Age	2.384	2.381	-0.003	0.330	2.452	2.454	0.002	-0.090
Inflation	0.021	0.020	-0.001	0.610	0.020	0.020	0.000	-0.210
GDP Growth	0.019	0.018	-0.001	0.630	0.018	0.018	0.000	0.110
Corruption	1.456	1.450	-0.006	0.880	1.450	1.450	0.000	-0.060

Panel **C** – Average Treatment Effects

	Treated group	Control group	Difference	t-statistic
Deviation from actual Cash (CCE)	-0.003	-0.005	0.002***	1.490
Deviation from actual Cash (CCR)	-0.002	-0.006	0.004***	1.990

Panel **D** – Re-estimate Baseline Regression on the Matched Sample

	Climate change exposure		Climate change risk	
	(1)	(2)	(1)	(2)
Deviation from target Cash	0.233***	.202***	.248***	.218***
	(48.944)	(34.626)	(25.861)	(19.024)
Climate change exposure	0.000	0.000		
	(-1.061)	(-0.995)		
Deviation from target Cash*	0.011***	0.01***		
Climate change exposure	(5.051)	(4.662)		
			0.001	0.002
Climate change risk			(0.305)	(0.497)
			0.131***	0.127***
Deviation from target Cash*			(3.401)	(3.321)
Climate change risk	28,336	28,333	7,726	7,726
R-squared	0.107	0.129	0.126	0.157
Adjusted R^2	0.105	0.124	0.119	0.141
Country FEs	YES	YES	YES	YES
Industry FEs	NO	YES	NO	YES
Year FEs	YES	YES	YES	YES

4.5 Cross-sectional analysis

4.5.1 The cash above and below the target

In this section, we estimated Equation (3) and (4) separately for the subsample of firm-year observations where the deviation from the target cash holdings is less than zero (a cash deficit), and for the subsample where the deviation is equal to or greater than zero (a cash surplus) by Equation (5) and (6). This enables us to examine whether the effect of climate change exposure (climate change risk) on adjustment speed is asymmetric, depending on the magnitude of cash holdings compared to the target.

Columns (1)-(3) in Table **8** and **9** present the results of the regression analysis when cash holdings ratio is below the target, while Columns (4)-(6) report the results when the cash holdings ratio is above the target. We also control for country, industry, firm, and year fixed effects. We present the results of estimating Equation (5) and (6) in Table **8** and **9** below.

In Columns (1)-(3) of Table **8**, where the Deviation from target cash is negative (a cash deficit), the coefficients for Deviation from target Cash is consistently positive and statistically significant (at the 1% level), suggesting that firms actively adjust their cash holdings upwards the target cash level when they are below the target. The coefficients for Climate change exposure are negative and statistically significant (at the 5% level), which implies that firms with greater exposure to climate change slower the adjustment speed of cash holdings in these situations. However, our main interest is that the coefficients of interaction term between Deviation from target Cash and Climate change exposure is positive and highly significant (at the 1% level) across all columns, which shows that firms with cash below their cash level (cash deficit firm) increase their adjustment speed when exposed to climate change, aligning with the precaution savings motives. Regarding to Columns (1)-(3), where cash holdings are above or at the target level (a cash surplus), the coefficients for Deviation from target Cash remains consistently positive and highly significant, this suggest that firms also reduce their actual cash holdings when they exceed the target level. The coefficients for Climate change exposure are statistically insignificant, suggesting no direct effect on cash adjustment speed of firms when they are above the target level. Nevertheless, the coefficients of interaction term between Deviation from target Cash and Climate change exposure, which is our focus, are positive and significant (at the 10% level), although they appear with a smaller magnitude compared to when cash is below the target level. This suggest that firms with a cash surplus also adjust their cash holdings faster due to climate change exposure, but to a lesser extent than those with a cash deficit.

Moreover, the similar findings were also found in the case of Climate change risk. In particular, in Columns (1)-(3) of Table **9**, where firms' actual cash holdings are below the target (a cash deficit), the coefficients for Deviation from target Cash remain positive and statistically significant (at the 1% level), indicating active adjustment efforts from firms. The coefficients for Climate change risk are negative and significant (at the 10% level), suggesting that climate change risk slightly reduces the speed of cash adjustments for firms with cash deficits. However, our primary interest is that the coefficient of the interaction term between Deviation from target Cash and Climate change risk is positive and highly significant (at the 1% level) across all 8 columns, which implies that firms with cash deficits significantly increase their cash adjustment speed when they face with higher climate change risk. This result stresses the urgency for firms to maintain sufficient liquidity under high uncertainty. Given the Columns (1)-(3), where firms' cash holdings are above or at the target level, the coefficients for Deviation from target Cash are positive and highly significant (at the 1% level), support the evidence that firms adjust their cash holdings downwards when they have excess cash. The coefficients for Climate change risk are statistically insignificant, indicating there are no direct effect on adjustment speed in the presence of excess cash. Nevertheless, the coefficients of the interaction term between Deviation from target Cash and Climate change risk is positive and statistically significant (at the 5% level with the exception for Column 2 at the 1% level), indicating that climate risk still forcing more quickly adjustments, although with less intensity compared to firms with cash deficits.

Overall, climate change increases significantly the speed at which firms modify their cash holdings then they are in cash deficit compared to firms in cash surpluses. The findings suggest that those firms are more cautious and take action rapidly to maintain their liquidity buffers when they expose to climate change compared to those cash surplus firms which are less pressured to accumulate cash reserves, as proposed by the precautionary motives. The findings are consistent with our argument by existing work of Almeida, Campello and Weisbach (2004); Baum et al. (2006); Bates, Kahle and Stulz (2009); and Palazzo (2012).

In summary, the results provide evidence to lend strong support to Hypothesis **2a**, suggesting that firms are more proactive in adjusting their actual cash holdings when facing with climate change, particularly when they are experiencing a cash deficit compared to firms in cash surplus. In contrast, we reject the competing Hypothesis **2b**, which proposed that the positive association between climate change and cash holdings adjustment speed is more pronounced when firms are in cash surplus compare to cash deficit firms.

Table 8 The Cash holdings asymmetry - Climate change exposure

	Deviation from target Cash < 0			*Deviation from target Cash ≥ 0*		
	Deviation from actual Cash			**Deviation from actual Cash**		
	(1)	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
Deviation from target Cash	0.166***	0.172***	0.175***	0.208***	0.209***	0.217***
	(14.064)	(14.546)	(14.565)	(17.848)	(18.990)	(18.326)
Climate change exposure	-0.001**	-0.001**	-0.001**	0.000	0.000	0.000
	(-2.071)	(-2.356)	(-2.251)	(-0.344)	(0.068)	(-0.206)
Deviation from target Cash*	0.017***	0.017***	0.017***	0.009*	0.009*	0.009*
Climate change exposure	(3.459)	(3.365)	(3.325)	(1.705)	(1.850)	(1.727)
Constant	0.004	0.008**	0.006	0.011	0.007	0.009
	(0.747)	(2.119)	(1.061)	(1.291)	(1.084)	(0.956)
Observations	19,333	19,329	19,329	12,433	12,432	12,432
R-squared	0.055	0.058	0.060	0.097	0.101	0.103
Controls	YES	YES	YES	YES	YES	YES
Country FEs	YES	NO	YES	YES	NO	YES
Industry FEs	NO	YES	YES	NO	YES	YES
Firm FEs	NO	NO	NO	NO	NO	NO
Year FEs	YES	YES	YES	YES	YES	YES

Note: *This table presents an analysis of the effect of climate change exposure on cash adjustment speeds when the cash ratio is below (Deviation from target cash < 0) and above (Deviation from target Cash ≥ 0), estimated by OLS. All of the variables are defined in* ***Appendix A****. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

Table 9 The Cash holdings asymmetry - Climate change risk

	Deviation from target Cash < 0			*Deviation from target Cash ≥ 0*		
	Deviation from actual Cash			**Deviation from actual Cash**		
	(1)	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
Deviation from target Cash	0.171***	0.178***	0.180***	0.208***	0.210***	0.217***
	(15.229)	(15.707)	(15.690)	(18.414)	(19.702)	(18.910)
Climate change risk	-0.012*	-0.012*	-0.012*	0.001	0.003	0.002
	(-1.768)	(-1.811)	(-1.819)	(0.077)	(0.352)	(0.175)
Deviation from target Cash*	0.307***	0.300***	0.302***	0.193**	0.199***	0.196**
Climate change risk	(4.242)	(4.151)	(4.179)	(2.525)	(2.611)	(2.559)
Constant	0.004	0.008**	0.005	0.011	0.007	0.008
	(0.646)	(1.968)	(0.936)	(1.252)	(1.062)	(0.905)
Observations	19,333	19,329	19,329	12,433	12,432	12,432
R-squared	0.056	0.059	0.061	0.097	0.101	0.104
Controls	YES	YES	YES	YES	YES	YES
Country FEs	YES	NO	YES	YES	NO	YES
Industry FEs	NO	YES	YES	NO	YES	YES
Firm FEs	NO	NO	NO	NO	NO	NO
Year FEs	YES	YES	YES	YES	YES	YES

Note: *This table presents an analysis of the effect of climate change risk on cash adjustment speeds when the cash ratio is below (Deviation from target cash < 0) and above (Deviation from target Cash ≥ 0), estimated by OLS. All of the variables are defined in* ***Appendix A****. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

4.5.2 The role of environmental policy stringency

We examine the moderating role of environmental policy stringency on the relation between climate change and cash holdings adjustment speeds, using the Equation (7). Our analysis focuses on the three-way interaction between climate change, deviation from target cash, and environmental policy stringency to understand how stringent environmental policies moderate the relationship between climate change and the speed of cash holdings adjustment. The environmental policy stringency (EPS) index is used as a proxy to measure external environmental policy (Botta & Koźluk, 2014). As discussed, we set firm-year observations with top-tercile of the environmental policy stringency (EPS) index as high environmental policy stringent (High Stringent) firms compared to those with bottom-tercile as low or lax environmental policy stringent firms. We also include the same set of control variables; country, industry, and year fixed effects as in the baseline model of Equation (3) and (4). In this section, we demonstrate that the coefficient for the three-way interaction terms $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\,i,t-1}) \times CC_{i,t-1} \times EPS_{i,t-1}$. The role of environmental policy stringency was estimated using the Equation (7), which its results presented in Table **10**.

The coefficients for Climate change exposure and Climate change risk remains statistically insignificant across Columns (1) and (2), indicating that Climate change exposure and Climate change risk by themselves does not have a significant direct effect on cash holdings adjustment speed. Similarly, the coefficients of interaction term $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\,i,t-1}) \times CCE_{i,t-1}$ and $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\,i,t-1}) \times CCR_{i,t-1}$ is also statistically insignificant (below the 5% level). This suggests that without considering the environmental policy stringency, the impact of climate change is not significant. With our main focus, the coefficients of the interaction term $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\,i,t-1}) \times CCE_{i,t-1} \times EPS_{i,t-1}$ and $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\,i,t-1}) \times CCE_{i,t-1} \times EPS_{i,t-1}$ is consistently positive and highly significant (at the 1% level). This indicates that environmental policy stringency significantly strengthens the positive relationship between climate change and cash holdings adjustment speed. In other words, firms in stricter environmental policies are more likely to adjust their cash holdings more rapidly when faced with climate change, emphasising the role of stringent regulations in forcing firms to maintain greater liquidity buffers to cope with issues related to climate change.

In the absence of regulatory pressures, climate change does not have sufficiently strong impact on cash adjustment behaviour. However, once we introduce the moderating variable High Stringent ($EPS_{i,t-1}$), we observe significant three-way interactions, indicating that stringency of environmental policies plays a key role in strengthening the link between climate changes and the speed at which cash holdings. This behaviour also aligns with and reinforces the precautionary motive for holding cash, stressing the need for better financial flexibility to deal with increased regulatory pressures and potential costs associated with compliance, adaptation, and risk mitigation. For example, in Columns (2) of both climate change exposure and climate change risk, the coefficient on the three-way interaction terms $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\ i,t-1}) \times CC_{i,t-1} \times EPS_{i,t-1}$ is 0.026 and 0.231, respectively, and statistically significant at 1% (t-statistics$=$ 4.952 and 3.066). This implies that 1%-point increase in climate change, the firms in nations with stricter environmental policies adjust their cash holdings levels faster around 2.60% with climate change exposure and approximately 2.31% with climate change risk than firms from nations with laxer environmental policies. For firms facing stringent environmental policies, the cash holdings adjustment speed under high climate change is given by $\sigma = \gamma_1 + \gamma_2 + \gamma_3 + \gamma_4$. In contrast, for firms facing lax environmental policies, the cash holdings adjustment under high climate change is defined by $\sigma = \gamma_1 + \gamma_3$. Hence, the cash holdings adjustment speed for firms facing high climate change and high stringent environmental policies are 0.219 $(0.206 + 0.026 + 0.002 - 0.015)$ and 0.531 $(0.204 + 0.231 + 0.099 - 0.003)$ respectively, whereas the cash holdings adjustment speed for firms with high climate change and lax environmental policies are 0.208 $(0.206 + 0.002)$ and 0.303 $(0.204 + 0.099)$.

Therefore, the results indicate that firms facing both high climate change and stringent environmental policies tend to adjust their cash holdings more quickly when deviating from their target levels. This suggests that for firms subject to stringent environmental regulations, the urgency to adjust cash holdings in response to climate change is more apparent, likely as a policy compliance strategy. The findings are in line with our prediction and prior studies (Ambec et al., 2013; Berrone et al., 2013; Hart & Dowell, 2011; Li et al., 2018; Ou & Jiang, 2023). Collectively, we find robust evidence to support the Hypothesis **3** demonstrating that environmental policy stringency significantly moderates the relationship between climate change and cash holding adjustment speed, forcing firms to adopt more proactive liquidity management practices in response to climate change-related issues and regulatory requirements.

Table 10 The role of environmental policy stringency

	Climate change exposure		**Climate change risk**	
	Deviation from actual Cash		**Deviation from actual Cash**	
	(1)	(2)	(1)	(2)
Deviation from target Cash	0.200***	0.206***	0.199***	0.204***
	(23.046)	(23.289)	(23.454)	(23.679)
Climate change exposure	0.000	0.000		
	(-0.955)	(-0.849)		
Climate change risk			0.001	0.001
			(0.102)	(0.193)
Deviation from target Cash* Climate change exposure	0.002	0.002		
	(0.582)	(0.505)		
Deviation from target Cash* Climate change risk			0.096*	0.099*
			(1.832)	(1.881)
Climate change exposure* High Stringent	0.001	0.001		
	(1.343)	(1.267)		
Climate change risk* High Stringent			-0.001	-0.001
			(-0.078)	(-0.129)
Deviation from target Cash* Climate change exposure*High Stringent	**0.026*** **	**0.026*** **		
	(5.007)	**(4.952)**		
Deviation from target Cash* Climate change risk*High Stringent			**0.236*** **	**0.231*** **
			(3.136)	**(3.066)**
Environmental Policy Stringency	0.002	0.002	0.002	0.002
	(0.958)	(1.035)	(1.337)	(1.401)
Deviation from target Cash* High Stringent	-0.016	-0.015	-0.004	-0.003
	(-1.410)	(-1.335)	(-0.335)	(-0.263)
Observations	20,690	20,688	20,690	20,688
R-squared	0.124	0.128	0.123	0.127
Firm Controls	NO	YES	NO	YES
Country Controls	YES	YES	YES	YES
Country FEs	YES	YES	YES	YES
Industry FEs	NO	YES	NO	YES
Year FEs	YES	YES	YES	YES

Note: *The table presents the influence of climate change and cash holdings adjustment speed conditional on the degree of environmental policy stringency estimated by the OLS. All of the variables are defined in Appendix A. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

4.5.3 The role of financial constraints

We explore how climate change influences the cash holdings adjustment speed, focusing on the role of financial constraints based on Equation (8). Our analysis focus on the three-way interaction between climate change, deviation form target cash, and financial constraints to explore how financial constraints moderate the relationship between climate change and the speed of cash holdings adjustment. The constraints measure is derived from internal financial constraints, using by the Whited-Wu (WW) index as a proxy (Whited & Wu, 2006). As discussed earlier, we set firm-year observations with top-tercile of the Whited-Wu (WW) index as high financial constraints (High Financial Constraints) firms compared to those with bottom-tercile as low financial constraints firms. We also include the same set of control variables; country, industry, and year fixed effects as in the baseline model of Equation (3) and (4). In this section, we examine that the coefficient for the three-way interaction terms $Cash/TA^{*}{}_{i,t} - Cash/TA_{\ i,t-1}) \times CC_{i,t-1} \times WWI_{i,t-1}$. Table **11**, for both climate change exposure and climate change risk, show the role of financial constraints based on Equation (8):

The coefficients for Climate change exposure and Climate change risk remains statistically insignificant across Columns (1) and 92), indicating that Climate change exposure and Climate change risk by themselves does not have direct significant effect on cash holdings adjustment speed. In similar, the coefficients of interaction term $Cash/TA^{*}{}_{i,t} - Cash/TA_{\ i,t-1}) \times CCE_{i,t-1}$ and $Cash/TA^{*}{}_{i,t} - Cash/TA_{\ i,t-1}) \times CCE_{i,t-1}$ are also statistically insignificant (below the 5% level). This suggests that climate change alone does not significantly influence cash adjustment speed without considering financial constraints. Our primary interest is that the coefficients of the interaction term $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\ i,t-1}) \times CCE_{i,t-1} \times WWI_{i,t-1}$ and $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\ i,t-1}) \times CCR_{i,t-1} \times WWI_{i,t-1}$ is consistently positive and statistically significant (above the 5% level) in both Columns (1) and (2). This suggests that financial constraints play a critical role in intensify the positive association between climate change and the speed at which firms adjust their cash holdings. Specifically, firms with financial constraints are more likely to adjust their cash holding reserves quickly in response to climate change due to their limited access to external financing and the heightened necessity to maintain internal liquidity.

In the absence of financial constraints, climate change does not have a sufficiently strong impact on cash adjustment behaviour. Nevertheless, once we introduce the moderating variable High Financial Constraint, we observe significant three-way interactions, indicating that financial constraints are an essential factor that intensify the link between climate change and cash holdings adjustment speed. This behaviour also aligns with and reinforces the pecking order theory, stressing the need for better financial flexibility to cope with limited access to external financing and the increased need to manage risks associated with climate change and potential financial distress.

The findings demonstrates that with increased climate change (climate change exposure and climate change risk), firms experience high financial constraints, leading to a faster cash holdings adjustment speed. Therefore, firms with greater climate change (climate change exposure and climate change risk) tend to be closer to their target cash ratio and adjust more quickly if they deviate, and it is accelerated when firms facing with high financial constraints.

For example, Columns (2) in both climate change exposure and climate change risk, the coefficient of three-way interaction term $(Cash/TA^{*}{}_{i,t} - Cash/TA_{\ i,t-1}) \times CC_{i,t-1} \times WWI_{i,t-1}$ is positive and statistically significant at the 1% level (t-statistics= 2.165 and 2.559) with a value of 0.012 and 0.193, respectively. This implies that a 1%-point increase in climate change leads financially constrained firms to adjust their actual cash holdings levels faster by around 1.20% with climate change exposure and approximately 19.30% with climate change risk compared to firms with low financial constraints. Firm with high financial constraints, the cash holdings adjustment speed by high climate change (climate change exposure and climate change risk) is represented by $\sigma = \gamma_1 + \gamma_2 + \gamma_3 + \gamma_4$. Meanwhile, the cash holdings adjustment speeds for high climate change of firms with low financial constraints is defined by $\sigma = \gamma_1 + \gamma_3$. Thus, the cash holdings adjustment speed for firms facing high climate change and high financial constraints are $0.203\ (0.202 + 0.012 + 0.001 - 0.012)$ and $0.458\ (0.201 + 0.193 + 0.07 - 0.008)$ respectively, whereas the cash holdings adjustment speed for firms with high climate change and low financial constraints are $0.203\ (0.202 + 0.001)$ and $0.273\ (0.201 + 0.072)$.

Hence, the results indicate that firms facing significant climate change exposure and financial constraints tend to adjust their cash holdings more rapidly when they deviate from their target levels. This behaviour is particularly evident among financially constrained firms due to their restricted access to external financing, making it essential to maintain adequate internal liquidity. Our findings support the initial expectation, which posited that the urgency to adjust cash holdings would be greater under these conditions, a conclusion consistent with earlier research (Almeida, Campello, & Weisbach, 2004; Bates, Kahle, & Stulz, 2009; Campello, Graham, & Harvey, 2010; Gao, Harford, & Li, 2013). In summary, we find robust evidence for the Hypothesis **4**, indicating that financial constraints intensify the impact of climate change on the speed at which cash holdings are adjusted, compelling firms to respond more swiftly because of their limited access to external funds and heightened liquidity needs.

Table 11 The role of financial constraints

	Climate change exposure		Climate change risk	
	Deviation from actual Cash		Deviation from actual Cash	
	(1)	(2)	(1)	(2)
Deviation from target Cash	0.193***	0.202***	0.192***	0.201***
	(22.186)	(22.665)	(23.358)	(23.857)
Climate change exposure	0.000	0.000		
	(0.399)	(0.849)		
Climate change risk			0.002	0.004
			(0.386)	(0.656)
Deviation from target Cash* Climate change exposure	0.001	0.001		
	(0.217)	(0.304)		
Deviation from target Cash* Climate change risk			0.066	0.072
			(1.071)	(1.149)
Climate change exposure* High Financial Constraint	-0.001	-0.001*		
	(-1.308)	(-1.672)		
Climate change risk* High Financial Constraint			-0.007	-0.008
			(-0.874)	(-1.065)
Deviation from target Cash* Climate change exposure*High Financial Constraint	**0.013****	**0.012****		
	(2.335)	**(2.165)**		
Deviation from target Cash* Climate change risk*High Financial Constraint			**0.203*****	**0.193****
			(2.690)	**(2.559)**
Financial Constraint	0.001	0.001	0.001	0.001
	(0.549)	(0.421)	(0.402)	(0.236)
Deviation from target Cash* High Financial Constraint	-0.006	-0.012	-0.001	-0.008
	(-0.468)	(-0.929)	(-0.121)	(-0.633)
Observations	19,303	19,300	19,303	19,300
R-squared	0.114	0.115	0.114	0.117
Firm Controls	NO	YES	NO	YES
Country Controls	YES	YES	YES	YES
Country FEs	YES	YES	YES	YES
Industry FEs	NO	YES	NO	YES
Year FEs	YES	YES	YES	YES

Note: *The table presents the influence of climate change and cash holdings adjustment speed conditional on the extent of financial constraints estimated by the OLS. All of the variables are defined in Appendix A. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

4.6 Robustness checks

Thus far, we have found substantial evidence that climate change faster firm's cash holdings adjustment speeds. However, there are several other explanations for our results. To reinforce the findings, we: (1) apply different measures of cash ratios; (2) use alternative indicators of climate change; and (3) consider the sensitivity of sample size.

4.6.1 Alternative measure of Cash ratios

We first evaluate the robustness of our findings through a sensitivity test, applying alternative measures of cash ratios. For the baseline model, the cash ratio is calculated using the ratio of cash and cash equivalents scaled by the book value of total assets ($Cash/TA$). For a robustness check of our findings, we use an alternative cash ratio, calculated by scaling cash and cash equivalents by total assets minus total liabilities, called cash ratio scaled by net assets ($Cash/NA$). Dittmar, Mahrt-Smith and Servaes (2003), Kalcheva and Lins (2007) and recently Guariglia and Yang (2018) also applied this alternative for their robustness check purposes. We re-estimate our Equation (1) and (2) using the new cash ratio measure, which serves to estimate the deviation from target cash in Equation (3) and (4). The results of climate change and cash holdings adjustment speed are presented in Table **12**. Overall, the coefficient for climate change remains positive and highly statistically significant, implying that climate change adjusts more quickly firms' cash holdings adjustment speed. The interaction term $(Cash/NA^{*}{}_{i,t} - Cash/NA_{i,t-1}) \times CCE_{i,t-1}$ and $(Cash/NA^{*}{}_{i,t} - Cash/NA_{i,t-1}) \times CCR_{i,t-1}$ are positive and statistically significant. This indicates that climate change has a positive relation with deviations from target cash. Therefore, firms facing high climate change tend to adjust more quickly their actual cash holdings level toward the target to closer this deviation. In conclusion, our findings are robust, regardless of the alternative definitions of cash ratio applied.

4.6.2 Alternative measure of Climate change

We further replace the measure of climate change. First, we utilise climate change exposure data from the Notre Dame Global Adaptation Index (ND-GAIN) published by the

University of Notre Dame Global Adaptation Initiative.[4] The ND-GAIN provides a yearly index for 182 countries over the period from 1995 to 2021. This index includes more than 40 core indicators, assessing a country's vulnerability across 6 essential sectors: food, water, health, ecosystem services, human habitat and infrastructure. We consult the technical report for the country index to obtain information on the methodology and data sources, published by (Chen et al., 2024). The ND-GAIN scales ranges from 0 to 1, using the "proximity-to-reference point" approach. They score vulnerability and readiness by measuring the distance from the ideal, where 0 denotes the least vulnerable and 1 signifies the most vulnerable. We follow a range of studies including Kling et al. (2021), Tenggren et al. (2020), Le, Tran and Mishra (2023) and Javadi et al. (2023) among others in employing this database as the alternative of measuring climate change. Second, for the baseline regression in Equation (3), the climate vulnerability index serves as our main measure of climate change exposure. We rerun and present the results of climate change exposure and cash holdings adjustment speed in Table **12**. As expected, we observe a positive relationship between exposure to climate change and deviation from target cash holdings. This supports the notion that firms experiencing significant climate change exposure are more likely to accelerate their adjustments of actual cash holdings to align with target levels, aiming to minimise the deviation. Hence, our findings remain consistent even after considering alternative definitions of climate change.

[4] We thank Chen et al. (2024) and University of Notre Dame Global Adaptation Initiative for free sharing the data. The technical report of the data is published at https://gain.nd.edu/assets/522870/nd_gain_countryindextechreport_2023_01.pdf

Table 12 Robustness checks - Alternative measures

	Different estimation methods of Cash ratio				Different estimation methods of Climate change risk			
	Deviation from actual Cash				Deviation from actual Cash			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Deviation from target Cash	0.000	0.000	0.000	0.000	-0.011	-0.014	0.420***	-0.001
	(-1.387)	(-1.349)	(0.578)	(0.586)	(-0.364)	(-0.466)	(9.141)	(-0.028)
Climate change exposure	0.000	0.000			0.000	0.000	0.000	0.000
	(-1.007)	(-0.677)			(0.231)	(-0.416)	(-0.074)	(0.348)
Deviation from target Cash*	0.001***	0.001***			0.004***	0.004***	0.002***	0.003***
Climate change exposure	(3.206)	(3.152)			(7.874)	(8.008)	(2.968)	(7.607)
Climate change risk			-0.001	0.000				
			(-0.419)	(-0.142)				
Deviation from target Cash*			0.009***	0.009***				
Climate change risk			(4.162)	(4.102)				
Constant	0.006	0.006	0.006	0.005	0.001	0.000	0.049***	0.001
	(1.259)	(1.134)	(1.239)	(1.112)	(0.115)	(-0.016)	(3.877)	(0.087)
Observations	31,744	31,740	31,744	31,740	66,997	66,951	66,017	66,951
R-squared	0.079	0.082	0.079	0.082	0.122	0.121	0.344	0.123
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Country FEs	YES	YES	YES	YES	YES	NO	NO	YES
Industry FEs	NO	YES	NO	YES	NO	YES	NO	YES
Firm FEs	NO	NO	NO	NO	NO	NO	YES	NO
Year FEs	YES	YES	YES	YES	YES	YES	YES	YES

Note: *This table presents an analysis of the effect of climate change exposure and climate change risk on cash holdings adjustment speeds by different estimation methods of cash ratio* (**Cash/NA**) *and climate change followed dataset of the* **Notre Dame Global Adaptation Initiative** *estimated by OLS. All of the variables are defined in Appendix A. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

4.6.2 The sensitivity of sample size

To the best of our understanding, the study's international reach distinguishes it from past relevant research and is one of the main advantages of our empirical approach. However, as shown earlier in Table **1**, the United States (U.S.) dominate our sample, accounting for 63.05% of the total sample. The United States emerges as the largest share of our sample, whereas Papua New Guinea and Thailand contribute minimally to the total observations. This raises a concern about whether the overrepresentation of U.S. data could lead to biased estimations. In order to mitigate this potential bias, we re-estimate the data with a reduced sample and simultaneously apply the weighted least squares (WLS) estimation. Specifically, Columns (1) and (2) of Table **13** present WLS estimation results, where the coefficients are weighted according to the count of observations per country, following the methodologies of Li (2019) and Le and Tran (2021). Moreover, to show that our results are not solely driven by U.S. firms, in the spirit of Le and Doan (2024), we re-evaluate our model using a subsample that excludes the United States. The evidence reported in Columns (1) and (2) of Table **13**, where excluding the U.S., reveals that the climate change remains negatively correlated with the speed adjustment of cash holdings (excepted for the Climate change risk proxy).

In the similar vein, our sample includes the data of climate change, which using two proxies comprising of Climate change exposure and Climate change risk. As discussed earlier in Section **2**, these measures are highly correlated with future uncertainties and potential financial distress. This raises a signal about the possibility that our estimation is biased as a result of containing other sources of uncertainties and distress, which is one of them is that observations of the Global Financial Crisis. Therefore, to deal with this issue, we drop all observations in the period 2007-2008 as the period of crisis to check whether financial crisis does not influence our main hypothesis. Columns (1) and (2) of Table **13**, where excluding financial crisis, show that our findings are quality similar to those obtained in Table **5**, indicating that climate change is positively associated with the speed at which firms adjust their cash holdings. In sum, we find robust evidence that climate change is positively linked to the speed of cash holdings adjustment, regardless of different robustness check methods. As a result, our previous findings are not influenced by overrepresentation within the sample.

Table 13 Robustness checks - Sensitivity of sample size

	Using WLS model		Excluding the U.S.		Excluding financial crisis	
	Deviation from actual Cash		Deviation from actual Cash		Deviation from actual Cash	
	(1)	(2)	(1)	(2)	(1)	(2)
Deviation from target Cash	0.197***	0.198***	0.206***	0.211***	0.197***	0.198***
	(998.639)	(1003.271)	(32.641)	(35.088)	(34.273)	(35.289)
Climate change exposure	-0.001***		0.000		0.000	
	(-175.298)		(0.770)		(-0.773)	
Deviation from target Cash*	0.010***		0.010***		0.008***	
Climate change exposure	(278.232)		(3.051)		(3.545)	
Climate change risk		-0.049***		0.000		-0.029***
		(-248.812)		(-0.106)		(-4.042)
Deviation from target Cash*		0.223***		0.077		0.166***
Climate change risk		(215.759)		(1.627)		(4.756)
Constant	-0.005***	-0.019***	0.008	0.008	0.004	-0.010**
	(-29.697)	(-106.390)	(1.318)	(1.398)	(0.810)	(-1.970)
Observations	31,744	31,740	11,734	11,734	27,426	27,426
R-squared	0.126	0.127	0.129	0.129	0.122	0.122
Controls	YES	YES	YES	YES	YES	YES
Country FEs	YES	YES	YES	YES	YES	YES
Industry FEs	YES	YES	YES	YES	YES	YES
Firm FEs	NO	NO	NO	NO	NO	NO
Year FEs	YES	YES	YES	YES	YES	YES

Note: *The table report the regression results for the impact of climate change on cash holdings adjustment speed using reduced samples, estimated by WLS and OLS. All of the variables are defined in Appendix A. T-statistics are computed. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

5. Conclusion

5.1 Summary

We examine the impact of climate change on firm's adjustment speed in cash holdings of companies in 49 countries globally. We find that firms have larger deviation between their actual cash holdings and the target tend to accumulate more cash to close the gap. This implies that those firms are more likely to adjust their actual cash level faster to reach the target level, thereby indicating the faster adjustment speed in cash holdings. Moreover, the key finding in the study was that climate change has substantial impact on the cash holdings adjustment speed. We found that both components of climate change including climate change exposure and climate change risk increase the speed of cash holdings adjustment which firms adjust their actual cash holdings toward the target. Since climate change pose significant risks to firms, including disrupted supply chains, increased operational costs, and heightened financial volatility. Therefore, these risks force firms to adjust their cash reserves to ensure liquidity and safeguard against future uncertainties and potential financial distress with support by the precautionary savings motive. Moreover, our results suggest that firms with cash holdings deficits (where actual cash holdings fall below the target) tend to adjust their cash more quickly than firms with cash holdings surpluses (where actual cash holdings exceed the target level). The findings support strong evidence for the pecking order theory, firms facing deficits are under greater pressure to restore liquidity rapidly to prevent financial distress related to climate change, while firms with surpluses may take more time to adjust as they experience less pressure to adjust their liquidity position. This difference emphasises the critical role of maintaining target cash level to enhance financial stability in an uncertain climate environment. Furthermore, our cross-sectional tests also reveal that positive impact of climate change on speed of cash holding adjustments is more significant for firms with high financial constraints or in countries with the presence of stricter environmental policies. Our findings suggest the importance of how firms behave and develop adaptive liquidity management strategies to enhance financial resilience in an era of growing external uncertainties from climate change and other factors such as financial constraints and environmental policies stringency. Unlike prior studies that employ data from single country, which are relatively limited in terms of generalisability, our research utilises internal data and thus can uncover the global trend on the link between climate change and cash holdings adjustment speed. Moreover, previous studies adapt the static models of cash holdings, where firm adjust immediate their cash holdings if existing deviation of cash, are ignore adjustment cost and financial friction. These assumptions are unrealistic and violent the market imperfection theory, therefore our studies consider the dynamic partial adjustment model (DPAM). With this approach, our findings provide more accurate reflection of real-world firm behaviour with a more comprehensive view of firm's cash management strategy. Our findings are robust to endogeneity caveats by firm-fixed effect model, system GMM estimation, alternative measure of climate change and cash ratio.

5.2 Policy Implications

Although the perspective of climate change is widely discussed among policymakers and scholars, this study more narrowly focuses on the issues in financial liquidity management and behaviour, thereby emphasise the important of firm liquidity in addressing climate change and its consequences as one of proxies of environment, social, government issues. This study provides important insights for all finance practitioners in devising strategies to curb effects of climate change. With the understanding of the effect of climate change on firms' cash holdings, mainly cash holdings adjustment speed, corporate managers design and apply more adaptive liquidity management strategies in response to the severe emerging risks posed by climate change. By adjusting cash holding quickly, firms can better navigate and mitigate disruption due to climate change. However, adjustment cash holdings result in a non-trivial cost. Out study offers insight for corporate managers in balancing the benefits and costs of cash adjustment. Combined with our findings from cross-sectional analysis, therefore, they evaluate to reassess their target cash levels and adjust cash holdings more flexibly to close the deviation. This proactive approach ensures the firm is better prepared for uncertainties related to climate change. Moreover, they allocate more effectively in resources management by firms, therefore, maintain firms' operations, afford more suitable investment opportunities, particularly in a financial distress from climate change, financial constraints and policies. Policymakers are crucial in promoting initiatives and adaptions to climate change for corporations. Our findings also provide valuable insights for them. This suggests that providing clear guidelines and frameworks can help firms better in both understanding and practicing to comply with environment, social, government (ESG) standards, especially mitigating climate related financial risks. By offering support for companies which follow sustainability practices, policymakers can encourage firms to by government financial aid package enhance their financial resilience, thereby maintain national and international economic stability. By our further analysis, the findings imply that enforcing stricter environmental policies is essential and effective. However, it is equally important for policymakers in balance policies with its economic impacts on firms, when regulation stringent can pose more adjustment costs for firms. Therefore, policymakers should implement industry-specific regulations that consider the varying degree of environmental impact cause by different sectors. For example, Companies in industries like heavy manufacturing, fossil fuel, ore intensive agriculture, which contribute more substantial to environmental degradation should face tighter regulations and higher compliance standards.

5.3 Limitations

Naturally, every study has its limitations, and our study is no exception. First, we could only gather data from 49 countries during our research period, leading to imbalance in country representation, which might introduce bias into our results, as our sample predominantly comprises firms from developed nations, with only small proportion from developing economies. Second, while we mitigate endogeneity concerns through system GMM approach, future research could employ alternative econometric methods, such as a difference-in-differences (DiD) approach utilising exogenous shocks or two-stage least squares (2SLS) approach, to better control for potential selection bias and endogeneity. Third, we obtained data from empirical approach developed by Sautner et al. (2023) and Chen et al. (2024) for measure climate change. However, measuring firms' exposure climate change and the associated risks is inherently complex. The proxies we used may not fully capture the multifaceted impacts of climate change on firms, which may potentially lead to biases in assessing its extent. Finally, our study concentrates on the firm's management behaviour and policies regarding climate change. However, we have not considered national or social norm such as culture and societal trust, which can also influence firms' management behaviour of cash holdings. Therefore, upcoming research could examine those factors when investigate the cash holdings.

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Appendix A. Variable definitions

Variable	Description	Sources
Climate change exposure (CCE)	The relative frequency of bigrams associated with climate change appearing in earnings conference call transcripts.	Constructed by Sautner et al. (2023)
Climate change risk (CCR)	The relative frequency of bigrams related to climate change that co-occur with the term's "risk" or "uncertainty" (or their synonyms) within the same sentence in earnings conference call transcripts.	As above
Deviation from target Cash (DevCash)	The deviation from the target, defined as the gap between actual cash holdings and the target cash holdings level.	Seft-calculated as suggested in Ozkan and Ozkan (2004)
Cash/TA	The ratio of cash and cash equivalents to total assets.	Compustat Global database
Cash/NA	The ratio of cash and cash equivalents to net assets, where net assets are defined as total assets minus total liabilities.	As above
Size	The natural logarithm of total assets, normalised by the book value of total assets.	As above
Tobin's Q	The ratio of enterprise value, calculated as (book value of total assets minus book value of equity plus market value of equity), to the book value of total assets.	As above
Industry CF risk (Industry)	The industry-level cash flow volatility, measured as the mean of the standard deviation of cash flow scaled by total assets over a 4-year period for firms within the same industry, as categorised by the two-digit SIC code.	As above
CFO	The ratio of earnings before depreciation, but after interest, dividends, and taxes, to the book value of total assets.	As above
NWC	The ratio of net working capital, excluding cash and equivalents, to the book value of total assets.	As above
CapEx	The ratio of capital expenditures to the book value of total assets.	As above
Leverage	The ratio of total debt to the book value of total assets.	As above
R&D	The ratio of research and development (R&D) expenditures to the book value of total assets.	As above
Dividend	A binary variable set to 1 if the firm paid a common dividend during the year, and 0 if it did not.	As above
Acquisition	A binary variable set to 1 if the firm undertook an acquisition during the year, and 0 otherwise.	As above
Age	The firm's age, measured as the number of years since the commencement of its operations.	As above
Inflation	The consumer price index (CPI), representing the annual percentage change in the cost to the average consumer of acquiring a standard basket of goods and services.	World Bank's World Development Indicators
GDP Growth	The natural logarithm of a country's gross domestic product (GDP) per capita.	As above
Corruption	The level of corruption, defined as the extent to which public power is exploited for private gain, encompassing both minor and major forms of corruption, as well as the undue influence or "capture" of the state by elites and private interests.	World Bank Worldwide Governance Indicators database.
High Financial Constraint	Firms are classified as having high financial constraints if they fall within the top tercile of the index, and as having low financial constraints if they fall within the bottom tercile.	Self-calculated following The Whited-Wu index (Whited & Wu, 2006)
High Stringent	Firms in the top tercile of the EPS index are classified as highly stringent, while firms in the bottom tercile are classified as having low stringency.	OECD website