



Firm Determinants and Consequences of the Voluntary Adoption of Task Force on Climate-Related Financial Disclosures

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Declaration of Authenticity

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Signed: Ola Abdelhamid

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Abstract

This PhD thesis, comprising three empirical chapters, examines the firm determinants and consequences of the Task Force on Climate-related Financial Disclosures (TCFD) compliance. Specifically, this thesis examines whether TCFD compliance is associated with improvements in corporate investment efficiency and investigates the association between environmental expertise, CEO characteristics, and TCFD compliance, using a global sample over the period 2017–2021.

Despite the growing body of research on TCFD reporting, the existing literature primarily concentrates on documenting the extent of firms' compliance without empirically examining the determinants of compliance. Moreover, limited attention has been directed toward examining the economic implications of TCFD compliance, particularly its influence on firms' investment efficiency. Furthermore, little is known about the internal governance mechanisms that influence firms' TCFD compliance (e.g., CEO power, environmental board committees). Therefore, the first empirical chapter examines the association between TCFD compliance and corporate investment efficiency. The second empirical chapter investigates the association between CEO power, CEO climate support and TCFD compliance. The third empirical chapter investigates the associations between environmental board committee presence, directors' environmental expertise, and TCFD compliance.

The first chapter's findings demonstrate that TCFD compliance is associated with improved investment efficiency. This result suggests that climate-related disclosure enhances information transparency and reduces information asymmetry between firms and investors. By providing clearer insights into climate risks and strategic responses, TCFD reporting appears to support more efficient capital allocation decisions and mitigate both overinvestment and underinvestment problems. The results also indicate that TCFD reporting contributes to improved financial stability through increased liquidity. This finding implies that climate-related transparency reduces uncertainty surrounding firms' exposure to climate risks, thereby improving market confidence.

Further, the findings of the second chapter show that CEO power plays a complex role in shaping climate disclosure practices. While higher CEO power reduces the likelihood of TCFD compliance, it is associated with higher reporting quality among firms that do comply. This finding suggests that powerful CEOs may exercise discretion in deciding whether to engage with voluntary climate disclosure frameworks and exert greater control over the credibility and

strategic framing of the information released. As such, CEO power may both constrain disclosure incentives and influence the depth and quality of reporting. Additionally, CEO climate support is positively associated with TCFD compliance, but does not fully mitigate the negative influence of CEO power on disclosure decisions. This finding highlights the persistence of managerial judgment in climate reporting and suggests that personal support for climate initiatives may encourage disclosure but cannot fully mitigate the effects of CEO power in decision-making.

Finally, the third chapter demonstrates that corporate governance mechanisms also play a critical role in strengthening climate disclosure practices. The presence of environmental committees and board-level environmental expertise significantly enhances the likelihood of TCFD compliance. However, only environmental expertise appears to mitigate the negative effect of CEO power on disclosure decisions. This finding suggests that specialised knowledge within the board is essential for challenging managerial influence and effectively promoting climate transparency. Finally, the association between TCFD compliance and investment efficiency is particularly strong in firms with environmental governance structures.

Overall, the findings of this thesis underscore the importance of regulatory frameworks and corporate governance mechanisms in shaping firms' climate reporting behaviour and its economic consequences. Stronger regulatory environments, effective board oversight, and environmental expertise appear to play a critical role in limiting managerial discretion and enhancing the effectiveness of climate disclosure practices. These insights offer valuable guidance for regulators and policymakers aiming to enhance climate disclosure reforms and encourage more sustainable corporate governance practices.

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Chapter One Introduction

1.1 Thesis Background

In recent decades, the accelerating impacts of climate change have established it as one of the most paramount global challenges, more likely due to climate events such as storms, influenced by the continual increase in atmospheric carbon levels (IPCC, 2021). This escalation has intensified environmental degradation and created substantial socio-economic risks across countries and industries (Sun et al., 2020; Kahn et al., 2021). At the same time, shifts in precipitation patterns have led to more frequent and severe extreme weather events, including droughts and floods, which undermine ecological stability and agricultural output (Dai, 2013). These environmental disruptions increasingly translate into significant economic and financial consequences (Friedrich et al., 2023; Sautner et al., 2023). Both the physical impacts of climate change and transition-related risks, including regulatory, market, and reputational pressures associated with the shift toward a low-carbon economy, can materially affect firms' asset values, cash flows, and long-term business models (Ilhan et al., 2023; Bose et al., 2025). The scale of these impacts is substantial; for instance, the United Nations Environment Programme (2023) estimates that climate-related disasters caused global losses and damages of at least USD 2.8 trillion between 2000 and 2019, equivalent to roughly USD 16 million per hour.

Accordingly, the World Economic Forum ranks climate-related threats among the most significant global risks expected over the coming decade, particularly extreme weather events and critical changes to earth systems (McLennan, 2022). Additionally, investors and other stakeholders have become increasingly concerned about how climate-related risks and opportunities may influence firms' performance, financial stability, and strategic decision-making. This heightened awareness has strengthened calls for stronger climate action and greater transparency regarding corporate exposure to climate-related risks (Ngo et al., 2022). In response, several international initiatives have been introduced to guide global climate policy. Early initiatives, such as the Kyoto Protocol (1997), followed by the adoption of the Sustainable Development Goals, particularly goal 13 and the United Nations Sustainable Development Summit in 2015, reflect a collective commitment to address climate change and promote sustainable development (UN, 2015). While these frameworks aim to encourage the

transition toward a low-carbon and environmentally sustainable economy, they primarily emphasise broad sustainability practices and environmental reporting. At the same time, widely used sustainability reporting frameworks, including the Carbon Disclosure Project (CDP) and the Global Reporting Initiative (GRI), largely focus on firms' environmental and social impacts. Although these frameworks enhance transparency regarding sustainability performance, they provide comparatively limited insight into the financial implications of climate-related risks and opportunities for firms' future cash flows, asset values, and financial stability. As a result, they provide limited guidance on integrating climate-related risks and opportunities into conventional financial reporting systems. This shortcoming has sparked concerns among investors and regulators regarding the sufficiency of existing disclosures for appraising climate-related financial risks (Ngo et al., 2022). Consequently, the lack of an internationally standardised framework for climate-related financial disclosure has diminished transparency and comparability among firms. Such inconsistencies in corporate reporting may lead to asset mispricing and inefficient capital allocation (Ilhan et al., 2023), underscoring the growing need for more structured and comparable climate-related disclosures (TCFD, 2017).

To address these concerns, the Financial Stability Board (FSB), an international body that monitors and makes recommendations to promote global financial stability, established the Task Force on Climate-related Financial Disclosures (TCFD) in 2015 (TCFD, 2017). The primary objective of the TCFD was to develop a voluntary and consistent framework for climate-related financial disclosure that provides useful information to investors, lenders, and insurers. According to the FSB, the framework seeks to improve the quality of climate-related information available to market participants and to support more informed investment and risk management decisions (FSB, 2015). The TCFD recommendations focus on four key areas: governance, strategy, risk management, and metrics and targets, and are designed to apply across industries and jurisdictions (TCFD, 2017). Importantly, this framework emphasises the financial implications of climate-related risks and opportunities, rather than focusing solely on firms' environmental impacts. Accordingly, the TCFD is widely considered a leading framework for climate-related corporate disclosure, particularly in comparison to earlier sustainability-focused frameworks such as the CDP and the GRI, which primarily emphasise environmental and social impacts rather than the financial implications of climate-related risks (Lombardi et al., 2022; Gebhardt et al., 2024). Greater availability of high-quality climate-related information may help investors and other stakeholders better understand firms'

exposure to climate risks and opportunities and improve firms' internal decision-making (Demaria & Rigot, 2021).

Following its establishment, the TCFD released its initial report (Phase I) in 2016, outlining the framework's scope, objectives, and strategic direction, as well as identifying gaps in existing climate-related reporting practices. The introduction of the TCFD framework has increased awareness among firms and investors of climate change as a financially material risk (KPMG, 2020). Consequently, climate-related disclosure has attracted growing attention in academic research and is increasingly recognised as an important mechanism through which firms respond to climate-related challenges (Demaria & Rigot, 2021; O'Dwyer & Unerman, 2020). However, an important debate remains regarding whether corporate climate reporting represents symbolic compliance or substantive organisational change (Ding et al., 2023). Symbolic disclosure involves communicating environmental responsibility primarily to maintain legitimacy without meaningful operational changes, whereas substantive disclosure reflects the integration of climate considerations into firms' strategies and decision-making processes (Rodrigue et al., 2013). While climate reporting may signal firms' environmental commitment and enhance investor confidence (Demaria & Rigot, 2021), prior research also finds that firms provide extensive environmental disclosure without corresponding improvements in environmental performance, a practice often referred to as greenwashing (Aragón-Correa et al., 2016; Li & Liu, 2025). This divergence raises important questions about whether climate disclosure frameworks lead to genuine corporate change, such as enhancing corporate investment behaviour.

Furthermore, despite growing global support, compliance with the TCFD framework remains voluntary and varies significantly across firms and countries (O'Dwyer & Unerman, 2020). Prior research suggests that voluntary sustainability disclosures often involve managerial discretion and selective reporting, which may limit their effectiveness in improving transparency (Christensen et al., 2021). In this context, managerial incentives and leadership characteristics may play an important role in shaping firms' disclosure decisions. Powerful executives may avoid extensive disclosure to limit external scrutiny of firms' climate-related risks and strategic responses (Bose et al., 2025). Consistent with managerial power theory, powerful CEOs may resist disclosures that constrain managerial discretion or increase accountability (Bebchuk et al., 2011; Sheikh, 2019). Despite the growing literature on climate disclosure, empirical research has paid limited attention to how internal governance,

particularly CEO power, influences firms' compliance with climate-related reporting frameworks such as the TCFD. Given the CEO's pivotal role in strategic decision-making and disclosure policies, understanding the association between CEO power and firms' engagement with climate reporting frameworks represents an important research question.

Finally, boards of directors play a key role in monitoring managerial behaviour, aligning managerial incentives with stakeholder interests, and enhancing reporting transparency (Jizi, 2017). Prior studies highlight the importance of board governance in shaping environmental disclosure and sustainability strategies (Al-Shaer & Zaman, 2018; Peters & Romi, 2015). However, existing research has mainly focused on general board characteristics such as independence, diversity, and board size. Compared with other governance structures, less attention has been paid to specialised governance structures, such as board-level environmental committees and directors' environmental expertise, which may more directly oversee climate-related risks and disclosure practices (Ngo et al., 2022).

Taken together, these debates highlight several gaps regarding the firm consequences of TCFD compliance, the role of managerial power in shaping voluntary climate reporting, and the governance mechanisms that influence firms' decisions to comply with the TCFD framework. The empirical studies in this thesis address these issues by examining whether TCFD compliance reflects substantive corporate behaviour, the association between CEO power and firms' compliance with TCFD-aligned disclosure, and how governance structures affect firms' climate-related decision-making.

1.2 Thesis Motivation

Several key motivations underpin this thesis. First, emerging evidence on TCFD compliance suggests that firms' engagement with the framework varies considerably across industries and organisational characteristics (Demaria & Rigot, 2021; Lombardi et al., 2022). While some studies document improvements in climate-related transparency following the introduction of the TCFD recommendations, the depth and quality of disclosure remain uneven across firms (Eccles & Krzus, 2017; Maji & Kalita, 2022; Amar et al., 2022). This variation is also evident across countries, with leading economies such as the United Kingdom and Germany demonstrating more advanced disclosure practices than follower countries, reflecting differences in institutional support and implementation (TCFD, 2020).

However, existing empirical evidence remains limited in several important respects. Much of the prior research focuses on single-country or single-industry settings (Demaria & Rigot, 2021; Maji & Kalita, 2022). This restricts our understanding of how firms' engagement with TCFD varies across different institutional environments. In addition, some studies examine TCFD adoption at an aggregate level without assessing the detailed implementation of specific disclosure recommendations. Moreover, limited attention has been paid to organisational and governance factors that may shape firms' engagement with climate-related reporting frameworks. Consequently, further research is needed to develop a more comprehensive understanding of the determinants of TCFD reporting across firms.

Second, despite growing interest in climate-related disclosure, empirical evidence on its consequences remains limited. Specifically, little is known about whether voluntary TCFD compliance is associated with firms' investment efficiency, particularly in terms of reducing investment misallocation, such as overinvestment or underinvestment. This issue is important because corporate investment efficiency plays a fundamental role in capital allocation and long-term firm performance. If climate-related disclosures enhance transparency and reduce information asymmetry, they may improve investment efficiency; however, if such disclosures are symbolic, their economic impact may be limited. Furthermore, the voluntary nature of climate disclosure suggests that internal governance mechanisms may play a critical role in shaping firms' reporting decisions. Managerial characteristics, particularly CEO power, may influence both the extent and credibility of disclosure. At the same time, board-level governance structures, such as environmental board committees and directors' environmental expertise, may strengthen oversight and encourage more substantive engagement with climate reporting.

Taken together, these considerations highlight the need for research that examines climate-related financial disclosure from both economic and governance perspectives. Accordingly, this thesis investigates whether TCFD reporting is associated with corporate investment efficiency. Further, it examines the association between CEO power, board-level environmental governance mechanisms, and firms' voluntary compliance with TCFD. Through three interconnected empirical studies, the thesis aims to provide new insights into the economic consequences and internal governance drivers of voluntary climate-related financial disclosure.

1.3 Theoretical Framework of TCFD

The TCFD framework provides a structured approach for firms to disclose climate-related financial risks and opportunities. The framework is organised around four interrelated pillars that guide firms in communicating climate-related information to investors and other stakeholders (TCFD, 2017). The governance pillar focuses on the roles of boards of directors and senior management in overseeing climate-related risks and opportunities. The strategy pillar examines how climate-related risks and opportunities affect firms' business models, strategic planning, and long-term financial performance. The risk management pillar addresses the processes firms use to identify, assess, and manage climate-related risks within their broader risk management systems. Finally, the metrics and targets pillar requires firms to disclose the indicators and performance measures used to monitor climate-related risks and track progress toward climate-related objectives.

In practice, measuring TCFD compliance involves a two-stage process. In the first stage, SEC filings, annual reports, and sustainability reports for each firm-year observation during 2017-2021 were manually reviewed to determine whether firms explicitly stated their adoption of, or alignment with, the TCFD framework. Only firms that explicitly referenced TCFD recommendations in their publicly available disclosures were classified as adopters, and firms that did not make such an explicit statement received a score of zero, reflecting genuine voluntary non-adoption rather than a reporting failure. During the 2017-2021 voluntary period, non-adopting firms were not required to explain their non-compliance, meaning the absence of TCFD disclosure represents a genuine managerial choice. In the second stage, for firms identified as TCFD adopters, their annual reports, standalone sustainability reports, and dedicated TCFD reports were evaluated against the 38-item Climate Compliance Index (CCI) developed by Demaria and Rigot (2021) to measure the depth and comprehensiveness of their climate-related disclosures. Each item was scored as 1 if the relevant information was disclosed and 0 otherwise, producing a continuous score ranging from 0 to 1. Among the 468 complying firm-year observations, the mean TCFD compliance score is 0.68, indicating that complying firms disclose approximately 68% of the 38 TCFD items on average, providing an early indication of the quality of reporting that is examined in greater detail in subsequent chapters

Beyond its practical reporting guidance, the TCFD framework also reflects broader developments in global sustainability reporting. In particular, the introduction of the

International Sustainability Standards Board (ISSB) Standard IFRS S2 climate-related Disclosures represents an important step toward harmonising climate-related reporting. IFRS S2 builds directly on the structure and recommendations of the TCFD framework while expanding disclosure requirements to enhance comparability and decision-usefulness for investors (IFRS, 2024). As many firms started to align their climate reporting practices with TCFD recommendations, understanding TCFD compliance provides important insights into firms' preparedness for emerging mandatory climate disclosure regimes (TCFD, 2017; Ding et al., 2023).

The increasing integration of the TCFD framework into global sustainability standards further strengthens its relevance for both practice and research. In 2023, the IFRS Foundation announced that the monitoring of TCFD implementation would transition from the FSB to the IFRS Foundation, with the ISSB incorporating TCFD principles into its climate-related disclosure standard. This development establishes a global baseline for climate-related financial reporting and reinforces the central role of TCFD recommendations in shaping the future of corporate climate disclosure (TCFD, 2023; IFRS, 2024).

Several theoretical perspectives provide useful insights into firms' engagement with climate-related financial disclosure frameworks such as the TCFD. From the perspective of voluntary disclosure theory, firms may choose to disclose climate-related information to reduce information asymmetry between managers and investors and to provide decision-useful information regarding their exposure to climate-related risks and opportunities (Verrecchia, 1983; Healy & Palepu, 2001). Voluntary disclosure theory is particularly well suited to this thesis because it explains firms' self-selection into disclosure when the benefits of transparency outweigh the proprietary costs of revealing strategic information (Verrecchia, 1983). This makes it the most relevant theoretical lens for examining TCFD compliance during 2017-2021, when no country mandated adherence to the framework (Healy & Palepu, 2001). Specifically, voluntary disclosure theory predicts that firms that comply with TCFD recommendations will experience a reduction in information asymmetry between managers and capital providers, improving investors' ability to assess firms' exposure to climate-related risks and facilitating more efficient capital allocation decisions (Biddle et al., 2009). This prediction directly motivates the first research paper, which examines whether voluntary TCFD compliance reduces information asymmetry and improves corporate investment efficiency.

However, legitimacy theory suggests that firms may comply with climate reporting practices primarily to maintain legitimacy and respond to external stakeholder pressure, potentially leading to symbolic disclosure rather than substantive organisational change (Suchman, 1995; Deegan, 2002). Accordingly, legitimacy theory is selected because it provides the most direct theoretical explanation for the symbolic versus substantive compliance debate central to this thesis, predicting that firms may comply with TCFD to satisfy external stakeholder expectations rather than to generate genuine transparency (Suchman, 1995; Cho & Patten, 2007). This theory is particularly relevant to examining the association between TCFD compliance and corporate investment efficiency, distinguishing substantive compliance from symbolic compliance.

At the same time, signalling theory suggests that firms with stronger environmental performance may voluntarily disclose climate-related information to signal their commitment to sustainability and differentiate themselves from competitors (Spence, 1973). Signalling theory is selected because it explains the strategic motivation behind voluntary TCFD compliance; firms with superior climate risk management may use TCFD compliance as a credible signal to differentiate themselves from less environmentally committed competitors, thereby reducing adverse selection in capital markets (Spence, 1973). This theory is particularly appropriate because TCFD's comprehensive disclosure requirements represent the type of costly, verifiable signal that credibly differentiates committed firms from less transparent competitors (Connelly et al., 2011).

In addition to these disclosure-related perspectives, corporate governance theories provide important insights into the internal organisational factors that shape firms' reporting decisions. Agency theory emphasises the role of governance mechanisms in mitigating information asymmetry and monitoring managerial behaviour (Jensen & Meckling, 1976). Agency theory is selected because it directly predicts the main tension examined in chapters three and four, that self-interested managers may resist voluntary disclosure that increases external monitoring and constrains managerial discretion. This theory is preferred over stewardship theory (Davis et al., 1997), which assumes managers act in shareholders' interests, because the empirical evidence consistently documents that powerful CEOs reduce voluntary climate transparency, consistent with self-interested behaviour (Bose et al., 2025).

Managerial power theory extends this perspective by highlighting how powerful executives may specifically influence disclosure policies to preserve managerial discretion (Bebchuk et al., 2002). While agency theory provides the general governance monitoring framework, managerial power theory is additionally selected because it captures the specific concentration of authority within the CEO role, combining duality, tenure, and ownership, which creates structural barriers to voluntary TCFD compliance (Finkelstein, 1992). Further, upper echelons theory suggests that top executives' characteristics and values can shape strategic decisions, including sustainability disclosure (Hambrick & Mason, 1984). Thus, it provides a crucial theoretical explanation for how personal executive characteristics, beyond structural governance factors, influence voluntary climate disclosure decisions (Hambrick, 2007).

Finally, resource dependence theory emphasises the role of boards in providing expertise and external connections that may support firms' engagement with climate-related reporting frameworks (Pfeffer & Salancik, 1978). This thesis uses this theory because it best explains how board-level environmental governance structures enhance firms' capacity to implement complex disclosure frameworks, specifically through knowledge provision and access to external resources rather than monitoring alone (Pfeffer & Salancik, 1978; Hillman & Dalziel, 2003).

Hence, these complementary theoretical perspectives highlight the importance of both firm-level incentives and internal governance mechanisms in climate disclosure practices. Accordingly, this thesis adopts an integrated multi-theoretical framework to examine whether TCFD reporting is associated with firms' investment efficiency, the association between CEO power, CEO climate support and firms' voluntary compliance with TCFD, and whether board-level environmental governance mechanisms are associated with variation in firms' compliance with TCFD-aligned reporting.

1.4 Research Aims and Objectives

This thesis investigates the implications and internal governance determinants of climate-related financial disclosure within the TCFD framework. Given the voluntary nature of TCFD compliance during the sample period, firms may vary significantly in their engagement with climate-related reporting and in the credibility of their disclosures. This period precedes the

broad introduction of mandatory climate-related disclosure requirements in several jurisdictions, including the United Kingdom and the European Union, where TCFD-aligned reporting has been progressively incorporated into regulatory frameworks and sustainability reporting standards (IFRS, 2024). Accordingly, the overarching aim of this thesis is to examine both the firm-level consequences of voluntary TCFD reporting and the managerial and governance factors underlying firms' engagement in climate-related financial disclosure. To address this aim, the thesis develops three interrelated research objectives that are examined through three empirical studies.

The first objective is to examine the consequences of voluntary TCFD reporting by investigating its association with corporate investment efficiency. This study assesses whether firms that comply with TCFD-aligned disclosure improve investment efficiency, providing evidence on whether TCFD compliance reduces investment inefficiencies, such as overinvestment and underinvestment, or whether such reporting is primarily symbolic. By focusing on firms' investment behaviour, the study provides insight into whether climate-related financial disclosure has meaningful implications for corporate decision-making and capital allocation.

The second objective is to investigate the organisational determinants of TCFD compliance, with a particular focus on the role of CEO power. Drawing on managerial power and upper echelons perspectives, this study examines whether powerful CEOs and CEO climate support are associated with firms' likelihood of compliance with TCFD-aligned reporting. The analysis provides insights into how managerial authority and leadership characteristics shape firms' engagement with voluntary climate disclosure frameworks.

The third objective is to examine the role of corporate governance mechanisms in firms' climate disclosure practices and associated economic outcomes. Specifically, this study investigates whether board-level environmental governance structures, including environmental board committees and directors' environmental expertise, are associated with firms' compliance with TCFD reporting and with variation in the relationship between climate disclosure and corporate investment decisions.

Accordingly, these three studies provide a comprehensive examination of climate-related financial disclosure from both economic and governance perspectives. By integrating insights from voluntary disclosure theory, managerial power theory, upper echelons theory, and resource dependence theory, this thesis contributes to the growing literature on climate-related

financial reporting by providing new evidence on the firm-level outcomes associated with TCFD reporting and the managerial and governance factors associated with firms' engagement with climate disclosure.

1.5 Thesis Questions and Findings

To address the research objectives outlined above, this thesis examines the following research questions.

1.5.1 Is the voluntary compliance with the TCFD framework associated with corporate investment efficiency?

This question is addressed in Chapter 2, which investigates the association between TCFD compliance and firm-level investment efficiency, with a particular focus on overinvestment and underinvestment. The findings provide robust evidence that TCFD compliance enhances corporate investment efficiency. Specifically, TCFD compliance is associated with a significant reduction in overall investment inefficiency. Decomposing this association further reveals that firms complying with TCFD exhibit lower levels of both overinvestment and underinvestment, suggesting that climate-related financial disclosure improves the quality of managerial investment decisions and mitigates inefficient capital allocation. To further examine the underlying mechanism, the study employs the bid–ask spread as a proxy for stock liquidity. The results reveal a negative association between TCFD compliance and the bid–ask spread, indicating that firms complying with TCFD experience improved stock liquidity. This suggests that climate-related disclosure enhances the information environment by reducing information asymmetry.

In addition, this chapter examines the moderating role of institutional factors, particularly the stringency of climate policy across countries. The findings suggest that stronger climate policies reinforce the negative association between TCFD compliance and investment inefficiency, indicating that the effectiveness of climate disclosure is enhanced in more stringent regulatory environments. Finally, the yearly analysis reveals that the impact of TCFD compliance on investment efficiency becomes stronger over time, particularly in the later years of the sample period, as the framework gains wider adoption and legitimacy. Overall, these findings provide comprehensive evidence that TCFD compliance improves investment

efficiency by enhancing the information environment, supporting voluntary disclosure theory, and aligning with He et al. (2022).

1.5.2 What is the association between CEO power, CEO climate support, and firms' voluntary compliance with TCFD?

Chapter 3 addresses this question by examining the association between CEO power and TCFD compliance and whether CEO support for climate initiatives is associated with this relationship. The findings reveal a negative association between CEO power and voluntary compliance with the TCFD framework, suggesting that more powerful CEOs may be less inclined to engage in climate-related financial disclosure. This result is consistent with managerial power arguments, which suggest that entrenched executives may resist disclosure initiatives that increase transparency and external monitoring (Bebchuk et al., 2011; Sheikh, 2019). However, the role of CEO power in voluntary climate disclosure is not uniform: among complying firms, CEO power is positively associated with the quality of climate-related reporting. This suggests that once firms commit to climate-related reporting, powerful CEOs may use their influence to enhance the credibility, depth, and strategic integration of climate disclosures. This nuanced finding extends prior literature by showing that the influence of CEO power on disclosure depends on the stage of the reporting process examined.

Furthermore, the results indicate that CEO climate support is positively associated with TCFD compliance, highlighting the role of managerial values and environmental awareness in shaping firms' engagement with climate reporting. At the same time, the broader institutional context appears to influence these relationships. Specifically, stronger climate policy environments weaken the negative association between CEO power and TCFD compliance, suggesting that regulatory pressure can partially constrain managerial resistance to climate disclosure. Overall, these findings emphasise the joint importance of managerial characteristics and institutional environments in shaping firms' engagement with voluntary climate-related disclosure.

1.5.3 What is the association between the presence of environmental board governance mechanisms and firms' compliance with the TCFD framework?

Chapter 4 addresses this question by examining the association between environmental board committees, the presence of environmental expert directors, and voluntary TCFD compliance. This chapter also examines whether environmental governance is associated with variation in

the relationship between CEO power and TCFD compliance, and between TCFD compliance and investment efficiency. The findings indicate that both the establishment of environmental board committees and the presence of directors with climate-related expertise are positively associated with firms' voluntary compliance with the TCFD framework. This suggests that environmental expertise strengthens firms' capacity to engage with climate-related reporting and enhances the credibility of their disclosures, supporting the upper echelons theory. The results also indicate that the influence of environmental board committees is particularly pronounced in countries characterised by stronger climate policy frameworks, highlighting how supportive institutional environments can reinforce the effectiveness of internal governance mechanisms in promoting climate transparency.

The analysis further shows that the presence of directors with genuine environmental expertise helps mitigate the negative association between CEO power and TCFD compliance. This finding suggests that specialised expertise within the board can enhance oversight and reduce managerial resistance to climate-related disclosure. Finally, the evidence indicates that environmental board committees play a complementary role, strengthening the relationship between climate disclosure and corporate investment decisions. Overall, these findings highlight the importance of combining formal governance structures with relevant expertise to improve the effectiveness of climate-related disclosure and its economic implications.

1.6 Thesis Contributions

This thesis contributes to several strands of the emerging literature on climate-related financial disclosure. First, it contributes to the growing research on the implications of climate reporting (Di Marco et al., 2023; Ding et al., 2023) by examining whether disclosure aligned with the TCFD framework is associated with corporate behaviour. In particular, the thesis provides new evidence on the firm-level implications of TCFD compliance by showing that climate-related financial disclosure can improve corporate investment efficiency. Consistent with voluntary disclosure theory, the findings suggest that TCFD compliance enhances the information environment, reduces information asymmetry, and supports more efficient capital allocation. Collectively, the findings across the three studies provide evidence consistent with substantive rather than purely symbolic TCFD compliance, as climate disclosure improves investment efficiency and is shaped by genuine governance mechanisms.

Second, the thesis extends the literature on the determinants of climate disclosure by responding to calls for further research on the drivers of TCFD reporting (Ngo et al., 2022). Specifically, it provides evidence on how managerial characteristics and governance mechanisms are associated with firms' engagement with voluntary climate disclosure frameworks. The findings indicate that CEO power is negatively associated with firms' compliance with TCFD reporting. In contrast, CEO climate support and board-level environmental governance mechanisms are associated with greater climate transparency.

Third, this thesis contributes to the broader corporate governance literature by highlighting the importance of specialised governance structures in overseeing climate-related risks and disclosure practices. In particular, the findings show that environmental board committees and directors with environmental expertise enhance firms' compliance with TCFD reporting and strengthen the relationship between climate disclosure and corporate investment decisions. These results provide new insights into how internal governance mechanisms can support more credible and decision-useful climate reporting.

Finally, the thesis offers important implications for policymakers, regulators, and investors. By providing evidence on the economic outcomes associated with TCFD compliance and identifying the governance factors associated with its compliance, the findings offer insights into the role of voluntary climate reporting frameworks in enhancing transparency. These insights are particularly relevant in light of the growing global shift toward mandatory climate disclosure standards.

1.7 Thesis Structure

The remainder of this thesis is organised into four chapters.

Chapter 2 addresses the first research question by examining whether voluntary climate-related disclosure influences corporate behaviour. Specifically, the chapter investigates the association between the compliance with TCFD recommendations and corporate investment efficiency. The analysis evaluates whether TCFD-aligned disclosure improves firms' investment decisions by reducing both overinvestment and underinvestment.

Chapter 3 examines the firm-level determinants of voluntary climate disclosure, with a focus on managerial characteristics. In particular, the chapter investigates how CEO power and CEO support for climate initiatives influence firms' decisions to comply with TCFD-aligned reporting.

Chapter 4 further explores the firm-level determinants of voluntary climate disclosure by examining board-level governance mechanisms. It analyses whether environmental board committees and directors with environmental expertise are associated with firms' compliance with TCFD reporting and evaluates how environmental governance mechanisms are associated with the association between climate disclosure, CEO power, and corporate investment efficiency.

Chapter 5 concludes the thesis by summarising the main findings, highlighting the theoretical and practical contributions of the research, and discussing the implications for investors, regulators, and policymakers. The chapter also outlines the limitations of the study and proposes directions for future research.

Chapter Two

The Association between the Task Force on Climate-Related Financial Disclosures Compliance and Corporate Investment Efficiency

2.1 Introduction

Climate change has become an urgent global issue in recent years (Carney, 2015). Climate-related disasters, such as the 2018 California wildfires, which resulted in economic losses of approximately \$148.5 billion, have significantly impacted the global economy and investment strategies, heightening stakeholder scrutiny of corporate climate responses (Wang et al., 2021; Yu et al., 2022; Sautner et al., 2023). Consequently, in 2015, the Paris Agreement heightened global awareness of climate change and emphasised the urgent need for businesses to address it (UN, 2015). However, corporations' inconsistent and reluctant disclosure of climate-related risks and opportunities has led to asset mispricing and capital misallocation, creating a significant information gap between firms and their investors (Ilhan et al., 2023). In response, in 2015, the Financial Stability Board (FSB) proposed the TCFD as explicit guidelines for consistent, transparent, and comparable reporting of climate-related financial information (FSB, 2015).

According to the FSB, TCFD is “*a principle-based framework designed to encourage firms to voluntarily disclose climate-related information in response to investor needs and to support more informed investment decision-making*”. Hence, TCFD promotes corporate transparency by encouraging firms to report climate-related financial information across four main categories (TCFD, 2017)¹. While prior studies have explored the TCFD framework and its global impact (Demaria & Rigot, 2021; Bingler et al., 2022; Ding et al., 2023), the economic implications of TCFD compliance for corporate behaviour remain largely unexplored (Lombardi et al., 2022; Ngo et al., 2022). In particular, no prior study has directly examined whether voluntary TCFD compliance influences corporate investment efficiency, an economic

¹ The four pillars are: governance, strategy, risk management, and metrics and targets (TCFD, 2017).

outcome that goes beyond market reactions to capture changes in firms' capital allocation decisions. This gap is particularly important given that TCFD disclosure is intended to provide decision-useful information about climate-related risks and opportunities that may influence firms' strategic and financial decisions (TCFD, 2017). Accordingly, this chapter examines whether voluntary TCFD compliance is associated with improved corporate investment efficiency and specifically whether TCFD compliance is associated with reduced overinvestment and underinvestment.

Climate-related financial disclosure has increasingly attracted attention as an important mechanism for improving corporate transparency and supporting more informed investment decisions (David & Giordano, 2022). The TCFD framework seeks to enhance corporate transparency by encouraging firms to identify, assess, and disclose climate-related risks and opportunities, thereby reducing information uncertainty faced by investors and other stakeholders (TCFD, 2017). From an agency theory perspective, enhanced disclosure can reduce information asymmetry between managers and investors, strengthen external monitoring of managerial actions, and limit managers' incentives to pursue self-interested investment strategies (Biddle et al., 2009). Improved transparency may also enhance firms' reputations in capital markets, attract external investors, and ease financial constraints, ultimately supporting more efficient corporate investment decisions (Cook et al, 2019).

Using a sample of 2,225 firm-year observations of international firms listed on the New York Stock Exchange (NYSE) and Nasdaq from 36 countries during the period 2017–2021, this study finds that compliance with TCFD guidelines is associated with improved corporate investment efficiency. Specifically, firms that disclose climate-related information in line with the TCFD framework exhibit lower levels of both overinvestment and underinvestment. These findings suggest that TCFD compliance enhances corporate transparency regarding climate-related risks and opportunities, thereby improving the information environment surrounding firms' investment decisions. This interpretation is further supported by mediation analysis, which shows that firms complying with TCFD-aligned disclosures experience higher stock liquidity. Consistent with information asymmetry theory, greater transparency reduces adverse selection in capital markets, thereby improving stock liquidity (Diamond & Verrecchia, 1991). By providing more decision-useful information, TCFD reporting enables investors and stakeholders to evaluate firms' long-term risk exposures and strategic responses to climate change, thereby supporting more efficient capital allocation. These results are consistent with

voluntary disclosure theory, which posits that enhanced transparency reduces information asymmetry and strengthens external monitoring of managerial behaviour (Chen et al., 2022). The results are robust to several additional analyses, including alternative measures of investment inefficiency, controlling for ESG disclosure, and accounting for cross-country variation in climate policy stringency. The findings remain robust also after employing additional analyses to mitigate concerns related to endogeneity and selection bias, including the Heckman selection model, 2SLS, and PSM.

This paper contributes to several strands of the literature. First, it contributes to the growing body of research examining the implications of the TCFD for corporate behaviour (Bingler et al., 2022; Ngo et al., 2022; Ding et al., 2023). To the best of my knowledge, this study provides new evidence on the association between TCFD compliance and corporate investment efficiency. While prior studies primarily examine the impact of climate risk on firms' investment behaviour (Yu et al., 2022), this study provides new evidence on how TCFD-aligned disclosure may influence corporate investment decisions by improving transparency regarding climate-related risks and opportunities.

Second, this study contributes to the literature on the determinants of investment efficiency (Biddle et al., 2009; Chen et al., 2011; Lara et al., 2016; Benlemlih & Bitar, 2018). Prior research has identified information asymmetry and agency problems as key factors affecting firms' investment decisions. This study extends this literature by highlighting climate-related information uncertainty as an additional factor influencing investment efficiency. Specifically, the findings suggest that TCFD compliance can reduce uncertainty surrounding climate-related risks and opportunities, thereby improving the information environment and supporting more efficient corporate investment decisions.

Third, this study contributes to the ongoing debate regarding the effectiveness of voluntary environmental disclosure frameworks (Wright & Nyberg, 2017; He et al., 2022). While some studies argue that voluntary environmental regulations impose additional costs on firms, this study suggests that TCFD compliance may enhance corporate decision-making by improving transparency and investment efficiency. These findings provide useful insights for policymakers and regulators by highlighting the potential role of climate-related financial disclosure frameworks in improving corporate transparency and supporting more efficient capital allocation.

The remainder of this chapter is organised as follows: Section 2.2 covers the theoretical framework and presents the development of hypotheses. Section 2.3 introduces the research design and sample selection process. Section 2.4 presents the regression results and robustness tests. Finally, Section 2.5 concludes the main points covered in this chapter.

2.2 Theoretical Framework and Hypotheses Development

2.2.1 Literature Review: Investment Efficiency and Corporate Disclosure

Corporate investment is a crucial driver of a country's overall economic health, serving as a bridge to business growth, increased shareholder value, and economic development (Biddle et al., 2009). Thus, prior literature has examined corporate investment efficiency as an indicator of the effectiveness of firms' investment decisions (Benlemlih & Bitar, 2018; Liu & Tian, 2021). According to dynamic capability theory, efficient corporate investment reflects a firm's ability to utilise its dynamic capabilities to respond optimally to market changes and technological advancements (Teece et al., 1997). From a resource-usage perspective, Zadeh et al. (2021) and Yu et al. (2022) defined investment efficiency as the extent to which a firm allocates its resources across projects, ensuring that investments contribute positively to its value and prospects. Accordingly, investment efficiency reflects how well investment managers achieve corporate goals by comparing actual investment levels to their optimal levels. A positive deviation from expected investment reflects a tendency to allocate excessive resources to projects with limited or negative returns, often referred to as overinvestment (Zadeh et al., 2021). By contrast, a negative deviation from expected investment indicates insufficient allocation of resources to value-enhancing opportunities, commonly described as underinvestment (Benlemlih & Bitar, 2018; Zeng et al., 2019).

The concept of perfect capital markets, where firms invest in all positive Net Present Value (NPV) projects and return excess cash to investors, is no longer applicable in today's dynamic economic environment. Managers may misuse resources by either overinvesting in unprofitable projects or underinvesting despite profitable opportunities, leading to inefficient investment. Prior research suggests that overinvestment often arises from agency problems, such as managerial empire-building (Jensen, 1986; Ahmed & Duellman, 2013), short-term incentives (Chen et al., 2017), career concerns (Roychowdhury et al., 2019; Ferracuti et al., 2019), and managerial overconfidence (Naeem & Li, 2019; Ho et al., 2023). In contrast,

underinvestment typically occurs when firms face financial constraints, information uncertainty, or difficulty accessing external financing, limiting their ability to pursue profitable opportunities (Myers, 1977; Biddle et al., 2009; Naeem & Li, 2019). Overall, market frictions such as agency conflicts, information asymmetry, and uncertainty contribute to inefficient corporate investment and may lead managers to make decisions that deviate from shareholders' interests (Biddle et al., 2009; Cook et al., 2019). Furthermore, recent research argues that climate-related risks have emerged as an additional source of market friction affecting firms' investment decisions. For instance, Kim and Kim (2023) show that climate risk increases corporate investment inefficiency due to higher costs and financial constraints. Similarly, Feng et al. (2022) document a significant decline in corporate investment following climatic disasters, while Zhang et al. (2023) find that climate policy uncertainty reduces investment efficiency as firms become more cautious under heightened uncertainty. These findings highlight the importance of climate-related disclosure in helping firms and investors better identify and assess climate risks. Consequently, this study investigates whether TCFD compliance can improve corporate investment efficiency.

A substantial body of literature demonstrates that high-quality financial reporting improves investment efficiency by mitigating these information frictions. For instance, Biddle et al. (2009), Chen et al. (2011), and Chen et al. (2022) show that better financial reporting quality reduces both overinvestment and underinvestment by improving the information environment and facilitating monitoring of managerial decisions. Similarly, studies across different institutional settings confirm that transparent financial reporting enhances capital allocation by reducing information asymmetry and external financing costs (Shroff et al., 2013; Gomariz & Ballesta, 2014; Lara et al., 2016). Overall, these findings suggest that improved disclosure enables investors and stakeholders to evaluate firms' investment opportunities and managerial decisions more effectively, thereby promoting more efficient capital allocation. However, while these studies consistently highlight the importance of financial reporting, they primarily focus on traditional accounting disclosures and provide limited insight into the role of non-financial information.

In response, a growing stream of literature has examined the role of non-financial disclosure in shaping corporate outcomes. Non-financial reporting provides stakeholders with information about firms' environmental, social, and governance (ESG) activities, allowing them to assess broader aspects of corporate performance and risk exposure (Dhaliwal et al., 2011; Deloitte,

2021; Khediri, 2021). Within this literature, CSR disclosure has emerged as an important mechanism influencing corporate investment behaviour, improving monitoring, reducing agency conflicts, and alleviating financing constraints (Cook et al., 2019; Khediri, 2021). However, CSR measures are often broad and lack standardisation, which may limit their ability to capture specific disclosure dimensions relevant to investment decision-making. Empirical evidence further suggests that enhanced risk disclosure reduces information asymmetry and facilitates more informed investment decisions (Kravet & Muslu, 2013; Campbell et al., 2014).

Consistent with these arguments, prior research suggests that Environmental disclosure can improve investment efficiency by enhancing transparency and reducing information asymmetry (Lai et al., 2014; Flammer, 2015). By constraining managerial opportunism and enabling better investor evaluation of firms' sustainability and financial performance, greater disclosure supports improved capital allocation and reduces over or underinvestment. However, firms may resist voluntary environmental disclosure due to high short-term implementation costs with uncertain long-term benefits (O'Dwyer & Unerman, 2020). Additionally, coercive environmental regulations can negatively affect firm value by increasing managerial pressure (Johnston, 2005), and climate disclosure frameworks like TCFD present challenges due to uncertainty and complex scenario analyses required (Haigh, 2019).

Climate-related disclosures represent a particularly important category of non-financial reporting, as climate change introduces significant risks and opportunities for firms and investors. Prior studies suggest that voluntary climate disclosure can improve corporate reputation, attract environmentally conscious investors, and reduce potential regulatory and litigation risks (Jacobs, 2014; He et al., 2022). Moreover, firms with proactive climate strategies and transparent disclosure practices tend to attract greater attention from capital market participants (Choi & Luo, 2021). However, existing studies largely focus on market-based outcomes or firm performance, with limited attention to real corporate investment decisions.

Despite this growing literature, empirical evidence on the economic consequences of climate-related disclosures remains limited, particularly regarding corporate investment decisions. While some studies examine the relationship between climate disclosure and corporate risk management or financial performance (Kim et al., 2022), the effect of structured climate disclosure frameworks, such as the TCFD, on corporate investment efficiency has received

little attention. Further, unlike broader sustainability frameworks such as the CDP and GRI, which primarily emphasise firms' environmental and social impacts, the TCFD framework is explicitly structured around the financial materiality of climate-related risks, requiring firms to conduct scenario analysis and disclose the potential impact on future cash flows and asset values (TCFD, 2017; Lombardi et al., 2022). This financial materiality focus makes TCFD compliance particularly relevant for studying economic outcomes such as corporate investment efficiency. Accordingly, this study seeks to address this gap by examining whether compliance with the TCFD framework influences firms' investment efficiency.

2.2.2 Hypotheses Development: Investment Efficiency and TCFD

This section develops the study's hypotheses by reviewing prior research on non-financial disclosure and investment efficiency, with a specific focus on identifying overinvestment and underinvestment.

The TCFD framework aims to enhance the transparency and comparability of climate-related financial information (TCFD, 2017). By requiring firms to disclose governance structures, risk management processes, and strategic responses to climate-related risks, TCFD reporting may influence corporate investment decisions by improving the information environment surrounding firms' exposure to climate risks.

Several theoretical perspectives provide insights into the potential relationship between TCFD compliance and investment efficiency. From the perspective of voluntary disclosure theory, firms voluntarily provide additional information to reduce information asymmetry and attract investors (Waheed & Zhang, 2022). Legitimacy theory further suggests that firms adopt environmental reporting practices to maintain social legitimacy and strengthen their reputation among stakeholders (Suchman, 1995; Palea & Drogo, 2020; Velte, 2023). Through these mechanisms, enhanced climate-related disclosure can improve investors' ability to monitor managerial behaviour and evaluate firms' long-term risk exposures, thereby supporting more efficient corporate investment decisions.

TCFD compliance may improve investment efficiency through several mechanisms. First, enhanced transparency reduces uncertainty regarding firms' exposure to climate-related risks and regulatory developments, enabling investors to better assess firms' future prospects (Ilhan et al., 2023). Accordingly, TCFD reporting may strengthen managerial accountability by

increasing stakeholder monitoring of firms' climate-related strategies and investment decisions (TCFD, 2017; Deloitte, 2021). Second, by providing forward-looking information on climate risks and opportunities, TCFD reporting can reduce information asymmetry between managers and external stakeholders, thereby improving capital allocation decisions (Khurana et al., 2018). Third, improved disclosure may enhance firms' access to external financing by strengthening investor confidence and corporate reputation, which can alleviate financing constraints and reduce both overinvestment and underinvestment (He et al., 2022; Maji & Kalita, 2022).

Finally, TCFD compliance may improve investment efficiency through an additional organisational learning channel. Chen et al. (2023) show that stricter disclosure requirements generate organisational learning benefits as firms exposed to structured disclosure obligations develop improved internal processes for identifying, assessing, and managing complex risks. Applied to the TCFD context, voluntary structured climate disclosure may prompt firms to develop more systematic internal processes for evaluating climate-related risks and opportunities. Furthermore, complying with TCFD's four pillars requires firms to conduct scenario analysis, quantify climate-related financial impacts, and integrate climate considerations into strategic planning (TCFD, 2017). This internal discipline may improve managers' ability to identify and respond to climate-related investment opportunities and risks, reducing both overinvestment in firms facing transition risk and underinvestment in climate-resilient opportunities.

However, alternative perspectives suggest that the effects of climate-related disclosure may not be uniformly positive. Agency theory argues that managers may use environmental disclosure strategically to enhance their reputation or divert attention from inefficient investment decisions (Barnea & Rubin, 2010). In this context, disclosure may serve as a symbolic or window-dressing mechanism rather than reflecting substantive changes in corporate behaviour (Liu & Tian, 2021). Moreover, implementing climate-related reporting frameworks may impose additional reporting costs and managerial constraints that could affect firms' investment decisions (Gao, 2010; Hermalin & Weisbach, 2012).

Despite these concerns, the overall theoretical arguments suggest that structured climate disclosure frameworks such as the TCFD are more likely to improve the corporate information environment and strengthen external monitoring. Therefore, the following hypothesis is proposed:

H1: There is a positive association between TCFD compliance and corporate investment efficiency.

Overinvestment occurs when firms commit resources to projects with negative net present value, often driven by agency problems between managers and shareholders (Roychowdhury et al., 2019). According to agency theory, the separation of ownership and control allows managers greater discretion over corporate investment decisions, which may encourage them to pursue projects that maximise their private benefits rather than shareholder value (Jensen, 1986). Prior research suggests that managerial overinvestment may arise from several motives, including empire-building behaviour, career concerns, short-term performance incentives, and managerial overconfidence (Roychowdhury et al., 2019; Ferracuti et al., 2019; Naeem & Li, 2019).

The role of non-financial disclosure in mitigating overinvestment remains theoretically ambiguous. On the one hand, disclosure may exacerbate agency problems. From a legitimacy perspective, managers may use sustainability reporting strategically to enhance corporate reputation without necessarily improving underlying practices (Suchman, 1995). In this context, disclosure may serve as a tool to justify inefficient investment decisions that provide private benefits. For example, Moussu and Ohana (2016) show that managers may engage in CSR activities to increase personal prestige or compensation, even when such investments do not maximise shareholder value. Similarly, environmental disclosure may function as a greenwashing mechanism, allowing managers to legitimise inefficient investment strategies while maintaining a favourable corporate image (Li et al., 2023). Extending this argument, TCFD compliance could be used strategically to justify excessive investments framed as climate-related initiatives.

On the other hand, a substantial body of literature suggests that enhanced disclosure improves external monitoring and reduces agency problems. Voluntary disclosure theory posits that firms provide additional information to reduce information asymmetry and improve transparency in corporate decision-making (Chen et al., 2022). Increased transparency enables investors and analysts to better evaluate managerial actions and constrain opportunistic behaviour, thereby improving investment efficiency (Chen et al., 2011; Benlemlih & Bitar, 2018). In particular, non-financial disclosure can enhance the information environment by reducing earnings management and improving analyst forecasts, which strengthens market-based monitoring (Hope & Thomas, 2008; Dhaliwal et al., 2012; Ward et al., 2019). In this

context, complying with TCFD recommendations provides a structured, standardised framework for reporting on climate-related risks, governance, and strategic responses. Compared to less standardised forms of ESG or CSR disclosure, TCFD reporting may enhance transparency and comparability, enabling investors to better assess firms' climate-related strategies and associated investment decisions. As a result, improved climate disclosure may reduce managerial discretion and constrain overinvestment.

However, some studies suggest that disclosure does not necessarily translate into improved investment outcomes. For instance, Chen et al. (2022) argue that disclosure may reflect underlying corporate strategy rather than directly influencing managerial behaviour. Similarly, Zamir et al. (2020) find that non-financial disclosure may affect firms' cost of capital but does not necessarily constrain entrenched managerial incentives.

Given these competing theoretical arguments, the association between climate-related financial disclosure and overinvestment remains an empirical question. Accordingly, the following hypothesis is proposed:

H2: TCFD compliance is negatively associated with corporate overinvestment.

With respect to the underinvestment hypothesis, it typically arises when firms forgo value-enhancing investment opportunities due to financing constraints, which are often driven by information asymmetry between firms and external capital providers (Jensen & Meckling, 1976; Jensen, 1986; Biddle et al., 2009). When investors cannot accurately assess the profitability and risk of corporate investment projects, they may demand higher returns or restrict the supply of capital, thereby limiting firms' access to external financing and leading to suboptimal investment levels.

From this perspective, enhanced corporate disclosure can play an important role in mitigating underinvestment by improving the information environment and strengthening investor confidence. Consistent with voluntary disclosure theory, firms may disclose additional information to reduce information asymmetry and improve market transparency (Shroff et al., 2013). In particular, climate-related disclosure frameworks such as the TCFD provide more comprehensive and standardised information regarding firms' exposure to climate-related risks and opportunities. By improving transparency, such disclosures can facilitate access to external financing, reduce the cost of capital, and alleviate financing constraints.

Empirical evidence largely supports this view. Prior studies show that firms with stronger environmental disclosure benefit from improved access to capital markets and lower financing costs (El Ghouli et al., 2018; Liu et al., 2022). Similarly, voluntary non-financial disclosure has been found to reduce underinvestment, particularly among firms facing higher levels of information asymmetry (Zamir et al., 2020). From a signalling perspective, climate-related disclosure may further enhance investor confidence by signalling firms' environmental responsibility and risk management capabilities, thereby reducing perceived investment risk and encouraging capital provision.

However, alternative arguments suggest that the impact of climate-related disclosure on underinvestment may be more complex. Increased transparency regarding climate risks may heighten perceived uncertainty about future cash flows, potentially leading managers to adopt more conservative investment strategies. Consistent with this view, prior studies document reductions in investment following exposure to climate-related shocks (Alok et al., 2020; Feng et al., 2022). Moreover, the implementation of climate disclosure frameworks may impose reporting and compliance costs that divert resources from productive investment activities (Frankel et al., 2025). In addition, some evidence suggests that non-financial disclosure may be more effective in addressing overinvestment than underinvestment, particularly when financing constraints remain binding (Liu & Tian, 2021).

Given these competing theoretical arguments, the association between climate-related financial disclosure and underinvestment remains an empirical question. However, the predominant theoretical perspective suggests that enhanced transparency improves access to external financing and alleviates financing constraints. Accordingly, the following hypothesis is proposed:

H3: TCFD compliance is negatively associated with corporate underinvestment.

2.3 Research Design and Sample

This section describes the research design and data used in the empirical analysis. Section 2.3.1 presents the sample selection procedure and data sources. Section 2.3.2 explains how the key variables are measured, including investment inefficiency, TCFD compliance, and the control variables used in the empirical models.

2.3.1 Sample Selection

The sample of this study consists of international firms listed on the New York Stock Exchange (NYSE) and NASDAQ over the period 2017–2021. The sample is restricted to the period 2017–2021, during which TCFD compliance was voluntary. This voluntary setting provides an ideal context for examining whether climate-related disclosure improves corporate investment efficiency, as cross-sectional variation in compliance reflects firms' genuine disclosure incentives rather than mandatory compliance. Further, focusing on internationally listed firms enables this study to capture a globally diverse sample of companies operating across different institutional, regulatory, and economic environments. At the same time, restricting the sample to firms listed on major U.S. exchanges helps maintain a more consistent disclosure framework, thereby reducing cross-country reporting heterogeneity that could otherwise affect empirical analyses. To mitigate concerns that empirical inferences may be driven by the dominant presence of US firms, which represent a substantial share of the initial sample, this study excludes all US-domiciled firms from the analysis, following the approach of Liao et al. (2024). This research setting, therefore, provides an appropriate context to examine the economic consequences of voluntary climate-related disclosure practices, such as compliance with the TCFD, while still reflecting the global nature of climate-related corporate reporting. The detailed country-level distribution of the sample is presented in Appendix 2.D.

Consistent with prior literature (Cook et al., 2019; Liu et al., 2022), financial firms (SIC codes 6000–6999) are excluded from the sample because financial institutions operate under distinct regulatory frameworks and capital structures that may affect investment decisions. This exclusion helps improve the comparability of investment efficiency measures across firms. After applying these filters, the final sample comprises 2,225 firm-year observations across 10 industries from 36 countries for the period 2017–2021. The sample represents 516 firms and forms an unbalanced panel due to missing observations and variation in firms' listing histories.

Firm-level financial data used to construct the investment efficiency measures and control variables are obtained from the London Stock Exchange Group (LSEG) database (formerly Refinitiv). Data on TCFD compliance are manually collected from firms' annual reports, sustainability reports, and other publicly available disclosures to identify whether firms explicitly report in line with the TCFD recommendations. Table 2.1 presents the sample screening process, while Table 2.2 reports the distribution of the final sample according to TCFD compliance status, distinguishing between TCFD-complying firms and non-complying

firms. Figure 2.1 illustrates the yearly distribution of TCFD compliance over the sample period (See Appendix 2.C)

As shown in Table 2.1, the final sample comprises 2,225 firm-year observations over the period 2017–2021 after excluding financial firms (SIC codes 6000–6999) and observations with missing financial data. The reduction from the initial sample of 4,368 to the final sample of 2,225 firm-year observations reflects two main data requirements. First, the McNichols and Stubben (2008) investment efficiency model requires lagged financial data, specifically lagged sales growth and Tobin's Q, meaning firms must have at least two consecutive years of complete financial data prior to the observation year. Firms with insufficient time-series data, particularly newly listed firms and those with reporting gaps, are therefore excluded. Second, financial firms are excluded because their investment patterns and capital structure differ fundamentally from non-financial firms (Biddle et al., 2009; Benlemlih & Bitar, 2018).

Table 2.2 reports the sample distribution by TCFD compliance. Firms are classified as TCFD compliers when their Climate Compliance Index (CCI) score is greater than zero, indicating disclosure of at least one TCFD-related item. The results show that 447 firm-year observations (20% of the sample) are classified as TCFD compliers, representing 185 unique firms. In contrast, the majority of the sample, 1,778 observations (80%), corresponding to 331 unique firms, consists of non-complying firms. These statistics indicate that TCFD compliance remains relatively limited within the sample, reflecting the voluntary nature of climate-related disclosure during the study period. This finding is consistent with Demaria and Rigot (2021), who document relatively low levels of TCFD-related disclosure among firms.

Table 2.1 Sample Selection Process

This table reports the sample screening process used to construct the final dataset. The initial sample consists of firms listed on the NYSE and NASDAQ over the period 2017–2021. Consistent with prior literature, financial firms (SIC codes 6000–6999) are excluded because their regulatory environment and capital structure differ substantially from those of non-financial firms. Firm-year observations with missing financial information required to compute the study variables are also removed. After applying these filters, the final sample comprises 2,225 firm-year observations representing international firms listed on U.S. exchanges.

Sample Distribution	No. of Observations
Initial sample	4,368
Less: Financial firms	(587)
Less: Missing financial data	(1,556)
Final Sample	2,225

Table 2.2 Sample Classification According to TCFD Compliance

This table reports the distribution of firm-year observations and unique firms in the sample, classified by TCFD compliance over the period 2017–2021. Financial firms (SIC codes 6000–6999) are excluded. For classification purposes, firms are considered TCFD compliers if their CCI score is greater than zero, indicating that they disclose at least one TCFD-related item.

Sample Classification	No. of Observations	% (Obs.)	No. of firms
TCFD compliers	447	20%	185
Non-TCFD compliers	1,778	80%	331
Total	2,225	100	516

2.3.2 Variables and Model

2.3.2.1 Dependent Variable: Investment Inefficiency

Prior literature commonly measures investment efficiency indirectly by estimating the level of investment inefficiency, defined as the deviation of actual investment from the expected optimal investment level. Following prior studies (McNichols & Stubben, 2008; Biddle et al., 2009; Cook et al., 2019), investment inefficiency is measured by comparing the firm's actual investment with the predicted optimal investment derived from an investment model. The difference between these two values, represented by the residual term, captures the degree of investment inefficiency. Consistent with prior literature (McNichols & Stubben, 2008; Gomariz & Ballesta, 2014; Cook et al., 2019), this study estimates expected investment as a function of firms' growth opportunities and internal financing capacity. Growth opportunities are proxied by sales growth and Tobin's Q, while internal financing capacity is captured by cash flow from operations (CFO). The investment model is specified as follows:

$$Investment_{i,t} = \beta_0 + \beta_1 SalesGrowth_{i,t-1} + \beta_2 TobinsQ_{i,t-1} + \beta_3 CFO_{i,t} + YearFE + IndustryFE + CountryFE + \epsilon_{i,t} \quad (2.1)$$

where Investment represents the ratio of the net increase in tangible and intangible assets to lagged total assets (Biddle et al., 2009; Gomariz & Ballesta, 2014). Sales growth is measured as the annual sales growth rate for firm i in year $t-1$. Tobin's Q captures the firm's market valuation and is calculated as the market value of equity plus total assets minus common equity, scaled by total assets (Cook et al., 2019; Al-Hiyari et al., 2023). CFO represents net cash flow from operating activities scaled by total assets (McNichols & Stubben, 2008). The industry, country, and year fixed effects are included to control for unobservable heterogeneity across industries, institutional environments, and time.

Investment inefficiency is measured using the absolute value of the residuals obtained from the investment model. Larger absolute residuals indicate a greater deviation from the predicted optimal investment level and therefore reflect higher investment inefficiency. In addition, the residuals can be used to distinguish between overinvestment and underinvestment. Positive residuals indicate that firms invest more than the predicted optimal level, suggesting

overinvestment. Conversely, negative residuals indicate that firms invest less than the predicted level, reflecting underinvestment (McNichols & Stubben, 2008; Biddle et al., 2009).

2.3.2.2 Independent Variable: TCFD

To measure firms' compliance with climate-related financial disclosures, this study employs the Climate Compliance Index (CCI) developed by Demaria and Rigot (2021), consistent with the approach adopted by Di Marco et al. (2023). The CCI is a comprehensive disclosure index composed of 38 items that captures the extent to which firms report information aligned with the four core pillars of the TCFD framework: governance, strategy, risk management, and metrics and targets. Each item evaluates whether firms provide relevant qualitative or quantitative disclosures in accordance with TCFD recommendations. For each firm-year observation, a disclosure score is computed by aggregating the number of disclosed items across the 38 indicators. The total score is then scaled by 38 to obtain a continuous index ranging from 0 to 1, where higher values indicate greater alignment with TCFD disclosure recommendations. Hence, this measure captures both the decision to comply with TCFD disclosure and the extent of reporting conditional on compliance, resulting in a hybrid variable. Firms that do not provide TCFD-aligned disclosures are assigned a value of 0, while firms that provide TCFD-aligned disclosures receive a value corresponding to their scaled CCI score.

The use of the CCI provides a comprehensive and comparable measure of climate-related disclosure across firms and countries, as it systematically captures multiple dimensions of TCFD reporting. However, consistent with prior studies, the index assigns equal weight to all disclosure items, which may not fully reflect differences in the relative importance of specific components. Appendix 2. F presents the detailed construction of the CCI used to measure TCFD compliance.

To ensure the reliability and validity of the TCFD compliance index, a structured validation process was implemented. First, a detailed coding protocol was developed based on the 38 disclosure items specified by Demaria and Rigot (2021), providing clear criteria for classifying each item as disclosed (1) or not disclosed (0). To assess inter-rater reliability, a random sample of 10% of firm-year observations was independently coded by a research assistant. Additionally, Cohen's Kappa statistic was calculated to measure agreement between the two researchers; the resulting value of 0.844 exceeds the commonly accepted threshold of 0.80 for

strong inter-rater reliability, indicating that the coding process is consistent and replicable (Cohen, 1960). The authors resolved differences between raters through discussion and reference to the original coding protocol. This validation process provides supporting evidence that the CCI captures a coherent and reliable measure of firms' compliance with TCFD recommendations.

2.3.2.3 Control Variables

Consistent with prior literature (Chen et al., 2011; Benlemlih & Bitar, 2018; Cook et al., 2019; Al-Hiyari et al., 2022), this study includes several firm-level control variables that may influence corporate investment efficiency. Specifically, the analysis controls for firm size, leverage, asset tangibility, cash holdings, market-to-book ratio, loss, and dividend payments.

Firm Size (Size) is measured as the natural logarithm of market capitalisation (Chen et al., 2023). Firm size is an important determinant of corporate investment decisions because larger firms typically have greater access to financial resources, more developed governance structures, and stronger information environments. These characteristics may improve managerial decision-making and enhance investment efficiency (Benlemlih & Bitar, 2018; Sun, 2016). Therefore, a positive association between firm size and investment efficiency is expected.

Leverage is measured as total debt divided by total assets (Phan et al., 2022; Ding et al., 2023). Leverage may influence investment efficiency through different channels. On one hand, debt can act as a governance mechanism by disciplining managers and reducing agency problems (Benlemlih & Bitar, 2018). On the other hand, highly leveraged firms may face financial constraints that limit their ability to undertake valuable investment opportunities, potentially leading to underinvestment (Cook et al., 2019). Accordingly, the expected sign of the coefficient on leverage is ambiguous, as these competing arguments suggest both positive and negative effects on investment efficiency. Consequently, the overall impact of leverage remains an empirical question.

Asset tangibility (Tangibility) is measured as the ratio of property, plant, and equipment (PPE) to total assets (Benlemlih & Bitar, 2018; Cook et al., 2019). Firms with higher tangible assets generally have greater collateral value, which improves their access to external financing and

supports more efficient investment decisions (Pawlina, 2010; Naeem & Li, 2019). Therefore, tangibility is expected to be positively associated with investment efficiency.

Cash ratio (Cash) is measured as cash and cash equivalents scaled by total assets (Benlemlih & Bitar, 2018). The availability of internal funds increases financial flexibility and allows firms to invest in profitable opportunities (Chen et al., 2011). However, higher cash holdings may also exacerbate agency problems, enabling managers to overinvest in low-return projects (Benlemlih & Bitar, 2018). Accordingly, the expected sign of the coefficient on the cash ratio is ambiguous, as these competing arguments suggest both positive and negative effects on investment efficiency.

Firm age (Age) is measured as the number of years since the firm was listed. Firm age is considered an important determinant of corporate investment decisions. Older firms are likely to possess greater industry experience, established relationships with market participants, and more stable operational structures, which may enhance managerial decision-making and lead to more efficient investment choices (Cook et al., 2019).

Loss is a dummy variable equal to 1 if a firm reports negative net income before extraordinary items and 0 otherwise (Chen et al., 2011; Benlemlih & Bitar, 2018). Firms experiencing losses may face financial constraints and difficulties accessing external financing, which can restrict investment opportunities and reduce investment efficiency. Therefore, a negative association between losses and investment efficiency is expected.

Dividend payment (Dividend) is a dummy variable equal to 1 if a firm pays dividends and 0 otherwise. Dividend payments may influence investment efficiency through their governance role. Paying dividends reduces free cash flow available to managers and may limit overinvestment in unprofitable projects (De Villiers et al., 2024). Therefore, dividend payments are expected to be positively associated with investment efficiency.

Appendix 2.A summarises the measurement definitions and data sources of all variables used in this study.

2.4 Empirical Results

This section presents the study's empirical findings. It begins with a univariate analysis that summarises the descriptive statistics of the main variables used in the analysis. It then reports the results of the multivariate regression analysis examining the association between TCFD recommendations compliance and investment inefficiency (H1). Finally, the section presents additional analyses that separately investigate the relationship between TCFD compliance and overinvestment and underinvestment scenarios (H2 and H3).

Table 2.3 reports the summary statistics of all current study variables. The results for investment inefficiency (Inv_Ineff) indicate a mean of 0.33, implying that, on average, the sampled firms exhibit inefficient investment levels. The results are similar to those reported by Cook et al. (2019) and Kim and Kim (2023). Regarding the independent variable, the mean of TCFD compliance (TCFD) is 0.13, indicating a relatively low level of TCFD compliance among firms, with companies implementing only around 13% of the recommended disclosure items. This is supported by the median value of 0, indicating that a large proportion of firms provide little or no climate-related disclosures, highlighting the voluntary nature of TCFD reporting during the sample period. These results align with those reported by Maji and Kalita (2021) and Ding et al. (2023) regarding low global compliance rates.

Regarding the control variables, the sample's average firm size (Size) is 9.45, while the mean leverage ratio is 0.23, indicating that firms, on average, finance about 23% of their assets with debt. The mean value of tangible assets accounts for approximately 27% of total assets, and the mean cash holding ratio is 0.15, suggesting that firms hold cash equivalent to about 15% of total assets. The average firm age is approximately 11 years, reflecting a sample that includes both relatively young and well-established firms. Furthermore, around 25% of the firm-year observations report losses, close to the average reported by Benlemlih and Bitar (2018). Finally, approximately 60% of firms pay dividends, highlighting variation in firms' financial performance and payout policies across the sample. Overall, the above results align with those reported in prior studies (Cook et al., 2019; Liu & Tian, 2021).

Table 2.4 presents the Pearson and Spearman correlation coefficients to assess the relationships among the dependent variable (Inv_Ineff), the independent variable (TCFD), and the control variables. Consistent with the theoretical expectations, the results indicate that investment

inefficiency is negatively associated with firm size, financial leverage, asset tangibility, and dividend payments, suggesting that larger firms, firms with higher debt obligations, firms with greater physical assets, and dividend-paying firms tend to make more efficient investment decisions. These findings are consistent with prior evidence that debt monitoring, asset collateral, and financial stability reduce managerial discretion and constrain inefficient investment behaviour (Biddle et al., 2009; Chen et al., 2011). In contrast, investment inefficiency is positively correlated with the loss indicator, indicating that financially distressed firms, which face greater resource constraints and operational challenges, tend to exhibit higher levels of investment inefficiency.

Regarding the determinants of TCFD compliance, the results show that TCFD compliance is positively and significantly correlated with firm size and firm age, indicating that larger and more established firms tend to provide more extensive climate-related disclosures. This is consistent with prior evidence that larger firms face greater stakeholder scrutiny and possess more resources to invest in voluntary reporting initiatives, while older firms have stronger reputational incentives to maintain transparency (Liao et al., 2024). Overall, the correlation coefficients indicate no serious multicollinearity concerns among the explanatory variables. Following Gujarati and Porter (2009), all pairwise correlations remain below the commonly used threshold of 0.8. In addition, the variance inflation factor (VIF) tests confirm that multicollinearity is not a concern in the regression models.

To assess potential econometric concerns, the Modified Wald test for heteroskedasticity and the Wooldridge test for serial correlation in panel data are conducted. The Modified Wald test rejects the null hypothesis of homoskedasticity, indicating heteroskedasticity across firms. In addition, the Wooldridge test rejects the null hypothesis of no autocorrelation, suggesting the presence of serial correlation within firms over time. To address these issues, the regression models are estimated using firm-clustered robust standard errors, which provide consistent inference in the presence of heteroskedasticity and within-firm serial correlation.

Table 2.3 Descriptive Statistics

This table presents the descriptive statistics for the 2,225 firm-year observations from 2017 to 2021. The descriptive statistics for the full sample include the number of observations, the mean, the standard deviation, the minimum, the 25th percentile, the median, the 75th percentile, and the maximum of all variables. TCFD is measured using the Climate Compliance Index. Investment Inefficiency (Inv_Ineff) is defined as the absolute value of the residuals from the expected investment model (2.1). Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before extraordinary items is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. All continuous variables are winsorised at their 1st and 99th percentiles.

Variables	N	Mean	SD	Min	p25	Median	p75	Max
Inv_Ineff	2,225	0.33	0.32	0.01	0.11	0.23	0.44	1.46
TCFD	2,225	0.13	0.28	0.00	0.00	0.00	0.00	0.97
Size	2,225	9.45	3.92	2.22	6.65	8.58	11.56	18.87
Leverage	2,225	0.23	0.19	0.00	0.06	0.21	0.37	0.68
Tangibility	2,225	0.27	0.25	0.00	0.07	0.16	0.42	0.84
Age	2,225	11.76	8.47	1.00	3.00	10.00	19.00	34.00
Cash	2,225	0.15	0.12	0.01	0.06	0.10	0.20	0.53
Loss	2,225	0.25	0.43	0.00	0.00	0.00	1.00	1.00
Dividend	2,225	0.60	0.49	0.00	0.00	1.00	1.00	1.00

Table 2.4 Pearson/Spearman Correlation Matrix

This table reports both Pearson and Spearman correlation coefficients. Pearson correlations are presented in the lower triangle, while Spearman rank correlations are reported in the upper triangle. TCFD is measured using the Climate Compliance Index. Investment Inefficiency (Inv_Ineff) is defined as the absolute value of the residuals from the expected investment model (2.1). Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before extraordinary items is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. All continuous variables are winsorised at their 1st and 99th percentiles. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

	Inv_Ineff	TCFD	Size	Leverage	Tangibility	Age	Cash	Loss	Dividend
Inv_Ineff	1	-0.126***	-0.048*	-0.215***	-0.282***	-0.127***	0.048*	0.235***	-0.208***
TCFD	-0.127***	1	0.298***	0.179***	0.241***	0.304***	-0.098***	-0.161***	0.271***
Size	-0.010	0.289***	1	0.089***	0.067***	-0.017	0.024	-0.381***	0.494***
Leverage	-0.195***	0.136***	0.046*	1	0.386***	0.061***	-0.208***	-0.165***	0.251***
Tangibility	-0.244***	0.213***	0.018	0.321***	1	0.210***	-0.075***	-0.175***	0.249***
Age	-0.089***	0.208***	0.043**	0.016	0.066**	1	-0.116***	-0.114***	0.164***
Cash	0.070**	-0.127***	0.027	-0.229***	-0.152***	-0.117***	1	-0.002	-0.110***
Loss	0.232***	-0.157***	-0.352***	-0.142***	-0.116***	-0.027	0.002	1	-0.481***
Dividend	-0.214***	0.273***	0.466***	0.219***	0.207***	0.081***	-0.092***	-0.48***	1
VIF		1.21	1.45	1.20	1.18	1.05	1.11	1.39	1.68

2.4.1 Multivariate Analysis

This section presents the multivariate regression analysis examining the association between TCFD compliance and investment inefficiency. The empirical models are estimated using fixed-effects OLS regressions, with standard errors clustered at the firm level to account for heteroscedasticity and within-firm correlation over time.

Consistent with prior literature (Phan et al., 2022; Chen et al., 2023), the models include industry, country, and year fixed effects to control for unobserved heterogeneity across firms and over time. Controlling for these fixed effects helps reduce potential omitted variable bias and improves the reliability of the estimated coefficients (Lin et al., 2021). To mitigate the influence of extreme values, financial variables are winsorised at the 1st and 99th percentiles. This section is organised into two subsections. Section 2.4.1.1 presents the model specifications, while Section 2.4.1.2 reports the regression results.

2.4.1.1 Model Specifications

To test the study hypotheses, three panel regression models are estimated to examine the association between TCFD compliance and investment inefficiency, as well as the effects on overinvestment and underinvestment. The baseline regression models are specified as follows:

$$Inv_Ineff_{i,t} = \beta_0 + \beta_1 TCFD_{i,t} + \beta_2 Size_{i,t} + \beta_3 Leverage_{i,t} + \beta_4 Tangibility_{i,t} + \beta_5 Age_{i,t} + \beta_6 Cash_{i,t} + \beta_7 Loss_{i,t} + \beta_8 Dividend_{i,t} + YearFE + IndustryFE + CountryFE + \epsilon_{i,t} \quad (2.2)$$

Inv_Ineff represents investment inefficiency and is measured as the absolute value of the residuals from the investment model (Equation 2.1), reflecting the deviation between the actual and predicted optimal investment level (Benlemlih & Bitar, 2018). Overinvestment is defined as positive residuals from the investment model, indicating that firms invest more than the optimal level. Underinvestment corresponds to negative residuals, indicating that firms invest less than the predicted optimal level. TCFD refers to TCFD compliance, which equals the CCI score if a firm reports climate-related financial information as recommended by the TCFD, and zero otherwise. The remaining independent variables represent control variables that may influence firms' investment decisions and are defined in Appendix 2.A. In addition, industry, country, and year fixed effects control for unobserved heterogeneity across industries,

countries, and time (Lin et al., 2021). The regression models are estimated using panel data techniques with clustered standard errors at the firm level to address potential heteroskedasticity and serial correlation.

2.4.1.2 Main Results

Table 2.5 reports the results of the fixed-effects panel regressions examining the relationship between TCFD compliance and corporate investment inefficiency. Specifically, Model (1) investigates the association between TCFD compliance and investment inefficiency, while Model (2) examines the association between TCFD compliance and overinvestment. Finally, Model 3 examines the association between TCFD compliance and underinvestment. All models include year, industry, and country fixed effects to control for unobserved heterogeneity across firms and over time.

The results presented in Model (1) show a significantly negative relationship between TCFD compliance and investment inefficiency. Specifically, the coefficient on TCFD indicates that TCFD compliance is associated with a 0.078 reduction in investment inefficiency. Given a sample mean of 0.33, this reduction represents approximately a 23.6% decrease, highlighting a substantial economic impact. This suggests that TCFD compliance is associated with a significant improvement in firms' investment efficiency. This finding is consistent with the view that climate-related financial disclosure improves the firm's information environment by enhancing transparency regarding climate risks and opportunities. Improved disclosure may reduce information asymmetry between managers and external stakeholders, thereby strengthening monitoring mechanisms and facilitating more efficient capital allocation decisions. Overall, these findings provide support for Hypothesis 1 and are consistent with voluntary disclosure theory, which posits that increased transparency improves monitoring and mitigates agency problems, thereby enhancing investment efficiency. The results are also consistent with prior studies showing that enhanced disclosure and corporate social responsibility reporting improve firms' investment decisions (e.g., Biddle et al., 2009; Shroff et al., 2013; Cook et al., 2019).

Regarding the control variables in Model (1), firm size is positively associated with investment inefficiency, suggesting that larger firms may experience greater organisational complexity, which could lead to less efficient capital allocation. In contrast, leverage, asset tangibility, and firm age exhibit negative and statistically significant coefficients, indicating that firms with

higher debt monitoring, greater collateralizable assets, and longer operating histories tend to make more efficient investment decisions. These results are consistent with the argument that debt monitoring and asset tangibility constrain managerial discretion and reduce inefficient investment. In addition, firms reporting losses exhibit significantly higher investment inefficiency, reflecting the financial constraints and operational challenges they experience. These findings are broadly consistent with prior literature (Cook et al., 2019; Feng et al., 2022).

Model (2) reports the results for the overinvestment subsample. The coefficient on TCFD is negative and statistically significant, indicating that firms complying with TCFD reporting exhibit approximately 0.02 lower levels of overinvestment. This finding suggests that enhanced climate-related disclosure may strengthen external monitoring and reduce managerial incentives to undertake excessively risky or unprofitable investment projects. From an agency perspective, improved disclosure increases transparency regarding firms' risk exposures and strategic decisions, thereby constraining managerial opportunism and promoting more disciplined investment behaviour. Consequently, these findings provide support for Hypothesis 2, which predicts an association between TCFD compliance and reduced overinvestment. The results are also consistent with prior studies suggesting that enhanced non-financial disclosure improves the information environment and reduces inefficient investment behaviour (Liu & Tian, 2021; He et al., 2022).

The control variables in Model (2) are generally consistent with theoretical expectations. Firm size is positively and significantly associated with overinvestment, suggesting that larger firms may engage in higher levels of excessive investment due to greater access to internal resources and managerial discretion. Loss-making firms also exhibit significantly higher overinvestment, possibly reflecting attempts by poorly performing firms to undertake riskier investments to improve future performance. In contrast, leverage and asset tangibility are negatively associated with overinvestment, indicating that higher debt levels and greater collateralizable assets impose financial discipline and constrain inefficient investment behaviour. Firm age is also negatively related to overinvestment, suggesting that more mature firms tend to adopt more conservative and disciplined investment policies.

Finally, Model (3) presents the results for the underinvestment scenario. The coefficient on TCFD is negative and statistically significant ($\beta = -0.049$, $p < 0.05$), indicating that firms complying with TCFD disclosures exhibit lower levels of underinvestment. This finding

suggests that improved climate-related transparency may reduce financing frictions and enhance firms' access to external capital, thereby enabling them to pursue value-enhancing investment opportunities that might otherwise be forgone. These results are also consistent with the voluntary disclosure theory, arguing that firms that provide more comprehensive climate-related information may reduce uncertainty among investors and creditors, enhance stakeholder confidence, and improve access to financial resources. Consequently, these findings provide support for Hypothesis 3, which predicts an association between TCFD compliance and reduced underinvestment. The results are consistent with prior studies suggesting that non-financial disclosure reduces financial constraints and facilitates corporate investment (Luo & Tang, 2014; Cook et al., 2019).

Furthermore, the distribution of firms between overinvestment and underinvestment in the sample is approximately 30% of firm-year observations classified as overinvesting and 70% as underinvesting. This finding broadly aligns with international cross-country evidence, where Cook et al. (2019) report 33%, Benlemlih and Bitar (2018) document 35%, and Liu and Tian (2021) indicate 30%. The cross-country composition of this sample, comprising firms from 36 countries including emerging markets, tends to encounter greater financial constraints and weaker investor protections, thereby increasing the propensity for underinvestment relative to the agency-driven overinvestment more typically observed in U.S. markets (Biddle et al., 2009).

Across the three specifications, the adjusted R^2 values range from 19% to 25%, indicating that the models explain a meaningful proportion of the variation in corporate investment inefficiency.

Table 2.5 The Association between TCFD Compliance and Investment Inefficiency

This table reports the results of ordinary least squares (OLS) regressions on the relationships between TCFD compliance and investment inefficiency (Model 1), overinvestment (Model 2), and underinvestment (Model 3). The TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. Investment Inefficiency (Inv_Ineff) is defined as the absolute value of the residuals from the expected investment model (2.1). Overinvestment is measured as the positive residuals from the investment model (2.1). Underinvestment is measured as the absolute value of the negative residuals from the investment model (2.1). Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. The sample comprises 2,225 firm-year observations from 2017 to 2021. All regressions are estimated using OLS with industry, year, and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) Inv_Ineff	(2) Overinvestment	(3) Underinvestment
TCFD	-0.078*** (-2.857)	-0.020* (-1.690)	-0.049** (-1.993)
Size	0.008*** (2.592)	0.019*** (3.205)	-0.001 (-0.308)
Leverage	-0.130** (-2.270)	-0.261*** (-2.745)	-0.071 (-1.535)
Tangibility	-0.267*** (-7.361)	-0.406*** (-5.540)	-0.129*** (-3.663)
Age	-0.001** (-1.977)	-0.003* (-1.719)	0.001 (1.151)
Cash	-0.120 (-1.252)	-0.334* (-1.780)	0.038 (0.622)
Loss	0.128*** (5.153)	0.192*** (3.869)	0.095*** (4.973)
Dividend	-0.068*** (-2.992)	-0.069 (-1.609)	-0.027 (-1.324)
Intercept	0.417*** (10.352)	0.499*** (6.246)	0.327*** (11.199)
Observations	2,225	568	1,657
Adj. R ²	0.204	0.254	0.190
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes

2.4.2 Endogeneity and Sample Selection Bias

A potential concern in examining the relationship between TCFD compliance and corporate investment efficiency is the presence of endogeneity and sample selection bias, which may affect the reliability of the baseline results. Endogeneity may arise from omitted variables or from reverse causality, whereby firms with more efficient investment practices may be more likely to comply with TCFD reporting. In addition, because TCFD compliance is voluntary, firms choosing to comply with the framework may differ systematically from those that do not, potentially introducing self-selection bias. To address these concerns, this study follows Cook et al. (2019) and Benlemlih & Bitar (2018) and employs a Heckman two-stage selection model to control for potential sample selection bias. Second, Propensity Score Matching (PSM) is applied to mitigate observable differences between firms that comply with TCFD and those that do not. Finally, Two-Stage Least Squares (2SLS) is used to address endogeneity concerns.

Heckman Selection Model

To address potential sample selection bias arising from the voluntary compliance with TCFD reporting, this study employs the two-stage Heckman (1979) selection model. Because TCFD compliance is voluntary, firms that comply with the framework may systematically differ from those that do not, potentially biasing baseline estimates.

Following Khediri (2021) and Phan et al. (2022), the first-stage selection equation includes an instrumental variable, TCFD_IND, defined as the industry-year average level of TCFD compliance excluding the focal firm. This variable captures the tendency of firms within the same industry to adopt similar disclosure practices because of shared regulatory pressures, market conditions, and stakeholder expectations regarding climate-related reporting. As such, TCFD_IND is expected to influence a firm's likelihood of TCFD reporting compliance. At the same time, it is unlikely to directly affect a firm's investment inefficiency after controlling for firm characteristics and fixed effects, thereby satisfying the exclusion restriction condition. Prior literature suggests that firms operating within the same industry often exhibit similar environmental governance and disclosure practices (Benlemlih & Bitar, 2018).

The relevance of TCFD_IND as an instrument is confirmed by the first-stage probit results; the coefficient on TCFD_IND is positive and highly significant ($\beta = 3.154$, $t = 10.244$), indicating that industry peer compliance strongly predicts firm-level TCFD compliance (Stock et al.,

2002). Further, the exclusion restriction is justified on two grounds. First, the instrument excludes the focal firm, ensuring that the firm's own investment efficiency and disclosure decisions cannot drive the industry average. Second, all specifications include industry, country, and year fixed effects, absorbing systematic industry-level factors that could create a direct path from peer compliance to firm-level investment efficiency. However, a potential concern is that industry peer compliance may reflect broader industry-level governance improvements that independently influence investment efficiency.

In the first stage, a probit model is estimated to predict the likelihood of TCFD compliance as a function of TCFD_IND and the control variables used in the baseline regression. Based on this estimation, the inverse Mills ratio (IMR) is calculated to capture the potential selection bias. In the second stage, the IMR is included as an additional regressor in the investment inefficiency regression, with investment inefficiency (Inv_Ineff) as the dependent variable and TCFD and the control variables as explanatory variables. The results of the heckman two-stage estimation are reported in Table 2.6.

As shown in Table 2.6, the first-stage results indicate that TCFD_IND has a positive, statistically significant coefficient, suggesting that firms operating in industries complying with the TCFD framework are more likely to comply with it. This finding supports the argument that industry-level pressures affect corporate behaviour (Phan et al., 2022). Further, the results of the outcome equation show that the coefficient on TCFD remains negative and statistically significant ($\beta = -0.062$, $p < 0.05$), indicating that firms complying with TCFD reporting exhibit lower levels of investment inefficiency. This finding is consistent with the baseline results and suggests that the association between TCFD compliance and improved investment efficiency is robust after controlling for potential selection bias. The results support the argument that enhanced climate-related disclosure improves the firm's information environment and facilitates more efficient capital allocation.

Regarding the control variables in the outcome equation, the results are largely consistent with the baseline regressions. Firm size is positively associated with investment inefficiency, whereas asset tangibility and cash holdings are negatively associated with investment inefficiency. Firms reporting losses exhibit higher levels of investment inefficiency, suggesting that financially distressed firms may face greater challenges in allocating capital efficiently. Overall, the Heckman results provide additional evidence that the documented relationship between TCFD compliance and investment efficiency is not driven by sample selection bias.

Table 2.6 Heckman Selection Model

This table reports the results of Heckman's (1979) two-step selection model to address the self-selection issue. The TCFD is measured as 0 for non-complying firms and the CCI score for complying firms. Investment Inefficiency (Inv_Ineff) is defined as the absolute value of the residuals from the expected investment model (2.1). Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. The sample comprises 2,225 firm-year observations from 2017 to 2021. All regressions are estimated with industry, year, and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

	Selection Equation	Outcome Equation
VARIABLES	TCFD binary	Inv_Ineff
TCFD		-0.062** (-2.240)
TCFD_IND	3.154*** (10.244)	
Size	0.105*** (8.154)	0.016*** (4.023)
Leverage	0.314 (1.207)	-0.081 (-1.459)
Tangibility	0.258 (1.264)	-0.258*** (-6.680)
Age	0.009*** (3.107)	-0.001 (-1.146)
Cash	-1.279*** (-2.970)	-0.211** (-2.165)
Loss	-0.320** (-2.569)	0.108*** (4.315)
Dividend	0.578*** (4.871)	-0.031 (-1.170)
INV_Mills		0.080*** (2.839)
Intercept	-6.344*** (-11.499)	0.163* (1.668)
Observations	2,225	2,225
Adj R ²		0.210
Pseudo R ²	0.431	
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

Propensity Score Matching (PSM)

To further address potential self-selection bias arising from voluntary compliance with TCFD disclosure, this study employs propensity score matching (PSM), following Liu and Tian (2021). Because firms that comply with TCFD may systematically differ from non-complying firms in observable characteristics, PSM is used to construct a matched sample of TCFD compliers and non-compliers with comparable firm characteristics. Table 2.7 reports the results of PSM.

The PSM procedure involves two stages. In the first stage, propensity scores are estimated using a logit model predicting the likelihood of voluntary TCFD compliance based on observable firm characteristics, specifically firm size, leverage, asset tangibility, firm age, cash holdings, loss indicator, and dividend payments, as well as year, industry, and country fixed effects. These variables are selected following Liu and Tian (2021) and Benlemlih and Bitar (2018) as matching criteria because they represent the observable characteristics most likely to influence both the voluntary decision to comply with TCFD and the level of investment inefficiency. The logit model achieves a pseudo R-squared of 0.391, indicating good model fit. Consistent with expectations, larger firms, firms with higher leverage, greater asset tangibility, and dividend-paying firms are more likely to comply with TCFD disclosure, while firms reporting losses are less likely to comply.

In the second stage, the treatment group; comprising firm-year observations that voluntarily comply with TCFD recommendations is matched with a control group of non-complying firm-year observations using one-to-one nearest-neighbour matching with a caliper width of 0.01 on the propensity score. The caliper restriction ensures that each complying firm is matched to the most comparable non-complying firm within a tight tolerance, reducing the risk of poor quality matches. This results in a final matched sample of 778 firm-year observations. After matching, all standardised biases fall below the conventional 10% threshold, confirming that the matched treatment and control groups are balanced on all observable characteristics (Stuart, 2010). Appendix 2.B reports the covariate balance before and after PSM.

The first-stage results show that larger firms, those with higher leverage, greater tangibility, older age, and dividend payments are significantly more likely to comply with TCFD. Conversely, firms with higher cash holdings and those reporting losses are less likely to comply. These findings suggest that firms with stronger financial positions are more inclined

to adopt voluntary environmental disclosure frameworks. To further assess the robustness of the results, the baseline regression model is re-estimated using the matched sample, as shown in Table 2.7. The results remain consistent with the baseline findings, indicating that the negative association between TCFD compliance and investment inefficiency is not solely driven by observable differences between complying and non-complying firms. Overall, the PSM analysis provides additional evidence that the documented relationship between TCFD compliance and investment efficiency is robust to potential selection bias associated with firms' voluntary disclosure decisions.

Table 2.7 Propensity Score Matching

This table reports the results of the propensity score matching (PSM) analysis examining the relationship between TCFD compliance and investment inefficiency over the period 2017–2021. In the first stage, propensity scores are estimated using a logit model predicting TCFD compliance based on firm characteristics, including firm size, leverage, tangibility, firm age, cash holdings, loss indicator, and dividend payment, as well as year, industry, and country fixed effects. Firms complying with TCFD are then matched with non-complying firms using one-to-one nearest-neighbour matching based on the estimated propensity scores. Column (1) reports the first-stage logit estimation, while column (2) reports the regression results estimated using the matched sample. The dependent variable is investment inefficiency (Inv_Ineff). The models include year, industry, and country fixed effects, and standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) TCFD binary	(2) Inv_Ineff
TCFD		-0.131** (-2.274)
Size	0.210*** (9.180)	0.010* (1.847)
Leverage	0.918** (2.049)	0.029 (0.337)
Tangibility	1.179*** (3.522)	-0.204*** (-2.898)
Age	0.017*** (3.180)	0.002 (0.903)
Cash	-2.417*** (-3.120)	-0.308 (-1.025)
Loss	-0.475** (-2.174)	0.091 (1.578)
Dividend	1.242***	-0.111 (-1.275)
Intercept	-11.229*** (-11.720)	0.385*** (4.008)
Observations	2,225	778
Adj. R ²		0.248
Pseudo R2	0.391	
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

Two-Stage Least Squares (2SLS)

To address potential endogeneity concerns, including omitted variable bias and reverse causality, this study employs a Two-Stage Least Squares (2SLS) following Khediri (2021). Endogeneity may arise if firms with more efficient investment practices are more likely to comply with TCFD reporting, or if unobserved firm characteristics simultaneously influence both TCFD compliance and investment efficiency.

The 2SLS estimation is implemented in two stages. In the first stage, TCFD compliance is regressed on the instrumental variable and the control variables included in the baseline model. In the second stage, investment inefficiency is regressed on the predicted TCFD values from the first stage, along with the control variables. Following Khediri (2021) and Phan et al. (2022), the instrumental variable TCFD_country is employed. This variable is defined as the peer-based industry–year average TCFD compliance rate within the same country, excluding the focal firm. The rationale for this instrument is that firms operating within the same industry and country are likely to face similar regulatory pressures, competitive dynamics, and stakeholder expectations regarding climate-related disclosures, which may influence their likelihood of TCFD compliance. At the same time, these peer-based industry averages are unlikely to directly affect a firm's investment inefficiency after controlling for firm characteristics and fixed effects. The results of the 2SLS estimation are reported in Table 2.8.

As shown in Table 2.8, the first-stage regression results indicate that the instrument TCFD_country is positive and significant. This finding suggests that firms operating in industries and countries with higher levels of TCFD compliance among peer firms are more likely to comply with TCFD reporting themselves. The value of the first-stage F-statistic is 64.51, indicating that the instrument is sufficiently strong (Stock et al., 2002). On the other hand, the results of the second-stage regression indicate that the coefficient on the predicted value of TCFD compliance (TCFD_Predict) is negative and statistically significant ($\beta = -0.45$, $p < 0.05$). This result indicates that firms complying with TCFD reporting exhibit significantly lower levels of investment inefficiency, suggesting that this remains robust after accounting for potential reverse causality and omitted variable bias. Further, The Durbin–Wu–Hausman test of endogeneity rejects the null hypothesis of exogeneity ($p < 0.01$), indicating that the explanatory variable is endogenous. These findings reinforce the baseline results and support

the argument that enhanced climate-related disclosure improves the information environment and promotes more efficient capital allocation.

The first-stage control variables show that larger, more leveraged, mature firms, firms with higher tangible assets, and those that pay dividends are more likely to comply with TCFD disclosure, while cash-rich firms show lower compliance rates, consistent with weaker external financing pressure reducing disclosure incentives. In the second stage, firm size is positively associated with investment inefficiency, while leverage, tangibility and cash holdings are negatively associated, consistent with the main findings. The loss indicator is positive and significant, confirming that financially distressed firms exhibit greater capital misallocation. Overall, control variable results across both stages are broadly consistent with the baseline specification and prior investment efficiency literature (Biddle et al., 2009; Cook et al., 2019).

Overall, the 2SLS results provide further evidence that the negative association between TCFD compliance and investment inefficiency is robust to potential endogeneity concerns, strengthening the validity of the main findings.

Table 2.8 Two-Stage Least Squares (2SLS) Analysis

This table reports the results from Two-Stage Least Squares to address endogeneity. The peer-based industry-year average TCFD compliance rate within the same country is used as an instrument. TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. Investment Inefficiency (Inv_Ineff) is defined as the absolute value of the residuals from the expected investment model (2.1). Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. The sample comprises 2,225 firm-year observations from 2017 to 2021. Models are estimated with industry, year, and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) First Stage TCFD	(2) Second Stage Inv_Ineff
TCFD_Predict		-0.405** (-2.098)
TCFD_country	0.180*** (8.071)	
Size	0.014*** (8.451)	0.013*** (2.775)
Leverage	0.064** (2.040)	-0.149** (-2.512)
Tangibility	0.062** (2.342)	-0.181*** (-4.087)
Age	0.002*** (6.152)	-0.000 (-0.560)
Cash	-0.144*** (-3.121)	-0.190* (-1.821)
Loss	-0.014 (-0.960)	0.141*** (4.922)
Dividend	0.083*** (5.879)	-0.041 (-1.346)
Intercept	-0.194** (-2.490)	0.186** (2.011)
Observations	2,225	2,225
Adj. R ²	0.293	0.141
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

2.4.3 Sensitivity Analysis

This section conducts additional analyses to examine whether the main findings remain robust under alternative model specifications and variable measurements. Specifically, Section 2.4.3.1 presents a robustness test using an alternative proxy for investment inefficiency. Section 2.4.3.2 examines the mediating role of stock liquidity in the relationship between TCFD compliance and investment inefficiency. Section 2.4.3.3 presents additional robustness tests that include further control variables. Section 2.4.3.4 reports the results of a yearly analysis of the association between TCFD compliance and investment inefficiency.

2.4.3.1 Alternative Measure of Investment Inefficiency

To further assess the robustness of the baseline results, an alternative proxy for investment inefficiency is employed. Using alternative measures helps ensure that the specific measurement of the dependent variable does not drive the main findings. Following prior studies (Benlemlih & Bitar, 2018; Liu & Tian, 2021; Ho et al., 2023), this study adopts the investment model proposed by Biddle et al. (2009) as an alternative measure of investment inefficiency.

Specifically, Biddle et al. (2009) estimate expected investment as a function of sales growth using the following model:

$$Investment_{i,t} = \beta_0 + \beta_1 SalesGrowth_{i,t-1} + YearFE + IndustryFE + CountryFE + \epsilon_{i,t} \quad (2.3)$$

where investment is measured as the ratio of the net increase in tangible and intangible assets to lagged total assets (Biddle et al., 2009; Gomariz & Ballesta, 2014), and sales growth represents the previous year's sales growth rate. The residual term captures deviations of actual investment from expected investment based on firm growth opportunities. Consistent with prior literature, the absolute value of the residuals from this model is used as the measure of firm-specific investment inefficiency. Larger absolute residuals indicate greater deviations from optimal investment levels and, therefore, higher investment inefficiency.

Table 2.9 presents the results of the robustness test using an alternative proxy for investment inefficiency based on the model proposed by Biddle et al. (2009).

Consistent with the baseline results, Table 2.9 shows that the coefficient on TCFD in Model (1) is negative and statistically significant, supporting Hypothesis 1 and indicating that firms

complying with TCFD disclosures exhibit lower levels of investment inefficiency. This finding suggests that the main results are not sensitive to the specific measurement of investment inefficiency and supports the robustness of the baseline evidence that TCFD compliance is associated with more efficient investment decisions. Further, Models (2) and (3) separately analyse overinvestment and underinvestment. The results show that TCFD compliance is negatively associated with both types of inefficient investment, indicating that firms complying with TCFD reporting exhibit lower levels of both overinvestment and underinvestment, consistent with the baseline findings.

These results are consistent with voluntary disclosure theory, suggesting that TCFD reporting may improve firms' information environments, thereby facilitating more efficient capital allocation decisions. The control variables are generally consistent with the baseline findings. Larger firms and firms reporting losses tend to exhibit higher investment inefficiency, whereas firms with greater asset tangibility display lower investment inefficiency. The findings align with those of Benlemlih and Bitar (2018), Liu and Tian (2021) and Ho et al. (2023). Overall, the results are consistent with the baseline analysis, providing further evidence that the documented relationship between TCFD compliance and investment efficiency is robust to alternative measures of investment inefficiency.

Table 2.9 The Association between TCFD and Investment Inefficiency: An Alternative Measure of Investment Inefficiency

This table reports the results of ordinary least squares (OLS) regressions on the relationships between TCFD compliance and investment inefficiency (Model 1), overinvestment (Model 2), and underinvestment (Model 3), using an alternative measure of investment inefficiency (Inv_Ineff_alt). TCFD is measured as 0 for non-complying firms and the CCI score for complying firms. Investment Inefficiency (Inv_Ineff_alt) is defined as the absolute value of the residuals from the expected investment model (2.5). Overinvestment is measured as the positive residuals from the investment model (2.5) estimated following Biddle et al. (2009). Underinvestment is measured as the absolute value of the negative residuals from the investment model (2.5). Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. The sample comprises 2,225 firm-year observations from 2017 to 2021. All models are estimated using OLS with industry, year, and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) Inv_Ineff_alt	(2) Overinvestment	(3) Underinvestment
TCFD	-0.086** (-2.585)	-0.018* (-1.751)	-0.089*** (-3.784)
Size	0.013*** (3.252)	0.002** (2.178)	0.001 (0.289)
Leverage	-0.140* (-1.813)	-0.001 (-0.044)	0.031 (0.513)
Tangibility	-0.302*** (-6.672)	-0.045*** (-3.559)	-0.230*** (-4.824)
Age	-0.002** (-2.272)	0.002* (1.702)	0.001* (1.906)
Cash	-0.101 (-0.738)	-0.056*** (-2.664)	0.073 (0.987)
Loss	0.160*** (4.881)	0.008 (1.174)	0.116*** (5.468)
Dividend	-0.106*** (-3.571)	-0.003 (-0.509)	-0.011 (-0.520)
Intercept	0.414*** (8.368)	0.152*** (16.788)	0.341*** (10.329)
Observations	2,225	608	1,617
Adj. R ²	0.149	0.252	0.266
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes

2.4.3.2 The Association between TCFD Compliance, Stock Liquidity, and Investment Efficiency

This section examines whether stock liquidity acts as a potential channel through which TCFD compliance influences corporate investment inefficiency. According to information asymmetry theory, increased transparency reduces adverse selection in capital markets, thereby enhancing stock liquidity (Diamond & Verrecchia, 1991). Prior research suggests that enhanced corporate disclosure can improve the firm's information environment and reduce information asymmetry, thereby increasing stock liquidity (Hamrouni et al., 2022). Improved liquidity may facilitate monitoring of capital markets and enhance firms' access to external financing, ultimately promoting more efficient investment decisions. To investigate this mechanism, the following mediation models are estimated:

$$\begin{aligned} Liquidity_{i,t} = & \beta_0 + \beta_1 TCFD_{i,t} + \beta_2 Size_{i,t} + \beta_3 Leverage_{i,t} + \beta_4 Tangibility_{i,t} + \\ & \beta_5 Age_{i,t} + \beta_6 Cash_{i,t} + \beta_7 Loss_{i,t} + \beta_8 Dividend_{i,t} + YearFE + IndustryFE + \\ & CountryFE + \epsilon_{i,t} \end{aligned} \quad (2.3)$$

$$\begin{aligned} Inv_Ineff_{i,t} = & \beta_0 + \beta_1 TCFD_{i,t} + \beta_2 Liquidity_{i,t} + \beta_3 Size_{i,t} + \beta_4 Leverage_{i,t} + \\ & \beta_5 Tangibility_{i,t} + \beta_6 Age_{i,t} + \beta_7 Cash_{i,t} + \beta_8 Loss_{i,t} + \beta_9 Dividend_{i,t} + YearFE + \\ & IndustryFE + CountryFE + \epsilon_{i,t} \end{aligned} \quad (2.4)$$

Following Rehse et al. (2019), stock liquidity is measured using the relative bid–ask spread, calculated as the average monthly ratio of the difference between the ask price and the bid price to the midpoint price over the year. A narrower bid–ask spread indicates higher stock liquidity and greater trading activity. Prior studies suggest that enhanced corporate disclosure can improve stock liquidity by reducing information asymmetry and increasing investor participation (Zheng et al., 2023; Hamrouni et al., 2022). In line with this argument, TCFD compliance may enhance transparency regarding climate-related risks and opportunities, thereby improving investor confidence and increasing stock liquidity. Increased liquidity may subsequently facilitate more efficient capital allocation by reducing financing frictions and strengthening market monitoring. Table 2.10 reports the results examining whether stock liquidity, proxied by the bid–ask spread, serves as a potential mechanism through which TCFD compliance influences corporate investment inefficiency.

As reported in Table 2.10, Model (1) presents the baseline regression, Model (2) examines the association between TCFD compliance and stock liquidity, and Model (3) reports the mediation

model including both TCFD compliance and the bid–ask spread. The results of Model (1) show that the coefficient on TCFD is significantly negative ($\beta = -0.077$, $p < 0.01$), supporting Hypothesis 1 and suggesting that complying with TCFD reduces investment inefficiency. This finding is consistent with the baseline results and suggests that enhanced climate-related disclosure improves firms’ information environments and promotes more efficient capital allocation. Further, the results of Model (2) show that the coefficient on TCFD is negative and significant ($\beta = -0.233$, $p < 0.01$), suggesting that firms complying with TCFD disclosures exhibit a lower bid–ask spread, which implies higher stock liquidity. This result is consistent with the voluntary disclosure theory, which posits that improved corporate disclosure reduces information asymmetry between firms and stakeholders, thereby narrowing the bid–ask spread and enhancing trading activity in capital markets (Hamrouni et al., 2022).

Finally, Model (3) presents the mediation model. The coefficient on the bid–ask spread is positive and statistically significant, indicating that stock liquidity explains part but not all of the association between TCFD compliance and investment efficiency. This finding suggests that lower market liquidity may increase financing frictions and weaken external market monitoring, ultimately leading to less efficient investment decisions, consistent with Zheng et al. (2023). Importantly, the coefficient on TCFD remains negative and statistically significant after including the bid–ask spread, although its magnitude decreases relative to the baseline specification. This reduction indicates that stock liquidity partially mediates the relationship between TCFD compliance and investment inefficiency. The Sobel (1982) test further confirms that the indirect effect of TCFD compliance on investment inefficiency through stock liquidity is negative and statistically significant ($z = -3.87$, $p < 0.01$). This finding provides strong evidence that stock liquidity serves as an important channel through which TCFD compliance improves investment efficiency. The analysis uses a reduced sample of 2,183 firm-year observations because LSEG bid–ask spread data are not available for all firms in the baseline sample, particularly smaller international firms with lower trading volumes and limited analyst coverage.

Overall, these results suggest that TCFD compliance improves firms’ investment efficiency partly through enhancing stock market liquidity. By increasing transparency regarding climate-related risks and opportunities, TCFD compliance may reduce information asymmetry, narrow the bid–ask spread, and facilitate more efficient capital allocation.

Table 2.10 The Association between TCFD Compliance, Stock Liquidity, and Investment Efficiency

This table presents the regression results examining the mediating role of stock liquidity, proxied by the bid–ask spread, in the relationship between TCFD compliance and corporate investment inefficiency. TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. Investment Inefficiency (Inv_Ineff) is defined as the absolute value of the residuals from the expected investment model (2.1). Firm size (Size) is measured as the natural logarithm of the firm’s market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm’s total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. The reduction in observations relative to the baseline regressions is due to missing values for the bid–ask spread variable. To ensure comparability, Models (1) and (2) are re-estimated on the restricted sample of 2,183 observations and the results remain qualitatively unchanged. All models are estimated with industry, year, and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) Inv_Ineff	(2) Bid–Ask Spread	(3) Inv_Ineff
TCFD	-0.077*** (-3.458)	-0.233*** (-4.126)	-0.066*** (-2.817)
Bid–Ask Spread			0.064** (2.232)
Size	0.005** (2.301)	-0.008 (-1.116)	0.006** (2.458)
Leverage	-0.078* (-1.707)	-0.186 (-1.404)	-0.085* (-1.860)
Tangibility	-0.217*** (-7.091)	-0.053 (-0.436)	-0.220*** (-7.297)
Age	-0.001 (-1.288)	-0.005*** (-4.201)	-0.000 (-0.571)
Cash	-0.064 (-0.945)	0.032 (0.232)	-0.070 (-1.065)
Loss	0.106*** (5.681)	0.191*** (2.953)	0.091*** (4.550)
Dividend	-0.046** (-2.520)	-0.231*** (-3.764)	-0.032* (-1.705)
Intercept	0.370*** (12.893)	-0.526*** (-6.805)	0.411*** (12.156)
Observations	2,183	2,183	2,183
Adj. R ²	0.242	0.331	0.260
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes

2.4.3.3 The Association between TCFD and Investment Inefficiency: Additional Tests

To further assess the robustness of the baseline findings, this study conducts additional analyses that examine the influence of institutional climate policies and broader sustainability disclosure practices. First, the analysis investigates whether country-level climate policy stringency moderates the relationship between TCFD compliance and corporate investment inefficiency. To capture cross-country variation in climate regulation, and consistent with Chalabi-Jabado and Ziane (2024) and Bolton et al. (2023), this study employs the Climate Policy Index from the Climate Change Performance Index (CCPI) as a proxy for climate policy stringency. The CCPI evaluates countries' efforts and progress in implementing climate policies aligned with the objectives of the Paris Agreement (Burck et al., 2020). The climate policy component of the CCPI is scored on a scale of 0 to 100, where higher values indicate stronger national climate policy frameworks (Burck et al., 2020). Annual CCPI climate policy scores are obtained directly from the CCPI reports published by Germanwatch for each year of the sample period 2017-2021 and matched to each firm-year observation by country of domicile, with scores available for all 36 countries represented in the sample (Germanwatch, 2021). Countries are subsequently classified as high climate policy when their CCPI score exceeds the sample median and low climate policy otherwise. Higher index values indicate stronger climate policy frameworks and greater regulatory commitment to mitigating climate change.

Second, an additional fixed-effects OLS regression is conducted to control for ESG disclosure, ensuring that the documented relationship between TCFD compliance and investment inefficiency is not driven by broader sustainability reporting practices. ESG reporting represents a broader framework that encompasses multiple dimensions of corporate sustainability and ethical conduct. Consequently, some studies argue that ESG disclosure may overlap with climate-related reporting and could potentially confound the observed effects of TCFD compliance. To address this concern, this study includes ESG disclosure as an additional control variable in the regression model to examine whether the association between TCFD compliance and investment inefficiency remains robust after accounting for firms' overall sustainability disclosure practices. ESG disclosure is measured using the natural logarithm of the ESG score obtained from the LSEG database (formerly Refinitiv), which captures firms' overall environmental, social, and governance disclosure quality on a scale of 0 to 100 (Ellili, 2022). Table 2.11 reports the results of the additional tests.

As shown in Table 2.11, Model (1) investigates whether country-level climate policy stringency moderates the relationship between TCFD compliance and corporate investment inefficiency, while Model (2) re-estimates the model after controlling for ESG disclosure to ensure that the documented effect of TCFD is not driven by broader sustainability disclosure practices.

The results in Model (1) show that the coefficient on TCFD remains significantly negative ($\beta = -0.047$, $p < 0.05$), suggesting that firms complying with TCFD disclosure exhibit lower investment inefficiency. More importantly, the moderating effect of climate policy is negative and highly significant. This finding indicates that the negative association between TCFD compliance and investment inefficiency is stronger in countries with more stringent climate policies. In other words, the effectiveness of TCFD disclosure in improving investment efficiency appears to be reinforced in institutional environments with stronger climate-related regulatory frameworks, aligning with the findings of Chalabi-Jabado and Ziane (2024). This result suggests that national climate policy environments complement firm-level climate disclosure practices, enhancing their impact on corporate investment decisions.

The results of Model (2) show that the coefficient on ESG disclosure is statistically significant and negative, suggesting that firms with higher levels of ESG disclosure tend to exhibit lower investment inefficiency. The significant negative coefficient on ESG disclosure is consistent with Ellili (2022), who finds that ESG disclosure improves transparency and mitigates information asymmetry, thereby enhancing investment efficiency. Importantly, the coefficient on TCFD remains negative and statistically significant, indicating that the association between TCFD compliance and improved investment efficiency persists even after controlling for ESG disclosure. This finding suggests that the effect of TCFD is not merely driven by broader sustainability reporting practices but reflects the specific informational value of climate-related financial disclosures. While ESG disclosure is a broad framework that captures firms' environmental, social, and governance performance, the TCFD focuses specifically on the financial implications of climate-related risks and opportunities for corporate strategy and investment decisions. Overall, these additional analyses provide further support for the main findings, indicating that the relationship between TCFD compliance and investment efficiency is robust and is strengthened in institutional environments characterised by stronger climate policy frameworks.

Table 2.11 Climate Policy Stringency and ESG Disclosure: Additional Tests

This table reports additional regression results examining the moderating role of climate policy stringency, measured by the Climate Policy Index from the Climate Change Performance Index (CCPI), and the robustness of the baseline results after controlling for ESG disclosure, measured as the natural logarithm of the ESG score. TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. Investment Inefficiency (Inv_Ineff) is defined as the absolute value of the residuals from the expected investment model (2.1). Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. All models are estimated using OLS with industry, year, and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) Inv_Ineff	(2) Inv_Ineff
TCFD	-0.047** (-2.230)	-0.048** (-2.594)
Climate Policy	-0.018 (-1.160)	
Climate PolicyxTCFD	-0.064** (-1.994)	
ESG Disclosure		-0.043*** (-4.203)
Size	0.004** (2.062)	0.007** (3.041)
Leverage	-0.058 (-1.589)	-0.076** (-2.353)
Tangibility	-0.198*** (-7.880)	-0.219*** (-4.341)
Age	-0.001 (-1.168)	0.000 (0.787)
Cash	-0.041 (-0.781)	-0.134** (-3.003)
Loss	0.093*** (5.704)	0.101*** (5.915)
Dividend	-0.034** (-2.342)	-0.065*** (-4.038)
Intercept	0.371*** (15.311)	0.504*** (16.444)
Observations	2,032	1,619
Adj. R ²	0.251	0.285
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

2.4.3.4 Yearly Analysis of the Association between TCFD Compliance and Investment Inefficiency

To further examine the robustness of the baseline findings, this study conducts a yearly analysis of the relationship between TCFD compliance and investment inefficiency for the period 2017–2021. Estimating the regressions separately for each year allows us to assess whether the association remains stable over time. Table 2.12 reports the results of yearly regressions examining the association between TCFD compliance and investment inefficiency over 2017–2021.

The results reported in Table 2.12 indicate that the coefficient on TCFD is statistically insignificant in the earlier years (2017–2019) but becomes negative and statistically significant in 2020 ($\beta = -0.082$, $p < 0.05$) and 2021 ($\beta = -0.098$, $p < 0.05$). These results suggest that the association between TCFD compliance and investment efficiency becomes more pronounced and economically meaningful in the later years of the sample period. The insignificant results in 2017–2019 are consistent with the emerging stage of TCFD compliance during this period. Early TCFD status reports confirm that corporate adoption of the framework remained relatively limited in the initial years following its introduction (TCFD, 2019), resulting in insufficient cross-sectional variation in disclosure practices to identify a statistically significant association. Furthermore, the strengthening association in 2020 and 2021 likely reflects the growing importance and adoption of climate-related financial disclosure frameworks following increased regulatory attention and investor demand for climate-related transparency after 2019. As firms increasingly comply with TCFD recommendations and stakeholders placed greater emphasis on climate-related risks, the informational value of TCFD disclosures became more relevant for corporate investment decisions (Demaria & Rigot, 2021).

Overall, this pattern suggests that the effectiveness of TCFD disclosure in improving investment efficiency strengthens as the framework gains broader compliance and recognition among firms and investors, consistent with voluntary disclosure theory, which posits that the informational benefits of disclosure are amplified as market participants become more familiar with and responsive to the disclosed information (Verrecchia, 1983).

Table 2.12 Yearly Analysis of the Association between TCFD Compliance and Investment Inefficiency

This table reports the results of the yearly regressions examining the association between TCFD compliance and investment inefficiency for the period 2017–2021. TCFD is measured as 0 for non-complying firms and the CCI score for complying firms. Investment Inefficiency (Inv_Ineff) is defined as the absolute value of the residuals from the expected investment model (2.1). Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Firm age (Age) is defined as the number of years since the firm was listed. Cash is calculated as the ratio of cash to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. All regressions are estimated using OLS with industry and country fixed effects. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) 2017	(2) 2018	(3) 2019	(4) 2020	(5) 2021
TCFD	-0.038 (-0.486)	-0.004 (-0.090)	-0.039 (-0.928)	-0.082** (-2.191)	-0.098** (-2.525)
Size	0.007* (1.678)	0.002 (0.391)	0.009** (1.994)	0.007* (1.781)	-0.000 (-0.032)
Leverage	0.150 (1.648)	-0.043 (-0.483)	-0.063 (-0.786)	-0.138* (-1.916)	-0.056 (-0.760)
Tangibility	-0.181*** (-2.963)	-0.217*** (-3.713)	-0.182*** (-2.912)	-0.196*** (-4.037)	-0.149*** (-2.832)
Age	-0.002 (-1.517)	-0.005*** (-3.100)	0.001 (0.461)	-0.001 (-1.598)	-0.001 (-1.210)
Cash	-0.129 (-0.930)	-0.326** (-2.321)	-0.080 (-0.619)	-0.228** (-2.403)	0.292*** (2.671)
Loss	0.061 (1.595)	0.127*** (3.191)	0.079** (2.023)	0.082*** (3.079)	0.061 (1.645)
Dividend	-0.068** (-2.179)	0.008 (0.223)	-0.092*** (-2.634)	0.018 (0.577)	0.008 (0.211)
Intercept	0.294*** (5.838)	0.341*** (6.189)	0.329*** (5.515)	0.360*** (7.850)	0.401*** (7.691)
Observations	394	406	445	482	498
Adj. R ²	0.213	0.244	0.253	0.290	0.282
Industry FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes

2.5 Conclusion

Climate change has become a critical concern for global financial markets, influencing corporate reporting practices and investment decisions (Yu et al., 2022). The growing awareness of climate-related risks has highlighted the importance of transparent, comparable climate disclosures to reduce information asymmetry and improve capital allocation. In response to these concerns, the FSB established the TCFD to provide a standardised framework for reporting climate-related financial information. While prior studies primarily focus on the determinants of TCFD compliance and its influence on firm value and transparency, empirical evidence regarding its economic consequences remains limited. This study contributes to this growing literature by examining the impact of TCFD compliance on corporate investment efficiency.

Using a global sample of 2,225 firm-year observations of firms listed on the NYSE and Nasdaq between 2017 and 2021 across 36 countries, this study finds that TCFD compliance is associated with significantly higher investment efficiency by reducing investment inefficiency. Specifically, firms complying with the TCFD framework exhibit lower levels of both overinvestment and underinvestment, suggesting that climate-related financial disclosure improves managerial investment decisions and reduces inefficient capital allocation. Further, TCFD compliance plays an important role in improving corporate investment efficiency by enhancing transparency regarding climate-related risks and opportunities. By improving the information environment, TCFD disclosure helps stakeholders assess firms' long-term risk exposures and investment strategies more effectively, thereby promoting more efficient capital allocation. These findings are consistent with voluntary disclosure theory, which posits that enhanced transparency reduces information asymmetry and strengthens external monitoring of managerial behaviour.

The results remain robust across a wide range of additional analyses. First, the results are robust to several approaches addressing potential endogeneity and selection bias, including the Heckman selection model, two-stage least squares, and propensity score matching. Second, the findings persist when an alternative measure of investment inefficiency is employed. Most importantly, the results remain robust after conducting a mediation analysis using stock liquidity. The analysis indicates that TCFD compliance enhances the corporate information environment by increasing stock liquidity. Third, additional sensitivity analyses confirm the

stability of the results when controlling for ESG disclosure and when considering cross-country variation in climate policy stringency. Fourth, the mediation analysis suggests that TCFD compliance affects investment efficiency partly through improvements in the firm's information environment, proxied by enhanced stock liquidity. Finally, yearly analysis shows that the relationship becomes stronger in the later years of the sample period as TCFD compliance becomes more widespread.

This study offers several practical implications. First, for policymakers, the findings provide empirical support for the growing global movement toward mandatory climate-related disclosure frameworks. Strengthening climate reporting standards may reduce information asymmetry, enhance market discipline, and improve capital market efficiency. Second, for corporate managers, the results highlight the potential benefits of compliance with comprehensive climate disclosure practices. Integrating climate-related financial reporting into corporate governance and investment decision-making processes may improve firms' transparency, reduce financing frictions, and support long-term value creation. Third, for investors, the findings emphasise the importance of climate-related disclosures as a valuable source of information for assessing firms' exposure to climate risks and evaluating investment efficiency. Overall, this study provides new empirical evidence that climate-related financial disclosure frameworks, such as the TCFD, can have meaningful economic implications by improving corporate investment efficiency and supporting more efficient capital allocation in global financial markets.

Appendices to Chapter Two

Appendix 2.A Variable Definitions

This table presents the definitions of variables used in the current study. The sources and data items used from each source are also provided.

Variable	Definition	Proxy for	Source
Dependent Variable Measures:			
Inv_Ineff	The absolute value of the residuals obtained from the investment expectation model. Larger absolute residuals indicate greater deviations from expected investment levels and, therefore, higher investment inefficiency. The expected investment model is estimated as follows: $Investment_{i,t} = \beta_0 + \beta_1 SalesGrowth_{i,t-1} + \beta_2 TobinsQ_{i,t-1} + \beta_3 CFO_{i,t} + \epsilon_{i,t}$ Where Investment equals the ratio of the net increase in tangible and intangible assets of firm I to lagged total assets, sales growth is the growth rate in sales at year t-1. Tobin's Q is the market value of a firm's total assets minus common equity, deflated by total assets. CFO equals net cash flow from operating activities scaled by total assets.	Investment Inefficiency (McNichols & Stubben Model, 2008)	LSEG (formerly Refinitiv)
Inv_Ineff_alt	The absolute value of the residuals obtained from the investment expectation model. Larger absolute residuals indicate greater deviations from expected investment levels and, therefore, higher investment inefficiency. The expected investment model is estimated as follows: $Investment_{i,t} = \beta_0 + \beta_1 SalesGrowth_{i,t-1} + \epsilon_{i,t}$ Investment equals the ratio of the net increase in tangible and intangible assets to lagged total assets. Sales	Investment Inefficiency (Biddle et al., 2011)	LSEG (formerly Refinitiv)

	growth is the rate of change in sales from year t-1 to year t.		
Independent Variable			
TCFD	Equals 0 if the firm does not disclose climate-related financial information aligned with the TCFD recommendations, and the CCI score if the firm complies with the TCFD framework.	TCFD compliance	ESG and Sustainability Reports
Control Variables			
Size	Natural logarithm of the firm's market capitalisation.	Firm Size	LSEG (formerly Refinitiv)
Age	The difference between the LSEG listing year and the fiscal year.	Firm Age	LSEG (formerly Refinitiv)
Leverage	Total debt divided by total assets.	Leverage	LSEG (formerly Refinitiv)
Tangibility	Ratio of property, plant, and equipment (PPE) to total assets.	Asset Tangibility	LSEG (formerly Refinitiv)
Loss	Dummy variable equal to 1 if net income before extraordinary items is negative, and zero otherwise.	Loss	LSEG (formerly Refinitiv)
Cash	Ratio of cash and cash equivalents to total assets.	Cash ratio	LSEG (formerly Refinitiv)
Dividend	Dummy variable that equals 1 if the firm pays dividends in the year and zero otherwise	Firm Earning	LSEG (formerly Refinitiv)

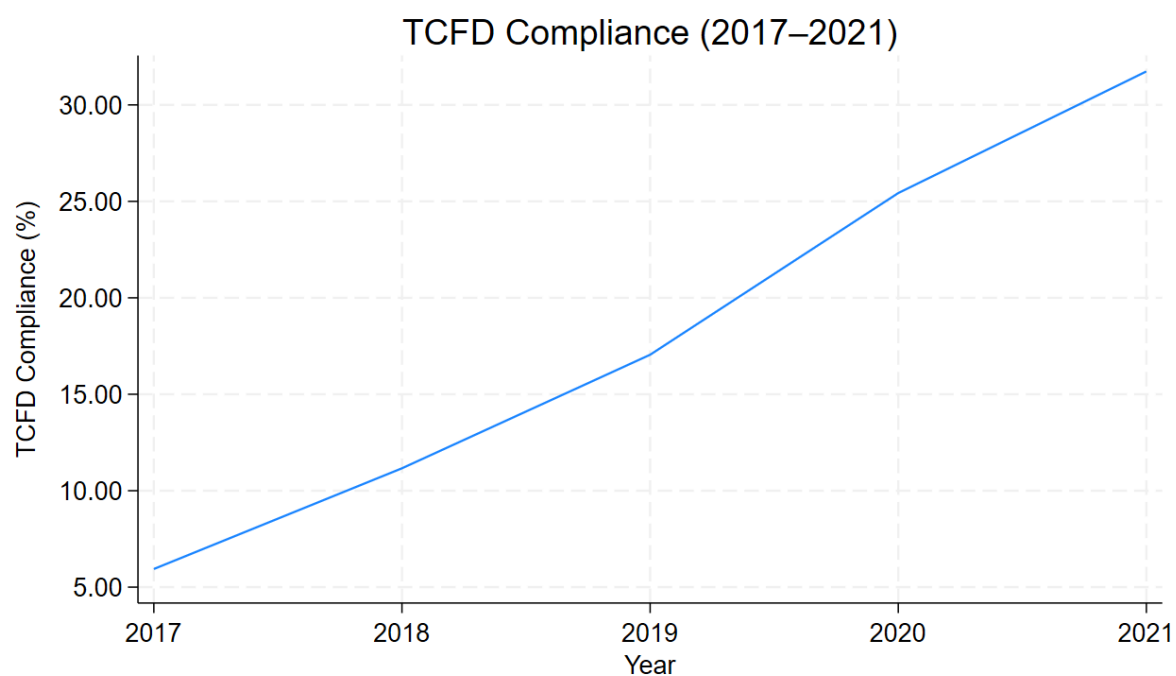
Appendix 2.B Covariate Balance Before and After Propensity Score Matching

Variable	Treated Mean (Unmatched)	Control Mean (Unmatched)	% Bias	Treated Mean (Matched)	Control Mean (Matched)	% Bias	t- stat	p- value
Size	11.916	9.0409	75.8	11.738	11.882	-3.8	-0.55	0.585
Leverage	0.2832	0.2149	38.2	0.2836	0.2667	-9.8	1.46	0.146
Tangibility	0.3672	0.2383	52.4	0.364	0.3568	2.9	0.4	0.687
Firm Age	18.576	11.612	48.6	17.346	16.222	8.0	1.02	0.310
Cash	0.1185	0.1593	-36.2	0.1196	0.1148	4.3	0.76	0.445
Loss	0.1074	0.2846	-45.8	0.1116	0.0791	8.4	1.63	0.104
Dividend	0.877	0.534	81.2	0.8721	0.8581	3.3	0.6	0.55

Appendix 2.C

Figure 2.1 Yearly Distribution of TCFD compliance

This figure illustrates the yearly distribution of TCFD compliance over the sample period. TCFD compliance is measured as the average level of climate-related disclosure across firms in each year.



Appendix 2.D Country-Level Sample Distribution

This table presents the country-level distribution of the sample. The sample includes firms from 36 countries, providing a geographically diverse research setting. However, the distribution of observations is not uniform across countries and is relatively concentrated in a few markets, particularly Canada, China, and the United Kingdom. This concentration may reflect differences in market size and data availability.

Country	Firms	Observations	% of Observations
Argentina	11	51	2.29
Australia	5	23	1.03
Belgium	7	34	1.53
Bermuda	14	66	2.97
Brazil	24	101	4.54
Canada	100	427	19.19
Cayman Islands	8	32	1.44
Chile	9	39	1.75
China	73	265	11.91
Colombia	3	15	0.67
Denmark	6	30	1.35
France	12	53	2.38
Germany	14	50	2.25
Greece	10	48	2.16
Hong Kong	11	50	2.25
India	7	35	1.57
Ireland	22	100	4.49
Italy	6	24	1.08
Japan	8	38	1.71
Luxembourg	14	59	2.65
Mexico	8	40	1.80
Monaco	4	20	0.90
Netherlands	13	63	2.83
Norway	2	7	0.31
Panama	1	5	0.22
Peru	3	15	0.67
Singapore	15	63	2.83
South Africa	10	49	2.20
South Korea	6	30	1.35
Spain	5	25	1.12
Sweden	7	32	1.44
Switzerland	15	55	2.47
Taiwan	11	52	2.34
Turkey	4	16	0.72
United Kingdom	48	213	9.57
Total	516	2,225	100.00

Appendix 2.E Robustness Analysis: Excluding Canadian Firms

This table reports the results of the baseline regression after excluding Canadian firms to ensure that the findings are not driven by sample concentration. The results remain consistent with the baseline findings. The coefficient on TCFD compliance is negative and statistically significant across all specifications, indicating that alignment with TCFD recommendations is associated with lower investment inefficiency. Overall, these results confirm that the main findings are robust to the exclusion of Canadian firms and are not driven by country-specific effects or sample concentration.

VARIABLES	(1) Inv_Ineff
TCFD	-0.141*** (-4.672)
Size	0.011*** (3.715)
Leverage	-0.159*** (-3.199)
Tangibility	-0.227*** (-6.154)
Age	-0.001* (-1.898)
Cash	-0.211** (-2.471)
Loss	0.105*** (4.276)
Dividend	-0.059** (-2.491)
Intercept	0.377*** (11.085)
Observations	1,793
Adj. R ²	0.186
Year FE	Yes
Industry FE	Yes
Country FE	Yes

Appendix 2.F TCFD Measurement

This section presents the 38 disclosure items used to construct the Climate Compliance Index (CCI), based on Demaria and Rigot (2021). The index captures firms' alignment with the four core pillars of the TCFD framework: governance, strategy, risk management, and metrics and targets. All disclosure items are coded as binary variables, equal to 1 if the item is disclosed and 0 otherwise.

Disclosure Item	Coding (0/1)
Governance	
1. Whether the board is informed about climate-related issues	0/1
2. Frequency of board discussions on climate-related issues	0/1
3. Integration of climate-related issues into strategic decision-making	0/1
4. Board monitoring and assessment of climate-related performance	0/1
5. Whether executive compensation is linked to climate-related indicators	0/1
6. Responsibilities of management regarding climate-related issues	0/1
7. Existence of climate-related information reporting processes	0/1
8. Management's approach to addressing climate-related risks and opportunities	0/1
Strategy	0/1
9. Identification of climate-related risks and opportunities across short, medium, and long-term horizons	0/1
10. Specification of time horizons for climate-related risks and opportunities	0/1
11. Financial quantification of climate-related risks and opportunities	0/1
12. Distribution of risks and opportunities across sectors or geographic regions	0/1
13. Impact of climate-related risks and opportunities on business and strategy	0/1
14. Identification of climate-related impacts on operations and financial performance	0/1
15. Integration of climate-related risks into corporate strategy	0/1
16. Disclosure of capital expenditures related to climate-related risks and opportunities	0/1
17. Disclosure of operating expenditures related to climate-related risks and opportunities	0/1
18. Assessment of business model resilience under climate-related scenarios	0/1
19. Use of climate-related scenario analysis	0/1
20. Specification of time horizons used in scenario analysis	0/1
21. Disclosure of conclusions from climate scenario analysis	0/1
Risk Management	0/1
22. Description of processes used to identify climate-related risks	0/1
23. Assessment of the materiality of climate-related risks	0/1
24. Consideration of current and future climate-related regulations	0/1
25. Existence of a formal climate-related materiality assessment	0/1
26. Description of processes used to manage climate-related risks	0/1
27. Identification and prioritisation of key climate-related risks	0/1
28. Integration of climate-related risk processes into overall risk management systems	0/1
Metrics and Targets	0/1
29. Disclosure of environmental performance indicators (e.g., energy, water, waste)	0/1

Disclosure Item	Coding (0/1)
30. Use of risk-related indicators linked to business performance	0/1
31. Disclosure of internal carbon pricing mechanisms	0/1
32. Reporting changes in environmental performance indicators over time	0/1
33. Disclosure of Scope 1 and Scope 2 greenhouse gas emissions	0/1
34. Disclosure of Scope 3 greenhouse gas emissions (if applicable)	0/1
35. Detailed breakdown of significant emission sources	0/1
36. Reporting trends in greenhouse gas emissions over time	0/1
37. Disclosure of climate-related targets	0/1
38. Reporting performance against climate-related targets	0/1

Chapter Three

The Association between CEO Power, CEO Climate Support and Voluntary Climate Change-Related Disclosure

3.1 Introduction

Climate change has emerged as a financially material risk that affects firms' operations, asset valuations, cash flows, and long-term sustainability (Sautner et al., 2023). Recent significant climate-related events, which have resulted in billions of dollars in insured losses and severe flooding in major financial centres such as Dubai in 2024, further highlight that climate risk has direct and substantial repercussions for capital markets (Hussein et al., 2025). Further, prior research demonstrates that climate risk represents an additional source of economic friction, limiting corporate investment, disrupting supply chains, heightening litigation and regulatory risks, and ultimately impairing firms' financial health and capital market performance (Kim & Kim, 2023; Addoum et al., 2020; Huang et al., 2018; Xu et al., 2025). Consequently, investors are increasingly requesting credible, decision-useful information on how firms identify, assess, and manage climate-related risks and opportunities (TCFD, 2019).

In response, the FSB established the TCFD framework in 2017 as the principal global benchmark for voluntary climate-related disclosure (Lombardi et al., 2022). Nevertheless, TCFD reports indicate that climate-related reporting remains insufficient, and compliance with the framework was voluntary until 2021 (TCFD, 2019). As a result, firms retain considerable discretion over whether and how to disclose climate-related information, creating an important governance challenge. On the one hand, climate disclosure can reduce information asymmetry by revealing firms' exposure to climate-related risks and their strategic responses (Lai et al., 2014). On the other hand, such disclosure may entail proprietary, political, and litigation costs, and may limit managerial flexibility by requiring firms to publicly commit to observable transition strategies (Wright & Nyberg, 2017; He et al., 2022). Consequently, in voluntary reporting environments, managers must weigh the potential benefits of transparency against the costs of disclosing sensitive information (O'Dwyer & Unerman, 2020). Climate-related disclosure, therefore, becomes a strategic governance decision rather than merely a symbolic or ethical practice.

Despite growing research on TCFD compliance, evidence on the internal governance determinants of voluntary TCFD compliance remains limited, with existing studies primarily focusing on regulatory developments, market reactions, or the economic consequences of disclosure (Bose et al., 2025). It therefore remains unclear whether concentrated managerial authority promotes or constrains voluntary climate transparency. Climate disclosure also differs from broader ESG reporting because it requires scenario analysis, risk quantification, and strategic resilience assessments, entailing higher proprietary costs and litigation risks that may further amplify the role of CEO authority in shaping disclosure decisions (O'Dwyer & Unerman, 2020). Beyond structural power, the CEO's personal environmental values may independently influence voluntary TCFD compliance; CEOs who publicly support climate action may be more willing to bear reporting costs regardless of their formal authority (Hambrick & Mason, 1984). Accordingly, this chapter addresses three research questions. First, is CEO power associated with firms' voluntary compliance with the TCFD framework? Second, conditional on compliance, is CEO power associated with TCFD reporting quality? Third, does CEO climate support independently influence or moderate the relationship between CEO power and voluntary TCFD compliance?

This chapter uses a sample of 2,353 firm-year observations of international firms listed on the New York Stock Exchange (NYSE) and Nasdaq during 2017-2021, when TCFD compliance remained voluntary. The results indicate that CEO power is negatively associated with voluntary TCFD compliance, consistent with managerial power theory, which suggests that powerful executives may have weaker incentives to promote transparency in discretionary disclosure settings, aligning with Bose et al. (2025). However, conditional on compliance, CEO power is positively associated with TCFD reporting quality, suggesting that powerful CEOs who choose to disclose may enhance the depth and sophistication of reporting. The results further document a positive association between CEO climate support and voluntary TCFD compliance, although climate support does not offset the negative association between CEO power and compliance decisions. These results are robust to alternative specifications, additional control variables, and endogeneity mitigation techniques. Additional analyses further indicate that the negative association between CEO power and voluntary TCFD compliance weakens during periods characterised by stronger climate regulatory pressure.

This chapter makes three contributions. First, it extends the literature on CEO power and corporate governance by examining how concentrated managerial authority is associated with

forward-looking decisions about climate disclosure. While prior research documents mixed evidence regarding the effect of CEO power on disclosure outcomes, this chapter provides new evidence that CEO power differentially affects the compliance decision and reporting quality of voluntary climate disclosure. This distinction deepens understanding of how managerial authority operates in discretionary transparency settings. Second, this chapter contributes to the growing literature on climate-related financial disclosure and TCFD compliance by identifying internal governance mechanisms as key determinants of voluntary reporting. Whereas prior research has primarily examined regulatory drivers, market consequences, or external pressures, this chapter highlights the role of managerial power in shaping firms' climate reporting strategies during the voluntary compliance period.

Finally, the findings inform ongoing policy discussions regarding the transition from voluntary to mandatory climate reporting regimes. By showing that disclosure decisions are sensitive to internal governance structures, the results suggest that regulatory effectiveness may depend not only on formal reporting requirements but also on the distribution of decision-making authority within firms. It advocates establishing more robust governance codes, emphasising the importance of separating the roles of CEO and chairman to mitigate potential risks associated with excessive power concentration. Additionally, it encourages standard setters to implement tailored incentives for corporate leadership to strengthen accountability and enhance the consistency of climate reporting.

The remainder of this chapter is organised as follows: Section 3.2 covers the theoretical framework and presents the development of hypotheses. Section 3.3 introduces the research design and sample selection process. Section 3.4 presents the regression results and robustness tests. Section 3.5 concludes the main points covered in this chapter.

3.2 Theoretical Framework and Hypotheses Development

3.2.1 Literature Review: CEO Power and Corporate Disclosure

The demand for transparent non-financial disclosure has increased substantially as stakeholders seek greater insight into firms' social responsibility, environmental exposure, and resilience to emerging risks (Muttakin et al., 2018). Prior research documents that higher levels of ESG and non-financial reporting are associated with lower cost of capital, reduced earnings

management, and enhanced firm value (Kim et al., 2022; Dhaliwal et al., 2011). Climate-related reporting represents a particularly important dimension of this literature as climate change exposes firms to physical, regulatory, reputational, and litigation risks (Ilhan et al., 2023), increasing investor demand for credible information on firms' climate risk exposure and mitigation strategies. However, this literature largely focuses on the outcomes of disclosure rather than the internal governance mechanisms that shape firms' disclosure decisions, particularly the role of CEO power in voluntary reporting settings.

Voluntary disclosure theory provides a useful framework for understanding managerial disclosure incentives; firms may voluntarily disclose additional information to reduce information asymmetry and improve transparency in capital markets (Verrecchia, 1983; Liu & Tian, 2021). However, because voluntary disclosure involves managerial judgment, executives may choose to withhold information when the perceived costs of disclosure outweigh its potential benefits (Verrecchia, 1983). Upper echelons theory (Hambrick & Mason, 1984) extends this framework by highlighting how individual executives' personal characteristics and authority shape firm-level disclosure decisions, positing that executives' cognitive frames and values directly influence strategic choices, including voluntary disclosure decisions.

CEO power represents a key governance mechanism that may shape voluntary disclosure decisions. Prior research provides mixed evidence on the relationship between CEO power and corporate transparency (Ali et al., 2024; Bose et al., 2025). On the one hand, greater CEO influence may facilitate coordination, reduce internal information frictions, and support long-term strategic decision-making, with evidence suggesting that powerful CEOs are associated with more effective ESG reporting and higher disclosure quality (Li et al., 2018; Korkeamäki et al., 2017; Ali et al., 2024). On the other hand, agency theory suggests that powerful CEOs may weaken monitoring mechanisms, pursue private benefits, and reduce disclosure transparency, with evidence associating greater CEO power with governance frictions, reduced stock price informativeness, and lower non-financial reporting quality (Bhandari & Javakhadze, 2017; Al Mamun et al., 2020; Bose et al., 2025).

Prior literature has employed a range of measures to capture the multidimensional nature of CEO power. Drawing on Finkelstein's (1992) taxonomy, executive power encompasses four dimensions: structural, expert, prestige, and ownership power. CEO duality, where the CEO simultaneously serves as board chairman, is the most widely used structural power measure,

concentrating leadership authority and limiting board independence (Finkelstein, 1992). Agency theory suggests that CEO duality weakens board monitoring and may reduce disclosure transparency (Gul & Leung, 2004; Muttakin et al., 2018), while stewardship theory argues that unified leadership enhances coordination and strengthens strategic decision-making (Donaldson & Davis, 1991; Davis et al., 1997). Empirical findings remain inconclusive, with studies reporting negative, positive, or insignificant associations between CEO duality and voluntary disclosure (Khlif et al., 2021).

CEO tenure captures the expert dimension of power. Hermalin and Weisbach (2012) demonstrate that CEOs with longer tenures progressively accumulate influence over board composition and decision-making processes, thereby gradually negotiating for weaker oversight as their tenure lengthens. Veprauskaite and Adams (2013) further show that CEO tenure is associated with greater entrenchment and reduced board effectiveness, suggesting that longer-serving CEOs are better positioned to resist external pressures for transparency. In the context of voluntary disclosure, Ali et al. (2024) find that CEO tenure is positively associated with ESG reporting quality through an expert power channel, where accumulated firm-specific knowledge enables more sophisticated disclosure, while Bose et al. (2025) find that tenure amplifies the negative effect of CEO power on climate transparency.

CEO ownership captures the ownership dimension of power. Jensen and Murphy (1990) argue that CEO equity ownership aligns managerial incentives with shareholder interests, reducing agency costs and potentially increasing transparency. However, Morck et al. (1988) document a non-linear relationship between ownership and firm outcomes, with higher ownership levels associated with entrenchment rather than alignment. Bebchuk et al. (2009) further show that high CEO ownership is associated with reduced board independence and weaker governance structures. In voluntary disclosure settings, Sheikh (2019) and Martínez and Álvarez (2024) find that CEO ownership increases managerial autonomy over strategic decisions, enabling powerful CEOs to shape disclosure policies to reflect their private interests rather than stakeholder demands.

Other measures employed in prior literature include CEO compensation relative to other executives capturing prestige power (Bebchuk et al., 2011) and board network centrality capturing social influence (Fracassi & Tate, 2012); however, these require data not consistently available across international samples. Accordingly, following Veprauskaite and Adams

(2013) and Sheikh (2019), this study constructs a composite CEO power index combining duality, tenure, and ownership, capturing the structural, expert, and ownership dimensions of CEO power identified by Finkelstein (1992).

The voluntary nature of the TCFD framework provides a particularly informative context for examining CEO power effects, as climate disclosure requires discretionary judgments about risk identification, scenario analysis, and forward-looking strategic responses that can materially influence investor perceptions and external monitoring (Matsumura et al., 2024; TCFD, 2017). In this context, agency theory posits that enhanced CEO power may diminish transparency and undermine external oversight (Bebchuk et al., 2011), while managerial power theory suggests that influential CEOs might avoid costly or potentially restrictive disclosures to safeguard private benefits and maintain strategic flexibility (Bebchuk et al., 2002). Conversely, stewardship theory contends that powerful CEOs can facilitate decisive strategic positioning and endorse credible climate disclosures that demonstrate resilience to investors (Korkeamäki et al., 2017; Abeysekera & Fernando, 2020). Consequently, whether CEO power amplifies or constrains voluntary TCFD compliance remains an empirical question.

Beyond structural power, upper echelons theory (Hambrick & Mason, 1984) suggests that executives' personal values and experiences directly influence strategic choices. In the context of climate disclosure, CEOs who publicly support climate action may be more willing to bear the costs of voluntary TCFD reporting irrespective of their formal power, making CEO climate support a distinct governance construct that complements the structural dimension of CEO power.

3.2.2 Hypotheses Development

This section briefly presents the current study's hypotheses by reviewing prior research on the association between CEO power and the compliance and quality of climate change disclosure.

3.2.2.1 TCFD Compliance and CEO Power and Reporting Quality

Corporate leadership plays a central role in integrating climate-related disclosure frameworks, such as the TCFD, into firms' reporting practices (O'Dwyer & Unerman, 2020). Prior research shows that executive attributes influence corporate disclosure outcomes, particularly in voluntary settings with high managerial discretion (Sheikh, 2019; Bose et al., 2025). CEO

power captured through mechanisms such as duality, ownership, and tenure concentrates decision-making authority and may therefore shape firms' transparency choices.

From a stewardship-oriented perspective, powerful CEOs may use their authority to facilitate unified strategic direction, reduce internal coordination frictions, and enable decisive long-term positioning (Adams & Ferreira, 2007). Evidence suggests that strong managerial leadership can improve environmental disclosure and signal commitment to managing climate risks (Reid & Toffel, 2009; El Ghouli et al., 2011). In discretionary regulatory environments, effective corporate management may strengthen climate reporting as a mechanism to attract environmentally conscious investors and enhance credibility (Rashid et al., 2020; Ali et al., 2024). From this perspective, powerful CEOs may leverage their authority to integrate TCFD into corporate strategy, signal resilience to capital markets, and strengthen reputational capital, thereby improving reporting quality.

In contrast, managerial power theory predicts that concentrated CEO authority may reduce incentives for transparency (Al Mamun et al., 2020). CEO duality and entrenched leadership structures can weaken board independence and impair monitoring (Fama & Jensen, 1983; Gul & Leung, 2004; Fabrizi et al., 2014). Greater ownership concentration and long tenure may increase entrenchment and encourage managerial opportunism (Cronqvist et al., 2009; Chen et al., 2019). In voluntary disclosure settings, powerful CEOs may therefore resist TCFD compliance because detailed climate reporting increases scrutiny, governance constraints, and potential litigation exposure (Christensen et al., 2021). These governance frictions may reduce the likelihood of voluntary TCFD compliance.

Importantly, the mechanisms influencing TCFD compliance may differ from those affecting reporting quality conditional on compliance. While powerful CEOs may resist initial compliance to avoid external scrutiny, once compliance occurs, concentrated authority may enable more coordinated implementation, consistent messaging, and strategic control over the depth of disclosure. Thus, CEO power may have asymmetric effects across TCFD compliance and reporting stages.

Given these competing theoretical perspectives, we formally state the following hypotheses:

H1a: There is a negative association between CEO power and voluntary TCFD compliance.

H1b: There is a positive association between CEO power and TCFD reporting quality.

3.2.2.2 TCFD Compliance and CEO Climate Support

CEO climate support is defined in this study as the explicit and voluntary public endorsement of climate action by the CEO in an official report, specifically in the CEO or Chairman letter included in the firm's annual report or standalone sustainability report. CEO climate support is measured as a binary variable equal to 1 when the CEO explicitly expresses support for climate-related initiatives such as references to climate change as a strategic priority, personal commitment to emissions reduction targets, support for climate disclosure frameworks such as TCFD, or endorsement of international climate agreements such as the Paris Agreement and 0 otherwise (Shahab et al., 2020; Amore et al., 2019).

To identify CEO climate support, we manually reviewed the CEO and chairman letters for each firm-year observation during 2017-2021, classifying statements as indicating support only when they contain explicit personal endorsement of climate action rather than generic references to environmental management or regulatory compliance. For example, CGI firm's president and CEO George D. Schindler states in the firm's 2021 CSR report: "In 2021, we made an even more ambitious pledge to reach net zero by 2030" and further notes participation in COP26 as a signatory of the United Nations Global Compact (CGI, 2021), reflecting explicit strategic commitment to climate action that is classified as CEO climate support in this study. In contrast, a statement such as "We continue to monitor our environmental performance and implement efficiency measures to reduce energy consumption" would receive a score of 0, reflecting general environmental management rather than explicit personal endorsement of climate action.

Managerial perceptions of climate risk exposure influence whether firms proactively address environmental challenges or delay organisational responses (Berkhout et al., 2006; Pinkse & Gasbarro, 2019). When executives perceive climate change as financially material and strategically urgent, they are more likely to implement climate-related initiatives and adopt transparency-enhancing reporting practices (Zhang et al., 2021). Upper Echelons theory (Hambrick & Mason, 1984) posits that organisational outcomes reflect top executives' cognitive bases, values, and experiences. CEO characteristics such as education, expertise, and personal environmental orientation shape strategic choices and disclosure behaviour (Neely et al., 2020). Empirical evidence suggests that CEOs with stronger environmental awareness or sustainability-oriented backgrounds are associated with improved environmental performance

and greater reporting transparency (Amore et al., 2019; Shahab et al., 2020). Similarly, managerial exposure to climate-related risks influences emission reduction strategies and environmental decision-making (Zhang et al., 2021).

In voluntary regulatory environments, where formal disclosure mandates are limited, the effectiveness of climate reporting initiatives may depend heavily on proactive leadership (Ali et al., 2024). Managers who recognise the urgency of climate change and perceive substantial exposure to climate-related risks are more likely to support structured frameworks such as TCFD and to engage in comprehensive reporting. Moreover, executive characteristics have been shown to influence disclosure quality, suggesting that managerial commitment may extend beyond compliance decisions to affect the depth and credibility of reporting (Plöckinger et al., 2016).

Accordingly, CEOs who demonstrate climate support and awareness are expected to increase both the likelihood of voluntary TCFD compliance and the quality of reporting conditional on compliance. Furthermore, climate-oriented CEOs may decrease the negative effect of concentrated CEO power on compliance decisions by prioritising long-term strategic resilience over short-term discretion.

We therefore state the following hypotheses:

H2a: There is a positive association between CEO climate Support and TCFD compliance.

H2b: There is a positive association between CEO climate Support and TCFD reporting quality.

H2c: CEO climate support mitigates the negative association between CEO power and voluntary TCFD compliance.

3.2.2.3 TCFD Compliance and Regulation Stringency

Political and regulatory environments play an important role in shaping corporate disclosure decisions (Pan et al., 2020). According to political economy theory, political and economic institutions influence corporate strategies and managerial behaviour (Maxwell et al., 2000). In particular, stronger regulatory quality enhances market discipline and encourages firms to provide more transparent voluntary disclosures (Cheng et al., 2006; Christensen et al., 2021), whereas weaker regulatory environments may reduce firms' incentives to disclose information

voluntarily. Accordingly, the effectiveness of a country's regulatory oversight and broader political environment can significantly influence corporate climate disclosure practices (Pour et al., 2023).

Regulatory stringency in this study refers to the strength and effectiveness of a country's national climate policy framework, including the breadth of climate legislation, the stringency of emissions reduction targets, the rigour of enforcement mechanisms, and the overall alignment of national policies with the goals of the Paris Agreement (Bolton et al., 2023). Following Chalabi-Jabado and Ziane (2024) and Bolton et al. (2023), this study employs the Climate Policy Index from the Climate Change Performance Index (CCPI) as a proxy for regulatory stringency.

In the context of voluntary TCFD compliance, regulatory stringency may alter the influence of internal governance mechanisms. When climate regulation and enforcement are strong, firms face greater external pressure to disclose climate-related information, thereby reducing the discretion associated with compliance decisions (Pour et al., 2023). Hence, the negative association between CEO power and voluntary TCFD compliance is expected to weaken, as external institutional forces constrain managerial resistance. In contrast, in less stringent regulatory environments, disclosure decisions remain highly discretionary, allowing the CEO to play a more pronounced role.

Accordingly, we state the following hypothesis:

H3: The negative association between CEO power and voluntary TCFD compliance is weaker in more stringent regulatory environments.

3.3 Research Design and Sample

This section outlines the procedures for the research design and is organised as follows: Section 3.3.1 describes the sample selection process, and the data sources used to collect parameters. Section 3.3.2 explains the proxies for measuring TCFD compliance, CEO power and control variables.

3.3.1 Sample Selection

This study examines international firms listed on the New York Stock Exchange (NYSE) and the Nasdaq during the period 2017–2021. The sample period begins with the release of the TCFD recommendations in 2017 and ends in 2021, a period during which TCFD compliance remained voluntary across jurisdictions. Focusing on this period allows us to examine firms' disclosure behaviour in the absence of mandatory climate reporting requirements, thereby capturing managerial discretion in adopting and implementing TCFD recommendations. The choice of the U.S. capital markets is driven by their maturity and significance. Recently, U.S. environmental regulations have become more stringent and prominent (Myers, 2020). Consequently, examining the level of TCFD compliance in this capital market will help determine the extent of voluntary support for climate-related initiatives. At the same time, the cross-country sample spanning 36 countries will reveal variations in legal and macro-environmental frameworks across nations, thereby helping standard-setters and future researchers focus on specific issues. Consistent with Liao et al. (2024), US-domiciled firms are excluded from the sample to ensure that inferences are not driven by the dominant presence of US observations. The detailed country-level distribution of the sample is presented in Appendix 2.D.

Data on CEO power variables are obtained from BoardEx, while firm-level financial variables are collected from the LSEG (formerly Refinitiv) database. CEO power data are manually collected from the BoardEx database, which provides detailed biographical and role information for executives and directors of listed firms worldwide. To construct the CEO duality measure, I searched the BoardEx board Profile module to identify whether the CEO also held the position of Chairman of the Board in the same firm-year, coding this as 1 when both roles were held by the same individual and 0 otherwise. CEO tenure was calculated by identifying each CEO's appointment date from the Executive Role History module and computing the number of years served up to the end of the relevant fiscal year. Finally, CEO ownership data were extracted from the BoardEx ownership module, which reports the percentage of shares held by each executive; CEOs above the sample median were coded as 1 and those below as 0.

Table 3.1 presents the sample selection process. The initial sample consists of international firms listed on the NYSE and Nasdaq. Observations with missing financial data are excluded. After applying these filters, the final sample comprises 2,353 firm-year observations

represented by 540 firms from 36 countries over the 2017–2021 period. Further, 609 firm-year observations were lost due to missing CEO power data, firstly because BoardEx did not cover international firms. Second, CEO ownership was the most frequently missing variable, as ownership disclosure requirements vary considerably across the 36 sample countries.

Table 3.1 Sample Selection Process

This table reports the sample screening process used to construct the final dataset. The initial sample consists of firms listed on the New York Stock Exchange (NYSE) and NASDAQ over the period 2017–2021. Firm-year observations with missing financial information and missing CEO power data required to compute the study variables are also removed. After applying these filters, the final sample comprises 2,353 firm-year observations representing international firms listed on U.S. exchanges.

Sample Distribution	No. of Observations
Initial sample	4,368
Less: Missing financial data	(1,406)
Less: Missing CEO power data	(609)
Final Sample	2,353

3.3.2 Variables and Model

3.3.2.1 Dependent Variables

TCFD Compliance

TCFD compliance is measured as a continuous variable to capture the degree of compliance. Specifically, a value of 0 is assigned to firm-year observations with no TCFD-aligned disclosure, while firms that provide at least one TCFD-aligned disclosure item are assigned their corresponding Climate Compliance Index (CCI) score developed by Demaria and Rigot (2021). The CCI is a structured disclosure index comprising 38 items aligned with the four pillars of the TCFD Disclosures: governance, strategy, risk management, and metrics and targets. The index captures both qualitative and quantitative disclosures and is designed to assess the extent to which firms comply with the TCFD framework's recommendations.

Using manual content analysis of annual and sustainability reports, each item is coded as 1 if the firm provides disclosure consistent with the corresponding TCFD recommendation and 0 otherwise. The total CCI score for each firm-year observation is calculated by summing the scores across all 38 items. To ensure comparability across firms, the index is scaled by dividing the total score by 38, yielding a continuous measure from 0 to 1, with higher values indicating greater compliance with TCFD recommendations.

TCFD Reporting Quality

To further distinguish the depth of disclosure, TCFD reporting quality is measured using the CCI score, following Demaria and Rigot (2021) and Di Marco et al. (2022). The CCI, as defined above, provides a comprehensive measure of firms' compliance with the TCFD recommendations. This measure is calculated only for firms that comply with TCFD disclosure, thereby capturing the quality and comprehensiveness of reporting conditional on compliance.

Following Demaria and Rigot (2021), Cronbach's alpha was calculated to assess the internal consistency of the CCI components. Cronbach's alpha assesses the extent to which items within a scale are interconnected and collectively represent the same underlying construct, with values exceeding 0.8 indicating good internal consistency (Cronbach, 1951). The resulting alpha value of 0.844 suggests good internal consistency, exceeding the commonly accepted threshold of

0.80 for strong reliability (Al-Shaer & Zaman, 2018; Hair et al., 2019). This also indicates that the components are sufficiently correlated to form a coherent measure of TCFD disclosure. Item-test correlations range from 0.79 to 0.86, indicating that each component is strongly associated with the overall scale (Al-Shaer & Zaman, 2018). While the TCFD framework captures multiple distinct disclosure dimensions, the index is treated as a composite measure of disclosure quality, and the reliability test provides supporting evidence of internal consistency.

3.3.2.2 Independent Variables

CEO Power

Measuring CEO power is challenging because it arises from multiple sources and cannot be fully captured by a single indicator. Prior research frequently relies on individual proxies such as CEO duality (Haynes & Hillman, 2010; Jiraporn & Chintrakarn, 2013) or CEO ownership (Kalyta, 2009; Lewellyn & Muller-Kahle, 2012) to represent executive authority. However, these single measures may not adequately capture the multidimensional nature of managerial power. Following Finkelstein (1992), CEO power is conceptualised as a multidimensional construct derived from several sources, including structural authority, expertise, and ownership influence.

Accordingly, consistent with Veprauskaite and Adams (2013) and Sheikh (2019), this study constructs a composite CEO power index based on three indicators reflecting different sources of executive influence: CEO duality, CEO tenure, and CEO ownership. The index captures the extent to which the CEO holds structural authority, possesses firm-specific expertise, and exercises financial influence within the firm. CEO duality represents the structural dimension of CEO power and captures the concentration of leadership authority when the CEO simultaneously serves as chair of the board (Finkelstein, 1992). This dual role increases the CEO's ability to influence board agendas and corporate decision-making. CEO duality is measured as a binary variable equal to 1 if the CEO also holds the position of board chair and 0 otherwise.

CEO tenure reflects the expert dimension of CEO power. CEOs with longer tenure accumulate firm-specific knowledge and develop stronger influence within the organisation (Veprauskaite & Adams, 2013). CEO tenure is a binary variable equal to 1 if the CEO's tenure exceeds the sample median and 0 otherwise. CEO ownership represents the ownership dimension of CEO

power. CEOs who hold substantial equity stakes may enjoy greater autonomy in corporate decision-making and increased influence over strategic policies (Martínez & Álvarez, 2024). CEO ownership is measured as a binary variable equal to 1 if the CEO's ownership exceeds the sample median and 0 otherwise.

The overall CEO power index is calculated by summing the three indicators and scaling the score by the total number of components. The resulting measure ranges from 0 to 1, with higher values indicating greater CEO power.

CEO Climate Support

CEO climate support captures the extent to which corporate leaders publicly endorse climate-related initiatives and acknowledge the importance of addressing climate risks. Consistent with the Upper Echelons perspective, which holds that executive values and beliefs influence organisational decisions, this variable reflects the CEO's expressed commitment to climate-related strategies and environmental responsibility (Hambrick & Mason, 1984). To measure CEO climate support, this study conducts a manual content analysis of leadership statements in firms' annual reports, sustainability reports, and official corporate disclosures. In particular, the analysis focuses on the CEO or Chairman's letter to shareholders, which typically communicates management's strategic priorities and organisational vision.

The coding procedure identifies statements in which the CEO explicitly supports climate-related initiatives or acknowledges the strategic importance of addressing climate change. Examples of such expressions include references to supporting climate-related initiatives, reducing greenhouse gas emissions, addressing climate-related risks, or committing to sustainability and environmental transition strategies. CEO climate support is coded as a binary variable equal to 1 if the CEO explicitly endorses climate-related initiatives or recognises the urgency of climate-related challenges, and 0 otherwise. This approach captures whether top leadership signals commitment to climate-related transparency and environmental responsibility.

3.3.2.3 Control Variables

Following prior literature on climate-related disclosure and sustainability reporting (Kouloukoui et al., 2019; Ben-Amar et al., 2015; Maji & Kalita, 2021), this study includes several firm-level and governance control variables that may influence TCFD compliance and

reporting quality. These variables capture firm characteristics, financial conditions, and governance structures that may affect voluntary disclosure decisions.

Firm Size (Size) is measured as the natural logarithm of market capitalisation (Chen et al., 2022). Larger firms tend to face greater scrutiny from investors and regulators and typically possess more resources to implement voluntary disclosure practices, including climate-related reporting (Ben-Amar et al., 2015). Therefore, this study expects a positive association between firm size and TCFD compliance.

Leverage is measured as the ratio of total debt to total assets (Cook et al., 2019). Firms with higher leverage face greater financial constraints and may have stronger incentives to signal financial stability through voluntary disclosure. Higher leverage also increases monitoring by debtholders, which may encourage more transparent reporting (Jensen & Meckling, 1976). Accordingly, this study expects a positive association between TCFD compliance and financial leverage.

Asset tangibility is measured as the ratio of property, plant, and equipment to total assets (Cook et al., 2019). Firms with higher asset tangibility may face greater exposure to physical climate risks, which can encourage more extensive disclosure of climate-related information (Clarkson et al., 2008). Hence, this study expects a positive association between asset tangibility and TCFD compliance.

Cash ratio (Cash) is measured as the ratio of cash and cash equivalents to total assets. Firms with greater liquidity may have more flexibility to invest in sustainability initiatives and related disclosure practices (Benlemlih & Bitar, 2018). Thus, this study expects a positive association between TCFD compliance and cash ratio.

Dividend payment is a binary variable equal to 1 if the firm paid dividends during the fiscal year and 0 otherwise. Dividend payment reflects the company's operational success and financial health. Dividend-paying firms may adopt greater transparency to maintain investor confidence and signal financial stability (De Villiers et al., 2024). Accordingly, a positive association between dividend payment and TCFD compliance is expected.

Loss, which reflects a firm's profitability, is a binary variable equal to 1 if net income before extraordinary items is negative and 0 otherwise (Chen et al., 2011). Firms experiencing losses may face financial constraints that limit their ability to invest in voluntary disclosure initiatives

(Maji & Kalita, 2021). Thus, a negative association is expected between loss and TCFD compliance.

Tobin's Q (TobinsQ) is used as a proxy for firm value and is calculated as the market value of equity plus total assets minus book equity, divided by total assets (Al-Hiyari et al., 2022). Firms with higher market valuations may have stronger incentives to maintain transparency and enhance reputation through voluntary disclosures (Bose et al., 2025). Hence, a positive relationship is expected between Tobin's Q and TCFD compliance.

Board size (Bsize) is measured as the natural logarithm of the number of board directors (Daradkeh et al., 2023). Larger boards may provide broader expertise and stronger monitoring, thereby enhancing environmental and sustainability disclosure (Muttakin et al., 2018). However, Lorenzo & Sanchez (2010) argue that a larger board leads to greater diversity in experience and opinions, which may result in a lack of consensus on voluntary disclosure decisions. This study follows Muttakin et al. (2018) and expects a positive association between board size and TCFD compliance.

Appendix 3.A summarises the measurement and data sources for all variables used in the current chapter.

3.4 Empirical Results

This section begins by presenting the univariate analysis of the study variables. It then reports the results of the multivariate analysis examining the relationship between CEO power and the likelihood of TCFD compliance (H1a). Next, the analysis investigates the association between CEO power and the quality of TCFD reporting (H1b). This section further examines the role of CEO climate support in influencing TCFD compliance and reporting quality (H2a and H2b), and its moderating effect on the relationship between CEO power and TCFD compliance (H2c). Finally, additional sensitivity analyses are conducted to assess the robustness of the main findings.

Table 3.2 reports summary statistics for all current study variables for the period 2017 to 2021. The mean of TCFD compliance (TCFD) is 0.13, indicating that climate-related financial disclosure remains relatively limited across the sample, with a median of 0, suggesting that many firms do not comply with TCFD reporting during the sample period. These results align with the findings reported by Maji and Kalita (2021) and Ding et al. (2023) regarding low TCFD compliance rates. Regarding the reporting quality of TCFD compliers, the average reporting quality (TCFDQ) is 0.68, indicating that adopting firms comply with approximately 68% of the disclosure items included in the Climate Compliance Index. These results are consistent with Braasch and Velte (2023) regarding TCFD reporting based on a global sample.

The average CEO power score is 0.58, suggesting a moderate concentration of managerial authority within the sampled firms, while CEO climate support is observed in approximately 27% of the firm-year observations. Regarding firm characteristics, average firm size is 14.7, and the mean leverage ratio is 0.24, indicating moderate reliance on debt financing. Asset tangibility and cash holdings average 0.29 and 0.25 of total assets, respectively, reflecting variation in firms' asset structure and liquidity positions. Additionally, approximately 63% of firms pay dividends, while 22% report losses during the sample period. Finally, the mean Tobin's Q is 2.49, and the average board size is 9 directors, consistent with values reported in prior corporate governance and voluntary disclosure studies (Bose et al., 2025).

Table 3.3 reports the Pearson correlation matrix for the main variables used in the empirical analysis. The table presents pairwise correlations among the dependent variable (TCFD

compliance), the key explanatory variables (CEO power and CEO climate support), and the control variables. Consistent with the theoretical expectations, TCFD compliance is negatively correlated with CEO power and positively correlated with CEO climate support. This indicates that firms whose CEOs publicly support climate initiatives tend to exhibit higher compliance levels of climate-related disclosure, whereas greater CEO power is associated with lower disclosure. TCFD compliance is also positively associated with firm size, board size, leverage, asset tangibility, and dividend payments, suggesting that firms with stronger governance structures and greater resources tend to exhibit higher levels of climate-related disclosure compliance. In contrast, firms with higher cash holdings or experiencing financial losses tend to display lower levels of TCFD compliance. The correlations among the explanatory variables are generally moderate, suggesting that multicollinearity is unlikely to bias the regression estimates. This conclusion is further supported by the variance inflation factors (VIFs), which range from 1.05 to 2.05, well below the commonly accepted threshold of 10.

Prior to estimating the regression models, diagnostic tests were conducted to assess the assumptions underlying the regression analysis. The Modified Wald test is employed to assess heteroscedasticity, while the Wooldridge test for panel data was used to detect first-order serial correlation. The results indicate significant heteroscedasticity ($p < 0.01$) and serial correlation ($F = 67.16$, $p < 0.01$) in the residuals. To address these issues and ensure reliable statistical inference, all regression models are estimated using robust standard errors clustered at the firm level, which correct for both heteroscedasticity and within-firm serial correlation.

Table 3.2 Descriptive Statistics

This table presents the descriptive statistics for the main variables used in the analysis based on 2,353 firm-year observations from 2017 to 2021. The table reports the number of observations, mean, standard deviation, minimum, 25th percentile, median, 75th percentile, and maximum values for all variables. TCFD is measured as 0 for non-complying firms and the CCI score for complying firms, while TCFDQ captures the quality of TCFD reporting and is calculated only for firms that comply with TCFD-related disclosure. CEO Power is measured as a composite index based on CEO duality, tenure, and ownership. CEO Climate Support is a binary variable equal to one when the CEO explicitly expresses support for climate-related initiatives. The control variables include firm size (log market capitalisation), leverage (total debt scaled by total assets), asset tangibility (PPE scaled by total assets), cash ratio (cash scaled by total assets), Tobin's Q (the market value of equity plus assets minus equity relative to assets), dividend payment, loss, and board size (number of board directors). All continuous variables are winsorised at the 1st and 99th percentiles to mitigate the influence of outliers. Detailed variable definitions are provided in Appendix 3.A.

Variables	N	Mean	SD	Min	p25	Median	p75	Max
TCFD	2,353	0.13	0.28	0.00	0.00	0.00	0.00	0.97
TCFDQ	468	0.68	0.18	0.02	0.55	0.73	0.82	0.97
CEO_power	2,353	0.58	0.29	0.00	0.33	0.66	0.66	1.00
CEO_support	2,353	0.27	0.44	0.00	0.00	0.00	1.00	1.00
Size	2,353	14.7	2.34	8.97	13.0	14.8	16.3	18.9
Leverage	2,353	0.24	0.22	0.02	0.03	0.21	0.38	0.69
Tangibility	2,353	0.29	0.27	0.03	0.06	0.19	0.46	0.88
Cash	2,353	0.25	0.23	0.02	0.05	0.15	0.35	0.58
Dividend	2,353	0.63	0.48	0.00	0.00	1.00	1.00	1.00
Loss	2,353	0.22	0.41	0.00	0.00	0.00	0.00	1.00
TobinsQ	2,353	2.49	2.35	0.55	1.11	1.61	2.87	11.40
Bsize	2,353	9.16	2.83	3.00	7.00	9.00	10.0	23.0

Table 3.3 Pearson Correlation Matrix

This table presents the Pearson correlation matrix for the main variables used in the analysis based on 2,353 firm-year observations from 2017 to 2021. TCFD is measured as 0 for non-complying firms and the CCI score for complying firms. TCFDQ is excluded from the correlation matrix because it is defined only for complying firms and represents a conditional measure of disclosure quality, making it not directly comparable across the full sample. CEO Power is measured as a composite index based on CEO duality, tenure, and ownership. CEO Climate Support is a binary variable equal to one when the CEO explicitly expresses support for climate-related initiatives. The control variables include firm size (log market capitalisation), leverage (total debt scaled by total assets), asset tangibility (PPE scaled by total assets), cash ratio (cash scaled by total assets), Tobin's Q (the market value of equity plus assets minus equity relative to assets), dividend payment, loss, and board size (log number of board directors). To further assess potential multicollinearity concerns, variance inflation factors (VIF) are also reported. All continuous variables are winsorised at the 1st and 99th percentiles to mitigate the influence of outliers. Detailed variable definitions are provided in Appendix 3.A.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) TCFD	1										
(2) CEO_power	-0.206***	1									
(3) CEO_support	0.561***	-0.139***	1								
(4) Size	0.473***	-0.135***	0.437***	1							
(5) Leverage	0.060***	-0.064***	0.061***	0.078***	1						
(6) Tangibility	0.193***	0.024	0.290***	0.264***	0.079***	1					
(7) Cash	-0.253***	0.062***	-0.299***	-0.463***	-0.238***	-0.521***	1				
(8) Dividend	0.288***	-0.084***	0.266***	0.455***	0.083***	0.195***	-0.366***	1			
(9) Loss	-0.179***	0.058***	-0.181***	-0.428***	-0.050**	-0.095***	0.334***	-0.547***	1		
(10) TobinsQ	-0.048**	-0.059***	-0.071***	-0.226***	0.123***	-0.120***	0.103***	0.02	0.013	1	
(11) Bsize	0.313***	-0.130***	0.253***	0.459***	0.017	0.084***	-0.261***	0.199***	-0.130***	-0.084***	1
VIF		1.05	1.32	2.05	1.09	1.47	1.84	1.63	1.57	1.11	1.33

3.4.1 Multivariate Analysis

This section presents the multivariate analysis examining the association between CEO power and voluntary TCFD compliance. Specifically, the analysis investigates the association between CEO power and both TCFD compliance and the quality of TCFD disclosure. In addition, the models examine whether CEO climate support moderates the relationship between CEO power and TCFD compliance.

The baseline models are estimated using fixed-effects ordinary least squares (OLS) regressions. Robust standard errors, clustered at the firm level, are used to address potential heteroscedasticity and serial correlation in the panel data. Consistent with prior studies (e.g., Veprauskaite and Adams, 2013; Sheikh, 2019), the regressions include year, industry, and country fixed effects to control for unobserved heterogeneity across firms and over time. Controlling for these fixed effects is particularly important because climate disclosure practices may vary systematically across industries and institutional environments (Lin et al., 2021).

All continuous variables are winsorised at the 1st and 99th percentiles to mitigate the influence of extreme observations. This section is organised as follows. Section 3.4.1.1 presents the model specifications used to test the hypotheses, while Section 3.4.1.2 reports and discusses the baseline regression results.

3.4.1.1 Model Specifications

To test the first and second hypotheses, this study estimates regression models examining the association between CEO power, CEO climate support, and TCFD compliance. The baseline model investigates whether CEO power influences firms' likelihood of TCFD compliance. The empirical specification is presented as follows:

$$\begin{aligned} TCFD_{i,t} = & \beta_0 + \beta_1 CEO_power_{i,t} + \beta_2 Size_{i,t} + \beta_3 Leverage_{i,t} + \beta_4 Tangibility_{i,t} + \\ & \beta_5 Cash_{i,t} + \beta_6 Dividend_{i,t} + \beta_7 Loss_{i,t} + \beta_8 TobinQ_{i,t} + \beta_9 Bsize_{i,t} + IndustryFE + \\ & CountryFE + YearFE + \epsilon_{i,t} \end{aligned} \quad (3.1)$$

To examine whether CEO climate support moderates the relationship between CEO power and TCFD compliance, the following interaction model is estimated:

$$\begin{aligned}
TCFD_{i,t} = & \beta_0 + \beta_1 CEO_power_{i,t} + \beta_2 CEO_support_{i,t} + \beta_3 (CEO_power_{i,t} \times \\
& CEO_support_{i,t}) + \beta_4 Size_{i,t} + \beta_5 Leverage_{i,t} + \beta_6 Tangibility_{i,t} + \beta_7 Cash_{i,t} + \\
& \beta_8 Dividend_{i,t} + \beta_9 Loss_{i,t} + \beta_{10} TobinQ_{i,t} + \beta_{11} Bsize_{i,t} + IndustryFE + CountryFE + \\
& YearFE + \epsilon_{i,t}
\end{aligned} \tag{3.2}$$

Where TCFD represents the level of TCFD compliance and equals the Climate Compliance Index (CCI) score when a firm reports climate-related financial disclosure in accordance with the TCFD recommendations, and zero otherwise. CEO_power is defined as the ratio of index composites of three variables related to power: CEO duality, tenure and stock ownership. CEO_support represents CEO climate support, equal to 1 if the CEO supports climate change initiatives and 0 otherwise. Other independent variables represent control variables defined in Appendix 3.A. Finally, industry, country, and year fixed effects have been included to account for potential heterogeneity and enhance the reliability of the results (Lin et al., 2021).

To examine the determinants of TCFD reporting quality, the following models are estimated using the subsample of firms that comply with TCFD disclosure:

$$\begin{aligned}
TCFDQ_{i,t} = & \beta_0 + \beta_1 CEO_power_{i,t} + \beta_2 Size_{i,t} + \beta_3 Leverage_{i,t} + \beta_4 Tangibility_{i,t} + \\
& \beta_5 Cash_{i,t} + \beta_6 Dividend_{i,t} + \beta_7 Loss_{i,t} + \beta_8 TobinQ_{i,t} + \beta_9 Bsize_{i,t} + IndustryFE + \\
& CountryFE + YearFE + \epsilon_{i,t}
\end{aligned} \tag{3.3}$$

$$\begin{aligned}
TCFDQ_{i,t} = & \beta_0 + \beta_1 CEO_power_{i,t} + \beta_2 CEO_support_{i,t} + \beta_3 (CEO_power_{i,t} \times \\
& CEO_support_{i,t}) + \beta_4 Size_{i,t} + \beta_5 Leverage_{i,t} + \beta_6 Tangibility_{i,t} + \beta_7 Cash_{i,t} + \\
& \beta_8 Dividend_{i,t} + \beta_9 Loss_{i,t} + \beta_{10} TobinQ_{i,t} + \beta_{11} Bsize_{i,t} + IndustryFE + CountryFE + \\
& YearFE + \epsilon_{i,t}
\end{aligned} \tag{3.4}$$

Where TCFDQ represents TCFD reporting quality measured using the Climate Compliance Index (CCI) developed by Demaria and Rigot (2021), and other independent variables represent control variables defined in Appendix 3.A.

3.4.1.2 Main Results

3.4.1.2.1 Results of Estimating the Association between CEO Power, CEO Climate Support and TCFD Compliance

Table 3.4 reports the results of the OLS regression examining the relationship between CEO power and voluntary TCFD compliance (Model 1). Additionally, it reports the results of investigating the moderating effect of CEO climate support on the association between CEO power and TCFD compliance (Model 2). The results reported in Model (1) indicate that CEO power is negatively and significantly associated with TCFD compliance. Specifically, the magnitude of the coefficient ($\beta = -0.11$) suggests that higher levels of CEO power are associated with a reduction in the extent of climate-related disclosure, indicating that more powerful CEOs tend to provide less comprehensive TCFD-aligned reporting. This result supports H1a and is consistent with the managerial power perspective, which argues that powerful executives may avoid transparency when disclosure imposes costs, increases scrutiny, or constrains managerial discretion (Bebchuk et al., 2002; Bose et al., 2025). In terms of economic significance, a one-standard deviation increase in CEO power is associated with a decrease of 0.032 in TCFD compliance, suggesting that CEO power has a meaningful impact on firms' voluntary climate reporting decisions. The findings are also consistent with prior literature suggesting that powerful CEOs may pursue private benefits, influence compensation structures, and reduce disclosure transparency, reflecting agency-related concerns (Bhandari & Javakhadze, 2017).

Model (2) introduces CEO climate support and the interaction term between CEO power and CEO climate support. The results show that CEO climate support is positively and significantly associated with TCFD compliance ($\beta = 0.28$), supporting H2a and indicating that firms whose CEOs publicly support climate initiatives are more likely to comply with climate-related reporting practices. This result supports the upper echelons theory and is consistent with Shahab et al. (2020) and Amore et al. (2019), who argue that CEOs with more environmental awareness are associated with improved environmental performance and greater reporting transparency. However, the interaction between CEO power and CEO climate support is negative and statistically significant ($\beta = -0.148$, $p < 0.01$), suggesting that the positive effect of CEO climate support on TCFD compliance weakens as CEO power increases. In other words, although climate-supportive CEOs tend to promote greater transparency, the concentration of decision-making authority limits the extent to which these preferences translate into voluntary disclosure decisions. This finding is contrary to the prediction of H2c, which proposed that CEO climate support would mitigate the negative association between CEO power and TCFD compliance. Instead, the results suggest that CEO power dominates personal climate orientation when authority is sufficiently concentrated, consistent with the

managerial power perspective (Bebchuk et al., 2002). This finding contributes to the upper echelons literature by demonstrating that personal executive values do not always outweigh structural governance incentives. The effectiveness of climate-oriented leadership in promoting disclosure is influenced by the governance environment in which the CEO operates.

Regarding the control variables, firm size, dividend payment, Tobin's Q, and board size exhibit positive, statistically significant associations with TCFD compliance, indicating that larger firms, firms paying dividends, firms with higher market valuation, and firms with larger boards tend to provide more extensive climate-related disclosures. These findings align with Sheikh's (2019) results. Other control variables, including leverage, tangibility, cash holdings, and losses, do not show statistically significant relationships with TCFD compliance. Finally, the explanatory power of the model improves after including the moderating variable, with the R-squared increasing from 0.39 in Model (1) to 0.47 in Model (2), suggesting that CEO climate support helps explain variation in firms' voluntary climate disclosure behaviour.

Table 3.4 The Association between CEO Power, CEO Climate Support and Voluntary TCFD Compliance

This table reports the baseline regression results examining the relationship between CEO power and voluntary TCFD compliance. Model (1) presents the baseline specification testing the association between CEO power and TCFD compliance. Model (2) extends the baseline model by incorporating CEO climate support and the interaction between CEO power and CEO climate support to examine the moderating role of managerial climate orientation. TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. CEO Power is measured as a composite index based on CEO duality, tenure, and ownership. CEO Climate Support is a binary variable equal to one when the CEO explicitly expresses support for climate-related initiatives. The control variables include Size (log market capitalisation), leverage (total debt scaled by total assets), asset tangibility (PPE scaled by total assets), cash ratio (cash scaled by total assets), Tobin's Q (the market value of equity plus assets minus equity relative to assets), dividend payment, loss, and board size (log number of board directors). All regressions include year, industry, and country fixed effects to control for unobservable heterogeneity across time, industries, and institutional environments. Standard errors are clustered at the firm level to address potential heteroskedasticity and serial correlation. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively. Variable definitions are reported in Appendix 3.A.

VARIABLES	(1) TCFD	(2) TCFD
CEO_power	-0.112*** (-4.819)	-0.049** (-2.459)
CEO_support		0.283*** (7.787)
CEO_supportxCEO_power		-0.148*** (-2.925)
Size	0.038*** (9.359)	0.028*** (7.154)
Leverage	-0.004 (-0.025)	0.006 (0.220)
Tangibility	0.049 (1.296)	0.017 (0.487)
Cash	-0.014 (-0.474)	-0.007 (-0.255)
Dividend	0.074*** (5.244)	0.055*** (4.168)
Loss	0.009 (0.678)	0.016 (1.301)
TobinsQ	0.027** (2.143)	0.026** (2.235)
Bsize	0.094*** (4.145)	0.070*** (3.396)
Intercept	-0.645*** (-7.980)	-0.521*** (-7.140)
Observations	2,353	2,353
Adj. R ²	0.392	0.475
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

3.4.1.2.2 Results of Estimating the Association between CEO Power, CEO Climate Support and TCFD Reporting Quality

Table 3.5 reports the results of the OLS regression examining the relationship between CEO power and voluntary TCFD reporting quality (Model 1). Additionally, it reports the results of investigating the moderating effect of CEO climate support on the association between CEO power and TCFD quality (Model 2). The results reported in Model (1) indicate that CEO power is positively associated with TCFD reporting quality ($\beta = 0.083$, $p < 0.05$). This finding suggests that among firms that comply with the TCFD framework, those led by more powerful CEOs tend to provide more comprehensive climate-related disclosures. This result implies that while powerful CEOs may exercise discretion over whether to comply with voluntary climate reporting, they may enhance the quality of disclosure once such reporting is undertaken. This result supports Hypothesis H1b, which posits an association between CEO power and the quality of TCFD reporting. This result is consistent with stewardship theory (Davis et al., 1997) and prior evidence suggesting that powerful CEOs who choose to engage with voluntary reporting frameworks can leverage their authority to commit organisational resources, ensure consistent messaging, and produce more comprehensive disclosures (Adams & Ferreira, 2007; Ali et al., 2024).

Model (2) introduces CEO climate support and the interaction term between CEO power and CEO climate support. The results show that CEO climate support is positively and significantly associated with TCFD reporting quality ($\beta = 0.223$, $p < 0.05$), supporting H2b and indicating that firms with climate-supportive CEOs tend to produce more comprehensive climate-related disclosures. This finding is consistent with the upper echelons theory, which suggests that executives' personal values and environmental awareness shape strategic decisions, including disclosure quality (Hambrick & Mason, 1984). The interaction between CEO power and CEO climate support is negative but statistically insignificant ($\beta = -0.138$), indicating that CEO climate support does not significantly moderate the relationship between CEO power and TCFD reporting quality. This result does not support H2c in the quality context and suggests that once firms comply with TCFD, the depth of reporting is driven more by internal reporting processes and organisational capabilities than by the interplay between CEO authority and personal climate orientation.

Regarding the control variables, firm size is positively and significantly associated with TCFD reporting quality in both models, suggesting that larger firms possess greater resources and face stronger stakeholder scrutiny, which encourages more comprehensive climate reporting. Board size is similarly positive and significant, indicating that larger boards provide broader expertise and stronger oversight, thereby enhancing disclosure depth. Dividend payments are positively associated with quality in Model (2), reflecting the tendency of financially stable firms to maintain higher standards of voluntary reporting. Other control variables, including leverage, tangibility, cash holdings, financial losses, and Tobin's Q, do not exhibit statistically significant associations with TCFD reporting quality, suggesting that financial characteristics play a limited role in determining disclosure depth among complying firms. The adjusted R^2 values of 0.322 and 0.335 indicate moderate explanatory power, consistent with prior studies examining the quality of voluntary disclosure (Li et al., 2018; Ali et al., 2024).

Table 3.5 The Association between CEO Power, CEO Climate Support and Voluntary TCFD Disclosure Quality

This table reports the regression results examining the relationship between CEO power and TCFD disclosure quality. Model (1) presents the results of the association between CEO power and TCFD disclosure quality. Model (2) extends the baseline model by incorporating CEO climate support and the interaction between CEO power and CEO climate support to examine the moderating role of managerial climate orientation. TCFDQ is measured using the CCI for complying firms, and CEO Power is measured as a composite index based on CEO duality, tenure, and ownership. CEO Climate Support is a binary variable that equals 1 when the CEO explicitly expresses support for climate-related initiatives. The control variables include firm size (log market capitalisation), leverage (total debt scaled by total assets), asset tangibility (PPE scaled by total assets), cash ratio (cash scaled by total assets), Tobin's Q (the market value of equity plus assets minus equity relative to assets), dividend payment, loss, and board size (log number of board directors). All regressions include year, industry, and country fixed effects to control for unobservable heterogeneity across time, industries, and institutional environments. Standard errors are clustered at the firm level to address potential heteroskedasticity and serial correlation. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively. Variable definitions are reported in Appendix 3.A.

VARIABLES	(1) TCFDQ	(2) TCFDQ
CEO_power	0.083** (2.082)	0.096* (1.752)
CEO_support		0.223** (2.247)
CEO_supportxCEO_power		-0.138 (-0.685)
Size	0.047*** (4.790)	0.058** (1.989)
Leverage	-0.113* (-1.656)	-0.143 (-0.645)
Tangibility	0.128** (2.071)	0.028 (0.037)
Cash	0.085 (0.764)	-0.108 (-0.292)
Dividend	0.000 (0.921)	0.192** (2.384)
Loss	-0.013 (-0.367)	-0.115 (-1.471)
TobinsQ	0.076 (0.961)	-0.152 (-0.701)
Bsize	0.104** (2.172)	0.294** (2.055)
Intercept	-0.492*** (-3.027)	-0.440** (-2.185)
Observations	468	468
Adj. R ²	0.322	0.335
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

3.4.1.3 The Moderation Effect of Country's Regulatory Environment

To capture cross-country variation in climate regulation and align with Chalabi-Jabado and Ziane (2024) and Bolton et al. (2023), this study employs the Climate Policy Index from the Climate Change Performance Index (CCPI) as a proxy for climate policy stringency. This index evaluates a country's commitment and progress in implementing effective climate policies consistent with the goals of the Paris Agreement (Burck et al., 2020).

In addition to cross-country regulatory differences, the United States' political environment provides a useful setting for examining how changes in policy priorities may influence firms' climate disclosure behaviour. During the Trump administration (2017–2020), climate policy was characterised by a more sceptical and deregulatory stance, including the U.S. withdrawal from the Paris Agreement in 2017. This environment may have reduced pressure on firms to prioritise climate-related reporting. In contrast, the Biden administration (2021–2022) has emphasised stronger climate action, including the U.S. re-joining the Paris Agreement and promoting climate-related regulatory initiatives. This shift may increase pressure on firms to align with climate initiatives and enhance transparency regarding climate-related risks (Bourveau et al., 2025).

Accordingly, Table 3.6 examines whether regulatory environments moderate the relationship between CEO power and voluntary TCFD compliance. Column (1) reports results using the CCPI climate policy index, while Columns (2) and (3) present subsample analyses distinguishing between the Trump administration (2017–2020) and the Biden administration (2021).

The results of Table 3.6 show that across all models, the coefficient on CEO power is negative and statistically significant. In Column (1), CEO power is negatively associated with TCFD compliance ($\beta = -0.15$, $p < 0.10$), suggesting that firms led by more powerful CEOs are less likely to comply with the TCFD framework. This finding supports the managerial power perspective, which argues that powerful CEOs may resist voluntary disclosure that could increase external monitoring and limit managerial discretion. Column (1) further shows that climate policy stringency has a negative and significant coefficient, indicating that firms operating in jurisdictions with stronger climate policy environments are less likely to comply with the TCFD voluntarily. This can be explained as; in jurisdictions with stronger mandatory climate regulations, firms may meet their disclosure obligations through regulatory compliance

rather than voluntary frameworks such as TCFD. In other words, firms in stricter regulatory environments may rely on mandatory reporting requirements to meet stakeholder expectations for climate transparency, reducing the need to voluntarily comply with frameworks such as TCFD (Christensen et al., 2021). However, the interaction between climate policy and CEO power is positive and statistically significant. This result supports H3 and suggests that stronger climate policy environments mitigate the negative effect of CEO power on TCFD compliance, implying that stricter regulatory environments constrain managerial discretion and encourage greater transparency in climate-related disclosure. This finding aligns with Pan et al. (2020), arguing that stronger regulatory quality enhances market discipline and transparency norms.

Columns (2) and (3) examine whether the association between CEO power and TCFD compliance differs across political periods. The results indicate that the negative relationship between CEO power and TCFD compliance persists during both administrations. Specifically, the coefficient on CEO power is ($\beta = -0.09$) during the Trump period and ($\beta = -0.17$) during the Biden period. These findings suggest that firms led by powerful CEOs are less likely to comply with the TCFD framework regardless of the political environment. However, the magnitude of the coefficient is larger during the Biden period, implying that even in a political environment characterised by stronger climate policy initiatives and greater regulatory pressure, powerful CEOs may remain reluctant to comply with voluntary climate disclosure practices. In other words, the political environment alone does not appear sufficient to offset the influence of CEO power on disclosure decisions.

Overall, the results indicate that CEO power consistently reduces the likelihood of voluntary TCFD compliance. At the same time, stronger climate policy environments partially constrain this negative effect, highlighting the important role of institutional and regulatory pressures in shaping corporate climate disclosure decisions. These results align with the arguments of Kouloukoui et al. (2019) and Bourveau et al. (2025).

Table 3.6 Moderating Effect of the Regulatory Environment on the Association between CEO Power and TCFD Compliance

This table presents the results examining the moderating role of the regulatory environment in the relationship between CEO power and voluntary TCFD compliance. Column (1) reports the baseline specification, including the interaction between CEO power and the climate policy index to capture cross-country variation in climate regulatory stringency. Columns (2) and (3) provide additional analyses by splitting the sample according to political periods, distinguishing between the Trump administration (2017–2020) and the Biden administration (2021). TCFD is measured as 0 for non-complying firms and the CCI score for complying firms, and CEO Power is measured as a composite index based on CEO duality, tenure, and ownership. CEO Climate Support is a binary variable equal to one when the CEO explicitly expresses support for climate-related initiatives. The control variables include firm size (log market capitalisation), leverage (total debt scaled by total assets), asset tangibility (PPE scaled by total assets), cash ratio (cash scaled by total assets), Tobin's Q (the market value of equity plus assets minus equity relative to assets), dividend payment, loss, and board size (log number of board directors). All regressions are estimated using OLS with industry, year, and country fixed effects. Standard errors are clustered at the firm level to address potential heteroskedasticity and serial correlation. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively. Variable definitions are reported in Appendix 3.A.

VARIABLES	(1) TCFD	(2) TCFD	(3) TCFD
CEO_power	-0.153*** (-4.960)	-0.091*** (-4.106)	-0.179*** (-3.846)
Climate Policy	-0.061*** (-2.721)		
Climate PolicyxCEO_power	0.082** (2.552)		
Size	0.047*** (9.384)	0.031*** (7.861)	0.071*** (9.518)
Leverage	-0.022 (-0.069)	0.011 (0.056)	-0.034 (-0.437)
Tangibility	0.059 (1.233)	0.051 (1.398)	0.048 (0.645)
Cash	-0.017 (-0.478)	0.017 (0.258)	-0.055 (-0.902)
Dividend	0.078*** (5.203)	0.079*** (5.304)	0.105*** (3.018)
Loss	0.019 (0.498)	0.029 (1.350)	-0.015 (-0.172)
TobinsQ	0.037** (2.295)	0.028 (1.578)	0.061** (1.973)
Bsize	0.098*** (4.223)	0.082*** (3.938)	0.131*** (2.989)
Intercept	-0.612*** (-7.351)	-0.566*** (-7.286)	-1.057*** (-7.515)
Observations	2,353	1,807	546
Adj. R ²	0.412	0.402	0.529
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes

3.4.2 Endogeneity and Sample Selection Bias

Potential endogeneity and sample selection bias may affect the validity of the empirical results (Veprauskaite & Adams, 2013). Endogeneity may arise from reverse causality, omitted variable bias, or unobserved firm characteristics that simultaneously influence CEO power and firms' climate disclosure decisions. In addition, because the analysis of TCFD reporting quality is limited to firms that voluntarily comply with the TCFD framework, the sample may suffer from selection bias. To address these concerns, this study employs two complementary approaches. First, following Sheikh (2019), a two-stage Heckman selection model is implemented to address potential sample selection bias in the analysis of TCFD reporting quality. Second, a Two-Stage Least Squares (2SLS) instrumental variable approach is used to mitigate potential endogeneity between CEO power and TCFD compliance. These methods help ensure that the reported results are not driven by selection bias or endogeneity concerns.

Heckman Selection Model

This study employs the Heckman (1979) two-stage selection model to address potential sample selection bias in the analysis of TCFD reporting quality. Because the quality analysis is conducted only for the 468 firm-year observations that voluntarily comply with the TCFD framework, complying firms may differ systematically from non-complying firms in unobservable ways, potentially biasing the estimated relationship between CEO power and TCFD reporting quality.

To implement the Heckman procedure, the first stage estimates a probit selection model in which the binary TCFD compliance indicator is regressed on the exclusion restriction variable and control variables. Following Daradkeh et al. (2023), this study employs TCFD_IND, defined as the industry-year average TCFD compliance within the same country, excluding the focal firm, as the exclusion restriction. This variable captures industry-level disclosure pressure and reflects the tendency of firms within the same industry and regulatory environment to exhibit similar disclosure practices due to comparable market conditions, stakeholder expectations, and regulatory pressures (Benlemlih & Bitar, 2018). TCFD_IND is expected to predict a firm's likelihood of TCFD compliance, satisfying the relevance condition, while being unlikely to directly affect the focal firm's reporting quality, satisfying the exclusion restriction.

CEO power is excluded from the selection equation, consistent with (Heckman, 1979; Sheikh, 2019), because including the primary explanatory variable in both the selection and outcome

equations would create multicollinearity between the inverse mills ratio and CEO power, preventing separate identification of CEO power's independent effect on TCFD reporting quality. The selection equation instead uses TCFD_IND as the exogenous exclusion restriction, allowing CEO power's effect to be cleanly identified in the outcome equation after correcting for selection bias.

In the second stage, TCFD reporting quality (TCFDQ) is regressed on CEO power, the IMR, and the control variables among the 468 complying firm-year observations. Including the IMR in the outcome equation corrects for the selection bias arising from firms' voluntary compliance decisions. Table 3.7 reports the results of the two-stage Heckman estimation.

As shown in Table 3.7, Column 1 presents the selection equation, which estimates the likelihood of TCFD compliance. The results confirm that TCFD_IND is positive and highly significant ($\beta = 6.363$, $p < 0.01$), indicating that firms in industries where peers adopt TCFD are significantly more likely to comply with the framework themselves. This finding supports the argument that industry-level peer effects and disclosure norms influence firms' voluntary climate reporting decisions (Daradkeh et al., 2023). The results also show that larger firms with stronger governance structures and better market valuation are more likely to engage in voluntary climate disclosure, while firms experiencing financial losses are less likely to comply with TCFD.

Column 2 presents the outcome equation for TCFD reporting quality (TCFDQ) among the 468 complying firm-year observations. The results show that CEO power is positively and significantly associated with TCFD reporting quality ($\beta = 0.099$, $p < 0.05$), suggesting that although powerful CEOs are less likely to comply with the TCFD framework voluntarily, they tend to provide more comprehensive climate disclosures once adoption occurs. This finding is consistent with H2b and confirms the positive effect of CEO power on TCFD quality, after correcting for self-selection bias. The IMR coefficient is statistically insignificant ($\beta = -0.024$), indicating that selection bias does not materially affect the relationship between CEO power and TCFD reporting quality and validating the reliability of the baseline quality estimates without Heckman correction.

Table 3.7 Heckman Selection Model

This table reports the results of Heckman's (1979) two-stage analysis to address the self-selection issue. The selection equation uses a binary indicator of TCFD compliance (TCFD_binary) as the dependent variable. The industry-year average of TCFD in the same country is employed as an instrumental variable. In the second stage, the inverse Mills ratio derived from the selection equation is included in the outcome regressions to correct for potential selection bias when examining the relationship between CEO power and TCFD reporting quality. All regressions are estimated with industry, year, and country fixed effects, with standard errors clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively. Variable definitions are reported in Appendix 3.A.

VARIABLES	Selection Equation (TCFD_binary)	Outcome Equation (TCFDQ)
CEO_power		0.099** (2.037)
TCFD_IND	6.363*** (9.039)	
Size	0.780*** (11.251)	0.039** (2.390)
Leverage	-0.171 (-0.343)	-0.122 (-1.233)
Tangibility	0.631 (1.434)	0.115 (1.221)
Cash	-1.171 (-1.578)	0.170 (1.264)
Dividend	0.861*** (3.686)	0.060* (1.887)
Loss	-0.525** (-2.092)	0.007 (0.161)
TobinsQ	1.131*** (3.343)	0.087 (0.912)
Bsize	1.092*** (2.958)	0.073 (1.252)
INV_Mills		-0.024 (-0.857)
Intercept	-24.367*** (-13.718)	-0.334 (-1.163)
Observations	2,353	468
Adj. R ²		0.445
Pseudo R ²	0.55	
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

Two-Stage Least Squares (2SLS)

To address potential endogeneity concerns arising from reverse causality and omitted variables, this study employs a Two-Stage Least Squares (2SLS) instrumental variable approach. Endogeneity may arise if CEO power influences firms' decisions to comply with TCFD disclosure. At the same time, firms with weaker climate disclosure practices may also be more likely to appoint or retain powerful CEOs. This simultaneity may bias the estimated relationship between CEO power and TCFD compliance.

Following Demerjian et al. (2020) and Daradkeh et al. (2023), this study uses the industry–country average CEO power excluding the focal firm (*Pow_Avg*) as an instrumental variable. Specifically, *Pow_Avg* is calculated as the average CEO power of other firms operating in the same industry and country-year, excluding the firm under consideration. This approach avoids mechanical correlation between the instrument and the firm's own CEO power and captures peer effects, governance norms, and industry practices that may influence CEO power. Accordingly, *Pow_Avg* is expected to be correlated with a firm's CEO power while remaining unlikely to directly affect its TCFD compliance decision, thereby satisfying the relevance and exclusion restriction conditions for a valid instrument.

The 2SLS estimation is conducted in two stages. In the first stage, CEO power is regressed on the instrumental variable (*Pow_Avg*) and the set of control variables included in the baseline model. In the second stage, TCFD compliance is regressed on the predicted CEO power values from the first stage, along with the control variables. This procedure isolates exogenous variation in CEO power and mitigates potential endogeneity bias. Table 3.8 reports the results of the 2SLS analysis.

As reported in Table 3.8, the first-stage results in Column (1) show that the instrumental variable *Power_AVG* is positively and significantly associated with CEO power. This finding supports the instrument's relevance condition, indicating that CEO power within a firm is strongly influenced by the average level of CEO power across peer firms operating in the same industry and country. This result is consistent with Daradkeh et al. (2023). Additionally, the F-statistic value is 14.1 in the first model. According to Stock et al. (2002), A high F-statistic value indicates that our instrumental variable is strong. Regarding the second-stage results reported in Column (2), the coefficient on the predicted CEO power variable (*Power_predict*) remains negatively associated with TCFD compliance, with a substantially larger magnitude

compared to the baseline OLS estimates, potentially due to omitted variable bias. This result indicates that greater CEO power reduces the likelihood of voluntary TCFD compliance, consistent with the earlier baseline findings. The magnitude of the coefficient indicates that firms led by more powerful CEOs are significantly less likely to comply with climate-related disclosure practices. The Durbin–Wu–Hausman test fails to reject the null hypothesis that CEO power is exogenous ($F = 0.19$, $p = 0.663$). This result suggests that endogeneity may not be a serious concern in the baseline regressions.

The results of the control variables are broadly consistent with the baseline findings. Firm size and board size remain positively and significantly associated with TCFD compliance, confirming that larger firms and firms with larger boards engage more extensively with voluntary climate disclosure. Dividend payments are also positively associated with TCFD compliance, reflecting the tendency of financially stable firms to maintain greater transparency.

Overall, the 2SLS results reinforce the study's main conclusion that CEO power negatively influences voluntary TCFD compliance, even after accounting for potential endogeneity. This provides additional evidence that powerful CEOs may resist voluntary climate disclosure, possibly due to concerns about increased transparency, regulatory scrutiny, or constraints on managerial discretion.

Table 3.8 Two-Stage Least Squares (2SLS) Analysis

This table reports the results of the Two-Stage Least Squares (2SLS) estimation used to address potential endogeneity concerns related to CEO power. To mitigate this concern, this study employs an instrumental variable approach using the industry–country average CEO power excluding the focal firm (Power_AVG) as an instrument for CEO power. Column (1) presents the first-stage regression, where CEO power is regressed on the instrumental variable and the set of control variables included in the baseline model. Column (2) reports the second-stage regression, where TCFD compliance is regressed on the predicted values of CEO power obtained from the first stage (Power_predict). All models are estimated with year, industry, and country fixed effects, and standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively. Variable definitions are reported in Appendix 3.A.

VARIABLES	(1) First Stage (Power)	(2) Second Stage (TCFD)
Power_predict		-0.570** (-2.567)
Power_AVG	0.812*** (3.644)	
Size	-0.014** (-2.169)	0.031*** (5.516)
Leverage	0.040 (0.731)	0.010 (0.261)
Tangibility	-0.014 (-0.264)	0.040 (0.959)
Cash	0.019 (0.357)	-0.012 (-0.337)
Dividend	0.006 (0.223)	0.077*** (4.163)
Loss	0.018 (0.843)	0.015 (0.790)
TobinsQ	-0.054* (-1.929)	0.004 (0.150)
Bsize	-0.037 (-0.976)	0.074** (2.458)
Intercept	0.391** (2.024)	-0.388 (-1.519)
Observations	2,353	2,353
Adj. R ²	0.213	0.215
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

3.4.3 Sensitivity Analysis: Climate Risk Sectors

To further examine the robustness of the baseline findings, this section presents a subsample analysis by industry climate risk classification. Prior research suggests that firms operating in carbon-intensive industries face greater exposure to climate-related risks and regulatory scrutiny. They are significant direct emitters of greenhouse gases, making them primary targets of climate regulation, and they are the firms that would be most financially affected by climate transition through stranded asset exposure, carbon pricing costs, and mandatory decarbonisation requirements (Ding et al., 2023; Bolton & Kacperczyk, 2021). Comprehensive TCFD disclosure would require these firms to publicly quantify these dual vulnerabilities through scenario analysis, creating the strongest CEO incentive to resist transparency precisely where disclosure is most consequential. Following Liu and Tian (2021) and Bose et al. (2025), this study conducts a subsample analysis by classifying industries into high- and low-climate-risk sectors. High climate risk sectors are defined as industries with significant direct exposure to physical climate risks such as extreme weather events and flooding, as well as transition risks, including regulatory carbon pricing and reputational costs associated with carbon-intensive operations (Bolton & Kacperczyk, 2021; Ilhan et al., 2023). Following Liu and Tian (2021), Ding et al. (2023), and Bose et al. (2025), high climate risk sectors comprise energy (SIC 12, 13, 29), materials (SIC 10, 14, 28, 33), industrials (SIC 34, 35, 37), and utilities (SIC 49). Low climate risk sectors comprise all remaining industries, which face predominantly indirect climate risks rather than direct operational exposure. This classification allows us to examine whether the relationship between CEO power and voluntary TCFD compliance differs across industries with varying levels of climate exposure. Table 3.9 presents the subsample analysis distinguishing between firms operating in high- and low-climate-risk environments.

As shown in Table 3.9, across all specifications, CEO power is negatively and statistically significantly associated with TCFD compliance, indicating that firms led by more powerful CEOs tend to exhibit lower levels of climate-related transparency. Notably, this effect is stronger in high climate-risk sectors ($\beta = -0.158$, $p < 0.01$) compared to low-risk sectors ($\beta = -0.085$, $p < 0.01$), suggesting that managerial power plays a more pronounced role in shaping disclosure decisions when firms face greater exposure to climate-related risks. This finding is theoretically consistent, as high climate risk sectors such as energy, materials, industrials, and utilities hold significant carbon-intensive assets facing stranded asset exposure and regulatory transition costs, meaning comprehensive TCFD disclosure would require firms to quantify

potentially value-destroying information about their climate vulnerabilities (Bolton & Kacperczyk, 2021; Matsumura et al., 2014). Powerful CEOs in these sectors therefore face the strongest strategic incentive to resist voluntary compliance, as transparency directly threatens their current business model and reduces managerial flexibility. In contrast, low climate risk sectors face substantially lower disclosure costs, reducing the CEO's incentive to use structural authority to constrain voluntary TCFD compliance.

The results further highlight the role of CEO climate support as a moderating factor. In high-risk sectors, CEO climate support is positively and significantly associated with TCFD compliance. In contrast, the negative and statistically significant interaction term ($\beta = -0.212$, $p < 0.01$) in high-risk sectors indicates that the positive effect of CEO climate support on TCFD compliance weakens as CEO power increases. In other words, in high climate-risk environments, concentrated CEO authority limits the extent to which climate-supportive leadership translates into voluntary disclosure, consistent with the main findings in Table 3.4. This may reflect strategic disclosure behaviour, in which powerful CEOs engage in symbolic signalling to external stakeholders while retaining control over the extent and depth of disclosure (Cho & Patten, 2007; Li et al., 2023). This finding is consistent with the rejection of H2c in the full-sample analysis and extends it by showing that the constraining effect of CEO power on climate-supportive leadership is particularly pronounced in high-climate risk environments. In contrast, the interaction effect is not statistically significant in low-risk sectors, suggesting that the tension between CEO climate support and CEO power is most pronounced when climate disclosure carries higher strategic stakes, specifically in industries facing greater regulatory scrutiny and stakeholder pressure (Bolton & Kacperczyk, 2021; Ding et al., 2023).

Across all four model specifications, the control variable results are broadly consistent with the baseline findings. Firm size, dividend payments, and board size are positively and significantly associated with TCFD compliance in both high- and low-risk sectors, confirming that larger firms, financially stable firms, and firms with larger boards consistently engage more with voluntary climate disclosure regardless of industry climate exposure. Asset tangibility is positively significant in the high-risk sector specification but insignificant in low-risk sectors, suggesting that physical asset intensity creates stronger climate disclosure incentives specifically in carbon-intensive industries, where tangible assets represent a direct source of transition risk (Bolton & Kacperczyk, 2021). Tobin's Q is positively significant in low-risk

sectors but insignificant in high-risk sectors, indicating that market valuation incentives for climate transparency are more relevant in industries with lower direct climate exposure. Cash holdings are marginally negative in low-risk sectors but insignificant in high-risk sectors.

Overall, the findings suggest that while supportive leadership encourages climate disclosure, excessive CEO power may constrain the effectiveness of such initiatives, particularly in environments with greater climate risk exposure.

Table 3.9 The Association between CEO Power and TCFD: Classification of Climate Risk Sectors

This table reports the results of the subsample analysis by climate-risk sector. The sample is divided into high- and low-climate-risk industries to examine whether the relationship between CEO power and voluntary TCFD compliance varies across sectors with different levels of climate exposure. TCFD is measured as 0 for non-complying firms and as the CCI score for complying firms, and CEO Power is measured as a composite index based on CEO duality, tenure, and ownership. CEO Climate Support is a binary variable equal to one when the CEO explicitly expresses support for climate-related initiatives. The control variables include firm size (log market capitalisation), leverage (total debt scaled by total assets), asset tangibility (PPE scaled by total assets), cash ratio (cash scaled by total assets), Tobin's Q (the market value of equity plus assets minus equity relative to assets), dividend payment, loss, and board size (log number of board directors). All regressions are estimated using OLS with industry, year, and country fixed effects. Standard errors are clustered at the firm level to address potential heteroskedasticity and serial correlation. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively. Variable definitions are reported in Appendix 3.A.

	High-Risk Sectors		Low-Risk Sectors	
VARIABLES	(1)	(2)	(3)	(4)
CEO_power	-0.158*** (-4.013)	-0.071* (-1.904)	-0.085*** (-2.828)	-0.046** (-2.074)
CEO_support		0.283*** (5.651)		0.258*** (4.740)
CEO_supportxCEO_power		-0.212*** (-2.985)		-0.071 (-0.938)
Size	0.035*** (5.465)	0.029*** (4.701)	0.035*** (6.534)	0.025*** (4.613)
Leverage	0.045 (0.908)	0.051 (1.135)	0.022 (0.514)	0.020 (0.499)
Tangibility	0.135** (2.450)	0.083 (1.597)	-0.075 (-1.551)	-0.059 (-1.248)
Cash	0.040 (0.868)	0.040 (0.958)	-0.073* (-1.917)	-0.048 (-1.483)
Dividend	0.091*** (3.771)	0.065*** (2.875)	0.067*** (3.766)	0.049*** (2.845)
Loss	0.015 (0.700)	0.021 (1.042)	-0.005 (-0.284)	0.003 (0.163)
TobinsQ	0.012 (0.303)	0.022 (0.571)	0.031** (2.231)	0.026** (2.137)
Bsize	0.080** (2.223)	0.058* (1.707)	0.081*** (2.884)	0.060** (2.403)
Intercept	-0.589*** (-4.694)	-0.538*** (-4.464)	-0.568*** (-5.100)	-0.438*** (-4.315)
Observations	1,092	1,092	1,261	1,261
Adj. R ²	0.495	0.544	0.388	0.480
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes

3.5 Conclusion

Climate change has emerged as a critical economic and financial challenge that increasingly affects corporate performance, investment decisions, and capital markets (Xu et al., 2024). As investors and regulators demand greater transparency regarding firms' exposure to climate-related risks and opportunities, climate-related financial disclosure has become an essential component of corporate reporting (TCFD, 2017). In response to these concerns, the TCFD was introduced as a globally recognised framework designed to improve the consistency and comparability of climate-related financial reporting. Despite its growing influence, compliance with TCFD recommendations has remained relatively limited and uneven across firms and jurisdictions, particularly during the early years following its release, when disclosure was voluntary. Prior reports and academic studies highlight that many firms still provide insufficient climate-related information, which restricts investors' ability to assess climate risks and opportunities effectively.

Consequently, several scholars have called for further research to investigate the determinants of voluntary TCFD compliance and to better understand the governance mechanisms that influence firms' climate disclosure decisions. In such voluntary settings, internal governance mechanisms and leadership characteristics may play a critical role in shaping firms' disclosure decisions. Among these governance factors, the CEO's power is particularly important, as CEOs hold significant authority over strategic decisions, resource allocation, and corporate communication with external stakeholders. Understanding how CEO power influences voluntary climate disclosure is, therefore, essential for evaluating the credibility and effectiveness of emerging climate reporting frameworks. Accordingly, this study investigates how corporate leadership influences voluntary climate-related financial disclosure. In particular, it examines the association between CEO power and the compliance and quality of disclosures aligned with the TCFD recommendations.

Using a sample of 2,353 firm-year observations of international firms listed on the NYSE and Nasdaq during 2017-2021, the empirical results indicate that CEO power is negatively associated with voluntary TCFD compliance, suggesting that more powerful CEOs are less likely to comply with TCFD. This finding is consistent with managerial power arguments, which suggest that powerful executives may resist disclosure initiatives that increase transparency and external monitoring. However, among firms complying with the TCFD

framework, CEO power is positively associated with the quality of climate-related disclosure, suggesting that powerful CEOs may seek to enhance the credibility and depth of reporting once the firm commits to disclosure. The results also show that CEO climate support is positively associated with TCFD compliance, highlighting the importance of managerial values and environmental awareness in shaping corporate climate reporting decisions. Furthermore, the negative association between CEO power and TCFD compliance is more pronounced in high-climate risk sectors, suggesting that managerial discretion is more influential in environments with greater climate exposure. While CEO climate support is positively associated with disclosure, the interaction results reveal that concentrated CEO authority limits the extent to which climate-supportive leadership translates into voluntary disclosure, suggesting that structural governance constraints may dominate personal climate orientation when managerial authority is sufficiently concentrated. This suggests that symbolic commitment to climate issues may substitute for substantive disclosure, highlighting the importance of managerial incentives and governance structures in driving transparent climate reporting. Additional analyses also demonstrate that the broader regulatory environment plays an important role, as stronger climate policy environments reduce the negative effect of CEO power on TCFD compliance. However, the political environment does not appear to significantly reduce the negative association between CEO power and TCFD compliance, suggesting that managerial discretion persists across different political climates. These findings remain robust across several endogeneity and sensitivity tests.

This study makes several contributions to the literature. First, it contributes to the growing literature on climate-related financial disclosure by providing new evidence on the governance determinants of voluntary TCFD compliance. Unlike prior studies that examine external determinants such as institutional investor pressure or regulatory environments, this study focuses on internal leadership characteristics, specifically, CEO power, as a key governance determinant of voluntary TCFD compliance. By examining the role of CEO power, this study extends the corporate governance literature by demonstrating how concentrated managerial authority influences firms' willingness to disclose climate-related information. Second, this study contributes to the emerging literature on TCFD reporting by distinguishing between the decision to adopt climate disclosure and the quality of disclosure among complying firms. The findings show that CEO power discourages initial compliance with TCFD recommendations but is associated with higher reporting quality once firms decide to disclose. Third, the study highlights the importance of managerial values and external institutional environments by

showing that CEO climate support and regulatory conditions play a significant role in shaping firms' climate disclosure behaviour. These findings provide useful insights for policymakers and regulators seeking to strengthen climate-related disclosure frameworks and improve transparency in capital markets.

The findings of this study also provide several practical implications. For policymakers and regulators, the results highlight the importance of corporate governance structures in shaping firms' climate disclosure behaviour. In particular, excessive concentration of decision-making power in the hands of CEOs may hinder voluntary compliance with climate reporting frameworks. Strengthening governance mechanisms, such as enhancing board independence and oversight, may therefore help promote greater transparency in climate-related disclosures. For stakeholders, the findings provide insights into how leadership characteristics influence firms' commitment to addressing climate risks and environmental transparency. Understanding the role of managerial power may help investors better assess the credibility of corporate climate disclosures and evaluate firms' long-term sustainability strategies.

Despite these contributions, this study has several limitations. First, the measurement of CEO power relies on three indicators that may not fully capture the power of executives. Future research may use more indicators, such as CEO compensation, to measure it. Second, the measurement of CEO climate support relies on textual analysis of leadership statements, which may not fully capture executives' underlying attitudes toward climate change. Future research may extend this study by examining other governance mechanisms and exploring additional measures of managerial environmental commitment. Third, this study examines voluntary TCFD compliance during 2017–2021, prior to the transition to mandatory ISSB standards in 2023. Future research could examine whether the governance determinants of climate disclosure identified here remain relevant under mandatory reporting regimes, where CEO discretion may be more constrained.

Appendices to Chapter Three

Appendix 3.A Variable Definition

This table presents the definitions of variables used in the current study. The sources and data items used from each source are also provided.

Variable	Definition	Proxy for	Source
Dependent Variable Measures:			
TCFD	Equals 0 if the firm does not disclose climate-related financial information aligned with the TCFD recommendations and equals the CCI score if the firm complies with the TCFD framework.	TCFD compliance	ESG and Sustainability Reports
Independent Variable			
CEO_power	A composite index is constructed based on three indicators: CEO duality (1 if the CEO is also board chair, 0 otherwise), CEO tenure (1 if CEO tenure exceeds the sample median, 0 otherwise), and CEO ownership (1 if CEO share ownership exceeds the sample median, 0 otherwise). The index is calculated as the sum of the three indicators, scaled by the total number of components, ranging from 0 to 1, with higher values indicating greater CEO power.	CEO Power	Boardex
Support	Equals 1 if the CEO explicitly endorses climate-related initiatives or recognises the urgency of climate-related challenges, and 0 otherwise.	CEO Climate Support	CEO Letters
Control Variables			
Bsize	Natural logarithm of the total number of board members.	Board Size	LSEG (formerly Refinitiv)
Size	Natural logarithm of the firm's market capitalisation.	Firm Size	LSEG (formerly Refinitiv)
Leverage	Total debt divided by total assets.	Leverage	LSEG (formerly Refinitiv)

Tangibility	Ratio of property, plant, and equipment (PPE) to total assets.	Asset Tangibility	LSEG (formerly Refinitiv)
Loss	Dummy variable equal to 1 if net income before extraordinary items is negative, and 0 otherwise.	Loss	LSEG (formerly Refinitiv)
Cash	Ratio of cash and cash equivalents to total assets.	Cash holding	LSEG (formerly Refinitiv)
Tobin's Q	Market value of equity plus total assets minus book value of equity, divided by total assets.	Firm value	LSEG (formerly Refinitiv)
Dividend	Dummy variable that equals “1” if the firm pays dividends in the year and zero otherwise	Firm Earning	LSEG (formerly Refinitiv)

Appendix 3.B Tobit Regression: CEO Power and TCFD Compliance

This table reports Tobit regression results examining the association between CEO power and TCFD compliance. The Tobit model is employed because of the nature of TCFD compliance, which has a median of zero and takes a value of zero for approximately 80% of observations. The lower censoring limit is set at zero (Tobin, 1958). The Tobit results are consistent with the baseline OLS findings across all specifications. In Column 1, CEO power remains negatively and significantly associated with TCFD compliance with a marginal effect of -0.049 ($p < 0.001$), confirming that the negative association between CEO power and voluntary TCFD compliance persists after correcting for the censored nature of the dependent variable. In Column 2, CEO power remains negative and significant, CEO climate support is positive and significant, with a marginal effect show that with firms whose CEOs express climate support showing expected TCFD compliance 12.6 percentage points higher than those without and the interaction term between CEO climate support and CEO power is negative and significant, confirming that CEO power constrains the positive effect of climate-supportive leadership on voluntary TCFD compliance. The direction and significance of all main variables are consistent with the baseline OLS results, confirming that the baseline findings are not driven by the censored nature of the TCFD compliance variable.

VARIABLES	(1) TCFD	(2) TCFD
CEO_power	-0.372*** (-3.431)	-0.039** (-2.180)
CEO_support		0.282*** (8.177)
CEO_supportxCEO_power		-0.130*** (-2.605)
Size	0.225*** (10.263)	0.025*** (6.544)
Leverage	-0.041 (-0.246)	0.002 (0.073)
Tangibility	0.037 (0.244)	0.013 (0.387)
Cash	-0.428* (-1.820)	-0.008 (-0.322)
Dividend	-0.001 (-0.099)	0.001*** (2.624)
Loss	-0.096 (-1.454)	-0.004 (-0.317)
TobinsQ	0.203** (2.133)	0.030** (2.520)
Bsize	0.261** (2.249)	0.065*** (3.003)
Intercept	-6.288*** (-13.477)	-0.635*** (-6.316)
Observations	2,353	2,353
Pseudo R ²	0.47	0.49
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

Appendix 3.C Country-Level Sample Distribution

This table presents the country-level distribution of the sample. The sample includes firms from 36 countries, providing a geographically diverse research setting. However, the distribution of observations is not uniform across countries and is relatively concentrated in a few markets, particularly Canada, China, and the United Kingdom. This concentration may reflect differences in market size and data availability.

Country	Firms	Observations	% of Observations
Argentina	11	53	2.25
Australia	7	31	1.32
Belgium	8	38	1.61
Bermuda	14	70	2.97
Brazil	25	108	4.59
Canada	112	487	20.70
Cayman Islands	9	35	1.49
Chile	9	39	1.66
China	64	248	10.54
Colombia	3	15	0.64
Denmark	7	33	1.40
France	13	58	2.46
Germany	17	65	2.76
Greece	10	49	2.08
Hong Kong	10	43	1.83
India	7	35	1.49
Ireland	18	82	3.48
Italy	7	27	1.15
Japan	8	39	1.66
Luxembourg	15	63	2.68
Mexico	8	40	1.70
Monaco	4	20	0.85
Netherlands	17	69	2.93
Norway	2	8	0.34
Panama	1	5	0.21
Peru	3	15	0.64
Singapore	17	68	2.89
South Africa	10	49	2.08
South Korea	6	30	1.27
Spain	3	15	0.64
Sweden	7	29	1.23
Switzerland	15	63	2.68
Taiwan	12	59	2.51
Turkey	4	16	0.68
United Kingdom	57	249	10.58
Total	540	2,353	100.00

Appendix 3.D Robustness Analysis: Excluding Canadian Firms

This table reports the results of the baseline regression after excluding Canadian firms to ensure that the findings are not driven by sample concentration. CEO power continues to exhibit a negative and statistically significant association with TCFD compliance, indicating that firms led by more powerful CEOs are less likely to engage in voluntary climate-related reporting. In contrast, CEO climate support remains positively and significantly associated with TCFD compliance, suggesting that managerial commitment to climate issues promotes transparency. The interaction term between CEO power and CEO climate support is negative and significant, implying that while climate-oriented CEOs are more likely to support disclosure, the constraining effect of concentrated managerial power persists. Overall, these findings confirm that the main results are not driven by sample concentration factors.

VARIABLES	(1) TCFD	(2) TCFD
CEO_power	-0.110*** (-4.291)	-0.047** (-2.090)
CEO_support		0.280*** (6.990)
CEO_supportxCEO_power		-0.158*** (-2.841)
Size	0.039*** (8.327)	0.029*** (6.293)
Leverage	0.003 (0.100)	0.019 (0.603)
Tangibility	0.012 (0.267)	-0.026 (-0.648)
Cash	-0.022 (-0.623)	-0.009 (-0.290)
Dividend	0.065*** (4.363)	0.046*** (3.316)
Loss	-0.010 (-0.695)	-0.002 (-0.126)
TobinsQ	0.038*** (2.661)	0.035** (2.571)
Bsize	0.107*** (4.091)	0.083*** (3.526)
Intercept	-0.694*** (-7.123)	-0.568*** (-6.419)
Observations	1,853	1,853
Adj. R ²	0.446	0.518
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

Appendix 3.E Alternative Measures for CEO Power

This Table presents two additional robustness tests examining alternative measures of CEO power. Model (1) uses CEO duality alone as a single-dimensional measure of structural CEO power, consistent with (Jiraporn & Chintrakarn, 2013; Muttakin et al., 2018). The coefficient on CEO duality is negative and statistically significant ($\beta = -0.020$, $p < 0.05$), confirming that structural CEO power independently reduces voluntary TCFD compliance. Model (2) employs an alternative composite index (Power_alt) that extends the baseline measure by incorporating CEO compensation as a fourth power dimension, following Sheikh (2019). Despite the reduced sample of 1,263 observations due to the availability of compensation data, the coefficient on Power_alt remains negative and highly significant ($\beta = -0.113$, $p < 0.01$), consistent with the baseline findings. Overall, these results confirm that the negative association between CEO power and voluntary TCFD compliance is robust to alternative operationalisations of executive authority.

VARIABLES	(1) TCFD	(2) TCFD
CEO_Duality	-0.020** (-2.053)	
Power_alt		-0.113*** (-6.42)
Size	0.013*** (8.201)	0.012*** (6.019)
Leverage	0.015 (0.688)	0.015 (0.621)
Tangibility	0.075*** (3.063)	0.078* (1.911)
Cash	-0.094*** (-4.438)	-0.092* (-2.024)
Dividend	0.070*** (6.061)	0.070*** (4.268)
Loss	-0.009 (-0.741)	-0.012 (-1.125)
TobinsQ	0.036*** (3.510)	0.037** (2.680)
Bsize	0.172*** (10.604)	0.166*** (7.786)
Intercept	-0.361*** (-8.903)	-0.280*** (-4.333)
Observations	2,353	1,263
Adj. R ²	0.368	0.376
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

Chapter Four

The Association between Environmental Board Committees, Environmental Experts and Voluntary Climate Disclosure

4.1 Introduction

In recent years, the role of climate-related disclosure has evolved from primarily serving reputational objectives to becoming an important mechanism for assessing financial materiality and informing capital allocation decisions (Ilhan et al., 2023; Matsumura et al., 2024). More broadly, research suggests that corporate public stances on social and environmental issues are increasingly scrutinised by investors for their financial implications (Brownen-Trinh & Orujov, 2023). Investors increasingly recognise that exposure to climate-related risks, including physical risks associated with extreme weather events and transition risks arising from regulatory and technological changes, can materially affect firms' future cash flows and valuations. For instance, evidence from a global survey by Amel-Zadeh and Serafeim (2018) indicates that institutional investors are increasingly incorporating climate-related information into their portfolio risk assessments and valuation models. These developments highlight the growing importance of transparent, decision-useful disclosure of firms' exposure to climate-related risks and opportunities (Demaria & Rigot, 2021).

Accordingly, several voluntary climate disclosure initiatives have emerged to guide firms in reporting climate-related risks and governance practices. Among these initiatives, the TCFD, established by the FSB in 2015, has become one of the most widely recognised frameworks for climate-related financial reporting (TCFD, 2017). Disclosing information regarding climate governance, strategy, risk management, and performance metrics, as recommended by the TCFD guidelines, enhances the consistency and comparability of climate-related disclosures (Lombardi et al., 2022).

Despite growing global support for the framework, TCFD compliance varies considerably across firms and jurisdictions (TCFD, 2019). Prior research suggests that voluntary sustainability disclosures often suffer from selective reporting and symbolic adoption, limiting their effectiveness in enhancing transparency (Hahn et al., 2015; Christensen et al., 2021).

Further, managerial incentives and leadership characteristics may influence firms' willingness to provide transparent climate-related information. For example, powerful executives may have incentives to limit disclosure to avoid external scrutiny of firms' exposure to climate-related risks or the adequacy of their risk management practices (Bose et al., 2025). Hence, this variation raises important questions about the internal organisational mechanisms that influence firms' climate disclosure practices. Particularly, corporate boards are expected to play a critical role in overseeing management decisions and promoting credible and transparent climate-related reporting (Ngo et al., 2022). Therefore, understanding how board-level governance structures influence firms' engagement with disclosure frameworks such as the TCFD is an important area for empirical investigation.

While prior research has examined the determinants of voluntary climate disclosures, much of this literature has focused primarily on external pressures, such as institutional ownership, stakeholder expectations, and regulatory environments (Luo & Tang, 2014; Amel-Zadeh & Serafeim, 2018). Furthermore, as demand for climate transparency grows, companies need strong internal structures to respond effectively to these external pressures. Corporate governance structures influence the monitoring of managerial actions, the alignment of managerial incentives with stakeholder interests, and the credibility of corporate reporting (Jizi, 2017). Consistent with this view, recent studies highlight the important role of board governance in promoting environmental transparency and shaping firms' sustainability strategies (Al-Shaer & Zaman, 2018; Peters & Romi, 2015). Nevertheless, most existing studies focus on board characteristics such as board independence, diversity, and size. Comparatively less attention has been paid to specialised governance mechanisms, such as board-level environmental committees and directors' environmental expertise, which may play a more direct role in overseeing climate-related risks and encouraging firms to engage with disclosure frameworks such as the TCFD (Dixon-Fowler et al., 2017). Hence, investigating how these governance tools are associated with firms' compliance with TCFD disclosure provides an important opportunity to deepen our understanding of the internal drivers of climate-related transparency.

Environmental board committees have emerged as specialised board structures designed to strengthen oversight of environmental and sustainability issues (Dixon-Fowler et al., 2017; Green & Homroy, 2018). By focusing specifically on environmental risks, these committees may enhance the board's ability to monitor climate-related challenges, integrate sustainability

considerations into corporate strategy, and improve the credibility of environmental disclosures (Gennari & Salvioni, 2019). In the context of voluntary disclosure frameworks such as the TCFD, environmental board committees may therefore play an important role in encouraging firms to adopt more comprehensive and transparent climate reporting practices. However, empirical evidence regarding the effectiveness of such committees remains limited and mixed. For example, Peters et al. (2019) find that sustainability committees may serve symbolic purposes, focusing primarily on satisfying stakeholder expectations and enhancing corporate reputation rather than improving substantive environmental performance. This raises important questions regarding whether environmental governance structures genuinely enhance firms' climate disclosure practices or merely contribute to symbolic reporting.

Drawing on resource dependence theory (Pfeffer & Salancik, 1978), this study argues that environmental board committees and directors with environmental expertise serve as governance mechanisms that strengthen board oversight of climate-related issues and facilitate firms' compliance with TCFD recommendations. Boards can enhance organisational effectiveness by providing access to specialised knowledge and external resources that help firms address complex environmental challenges (Homroy & Slechten, 2019). Further, agency theory (Jensen & Meckling, 1976) provides a complementary perspective by suggesting that specialised board committees enhance monitoring of managerial decisions, thereby reducing agency costs associated with environmental risk management and disclosure. Environmental board committees are typically responsible for incorporating environmental considerations into corporate strategy and overseeing the accuracy and credibility of climate-related disclosures (Driss et al., 2024). Prior research indicates that firms adopting sustainability-oriented practices are more likely to establish specialised board committees that enhance stakeholder engagement and strengthen environmental oversight (Eccles et al., 2014). Through these roles, environmental committees may improve corporate accountability and transparency regarding environmental practices, thereby strengthening stakeholder trust and confidence (Unerman et al., 2018).

Furthermore, compliance with TCFD recommendations requires firms to identify material climate risks, assess their potential impacts, and translate these risks into standard financial metrics, tasks that can be technically complex (TCFD, 2019). Directors with environmental expertise may therefore enhance the board's capacity to understand and address long-term climate risks (Li et al., 2023). Environmental board committees, particularly when supported

by directors with relevant expertise, can help firms better identify and manage climate-related challenges, including physical disruptions, regulatory changes, and reputational risks (Driss et al., 2024). By contributing specialised knowledge and access to external resources, these governance structures may facilitate more effective evaluation and communication of climate-related risks and opportunities (Ben-Amar & McIlkenny, 2015; Li et al., 2023).

Finally, insufficient climate disclosure may expose firms to legal risks, higher compliance costs, and negative investor reactions (Matsumura et al., 2014). Governance mechanisms that support disclosures aligned with TCFD recommendations may therefore reduce information asymmetry and enable stakeholders to better assess firms' exposure to climate-related risks. In doing so, environmental board committees may strengthen the credibility of climate disclosures, reduce uncertainty, and enhance market confidence (Unerman et al., 2018).

Despite these theoretical arguments, empirical evidence regarding the effectiveness of environmental governance structures remains mixed. While some studies find that specialised board committees enhance sustainability accountability, others report insignificant effects, suggesting that such committees may sometimes serve symbolic purposes aimed at legitimacy rather than substantive oversight (Elsayih et al., 2018; Burke, 2022). These mixed findings highlight the need for further empirical investigation into whether environmental board governance mechanisms are associated with climate disclosure practices. Accordingly, this study addresses a gap in the literature by examining whether environmental governance mechanisms, specifically the presence of environmental board committees and directors with environmental expertise, affect firms' compliance with TCFD recommendations.

Beyond influencing firms' compliance with climate disclosure practices, environmental governance structures may also shape the organisational consequences of such disclosures. Corporate investment plays a central role in enhancing firm performance and supporting economic growth; however, the efficiency of investment decisions increasingly depends on how firms identify and manage emerging risks, particularly those associated with climate change (Biddle et al., 2009; Xu et al., 2025). Climate-related disclosures can improve investment efficiency by reducing information asymmetry and uncertainty regarding firms' exposure to environmental risks. Nevertheless, the extent to which climate disclosures translate into more efficient investment decisions may depend on the strength of internal governance mechanisms that oversee environmental issues. Environmental board committees, as specialised board-level structures, may enhance the effective integration of climate-related

information into corporate decision-making processes. By strengthening board oversight of climate risks and ensuring that disclosed information is meaningfully incorporated into strategic planning, environmental board committees may reinforce the positive impact of TCFD compliance on firms' investment efficiency.

In addition, environmental governance structures can influence the relationship between managerial power and climate disclosure. Prior research suggests that powerful CEOs may have incentives to limit transparency in voluntary disclosure frameworks to avoid external scrutiny of firms' environmental risks and performance. For example, Bose et al. (2025) show that CEO power can significantly constrain firms' climate transparency by weakening internal accountability and reducing overall disclosure. Similarly, Li et al. (2018) find that powerful executives tend to suppress climate-related disclosures by limiting firm-level transparency. However, Chen et al. (2023) argue that governance mechanisms that strengthen monitoring, such as institutional ownership or analyst coverage, can mitigate these negative effects of CEO power.

Despite growing research on CEO power and environmental reporting, limited attention has been given to how internal board governance structures moderate the relationship between CEO influence and TCFD compliance. Environmental board committees and directors with environmental expertise may serve as important monitoring mechanisms by overseeing climate strategy, environmental performance, and sustainability reporting (Tingbani et al., 2020). Accordingly, this study addresses the following questions: whether environmental board committees and directors' environmental expertise are associated with voluntary TCFD compliance; whether these governance structures reduce the negative influence of CEO power on disclosure decisions; and, finally, whether they strengthen the association between TCFD compliance and corporate investment efficiency.

This study responds to prior calls for cross-country research examining firm-level determinants of climate disclosure across different institutional environments (Ngo et al., 2022). Accordingly, it examines the role of environmental governance in shaping firms' compliance with climate-related disclosure frameworks using a sample of 2,895 firm-year observations from 36 countries over the period 2017–2021. The presence of a board-level environmental committee variable reflects whether firms have formal governance structures dedicated to overseeing environmental and sustainability issues. In contrast, environmental expertise is measured by the number of directors with environmental expertise. Both measures are

constructed using data from the BoardEx database, following Homroy and Slechten (2019). Voluntary TCFD compliance is measured using a hybrid approach based on the Climate Compliance Index (CCI) developed by Demaria and Rigot (2021). Specifically, the variable equals zero for firms that do not provide TCFD-aligned disclosure and takes the CCI score for firms that comply with the TCFD recommendation.

The findings show that environmental board committees are positively associated with the likelihood of TCFD compliance, with a stronger association observed in countries characterised by higher climate policy performance, highlighting the importance of institutional context in shaping disclosure practices. Further analysis indicates that environmental governance structures are associated with differences in the association between TCFD compliance and investment efficiency. Specifically, the negative association between TCFD compliance and investment inefficiency is observed only in firms with environmental committees. These findings suggest that board-level environmental governance is related not only to firms' disclosure decisions but also to the extent to which climate-related information is reflected in investment efficiency.

Moreover, the findings indicate that the positive association between environmental board committees and TCFD compliance weakens in firms with more powerful CEOs, suggesting that the effectiveness of governance structures may depend on managerial influence. In contrast, environmental expertise is associated with mitigating this effect, highlighting the role of knowledgeable directors in strengthening board oversight of climate-related reporting. Overall, these findings are consistent with prior research suggesting that environmental governance mechanisms enhance firms' ability to identify and evaluate climate-related risks and opportunities (Homroy & Slechten, 2019). The results remain robust across several additional analyses designed to address potential endogeneity concerns.

This study makes several contributions to the literature on climate-related disclosure and corporate governance. First, it extends the emerging literature on TCFD compliance by focusing on internal governance mechanisms as firm determinants of climate disclosure. While prior studies primarily examine external drivers of climate disclosure, such as regulatory pressure and stakeholder demand (e.g., Eccles & Krzus, 2017; Maji & Kalita, 2022), they provide limited evidence on how board-level structures influence firms' compliance decisions. In particular, existing research has not explicitly examined the association between

environmental board committees or directors' environmental expertise and TCFD compliance. This study addresses this gap by providing evidence on how these internal governance mechanisms are associated with firms' engagement with TCFD recommendations.

Second, this study contributes to the corporate governance literature by examining how environmental governance interacts with CEO power in relation to climate disclosure decisions. Although prior research documents that CEO power can influence disclosure practices, it remains unclear whether board-level environmental governance can mitigate this association. This study addresses this limitation by investigating whether environmental board committees moderate the association between CEO power and TCFD compliance, thereby providing new insights into how governance mechanisms can balance managerial influence.

Third, by focusing on a period characterised by voluntary climate disclosure, this study contributes to the voluntary disclosure literature by providing cross-country evidence on firms' engagement with TCFD recommendations in the absence of mandatory regulation. This setting allows for a clearer examination of how internal governance mechanisms are associated with disclosure practices beyond regulatory compliance. In addition, the cross-country design responds to prior calls for research examining variation in climate disclosure across institutional settings (Ngo et al., 2022).

Finally, the study offers practical implications for policymakers, regulators, and investors concerned with the credibility of climate-related reporting. The findings show that environmental governance mechanisms, particularly environmental board committees, play a critical role in enhancing the effectiveness of TCFD disclosure, while environmental expertise further strengthens this relationship. These results contribute to ongoing debates on symbolic versus substantive reporting by demonstrating that governance structures are essential in ensuring that climate disclosures translate into economic outcomes.

The remainder of this chapter is organised as follows: Section 4.2 covers the theoretical framework and presents the development of hypotheses. Section 4.3 introduces the research design and sample selection process. Section 4.4 presents the regression results and robustness tests for the study. Finally, section 4.5 concludes the main points covered in this chapter.

4.2 Theoretical Framework and Hypotheses Development

4.2.1 Literature Review: Environmental Board Committee, Environmental Expertise and Corporate Disclosure

Boards of directors play a central role in corporate governance, particularly in overseeing sustainability strategies and responding to increasing stakeholder expectations regarding environmental accountability (Bui & de Villiers, 2017; Gebhardt et al., 2024). Prior research shows that board characteristics significantly influence firms' environmental, social, and governance (ESG) reporting practices, including the monitoring, implementation, and credibility of sustainability disclosures (Rossi et al., 2021; Singh et al., 2018). In response to growing environmental risks and stakeholder scrutiny, many firms have voluntarily established specialised board-level committees, such as sustainability or environmental board committees, to strengthen oversight of environmental and social issues (Dixon-Fowler et al., 2017; Green & Homroy, 2018). These committees institutionalise sustainability expertise within the board, enhance accountability, and oversee the development, implementation, and revision of environmental policies and reporting practices (Gennari & Salvioni, 2019). They also play a strategic role by ensuring sustainability objectives align with corporate strategy and by monitoring resource allocation to environmental initiatives (Endrikat et al., 2021). Beyond their monitoring function, environmental board committees may also provide advisory input that shapes firms' environmental and climate strategies, thereby supporting long-term organisational resilience (Green & Homroy, 2018).

Resource dependence theory (Pfeffer & Salancik, 1978) provides a useful theoretical framework for explaining the roles of environmental board committees and directors with environmental expertise. According to this theory, boards enhance organisational effectiveness by providing access to specialised knowledge, external networks, and critical resources, enabling firms to respond to complex environmental challenges (Gebhardt et al., 2024). These functions are particularly relevant in the context of climate governance, where decision-making often involves long-term uncertainty, regulatory developments, and significant financial implications. Directors with environmental expertise can strengthen the board's ability to evaluate climate-related risks, interpret evolving sustainability standards, and integrate emerging environmental technologies into corporate strategy. Empirical evidence supports this perspective. For instance, Homroy and Slechten (2019) find that UK firms with environmentally experienced directors and sustainability-focused board committees exhibit

lower greenhouse gas emissions, suggesting that board expertise and specialised committee structures enhance environmental performance through improved knowledge exchange and external engagement.

From a disclosure perspective, environmental board committees may also play an important role in shaping the compliance and quality of climate-related reporting. By overseeing environmental risk management and disclosure processes, these committees can influence the extent to which firms adopt and implement voluntary climate disclosure frameworks. In particular, environmental board committees may enhance the credibility and consistency of climate reporting by ensuring that disclosures are accurate, standardised, and aligned with investor information needs. Such governance mechanisms are especially relevant to frameworks such as the TCFD, which require firms to report information on climate governance, strategy, risk management, and metrics. However, prior research also suggests that governance mechanisms may face organisational challenges. For example, Christensen et al. (2021) argue that increased transparency associated with climate disclosures may generate managerial resistance, particularly when disclosure exposes potential vulnerabilities or strategic risks.

Despite these insights, existing research has largely focused on the presence of environmental board committees and their association with firms' environmental performance or sustainability outcomes (Christensen et al., 2021). However, less attention has been devoted to understanding how environmental governance structures influence firms' decisions to comply with climate-related disclosure frameworks, particularly the TCFD. Moreover, the role of directors' environmental expertise in shaping the compliance with climate disclosure practices remains underexplored. Addressing this gap is important for understanding how internal governance mechanisms influence firms' engagement with voluntary climate reporting initiatives. Accordingly, this study examines how environmental committee structures and directors' environmental expertise influence firms' compliance with TCFD-aligned climate disclosures.

4.2.2 Hypothesis Development

4.2.2.1 Environmental Board Committee and TCFD

Boards of directors play a fundamental role in corporate governance and are increasingly recognised as key drivers of sustainability practices and reporting (Harjoto & Laksmana, 2018; Bui & De Villiers, 2017). Prior research shows that effective board structures are associated with greater transparency, improved stakeholder trust, and reduced transaction costs (Ntim & Soobaroyen, 2013; Al-Shaer & Zaman, 2018). From a theoretical perspective, resource dependence theory suggests that boards enhance organisational effectiveness by providing firms with expertise, access to external knowledge, and valuable networks (Pfeffer & Salancik, 1978). These benefits are particularly relevant in the context of climate governance, where corporate decision-making involves long time horizons, financial uncertainty, and increasing regulatory pressure (Zhang et al., 2021). Environmental board committees may therefore strengthen firms' capacity to identify climate-related risks, integrate sustainability considerations into corporate strategy, and oversee climate-related reporting practices.

Empirical research examining the role of environmental committees provides mixed evidence regarding their effectiveness. One strand of literature suggests that such committees contribute positively to firms' environmental performance and sustainability initiatives. For example, Homroy and Slechten (2019) find that firms with environmentally experienced boards exhibit lower greenhouse gas emissions. Similarly, Gerged et al. (2023) report that sustainability committees strengthen the relationship between board diversity and environmental disclosure in sub-Saharan Africa, while Orazalin et al. (2024) show that sustainability committees are associated with higher firm value and greater engagement in climate initiatives. These findings suggest that specialised governance structures may enhance board oversight of environmental issues.

Another strand of research argues that environmental board committees may sometimes serve symbolic purposes, signalling commitment to sustainability without substantially influencing corporate practices (Berrone & Gomez-Mejia, 2009; Rodrigue et al., 2013). Tingbani et al. (2020) note that the mere presence of environmental committees does not necessarily lead to improved environmental disclosure, as their effectiveness depends on their authority, functionality, and expertise. Similarly, Christensen et al. (2021) argue that increased transparency associated with climate disclosure may encounter managerial resistance, particularly when such disclosures reveal strategic vulnerabilities. Dixon-Fowler et al. (2017) further suggest that the positive effects of environmental committees on environmental outcomes depend on the presence of genuine oversight and institutional support.

These insights have important implications for firms' compliance with climate-related disclosure frameworks such as the TCFD. While existing research has primarily focused on the relationship between environmental board committees and environmental performance, less attention has been given to their role in shaping firms' compliance with climate-related financial disclosures. Given that the TCFD framework requires firms to disclose information related to governance, strategy, risk management, and climate-related metrics, environmental board committees may play a critical role in overseeing the integration of climate-related risks into corporate decision-making and disclosure processes. Consequently, firms with environmental board committees may be more likely to comply with TCFD recommendations and provide more credible climate-related disclosures.

Accordingly, the following hypothesis is proposed:

H1: There is a positive association between the presence of an environmental board committee and TCFD compliance.

4.2.2.2 Environmental Expert Directors and TCFD

While the presence of environmental board committees may strengthen board oversight of sustainability issues, the effectiveness of such governance structures often depends on the directors' expertise. Recent research, therefore, emphasises the importance of specialised environmental knowledge and expertise in improving firms' environmental performance and disclosure practices (Tingbani et al., 2020). This perspective is consistent with upper echelons theory (Hambrick & Mason, 1984), which suggests that organisational outcomes reflect the cognitive characteristics, experiences, and values of top decision-makers. According to this theory, directors with specialised knowledge or professional experience in environmental and sustainability-related fields can influence strategic decisions by shaping how firms interpret and respond to emerging environmental risks and opportunities.

Environmental expertise may be particularly important in the context of climate-related financial disclosures. Compliance with TCFD recommendations requires firms to identify material climate risks, assess their potential financial implications, and translate these risks into standardised metrics and disclosures. However, the TCFD report (2019) highlights that the complexity and uncertainty associated with climate-risk assessment represent significant challenges for firms adopting the framework. Therefore, directors with environmental expertise, such as those with experience or education in sustainability, climate policy, pollution

management, or environmental science, may enhance firms' ability to interpret climate-related risks and implement TCFD recommendations effectively. By contributing specialised knowledge regarding emissions metrics, physical and transition risks, and mitigation strategies, environmental experts can improve both the credibility and the materiality of climate-related disclosures across the TCFD's four pillars: governance, strategy, risk management, and metrics and targets (TCFD, 2017).

Empirical evidence supports the role of environmental expertise in enhancing non-financial reporting. For example, García-Sánchez et al. (2023) find that directors with specialised expertise on CSR committees improve the readability and transparency of sustainability reports. Similarly, Homroy and Slechten (2019) show that boards with climate-literate directors are less likely to engage in greenwashing and are more likely to align climate disclosures with firms' underlying environmental practices. However, Tingbani et al. (2020) caution that environmental expertise may have a limited impact when directors lack sufficient decision-making authority or when sustainability is not integrated into firms' strategic priorities.

Overall, these arguments suggest that environmental expertise at the board level may enhance firms' ability to understand and respond to climate-related risks and to implement voluntary climate disclosure frameworks such as the TCFD. Accordingly, the following hypothesis is proposed:

H2: There is a positive association between the presence of environmental expert directors and TCFD compliance.

4.2.2.3 Environmental Governance, CEO Power, and TCFD Compliance

Upper echelons theory emphasises the important role of executive characteristics in shaping organisational strategies and disclosure practices (Hambrick & Mason, 1984). Prior research suggests that powerful CEOs can influence corporate decision-making and strategic direction, particularly in environments characterised by complex regulatory and competitive pressures (Davis et al., 2010; Chen et al., 2019). While CEO power may enhance strategic coordination and reduce internal conflict, excessive concentration of managerial power can also weaken internal oversight and increase the likelihood of opportunistic behaviour (Haynes et al., 2019; Saiyed et al., 2023). In the context of voluntary disclosure frameworks, powerful CEOs may have incentives to limit transparency in order to avoid external scrutiny of corporate practices and strategic vulnerabilities.

Consistent with this view, prior studies suggest that CEO power may negatively influence firms' willingness to comply with voluntary climate disclosure frameworks. For example, Bose et al. (2025) argue that powerful executives may avoid adopting voluntary climate disclosure initiatives that increase external monitoring and stakeholder scrutiny. This behaviour aligns with managerial power theory, which suggests that managers may use their authority to control information flows and minimise investor attention when transparency threatens their discretion or reputation (Chen et al., 2011).

However, effective corporate governance mechanisms may constrain the influence of powerful executives on disclosure decisions. In particular, specialised board structures, such as environmental board committees and directors with environmental expertise, may strengthen board monitoring and reduce managerial discretion in climate-related reporting. Prior research indicates that specialised board committees improve oversight, reduce information asymmetry, and encourage more transparent environmental disclosures (Tingbani et al., 2020). Similarly, effective governance mechanisms have been shown to limit opportunistic managerial behaviour and align executive decisions with broader stakeholder interests (Moffitt et al., 2024).

In the context of climate-related disclosure frameworks such as the TCFD, environmental board committees and environmental expertise may therefore play an important monitoring role by strengthening board oversight of climate governance and disclosure practices. By increasing accountability and reducing managerial discretion, these governance mechanisms may mitigate the potential negative influence of CEO power on firms' compliance with TCFD-aligned disclosures.

Accordingly, the following hypothesis is proposed:

H3: The presence of environmental governance mechanisms weakens the negative association between CEO power and TCFD compliance.

4.2.2.4 Environmental Governance, TCFD and Investment Efficiency

The efficiency of corporate investment decisions plays a crucial role in firms' long-term performance and value creation (Yu et al., 2022). However, prior research shows that corporate investment decisions often deviate from optimal levels due to agency problems and information asymmetry between managers and external capital providers (Myers, 1984; Jensen, 1986; Biddle et al., 2009). These frictions can lead to both overinvestment and underinvestment by

weakening monitoring mechanisms and allowing managerial discretion in capital allocation decisions.

In recent years, climate risk has emerged as an important factor influencing firms' investment behaviour. Exposure to climate-related risks can create uncertainty regarding future cash flows, operational disruptions, and regulatory changes, which may distort managerial decision-making and reduce investment efficiency (Yu et al., 2022). For example, extreme climate conditions may impair managerial cognitive performance and reduce productivity (Graff Zivin et al., 2018; Alok et al., 2020), while operational disruptions caused by climate-related events may increase uncertainty regarding project outcomes (Trudel, 2019). In response to such uncertainty, firms may increase precautionary cash holdings, potentially leading to underinvestment in profitable projects (Adachi-Sato & Vithessonthi, 2016; Huang et al., 2018).

Climate-related disclosure frameworks, such as the TCFD, aim to improve transparency regarding firms' exposure to climate risks and their strategies for managing them (TCFD, 2017). By providing structured, detailed information about climate-related risks and opportunities, TCFD compliance may reduce information asymmetry between firms and capital providers, thereby improving investment decision-making and enhancing investment efficiency (Biddle et al., 2009; Chen et al., 2011).

However, the extent to which climate disclosures translate into improved investment decisions may depend on the strength of internal governance mechanisms. Drawing on agency theory, environmental board committees may serve as specialised monitoring mechanisms that oversee climate-related risks and reduce managerial opportunism in investment decisions (Homroy & Slechten, 2019). In addition, resource dependence theory suggests that directors with environmental expertise can provide access to valuable knowledge and external resources, thereby improving firms' ability to evaluate climate-related risks and opportunities (Pfeffer & Salancik, 1987). Prior research indicates that specialised governance structures influence firms' environmental behaviour and sustainability practices (Orazalin et al., 2024). Moreover, climate disclosure can improve firms' information environment and facilitate access to external financing by reducing uncertainty for investors (Xue, 2023).

Accordingly, environmental governance mechanisms may strengthen the association between TCFD compliance and investment efficiency through two mechanisms. First, they can improve the quality of climate disclosures by ensuring accuracy and relevance, which reduces information asymmetry and supports better investment decisions (Biddle et al., 2009). Second,

they may ensure that climate-related information is embedded in internal decision-making rather than disclosed externally, thereby reducing investment distortions caused by information gaps (Jensen, 1986).

Accordingly, the following hypothesis is proposed:

H4: The presence of environmental governance mechanisms strengthens the positive association between TCFD compliance and investment efficiency.

4.3 Research Design and Sample

This section outlines the procedures for the research design and is organised as follows: Section 4.3.1 describes the sample and the data sources used to collect parameters. Section 4.3.2 explains the proxies used to measure TCFD compliance, the presence of environmental board committees and environmental expert directors, CEO power, investment efficiency, and control variables.

4.3.1 Sample Selection

The sample of this study comprises international-listed firms on the New York Stock Exchange and the Nasdaq over the period 2017-2021. This study focuses on the voluntary compliance of the TCFD framework, as it provides a unique setting to examine how firms weigh the costs and benefits of climate disclosure. This provides valuable insights into the governance and leadership factors that drive reporting beyond regulatory requirements. Thus, the sample period covers 2017 to 2021, beginning with the introduction of the TCFD guidelines by the Financial Stability Board (FSB) in 2017 and continuing through 2021, during which no country mandated adherence to these guidelines. The final sample of this study comprises 2,895 observations, drawn from 646 unique firms across 36 countries. In line with Liao et al. (2024), US-domiciled firms are excluded to prevent the results from being driven by the dominant presence of US observations in the sample. The detailed country-level distribution of the sample is presented in Appendix 4.D.

This study employs the Climate Compliance Index (CCI) developed by Demaria and Rigot (2021) to measure firms' compliance with the TCFD framework, using data from firms' publicly available TCFD and sustainability reports. Additionally, data for the environmental

board committee and environmental expert directors have been gathered from BoardEx, while other financial variables have been collected from the LSEG database (formerly Refinitiv). Table 4.1 presents the sample selection process.

Table 4.1 Sample Selection Process

This table reports the sample screening process used to construct the final dataset. The initial sample consists of firms listed on the New York Stock Exchange (NYSE) and NASDAQ over the period 2017–2021. Firm-year observations with missing financial and governance data required to compute the study variables are also removed. After applying these filters, the final sample comprises 2,895 firm-year observations representing international firms listed on U.S. exchanges.

Sample Distribution	No. of Observations
Initial sample	4,368
Less: Missing governance and financial control variables	(1,473)
Final Sample	2,895

4.3.2 Variables and Model

4.3.2.1 Dependent Variable: TCFD Compliance

To measure firms' compliance with climate-related financial disclosures, this study employs the Climate Compliance Index (CCI) developed by Demaria and Rigot (2021), consistent with the approach used by Di Macro et al. (2023). The CCI is a comprehensive disclosure index composed of 38 items that capture the extent to which firms report information aligned with the four core pillars of the TCFD framework. Each item assesses whether firms disclose relevant qualitative or quantitative information in line with the TCFD recommendations. For each firm-year observation, a disclosure score is computed by aggregating the number of items disclosed across the 38 indicators. The total score is then scaled to a maximum of 38 to obtain a continuous index ranging from 0 to 1, where higher values indicate greater alignment with TCFD disclosure recommendations (Di Macro et al., 2023). Importantly, this study adopts a hybrid specification of TCFD compliance. Firms that do not provide any TCFD-aligned disclosure receive a value of 0, while firms that disclose at least one TCFD-aligned item are assigned their corresponding CCI score.

4.3.2.2 Independent Variables:

Environmental Board Committee

The environmental board committee (EnvComm) indicates whether a firm has a board-level committee dedicated to overseeing environmental or sustainability-related issues and implementing its environmental strategy. Following Homroy and Slechten (2019), the presence of an environmental board committee is measured as a binary variable equal to 1 if the firm maintains a dedicated board-level committee with an explicit environmental, sustainability, or climate mandate. Data are collected from BoardEx, particularly the Board Profile, which records the committee memberships of each director, through manual review of all board committees for each firm-year observation. A firm is classified as EnvComm = 1 when BoardEx records a standing committee whose title explicitly references environmental, sustainability, climate, or ESG responsibilities, such as an environmental and safety committee, a sustainability committee, a corporate responsibility and environment committee, or an ESG and governance committee. General audit, risk, or nomination committees that do not

specifically reference environmental responsibilities are not classified as environmental committees. For example, a firm whose BoardEx profile records only an audit committee and a remuneration committee receives $\text{EnvComm} = 0$.

Environmental Expert Directors

Following Homroy and Slechten (2019), this study measures environmental expertise at the board level as the number of directors with environmental expertise serving on the firm's board. For each firm-year observation, directors' BoardEx profiles were manually reviewed to identify environmental keywords in their educational background and professional experience. These qualifying directors were aggregated at the firm-year level to construct the board-level environmental expertise measure, using biographical information, employment histories, and academic qualifications from BoardEx's individual characteristics section.

A director is classified as an environmental expert when their BoardEx profile records prior professional roles or educational background containing keywords related to environmental issues such as environment, ecology, pollution, sustainability, climate, or conservation, according to BoardEx classification criteria. In practice, this includes directors with prior roles such as chief sustainability officer, environmental director, head of climate risk, or equivalent positions in environmental regulatory bodies, as well as directors holding academic qualifications in environmental science, climate science, or sustainability management. For example, a director whose BoardEx profile records prior employment as chief sustainability officer would be classified as an environmental expert, while a director with a general finance or legal background with no environmental keywords in their profile would not receive this classification.

CEO Power

Consistent with Veprauskaite and Adams (2013) and Sheikh (2019), this study constructs a composite CEO power index based on three indicators reflecting different sources of executive influence: CEO duality, CEO tenure, and CEO ownership. The index captures the extent to which the CEO holds structural authority, possesses firm-specific expertise, and exercises financial influence within the firm. CEO duality represents the structural dimension of CEO power and captures the concentration of leadership authority when the CEO simultaneously serves as chair of the board (Finkelstein, 1992). This dual role increases the CEO's ability to

influence board agendas and corporate decision-making. CEO duality is measured as a binary variable equal to 1 if the CEO also serves as the board chair and 0 otherwise.

CEO tenure reflects the expert dimension of CEO power. CEOs with longer tenure accumulate firm-specific knowledge and develop stronger influence within the organisation (Veprauskaite & Adams, 2013). CEO tenure is measured as a binary variable equal to 1 if the CEO's tenure exceeds the sample median and 0 otherwise. CEO ownership represents the ownership dimension of CEO power. CEOs who hold substantial equity stakes may enjoy greater autonomy in corporate decision-making and increased influence over strategic policies (Martínez & Álvarez, 2024). CEO ownership is measured as a binary variable equal to 1 if the CEO's ownership exceeds the sample median and 0 otherwise.

The overall CEO power index is calculated by summing the three indicators and scaling the score by the total number of components. The resulting measure ranges from 0 to 1, with higher values indicating greater CEO power.

Investment Inefficiency

Following Benlemlih and Bitar (2018) and Liu and Tian (2021), this study uses the Biddle et al. (2009) model to measure investment inefficiency. Biddle et al. (2009) measure investment inefficiency as a function of sales growth as follows:

$$Investment_{i,t} = \beta_0 + \beta_1 SalesGrowth_{i,t-1} + YearFE + IndustryFE + CountryFE + \epsilon_{i,t} \quad (4.1)$$

Where Investment equals the ratio of the net increase in tangible and intangible assets to lagged total assets (Gomariz & Ballesta, 2014), and sales growth is the growth rate in sales at year $t-1$. As shown in model (1), the absolute values of residuals are used to estimate firm-specific investment inefficiency. Larger absolute values of residuals indicate greater investment inefficiencies (McNichols & Stubben, 2008; Biddle et al., 2009).

4.3.2.3 Control Variables

Following prior studies on climate disclosure and corporate governance (Driss et al., 2024; Homroy & Slechten, 2019), this study includes several control variables that may influence firms' compliance with TCFD disclosures and the level of compliance with climate-related reporting recommendations. These variables account for firm characteristics and governance

structures that could affect disclosure decisions. Specifically, the control variables include board size, board independence, firm size, leverage, asset tangibility, cash ratio, capital expenditure, firm profitability, and dividend payments.

Board size (Bsize) is measured as the natural logarithm of the total number of directors on the board (Daradkeh et al., 2023). Board size is an important governance mechanism that may influence corporate disclosure decisions. Prior studies provide mixed evidence regarding the effect of board size on environmental and sustainability disclosures. Some studies suggest that larger boards may face coordination challenges and slower decision-making processes, which could limit voluntary disclosure initiatives (Cheng, 2008; Lorenzo & Sanchez, 2010). In contrast, other studies argue that larger boards provide greater expertise and monitoring capacity, which may enhance corporate social responsibility (CSR) reporting and transparency (Muttakin et al., 2018). This study expects a positive association between board size and TCFD compliance, consistent with Muttakin et al. (2018).

Board independence (Bindep) is measured as the proportion of independent directors on the board (Driss et al., 2024). Board independence is considered an important governance mechanism that strengthens board monitoring and enhances transparency in corporate reporting. Prior studies suggest that boards with a higher proportion of independent directors are more likely to provide transparent non-financial and sustainability disclosures (García-Sánchez et al., 2023; Driss et al., 2024). Accordingly, this study expects a positive association between board independence and TCFD compliance.

Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation (Chen et al., 2022). Firm size is widely recognised as an important determinant of corporate disclosure decisions. Larger firms typically possess greater financial resources, more experienced management teams, and face higher public and regulatory scrutiny, which may encourage greater transparency in climate-related reporting (Ben-Amar et al., 2015). Therefore, this study expects a positive relationship between firm size and TCFD compliance.

Leverage is measured as total debt divided by total assets. Financial leverage is an important determinant of corporate disclosure, as firms with higher debt levels face greater monitoring from creditors and capital providers (Ben-Amar et al., 2015; Stanny & Ely, 2008). Highly leveraged firms may therefore provide more comprehensive disclosures to demonstrate their

ability to manage risks and maintain financial stability (Veprauskaite & Adams, 2013). Accordingly, this study expects a positive association between leverage and TCFD compliance.

Asset tangibility (tangibility) is measured as the ratio of property, plant, and equipment (PPE) to total assets (Cook et al., 2019). Asset tangibility is often associated with firms operating in asset-intensive industries that may be more exposed to climate-related physical risks (Ben-Amar et al., 2015). Firms with higher tangible assets may therefore have stronger incentives to disclose climate-related information to demonstrate their ability to manage environmental risks and protect long-term asset value (Clarkson et al., 2008). Accordingly, this study expects a positive association between asset tangibility and TCFD compliance.

Cash ratio (Cash) is measured as the ratio of cash holdings to total assets. The availability of internal funds may influence firms' disclosure decisions, as firms with greater liquidity possess more financial flexibility to engage in voluntary reporting initiatives (Benlemlih & Bitar, 2018). Firms with higher cash reserves may also have greater capacity to invest in climate-related risk management and sustainability reporting systems (Chen et al., 2011). Accordingly, this study expects a positive association between the cash ratio and TCFD compliance.

Capital expenditure (CAPEX) is measured as the ratio of capital expenditures to total assets. Capital expenditure is included as a control variable following Homroy and Slechten (2019), who find that investment-intensive firms face greater climate-related risk exposure and are therefore more likely to engage with voluntary environmental disclosure frameworks. Accordingly, this study expects a positive relationship between capital expenditure and TCFD compliance.

Loss is measured as a dummy variable equal to 1 if net income before extraordinary items is negative and 0 otherwise (Chen et al., 2011). Firms experiencing financial losses may face resource constraints that limit their ability to invest in voluntary reporting initiatives and sustainability-related disclosures. As a result, financially distressed firms may be less likely to comply with climate-related disclosure frameworks. Accordingly, this study expects a negative association between loss and TCFD compliance (Maji & Kalita, 2021).

Dividend payment (Dividend) is measured as a dummy variable equal to 1 if the firm pays dividends and 0 otherwise. Dividend payments often signal strong financial performance and stable cash flows. Firms that distribute dividends may therefore have greater incentives to

maintain investor confidence by providing transparent and credible disclosures, including climate-related financial information (De Villiers et al., 2022). Accordingly, this study expects a positive association between dividend payments and TCFD compliance.

Appendix 4.A summarises the measurement and data sources for all variables used in the current study.

4.4 Empirical Results

This section presents the empirical results of the study. It begins with a univariate analysis of the key variables. The section then reports the results of the multivariate regression models examining the relationship between environmental governance mechanisms and TCFD compliance. Specifically, the analysis investigates the association between the presence of an environmental board committee and the likelihood of TCFD compliance (H1), and between directors' environmental expertise and TCFD compliance (H2). Furthermore, this section examines the moderating role of environmental governance by analysing whether environmental board committees influence the relationship between CEO power and TCFD compliance (H3), as well as the relationship between TCFD compliance and corporate investment efficiency (H4).

Table 4.2 reports the summary statistics for all variables in the current study during the period 2017 to 2021. The mean TCFD compliance (TCFD) is 0.10. This average rate is notably low, reflecting voluntary reporting in the early phase (2017–2021). This compliance rate aligns with the findings of Di Marco et al. (2023) and Braasch and Velte (2023). Regarding environmental governance mechanisms, approximately 25% of firms have an environmental board committee. This aligns with the results of Bui et al. (2020). Additionally, Environmental expertise at the board level appears relatively limited, with the average number of environmental expert directors (EnvExpert) at 0.27 and a median of 0, suggesting that most firms do not have directors with specialised environmental expertise. Furthermore, the mean CEO power (power) indicates that 58% of the sample has a relatively high level of executive power, aligning with Sheikh (2019). The mean investment inefficiency (Inv_Ineff) is 0.33, implying that, on average, the sampled firms exhibit inefficient investment levels. These results are consistent with those of Cook et al. (2019).

Regarding board characteristics, the average board size is approximately 9 directors, while board independence averages 47%, indicating that nearly half of the board members are independent directors. Firm-level characteristics show that firm size has a mean of 14.64, while financial leverage is 22%, indicating a relatively low to moderate reliance on external debt financing. Moreover, many firms may adopt conservative capital structures. Furthermore, Tangibility's mean value is 25%, while the mean cash ratio is 15%, indicating relatively moderate liquidity for the sampled firm. Furthermore, the capital expenditure ratio averages 4%, indicating a relatively cautious overall expansion among the sampled firms. Moreover, firm loss stands at a mean of 29%. The dividend payout shows a mean of 58%, indicating that most firms distribute profits to shareholders, which may reflect stable earnings and shareholder-friendly policies.

Table 4.3 presents the Pearson correlation matrix for the variables used in the empirical analysis. The table reports pairwise correlations between the dependent variable (TCFD compliance), the key explanatory variables (environmental board committee and environmental expertise), and the control variables. Consistent with the theoretical expectations, TCFD compliance is positively and significantly correlated with both the presence of an environmental board committee and the number of directors with environmental expertise. This preliminary evidence suggests that environmental governance mechanisms may play an important role in encouraging firms to comply with climate-related disclosure frameworks. Regarding CEO power and investment inefficiency, the results indicate negative correlations between CEO power and the presence of environmental board committees, and between investment inefficiency and environmental governance variables. These findings provide initial evidence that stronger environmental governance may be associated with reduced managerial dominance and more efficient corporate decision-making.

Regarding the control variables, TCFD compliance is positively correlated with firm size, board independence, leverage, asset tangibility, and dividend payments, suggesting that larger firms and those with stronger governance structures may be more likely to engage in climate-related disclosure practices. In contrast, firms with higher cash holdings or those reporting financial losses appear less likely to comply with TCFD disclosures. Finally, the correlation coefficients indicate no serious multicollinearity concerns among the explanatory variables. Following Gujarati and Porter (2009), all pairwise correlations remain below the commonly

used threshold of 0.8. In addition, the variance inflation factor (VIF) tests confirm that multicollinearity is not a concern in the regression models.

To assess the assumptions underlying the regression models, diagnostic tests for heteroscedasticity and serial correlation were conducted. The Modified Wald test for groupwise heteroscedasticity rejects the null hypothesis of homoscedasticity across panels (significant at the 1% level), indicating heteroscedasticity in the residuals. In addition, the Wooldridge test for autocorrelation rejects the null hypothesis of no autocorrelation ($F = 68.956, p < 0.001$), suggesting the presence of serial correlation within panel units. To address these issues, the regression models are estimated using standard errors clustered at the firm level, which provides consistent inference in the presence of both heteroscedasticity and serial correlation.

Table 4.2 Descriptive Statistics

This table presents the descriptive statistics for the 2,895 firm-year observations from 2017 to 2021. The variation in the number of observations across variables reflects data availability constraints for CEO power and the exclusion of financial institutions for investment efficiency data. The descriptive statistics for the full sample include the number of observations, the mean, the standard deviation, the minimum, the 25th percentile, the median, the 75th percentile, and the maximum of all variables. TCFD is measured as 0 for non-complying firms and as the Climate Compliance Index (CCI) score for complying firms. Environmental committee (EnvComm) is a binary indicator that equals 1 if the company has an environmental committee and 0 otherwise. Environmental expert (EnvExpert) is the total number of environmental experts on the company's board. CEO power (Power) is an index covering three dimensions: CEO duality, CEO ownership, and CEO tenure. Investment Inefficiency (Inv_ineff) is measured using Biddle et al.'s (2009) model. Board size (Bsize) is defined as the total number of board members. Board independence (Bindep) is defined as the ratio of independent directors to the total number of directors on a board. Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Cash is calculated as the ratio of cash to total assets. CAPEX is defined as the ratio of capital expenditures to total assets. Loss is a dummy variable that equals 1 if the net income before extraordinary items is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. All continuous variables are winsorised at their 1st and 99th percentiles.

	N	Mean	SD	Min	p25	Median	p75	Max
TCFD	2,895	0.10	0.26	0.00	0.00	0.00	0.00	0.97
EnvComm	2,895	0.25	0.47	0.00	0.00	0.00	1.00	1.00
EnvExpert	2,895	0.27	1.18	0.00	0.00	0.00	0.00	9.00
Power	2,353	0.58	0.29	0.00	0.33	0.66	0.66	1.00
Inv_ineff	2,225	0.33	0.32	0.01	0.11	0.23	0.44	1.46
Bsize	2,895	9.04	2.79	3.00	7.00	9.00	10.87	25.00
Bindep	2,895	0.47	0.34	0.00	0.05	0.53	0.77	1.00
Size	2,895	14.64	2.28	9.65	13.00	14.75	16.41	18.80
Leverage	2,895	0.22	0.19	0.00	0.03	0.19	0.36	0.68
Tangibility	2,895	0.25	0.24	0.00	0.05	0.13	0.39	0.84
Cash	2,895	0.15	0.13	0.01	0.07	0.09	0.20	0.53
Capex	2,895	0.04	0.05	0.00	0.01	0.03	0.05	0.29
Loss	2,895	0.29	0.46	0.00	0.00	0.00	1.00	1.00
Dividend	2,895	0.58	0.49	0.00	0.00	1.00	1.00	1.00

Table 4.3 Pearson Correlation Matrix

This table presents the Pearson correlation matrix among variables. TCFD is measured as 0 for non-complying firms and as the Climate Compliance Index (CCI) score for complying firms. Environmental board committee (EnvComm) is a binary indicator, which equals 1 if the company has an environmental committee and 0 otherwise. Environmental expert (EnvExpert) is the total number of environmental experts on the company's board. CEO power (Power) is an index covering three dimensions: CEO duality, CEO ownership, and CEO tenure. Investment Inefficiency (Inv_ineff) is measured using Biddle et al. (2009). Board size (Bsize) is defined as the natural logarithm of the total number of board members. Board independence (Bindep) is defined as the ratio of independent directors to the total number of directors on a board. Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Cash is calculated as the ratio of cash to total assets. CAPEX is defined as the ratio of capital expenditures to total assets. Loss is a dummy variable that equals 1 if the net income before extraordinary items is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively. All continuous variables are winsorised at their 1st and 99th percentiles. Variable definitions are reported in Appendix 4.A.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(1) TCFD	1													
(2) EnvComm	0.44***	1												
(3) EnvExpert	0.25***	0.23***	1											
(4) Power	-0.15**	-0.14***	-0.04*	1										
(5) Inv_ineff	-0.12**	-0.18***	-0.16***	0.01	1									
(6) Bsize	0.32***	0.34***	0.17***	-0.1***	-0.13***	1								
(7) Bindep	0.30***	0.39***	0.26***	-0.15***	-0.11***	0.16***	1							
(8) Size	0.47***	0.52***	0.18***	-0.13***	-0.27***	0.48***	0.43***	1						
(9) Leverage	0.10***	0.23***	0.09***	-0.02	-0.19***	0.15***	0.15***	0.12***	1					
(10) Tangibility	0.10***	0.18***	0.25**	-0.01	-0.23***	0.17***	0.19***	0.01	0.32***	1				
(11) Cash	-0.24**	-0.18***	-0.16***	0.04**	0.06***	-0.15***	-0.15***	-0.33***	-0.22***	-0.15***	1			
(12) Capex	0.01	0.08***	0.09**	-0.01	-0.11***	0.08***	0.05***	0.01	0.17***	0.53***	-0.04**	1		
(13) Loss	-0.14**	-0.20***	-0.02	0.01	0.20***	-0.13***	-0.08***	-0.35***	-0.13*	-0.10***	-0.01	-0.12***	1	
(14) Dividend	0.05***	-0.05***	0.01	-0.12***	-0.19***	0.14***	0.13***	0.35***	0.07***	0.20***	-0.09***	0.12***	-0.50***	1
VIF		1.48	1.18	1.06	1.19	1.30	1.76	2.35	1.34	1.98	1.15	1.40	1.42	1.30

4.4.1 Multivariate Analysis

This section presents the multivariate regression analysis examining the effect of environmental governance mechanisms on TCFD compliance. Specifically, the analysis examines the associations between the presence of an environmental board committee, directors' environmental expertise, and firms' compliance with TCFD disclosures. The empirical models are estimated using fixed-effects OLS regressions, with standard errors clustered at the firm level to account for heteroscedasticity and within-firm correlation over time.

Consistent with prior literature (Veprauskaite & Adams, 2013; Sheikh, 2019), the models include industry, country, and year fixed effects to control for unobserved heterogeneity across firms and over time. Controlling for these fixed effects helps reduce potential omitted variable bias and improves the reliability of the estimated coefficients (Lin et al., 2021). To mitigate the influence of extreme values, most financial variables are winsorised at the 1st and 99th percentiles. This section is organised into two subsections. Section 4.4.1.1 presents the model specifications, while Section 4.4.1.2 reports the regression results.

4.4.1.1 Model Specifications

To test the study hypotheses, a series of panel regression models is estimated to examine the relationship between environmental governance mechanisms and firms' TCFD compliance. The first set of models tests H1 and H2, which examine whether the presence of an environmental board committee and directors' environmental expertise influence firms' compliance with TCFD recommendations.

$$TCFD_{i,t} = \beta_0 + \beta_1 EnvComm_{i,t} + \beta_2 Bsize_{i,t} + \beta_3 Bindep_{i,t} + \beta_4 Fsize_{i,t} + \beta_5 Leverage_{i,t} + \beta_6 Tangibility_{i,t} + \beta_7 Cash_{i,t} + \beta_8 CAPEX_{i,t} + \beta_9 Loss_{i,t} + \beta_{10} Dividend_{i,t} + YearFE + IndustryFE + CountryFE + \epsilon_{i,t} \quad (4.2)$$

$$TCFD_{i,t} = \beta_0 + \beta_1 EnvExpert_{i,t} + \beta_2 Bsize_{i,t} + \beta_3 Bindep_{i,t} + \beta_4 Fsize_{i,t} + \beta_5 Leverage_{i,t} + \beta_6 Tangibility_{i,t} + \beta_7 Cash_{i,t} + \beta_8 CAPEX_{i,t} + \beta_9 Loss_{i,t} + \beta_{10} Dividend_{i,t} + YearFE + IndustryFE + CountryFE + \epsilon_{i,t} \quad (4.3)$$

The second set of models tests H3, which investigates whether environmental governance mechanisms moderate the relationship between CEO power and TCFD compliance.

$$TCFD_{i,t} = \beta_0 + \beta_1 CEO_power_{i,t} + \beta_2 EnvComm_{i,t} + \beta_3 (CEO_power_{i,t} \times EnvComm_{i,t}) + \beta_4 Bsize_{i,t} + \beta_5 Bindep_{i,t} + \beta_6 Fsize_{i,t} + \beta_7 Leverage_{i,t} + \beta_8 Tangibility_{i,t} + \beta_9 Cash_{i,t} + \beta_{10} CAPEX_{i,t} + \beta_{11} Loss_{i,t} + \beta_{12} Dividend_{i,t} + YearFE + IndustryFE + CountryFE + \epsilon_{i,t} \quad (4.4)$$

$$TCFD_{i,t} = \beta_0 + \beta_1 CEO_power_{i,t} + \beta_2 EnvExpert_{i,t} + \beta_3 (CEO_power_{i,t} \times EnvExpert_{i,t}) + \beta_4 Bsize_{i,t} + \beta_5 Bindep_{i,t} + \beta_6 Fsize_{i,t} + \beta_7 Leverage_{i,t} + \beta_8 Tangibility_{i,t} + \beta_9 Cash_{i,t} + \beta_{10} CAPEX_{i,t} + \beta_{11} Loss_{i,t} + \beta_{12} Dividend_{i,t} + YearFE + IndustryFE + CountryFE + \epsilon_{i,t} \quad (4.5)$$

Where TCFD refers to the TCFD compliance score, which equals the CCI score if a firm reports climate-related financial information as recommended by the TCFD, and zero otherwise. EnvComm is a dummy variable indicating the presence of a board-level environmental board committee, taking the value 1 if such a committee exists and 0 otherwise. EnvExpert denotes the number of directors on the board with environmental expertise. CEO_power is a composite index that captures CEO power, constructed from key governance characteristics, including CEO duality, CEO tenure, and CEO stock ownership. All other independent variables represent control variables defined in Appendix 4.A. In addition, industry, country, and year fixed effects are included to control for unobserved heterogeneity across firms and over time (Lin et al., 2021).

Finally, to test H4, the sample is partitioned based on the presence of environmental board committees, and the model is estimated separately for firms with and without environmental committees to examine whether the relationship between TCFD compliance and investment efficiency differs across these groups.

4.4.1.2 Main Results

4.4.1.2.1 Results of the Association between Environmental Board Committees, Environmental Expertise, and TCFD Compliance

Table 4.4 reports the results of the fixed-effects panel regressions examining the relationship between environmental governance mechanisms and firms' compliance with TCFD disclosures. Model (1) investigates the effect of the presence of an environmental board committee, while Model (2) examines the influence of directors' environmental expertise. Both models include year, industry, and country fixed effects to control for unobserved heterogeneity across firms and over time.

The results of Model 1 indicate that the coefficient on EnvComm ($\beta = 0.098$, $p < 0.01$) is statistically and economically significant. Given that the sample mean TCFD score is 0.10, a coefficient of 0.098 represents a substantial increase in climate disclosure relative to the average level observed across the full sample, highlighting the important role of environmental board committees in promoting voluntary climate transparency. This finding is consistent with resource dependence theory, which emphasises the crucial role these committees play in improving climate-related transparency, rather than merely serving as a superficial strategy for corporate boards. Accordingly, this result supports Hypothesis 1 (H1), which posits that the presence of an environmental board committee is associated with TCFD compliance. This result aligns with those of Driss et al. (2024) and Tingbani et al. (2020).

The results of Model (2) show that the coefficient on environmental Experts is positive and statistically significant ($\beta = 0.019$, $p < 0.05$), indicating that firms with directors possessing environmental expertise are more likely to comply with TCFD disclosure. Given that the mean TCFD compliance in the sample is 0.10, this effect corresponds to an approximately 19% increase relative to the average disclosure level. This magnitude is economically meaningful and consistent with the incremental role of environmental expertise in enhancing firms' climate-related disclosure practices. This finding suggests that environmental expertise enhances the firm's capacity to understand and manage climate-related risks and to engage with voluntary disclosure frameworks such as the TCFD. Therefore, the results support the upper echelons theory argument regarding the importance of directors' knowledge and experience and provide empirical support for H2. This result also aligns with those of Homroy and Slechten (2019).

Regarding the control variables, the results indicate that board size (Bsize) is positively and significantly associated with TCFD compliance across the models. This finding suggests that larger boards may offer greater diversity of expertise and stronger monitoring capacity, encouraging firms to enhance transparency in climate-related disclosures. This result is

consistent with the findings of Dixon-Fowler et al. (2017) and Muttakin et al. (2018). Similarly, firm size (Size) is positively and statistically significantly associated with TCFD compliance, indicating that larger firms are more likely to disclose climate-related information, possibly due to greater stakeholder scrutiny and greater availability of resources to implement sustainability reporting practices. This finding aligns with Ben-Amar et al. (2017). In addition, asset tangibility is positively associated with TCFD compliance, suggesting that firms with higher levels of tangible assets may face greater exposure to climate-related physical risks and therefore have stronger incentives to disclose climate-related financial information.

Among the financial variables, the cash ratio shows a negative, statistically significant relationship with TCFD compliance, implying that firms with higher liquidity may face less external financing pressure and therefore have weaker incentives to voluntarily disclose climate-related risks. In contrast, dividend payments are positively and significantly associated with TCFD compliance, indicating that financially stable and shareholder-oriented firms tend to provide more transparent climate disclosures. Other control variables, including board independence, leverage, capital expenditure, and firm losses, do not exhibit statistically significant relationships with TCFD compliance. Overall, the results for the control variables are broadly consistent with prior research on climate disclosure and corporate governance (e.g., Braasch & Velte, 2023; Shahab et al., 2020; Li et al., 2023). The models include year, industry, and country fixed effects to control for unobserved heterogeneity, and the adjusted R^2 values of approximately 0.45–0.46 indicate moderate explanatory power for variation in TCFD compliance, consistent with the model fit reported by Driss et al. (2024).

Table 4.4 The Association between Environmental Board Committee, Environmental Expert Existence and TCFD Compliance

This table reports the results of ordinary least squares (OLS) regressions on the relationship between environmental committee presence and TCFD compliance (Model 1) and on the association between environmental expertise and TCFD compliance (Model 2). TCFD is measured as 0 for non-complying firms and as the Climate Compliance Index (CCI) score for complying firms. Environmental committee (EnvComm) is a binary indicator that equals 1 if the company has an environmental committee and 0 otherwise. Environmental expert (EnvExpert) is the total number of environmental experts on the company's board. Board size (Bsize) is defined as the natural logarithm of the total number of board members. Board independence (Bindep) is defined as the ratio of independent directors to the total number of board members. Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Cash is calculated as the ratio of cash to total assets. CAPEX is defined as the ratio of capital expenditures to total assets. Loss is a dummy variable that equals 1 if the net income before extraordinary items is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise. The sample comprises 2,895 firm-year observations from 2017 to 2021. OLS regression includes fixed effects on industry, time, and country. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) TCFD	(2) TCFD
EnvComm	0.098*** (4.806)	
EnvExpert		0.019** (2.548)
Bsize	0.112*** (5.808)	0.114*** (5.841)
Bindep	0.008 (0.044)	0.019 (0.986)
Size	0.031*** (7.456)	0.037*** (9.005)
Leverage	0.023 (0.743)	0.031 (0.950)
Tangibility	0.062* (1.690)	0.053 (1.461)
Cash	-0.043* (-1.666)	-0.072*** (-2.667)
Capex	-0.152 (-1.430)	-0.156 (-1.455)
Loss	-0.009 (-0.834)	-0.012 (-1.085)
Dividend	0.035** (2.383)	0.032** (2.080)
Intercept	-0.386*** (-7.343)	-0.402*** (-7.565)
Observations	2,895	2,895
Adj. R ²	0.464	0.455
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

4.4.1.2.2 The Moderating Effect of the Environmental Governance Mechanisms on the Association between CEO Power and TCFD Compliance

To further examine the governance mechanisms that shape firms' climate disclosure practices, this section investigates whether environmental governance mechanisms moderate the relationship between CEO power and TCFD compliance. Specifically, the analysis tests whether the presence of an environmental board committee and directors' environmental expertise mitigates the potential negative influence of CEO power on firms' compliance with TCFD recommendations. Table 4.5 presents the results of the moderation analysis.

As shown in Table 4.5, Model 1 focuses on the role of the environmental board committee (EnvComm), while Column (2) examines the role of environmental experts (EnvExpert). In both models, CEO power is negatively and significantly associated with TCFD compliance. These results support Bose et al (2025) and Bhandari and Javakhadze (2017), indicating that firms led by more powerful CEOs are less likely to comply with TCFD disclosure. The results are also consistent with the managerial power perspective, which posits that entrenched managers may avoid transparency to reduce external monitoring and preserve the private benefits of control. Furthermore, in Column (1), the coefficient of the environmental board committee is positive and highly significant, indicating that firms with an environmental board committee are more likely to comply with TCFD disclosure.

However, the moderating effect of the environmental board committee is negative and statistically significant. This suggests that the positive effect of environmental board committees on TCFD compliance weakens as CEO power increases. In other words, although environmental board committees generally promote climate disclosure, their effectiveness appears to be constrained in firms where CEOs hold substantial decision-making power. One possible explanation is that committees, if lacking real authority or independence, may serve as symbolic governance structures, making them vulnerable to managerial influence. This result is consistent with Tingbani et al. (2020) and Christensen et al. (2021), who find that environmental board committees do not necessarily lead to improved environmental disclosure as they may encounter managerial resistance. This result also underscores the risk of symbolic compliance or greenwashing when authority and expertise are lacking.

In Column (2), EnvExpert is negative but statistically insignificant, suggesting that when the interaction between CEO power and environmental expertise is introduced, the direct effect of

environmental experts becomes statistically insignificant. However, the interaction between CEO power and environmental expertise is positive and significant. This indicates that environmental expertise mitigates the negative effect of CEO power on TCFD compliance by providing specialised knowledge and advisory support that facilitates climate-related disclosure. These results are consistent with those of Ntim and Soobaroyen (2013) and Gerged et al. (2023), arguing that climate monitoring is more likely to detect and deter greenwashing. Unlike environmental board committees, which appear to discipline managerial power, environmental experts play an enabling role by helping powerful CEOs navigate the complexity of climate-related reporting.

The contrasting moderating effects of environmental committees and expertise on CEO power reveal an important distinction between structural and human capital governance mechanisms. Environmental committees, as formal oversight structures, may be perceived by powerful CEOs as monitoring threats that limit their discretion, consistent with agency theory's prediction that governance mechanisms constrain managerial opportunism (Jensen & Meckling, 1976). In contrast, environmental expertise provides specialised knowledge that powerful CEOs can leverage to navigate complex climate reporting requirements, consistent with resource dependence theory's emphasis on knowledge as an enabling rather than constraining resource (Pfeffer & Salancik, 1978). Together, these findings suggest that structural and knowledge-based governance mechanisms operate through fundamentally different channels in shaping the association between CEO power and TCFD compliance. Overall, these results reveal that committees alone may be insufficient to counteract managerial entrenchment, but when combined with genuine expertise, they can transform CEO influence from a liability into a potential asset for climate transparency.

Table 4.5 The Moderating Effect of the Environmental Governance Mechanisms on the Association between CEO Power and TCFD Compliance

This table reports the OLS regression results testing the moderating effect of environmental governance mechanisms on the relationship between CEO power and TCFD compliance. Model (1) examines whether the presence of an environmental committee moderates the association between CEO power and TCFD compliance. Model (2) investigates the effect of environmental expertise on the moderating role of the association between CEO power and TCFD compliance. TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. Environmental committee (EnvComm) is a binary indicator that equals 1 if the company has an environmental committee and 0 otherwise. Environmental expert (EnvExpert) is the total number of environmental experts on the company's board. CEO power is an index covering three dimensions: CEO duality, CEO ownership, and CEO tenure. Definitions of the control variables are reported in Appendix 4.A. The sample comprises 2,353 firm-year observations from 2017 to 2021. OLS regression includes fixed effects on industry, time, and country. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) TCFD	(2) TCFD
CEO-power	-0.05** (-2.32)	-0.03*** (-2.02)
EnvComm	0.16*** (4.42)	
PowerxEnvComm	-0.15*** (-3.02)	
EnvExpert		-0.01 (-0.32)
PowerxEnvExpert		0.04* (1.76)
Bsize	0.10*** (4.41)	0.10*** (4.56)
Bindep	0.04** (2.04)	0.05** (2.34)
Size	0.03*** (6.57)	0.03*** (8.19)
Leverage	0.00 (0.03)	0.00 (0.10)
Tangibility	0.04 (1.11)	0.03 (0.80)
Cash	0.01 (0.23)	-0.01 (-0.27)
Capex	0.04 (1.36)	0.05* (1.65)
Loss	0.00 (0.34)	0.00 (0.14)
Dividend	0.07*** (5.11)	0.07*** (5.13)
Intercept	-0.55*** (-7.61)	-0.57*** (-7.63)
Observations	2,353	2,353
Adj. R ²	0.43	0.42
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

4.4.1.2.3 Environmental Governance Mechanisms, TCFD Compliance and Investment Inefficiency

This section presents the results of the subsample analysis examining the association between TCFD compliance and investment inefficiency across firms with different environmental governance structures. Specifically, the sample is classified based on the presence of environmental board committees (EnvComm) and environmental experts (EnvExpert). Table 4.6 reports the results of a subsample analysis examining the association between TCFD compliance and investment inefficiency across firms with different environmental governance structures. The sample is classified by the presence of an environmental board committee (Models 1 and 2) and by environmental expertise at the board level (Models 3 and 4).

The results in Models (1) and (2) examine the role of the environmental board committee in moderating the relationship between TCFD compliance and investment inefficiency. The coefficient on TCFD is negative and statistically significant only for firms with an environmental board committee (Model 1), whereas it is insignificant for firms without such a committee (Model 2). This finding suggests that governance structures dedicated to environmental oversight enhance the effectiveness of climate-related disclosure in improving investment decisions. In other words, environmental board committees appear to facilitate the translation of climate-related information into more efficient capital allocation. This evidence supports Hypothesis 4 and is consistent with Homroy and Slechten (2019), who highlight the importance of specialised governance mechanisms in improving firms' environmental oversight.

Models (3) and (4) further examine the role of environmental expertise on the board. The coefficient on TCFD is negative and statistically significant in both subsamples; however, the magnitude is larger for firms with environmental experts on the board. This result suggests that environmental expertise strengthens boards' ability to interpret and utilise climate-related information, thereby reducing investment inefficiency. Directors with environmental knowledge may be better positioned to assess climate-related risks and incorporate them into corporate investment decisions.

Overall, these findings indicate that environmental governance mechanisms, particularly the presence of environmental board committees and environmental expertise on the board, enhance the effectiveness of TCFD disclosure in improving firms' investment efficiency. These results align with Driss et al. (2024) and are consistent with agency theory, which

suggests that specialised governance structures improve monitoring and facilitate the effective use of information in corporate decision-making.

Table 4.6 The Role of Environmental Governance in the Relationship between TCFD Compliance and Investment Inefficiency: Subsample Analysis

This table reports the subsample analysis examining whether the effect of TCFD varies across environmental governance structures. Columns (1) and (2) present the results for firms with and without environmental committees (EnvComm), respectively, while Columns (3) and (4) report the results for firms with and without environmental experts (EnvExpert). The dependent variable is investment inefficiency. The models control for firm size, leverage, asset tangibility, firm age, dividend payment, cash ratio, and firm losses. All regressions include year, industry, and country fixed effects, and standard errors are clustered at the firm level. The analysis is conducted on firm-year observations from the study sample. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	Investment Inefficiency		Investment Inefficiency	
	(1) EnvComm=1	(2) EnvComm=0	(3) EnvExpert=1	(4) EnvExpert=0
TCFD	-0.024*** (-3.523)	-0.006 (-0.487)	-0.020** (-2.183)	-0.016** (-2.204)
Size	0.005*** (3.348)	0.009*** (4.940)	0.008*** (3.809)	0.009*** (6.217)
Leverage	0.173*** (2.620)	0.039 (0.650)	0.166* (1.697)	0.006 (0.102)
Tangibility	-0.033*** (-4.823)	-0.015** (-2.456)	-0.047*** (-5.439)	-0.016*** (-3.070)
Age	-0.009** (-2.352)	-0.017*** (-3.624)	-0.002 (-0.483)	-0.018*** (-5.104)
Cash	0.049* (1.761)	0.061*** (2.739)	0.048 (1.018)	0.067*** (3.262)
Dividend	-0.009 (-1.361)	-0.018*** (-3.788)	-0.026*** (-3.545)	-0.011*** (-2.862)
Loss	-0.002 (-0.447)	0.017*** (2.739)	-0.003 (-0.498)	0.014*** (2.658)
Intercept	0.130*** (4.760)	0.115*** (4.496)	0.087*** (2.602)	0.103*** (4.827)
Observations	1062	1,163	582	1,643
Adj R ²	0.482	0.454	0.56	0.483
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes

4.4.2 Endogeneity and Sample Selection Bias

The potential presence of endogeneity and sample selection bias may affect the reliability of the baseline results. In this context, firms that have environmental board committees or environmental experts may differ from other firms in ways that influence their likelihood of complying with TCFD disclosure. Consequently, following Homroy and Slechten (2019), this study employs the Heckman two-stage selection model to mitigate potential sample selection bias. Second, entropy balancing is applied to construct a balanced sample of treated and control. Finally, a Two-Stage Least Squares (2SLS) approach is used to address potential endogeneity arising from reverse causality and omitted variables.

Heckman Selection Model

This study employs the Heckman (1979) two-stage selection model to address potential sample selection bias. Investigating the effects of environmental board committee and environmental expert directors on TCFD compliance may not be consistent with the assumption of random distribution. Hence, following Green and Homroy (2018), to address endogeneity concerns in estimating the presence of environmental board committees and TCFD compliance, this study employs *Env_Ind*, defined as the industry–year average presence of environmental board committees, as an instrument in the first model. In the second model, *Expert_Ind*, measured as the industry–year average availability of environmental experts, is used as the exclusion restriction. These variables are expected to influence a firm's likelihood of complying with environmental governance mechanisms but are unlikely to directly affect the level of TCFD compliance, thereby satisfying the exclusion restriction condition. Prior studies suggest that firms operating within the same industry tend to face similar regulatory pressures, market conditions, and stakeholder expectations, which often lead to similar environmental governance and disclosure practices (Benlemlih & Bitar, 2018).

To implement the Heckman procedure, the first stage estimates a probit selection model in which the presence of an environmental board committee (*EnvComm*) or environmental expert directors (*Expert_Presence*) is regressed on the corresponding instrumental variable (*Env_Ind* or *Expert_Ind*) along with the control variables included in the main regression model. Based on this estimate, the Inverse Mills Ratio (IMR) is calculated to capture the potential selection effect. In the second stage, TCFD compliance is used as the dependent variable, while *EnvComm* (*Expert_Presence*), the IMR, and the control variables are included as explanatory

variables. Table 4.7 reports the results of the Heckman two-step model.

As shown in Table 4.7, the results for the environmental board committee model indicate that *Env_Ind* has a positive and statistically significant coefficient in the selection equation, suggesting that firms operating in industries with a higher prevalence of environmental board committees are more likely to establish such committees (Homroy & Green, 2018). This finding supports the argument that industry-level pressures and governance norms influence firms' environmental governance structures. The results of the outcome equation show that the coefficient on *EnvComm* is positive and statistically significant, confirming that the presence of an environmental board committee is associated with higher levels of TCFD compliance. This result is consistent with the main regression findings and supports the argument that internal environmental governance mechanisms play an important role in promoting climate-related disclosure.

Among the control variables, board size, board independence, firm size, leverage, and asset tangibility are positively and significantly associated with TCFD compliance, suggesting that stronger governance structures and greater firm resources facilitate climate disclosure practices. Conversely, cash holdings, capital expenditure, and loss indicators are negatively associated with TCFD compliance. Furthermore, the coefficient on the IMR is positive and statistically significant, indicating selection bias and confirming the appropriateness of the Heckman correction.

Similarly, the results for the environmental expert model show that *Expert_Ind* is positively and significantly associated with the presence of environmental experts on the board in the selection equation. This suggests that firms operating in industries where environmental expertise is more prevalent are more likely to appoint directors with environmental expertise, aligning with Homroy and Green (2018). In the outcome equation, the coefficient on *EnvExpert* is positive and statistically significant, indicating that the presence of environmental experts on the board enhances the likelihood of TCFD compliance. This finding supports Hypotheses 1 and 2 and further reinforces the argument that internal governance structures and board expertise contribute to improved climate disclosure practices.

Regarding the control variables, board size, firm size, and dividend payments remain positively associated with TCFD compliance, whereas cash holdings are negatively associated. Finally, the coefficient on the IMR is statistically insignificant in this specification, suggesting that selection bias is less pronounced in the environmental expert model.

Overall, the Heckman estimation confirms the robustness of the main findings, indicating that both the presence of environmental board committees and environmental expertise on corporate boards significantly enhance firms' compliance with the TCFD framework.

Table 4.7 Heckman Selection Model

This table reports the results of two separate Heckman selection models that were estimated. The first model examines the presence of environmental board committees, and the second model examines environmental expertise. The industry-year average of environmental board committee presence is used as an instrument for the environmental board committee model. The industry average of available environmental experts is an instrument for the environmental expert model. The outcome equation regresses TCFD compliance on the environmental committee, the number of environmental experts and the control variables. TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. The Environmental board committee (EnvComm) is a binary indicator that equals 1 if the company has an environmental board committee and 0 otherwise. Expert presence is a binary indicator equal to 1 if at least one environmental expert is present on the board. The Environmental expert (EnvExpert) is the total number of environmental experts on the company's board. Definitions of control variables are reported in Appendix 4.A. Both models include industry, year and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	EnvComm Model		EnvExpert Model	
	Selection Equation	Outcome Equation	Selection Equation	Outcome Equation
EnvComm		0.08*** (4.16)		
Env_Ind	0.74*** (4.15)			
EnvExpert				0.02** (2.50)
Expert_Ind			0.36*** (6.59)	
Bsize	0.10 (0.78)	0.12*** (6.33)	0.56*** (5.40)	0.12*** (3.30)
Bindep	1.29*** (9.45)	0.40*** (8.72)	0.78*** (6.43)	0.02 (0.52)
Size	0.28*** (11.84)	0.12*** (11.56)	-0.04* (-1.94)	0.04*** (8.66)
Leverage	0.41** (2.24)	0.15*** (4.41)	-0.23 (-1.32)	0.02 (0.65)
Tangibility	0.25 (1.35)	0.12*** (3.21)	0.57*** (4.04)	0.05 (0.93)
Cash	-1.70*** (-7.68)	-0.60*** (-8.79)	-0.68*** (-3.54)	-0.08* (-1.79)
Capex	-0.61 (-0.71)	-0.35*** (-3.33)	-1.47* (-1.91)	-0.23 (-1.63)
Loss	-0.14* (-1.72)	-0.06*** (-4.81)	0.18** (2.42)	-0.02 (-1.45)
Dividend	-0.06 (-0.82)	0.01 (0.62)	0.24*** (3.58)	0.04** (2.21)
INV_Mills		0.39*** (9.33)		-0.00 (-0.02)
Intercept	-2.76*** (-5.93)	-1.67*** (-11.57)	-2.70*** (-9.83)	-0.42** (-2.26)
Observations	2,895	2,895	2,895	2,895
Adj R ²		0.45		0.42
Pseudo R ²	0.40		0.14	
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes

Entropy Balance Analysis

To address potential endogeneity concerns arising from differences between firms that establish environmental board committees and those that do not, this study employs the entropy balancing approach following Bose et al. (2025). Entropy balancing is applied as an alternative to the widely used Propensity Score Matching (PSM). Although PSM is commonly employed to address selection bias, it has been criticised for its sensitivity to model specification and its vulnerability to researcher discretion in selecting matching algorithms and covariates (King & Nielsen, 2019). In contrast, entropy balancing directly reweights the control group to achieve covariate balance across treatment groups, reducing reliance on model assumptions and limiting potential researcher-induced bias (McMullin & Schonberger, 2020; Ali et al., 2022).

Entropy balancing operates through a weighting procedure rather than a matching process. Specifically, the method assigns continuous weights to control observations to ensure that the distribution of covariates in the control group closely matches that of the treatment group (Hainmueller, 2012). Accordingly, firms are first categorised into a treatment group (firms with an environmental committee) and a control group (firms without an environmental committee). The entropy-balancing procedure then reweights the control observations so that the covariate distributional moments, such as means and variances, are identical across the two groups (Ali et al., 2022). After achieving covariate balance, the baseline regression model is re-estimated using the entropy-balanced weights. Table 4.8 presents the results of the weighted regression analysis. Appendix 4.B also reports the covariate balance after entropy balance analysis.

The results in Table 4.8 indicate that the presence of an environmental board committee remains positively and statistically significantly associated with TCFD compliance ($\beta = 0.06$). This finding suggests that firms with environmental board committees exhibit higher levels of climate-related disclosure, supporting the argument that specialised governance structures enhance firms' commitment to climate transparency and reporting. This finding suggests that the study's baseline results remain robust after controlling for observable selection bias. Overall, the entropy balancing analysis provides further evidence that the positive relationship between environmental board committees and TCFD compliance is robust after accounting for potential differences in firm characteristics between treated and control firms.

Table 4.8 Entropy Balance Analysis

This table reports the results of regressing TCFD compliance on environmental board committee and other control variables using the using entropy balancing weights. Entropy-balancing weights are applied in the OLS regression to balance covariates across firms with and without an environmental board committee. TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. The Environmental board committee (EnvComm) is a binary indicator that equals 1 if the company has an environmental board committee and 0 otherwise. Board size (Bsize) is defined as the natural logarithm of the total number of board members. Board independence (Bindep) is defined as the ratio of independent directors on a board. Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Cash is calculated as the ratio of cash to total assets. CAPEX is defined as the ratio of capital expenditures to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0. The sample comprises 2,895 firm-year observations from 2017 to 2021. OLS regression includes fixed effects on industry, time, and country. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) TCFD
EnvComm	0.060** (2.338)
Bsize	0.139*** (3.680)
Bindep	0.108*** (2.607)
Size	0.061*** (7.617)
Leverage	0.096 (1.577)
Tangibility	0.084 (1.142)
Cash	-0.049 (-0.657)
Capex	-0.366* (-1.722)
Loss	-0.037* (-1.743)
Dividend	0.020 (0.783)
Intercept	-0.755*** (-7.745)
Observations	2,895
Adj. R ²	0.465
Year FE	Yes
Industry FE	Yes
Country FE	Yes

Two-Stage Least Squares (2SLS)

To address potential endogeneity concerns arising from omitted variables and reverse causality, this study employs the Two-Stage Least Squares (2SLS) estimation approach, following Driss et al. (2024). Endogeneity may arise because firms that establish environmental governance mechanisms, such as environmental board committees or environmental expert directors, differ systematically from those that do not, potentially biasing baseline regression estimates.

The 2SLS procedure is implemented in two stages. In the first stage, the presence of environmental board committees (or environmental experts in Model 3) is regressed on the instrumental variable and the control variables included in the baseline model. In the second stage, TCFD compliance is regressed on the predicted values of environmental board committee presence (or environmental experts) obtained from the first stage, together with the control variables. Following Tingbani et al. (2020), this study employs *Env_Ind*, defined as the one-year lagged peer-based industry-year average presence of environmental board committees (excluding the focal firm), as an instrument in the environmental board committee model. Similarly, *Expert_Ind*, defined as the one-year lagged peer-based industry-year average availability of environmental experts (excluding the focal firm), is used as an instrument in the environmental expert model. The use of these instruments is motivated by the notion that firms operating within the same industry are subject to similar regulatory pressures, competitive dynamics, and stakeholder expectations, which may influence the adoption of environmental governance structures (Tingbani et al., 2020). At the same time, these peer-based industry averages are unlikely to directly affect a firm's TCFD compliance decisions.

Table 4.9 reports the results of the 2SLS estimation. In Model 1, the first-stage regression shows that *Env_Ind* is positively and statistically significantly associated with the presence of environmental board committees ($\beta = 1.711$, $p < 0.05$), indicating that firms are more likely to establish such committees when they are prevalent among industry peers, aligning with Tingbani et al. (2020). The value of the first-stage F-statistic is 24.51, indicating that the instrument is sufficiently strong (Stock et al., 2002). The second-stage results indicate that the coefficient on *EnvComm* remains positive and statistically significant ($\beta = 0.694$, $p < 0.05$), suggesting that firms with environmental board committees exhibit higher levels of TCFD compliance. This finding is consistent with the baseline results and provides further evidence that environmental governance structures play an important role in promoting climate-related

disclosure. Moreover, the Durbin–Wu–Hausman Test rejects the null hypothesis of exogeneity, indicating that the environmental board committee is endogenous. This suggests that the baseline estimates may be affected by endogeneity concerns, thereby supporting the use of the 2SLS estimator. The control variable results are consistent with the baseline findings. Firm size and board size are positively associated with the dependent variable, indicating that larger firms and boards are more engaged in TCFD disclosure. In contrast, leverage, capital expenditure, and dividend payments exhibit significant negative effects, suggesting that financial constraints and payout policies may limit such engagement.

Turning to the environmental expert model, the first-stage results show that *Expert_Ind* is positively and statistically significantly associated with the presence of environmental experts on corporate boards ($\beta = 0.675$, $p < 0.01$). The corresponding first-stage F-statistic of 44.7 further confirms the instrument's strength and supports its relevance. In the second stage, the coefficient on *EnvExpert* is positive and statistically significant ($\beta = 0.128$, $p < 0.05$), indicating that firms with environmental expert directors are more likely to comply with the TCFD framework. This finding reinforces the argument that board-level environmental expertise enhances firms' ability to respond to climate-related reporting demands. Finally, the Durbin–Wu–Hausman test also indicates that environmental expertise is endogenous to TCFD compliance, further supporting the use of the 2SLS approach. The control variable results are broadly consistent with the baseline findings. Firm size and board size are positively and significantly associated with TCFD compliance, highlighting the importance of firm structure and governance mechanisms. Cash holdings exhibit a negative and significant association in the *EnvExpert* model, consistent with the view that cash-rich firms face less external financing pressure and therefore have weaker incentives for voluntary disclosure (Driss et al., 2024).

Overall, the 2SLS results confirm the robustness of the main findings and suggest that both environmental board committees and environmental expert directors play a significant role in promoting TCFD compliance.

Table 4.9 Two-Stage Least Squares (2SLS) Analysis

This table reports the results from Two-Stage Least Squares to address endogeneity. One-year-lagged peer-based industry–year average presence of environmental board committees is used as an instrument for the environmental board committee model (1 & 2). One-year-lagged, peer-based industry–year average availability of environmental experts is an instrument for the environmental expert model (3 & 4). TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. The environmental board committee (EnvComm) is a binary indicator that equals 1 if the company has an environmental board committee and 0 otherwise. The Environmental Expert (EnvExpert) is the total number of environmental experts on the company’s board. Definitions of control variables are reported in Appendix 4.A. Both models include industry, year and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	EnvComm Model		EnvExpert Model	
	(1) First Stage	(2) Second Stage	(3) First Stage	(4) Second Stage
EnvComm		0.694** (2.526)		
Env_Ind	1.711** (2.274)			
EnvExpert				0.128** (2.345)
Expert_Ind			0.675*** (3.710)	
Bsize	0.061 (1.165)	0.119* (1.764)	0.367*** (3.091)	0.083*** (2.920)
Bindep	-0.141* (-1.765)	-0.493*** (-3.011)	0.513*** (4.716)	-0.059 (-1.631)
Size	0.006 (0.382)	0.174*** (2.839)	-0.016 (-1.000)	0.046*** (9.256)
Leverage	-0.017 (-0.295)	-0.111** (-2.512)	-0.128 (-0.700)	0.012 (0.285)
Tangibility	-0.018 (-0.242)	-0.033 (-0.906)	0.286 (1.019)	-0.041 (-0.616)
Cash	0.070 (0.824)	0.118** (2.151)	-0.872*** (-4.472)	-0.072** (-2.337)
Capex	-0.221 (-0.984)	-0.811*** (-3.126)	-0.546 (-0.606)	-0.044 (-0.262)
Loss	0.009 (0.385)	0.002 (0.181)	0.029 (0.477)	-0.025** (-2.103)
Dividend	0.043* (1.792)	0.114** (2.114)	0.230*** (3.065)	0.019 (0.891)
Intercept	-0.403** (-2.296)	0.253*** (2.886)	-0.801*** (-2.722)	-0.481*** (-6.148)
Observations	2,371	2,371	2,371	2,371
Adj. R ²	0.380	0.431	0.161	0.236
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes

4.4.3 Sensitivity Analysis

This section conducts additional analyses to examine whether the main findings remain robust under alternative model specifications and variable measurements. Specifically, two sensitivity tests are conducted. First, lagged environmental governance variables are used to mitigate potential reverse causality. Second, the environmental pillar score is introduced as an additional control variable to account for firms' overall environmental performance. The results of these analyses are reported in Table 4.10.

4.4.3.1 Lagged Independent Variables

A potential concern with the baseline specification is reverse causality as firms already engaged in TCFD disclosure may subsequently establish environmental governance structures to signal commitment to climate transparency, rather than governance structures driving disclosure decisions. To address this concern, following Martínez-Ferrero et al. (2018), this study re-estimates the baseline models using one-year lagged values of all independent variables. By lagging all independent variables by one year, the analysis ensures that the explanatory variables are determined prior to the current period's TCFD compliance decision, thereby strengthening the causal interpretation of the results and mitigating potential simultaneity between governance structures, firm characteristics, and climate disclosure decisions.

4.4.3.2 Controlling for Environmental Performance

To further assess the robustness of the main findings, this study, following Driss et al. (2024) and Christensen et al. (2021), examines the relationship between environmental governance mechanisms and TCFD compliance while controlling for firms' environmental performance. Firms with stronger environmental performance may be more inclined both to establish environmental governance structures and to engage in climate-related disclosure. To address this concern, this study incorporates the environmental pillar score, which captures a firm's overall environmental performance and policies, including emissions reduction initiatives, resource management practices, and environmental innovation (Bose et al., 2025). Controlling for this variable allows the analysis to isolate the effect of environmental governance mechanisms from firms' broader environmental performance.

Prior research provides theoretical support for this approach. For instance, Matsumura et al. (2014) show that environmentally proactive firms are more likely to engage in voluntary

climate disclosure. Similarly, Christensen et al. (2021) argue that firms may strategically disclose favourable environmental information while withholding unfavourable performance outcomes. Consistent with these studies, controlling for environmental performance helps ensure that the observed relationship between environmental governance mechanisms and TCFD compliance is not driven solely by firms' underlying environmental board commitment. Environmental performance is measured using the natural logarithm of the environmental pillar score sourced from the LSEG database (formerly Refinitiv).

Table 4.10 reports the results of two additional sensitivity tests designed to assess the robustness of the main findings. Models (1) and (2) estimate the association between environmental governance mechanisms and TCFD compliance using one-year lagged independent variables. This specification helps mitigate potential endogeneity concerns arising from reverse causality, ensuring that environmental governance structures precede firms' climate disclosure decisions. Models (3) and (4) extend the analysis by incorporating firms' environmental performance as an additional control variable through the environmental pillar score. The number of observations varies across models due to differences in the availability of lagged variables and the environmental pillar score.

The results in Models (1) and (2) indicate that the lagged environmental board committee remains positively and significantly associated with TCFD compliance ($\beta = 0.122$, $p < 0.01$), and the lagged environmental expertise variable similarly remains positive and significant ($\beta = 0.022$, $p < 0.05$), consistent with the baseline findings reported in Table 4.4 and align with Braasch and Velte (2023). Furthermore, Models (3) and (4) show that environmental board committees and environmental expert directors continue to exhibit a positive and statistically significant association with TCFD compliance after controlling for firms' environmental performance. This indicates that the governance effect is not solely driven by firms' underlying environmental engagement. In addition, the environmental pillar score is positively and significantly related to TCFD compliance, suggesting that firms with stronger environmental performance are more likely to engage in climate-related reporting, consistent with the findings of Driss et al. (2024).

Overall, these results reinforce the robustness of the primary analysis and provide further evidence that environmental governance mechanisms play a meaningful role in promoting climate-related disclosure. Importantly, the findings suggest that environmental board committees and environmental expert directors perform a substantive governance function

promoting voluntary TCFD compliance through both oversight capacity and specialised knowledge, independently of firms' broader environmental performance. Finally, the results highlight the conceptual distinction between the environmental pillar score and TCFD reporting: while the environmental pillar score captures a firm's broader environmental performance, TCFD specifically reflects firms' climate-related disclosure practices.

Table 4.10 The Association between Environmental Board Committee, Environmental Expert and TCFD Compliance: Sensitivity Analysis

This table reports the results of ordinary least squares (OLS) regressions on the relationship between environmental board committee presence and TCFD compliance (Model 1) and the association between environmental expertise and TCFD compliance (Model 2), using one-year-lagged independent variables to address potential reverse causality. This table also reports the results of estimating the relationship between the presence of environmental board committees and the use of environmental experts in TCFD compliance with the environmental pillar score as an additional control variable (Models 3 and 4). TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. The environmental board committee (EnvComm) is a binary indicator variable that equals 1 if the company has an environmental board committee and 0 otherwise. The Environmental Expert (EnvExpert) is the total number of environmental experts on the company's board. Definitions of control variables are reported in Appendix 4.A. All models include industry, year and country fixed effects. Standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) TCFD	(2) TCFD	(3) TCFD	(4) TCFD
EnvComm	0.122*** (5.434)		0.038** (2.275)	
EnvExpert		0.022** (2.497)		0.014** (2.055)
Environmental Pillar			0.251*** (7.692)	0.270*** (9.090)
Bsize	0.112*** (4.908)	0.117*** (5.147)	0.066*** (3.268)	0.061*** (3.039)
Bindep	0.001 (0.074)	0.031 (1.337)	0.049** (2.384)	0.058*** (3.048)
Size	0.042*** (9.049)	0.048*** (10.26)	0.027*** (6.638)	0.028*** (6.999)
Leverage	0.043 (1.169)	0.048 (1.264)	0.012 (0.398)	0.0170 (0.521)
Tangibility	0.058 (1.361)	0.053 (1.248)	0.105*** (2.838)	0.094*** (2.617)
Cash	-0.066** (-2.272)	-0.101*** (-3.310)	-0.005 (-0.233)	-0.011 (-0.483)
Capex	-0.243* (-1.823)	-0.238* (-1.785)	-0.253** (-2.424)	-0.238** (-2.330)
Loss	-0.013 (-0.979)	-0.016 (-1.168)	-0.012 (-1.045)	-0.013 (-1.138)
Dividend	0.041** (2.431)	0.040** (2.298)	0.059*** (3.566)	0.057*** (3.420)
Intercept	-0.442*** (-7.585)	-0.469*** (-7.945)	-0.405*** (-7.955)	-0.403*** (-7.870)
Observations	2,371	2,371	2,393	2,393
Adj R ²	0.463	0.452	0.444	0.445
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes

4.4.3.3 The Role of Country Climate Policy

According to the institutional theory, firms seek legitimacy by aligning their practices with the norms and expectations of their institutional environments (Tsang et al., 2023). Thus, the voluntary establishment of environmental governance mechanisms, such as environmental board committees, may reflect how regulatory frameworks, cultural influences, and national policy priorities shape firms' responses to climate-related risks (Krueger et al., 2024). Because firms operate across countries with different legal systems, regulatory regimes, and environmental policies, their approaches to climate governance and disclosure may vary substantially (Feng et al., 2022).

To further explore this institutional dimension, this study examines whether country-level climate policy stringency influences the relationship between the presence of environmental board committees and TCFD compliance. Stronger national climate policies may increase regulatory pressure and stakeholder expectations, thereby encouraging firms to strengthen internal environmental governance mechanisms and enhance climate-related disclosure practices (Tsang et al., 2023). Following Chalabi-Jabado and Ziane (2024) and Bolton et al. (2023), this study uses the Climate Policy Index from the Climate Change Performance Index (CCPI) as a proxy for national climate policy stringency. The index evaluates countries based on the effectiveness of their climate policies and their alignment with the goals of the Paris Agreement (Burck et al., 2020). Higher index values indicate stronger national climate policy frameworks. Therefore, countries are classified as high climate policy when their CCPI score exceeds the sample median, and low climate policy otherwise. Table 4.11 reports the results of the relationship between the presence of environmental board committees and TCFD compliance across countries classified by the strength of their climate policies.

As shown in Table 4.11, the results indicate that the presence of an environmental board committee is positively associated with TCFD compliance in both institutional settings. However, the coefficient is stronger in countries with higher climate policy performance ($\beta = 0.105$, $p < 0.01$) compared to those with weaker policy frameworks ($\beta = 0.073$, $p < 0.05$). This suggests that environmental board committees are more effective in promoting climate-related disclosure when firms operate in institutional environments characterised by stronger climate regulations and enforcement mechanisms. Greater institutional pressure in such contexts may

encourage firms to strengthen internal governance structures and improve their climate-related transparency. These findings are consistent with the arguments of Albitar et al. (2020) and Ben-Amar and McIlkenny (2015), who highlight the significant role of coercive institutional pressures in shaping firms' voluntary compliance with enhanced climate disclosure practices.

Across both subsamples, the control variables produce consistent results. Board size and firm size are positively and statistically significantly associated with TCFD compliance across both subsamples, suggesting that larger boards and firms provide greater expertise and monitoring capacity to support climate-related reporting. In contrast, cash holdings are negatively associated with TCFD compliance in both subsamples, indicating that firms with higher liquidity face weaker external pressure to disclose detailed climate information. Additionally, asset tangibility is positively associated with TCFD compliance, whereas capital expenditure and loss indicators are negatively associated with it, particularly in countries with weaker climate policies. This suggests that financially constrained firms operating in less stringent institutional environments face greater barriers to voluntary climate disclosure due to limited resources and reduced institutional pressure.

Finally, the adjusted R-squared values indicate that the model explains 44% of the variation in environmental disclosure in high-climate policy countries, compared to 28% in low-climate policy countries. Overall, these findings suggest that stronger institutional environments and climate policy frameworks reinforce the effectiveness of environmental governance mechanisms in promoting TCFD compliance.

Table 4.11 The Association between Environmental Board Committee and TCFD Compliance: Country Climate Policy

This table reports the results of a subsample analysis examining the relationship between the presence of environmental board committees and TCFD compliance, after classifying countries by climate policy stringency. TCFD is measured as 0 for non-complying firms and the Climate Compliance Index (CCI) score for complying firms. Environmental board committee (EnvComm) is a binary variable equal to 1 if a firm has an environmental board committee and 0 otherwise. Definitions of the control variables are provided in Appendix 4.A. All models include industry, year, and country fixed effects, and standard errors are clustered at the firm level. The symbols *, **, and *** indicate statistical significance levels at 10%, 5%, and 1%, respectively.

VARIABLES	(1) High climate policy	(2) Low climate policy
EnvComm	0.105*** (4.603)	0.073** (2.481)
Bsize	0.102*** (4.774)	0.150*** (4.548)
Bindep	-0.001 (-0.0591)	0.045 (1.322)
Size	0.028*** (6.186)	0.044*** (6.851)
Leverage	0.013 (0.378)	0.016 (0.348)
Tangibility	0.053 (1.291)	0.093* (1.696)
Cash	-0.045* (-1.723)	-0.078* (-1.695)
Capex	-0.177 (-1.487)	-0.412** (-2.316)
Loss	-0.005 (-0.390)	-0.038* (-1.763)
Dividend	0.040** (2.139)	0.045* (1.948)
Intercept	-0.361*** (-6.457)	-0.517*** (-6.592)
Observations	1,889	1,006
Adj R ²	0.442	0.283
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

4.5 Conclusion

Effective capital markets rely on the timely and reliable disclosure of material information; however, the adequacy of climate-related reporting remains widely debated (Di Marco et al., 2023). In response, the TCFD has been used as a framework to improve transparency regarding firms' exposure to climate-related risks and opportunities (TCFD, 2017). As highlighted by O'Dwyer and Unerman (2020), the TCFD framework represents an important step toward supporting the transition to a low-carbon economy.

Despite these developments, concerns persist regarding the voluntary nature of climate disclosure and the extent to which internal governance mechanisms are associated with firms' compliance with such frameworks. In particular, limited evidence exists on how board-level environmental governance, such as environmental board committees and directors with climate-related expertise, is related to firms' engagement with TCFD recommendations. Accordingly, this study examines the association between environmental board committees, environmental expert directors, and the voluntary compliance with the TCFD framework using a global sample of firms over the period 2017–2021.

The findings indicate that both the presence of an environmental board committee and the appointment of directors with climate expertise are positively associated with firms' compliance with TCFD reporting. These results remain robust after addressing potential endogeneity and selection concerns through several empirical approaches, including instrumental-variable estimation, entropy balancing, and selection models. Furthermore, the effect of environmental board committees is more pronounced in countries characterised by stronger climate policy frameworks, suggesting that institutional environments reinforce the effectiveness of internal governance mechanisms in promoting climate-related transparency.

Additionally, the study explores whether environmental board committees influence the relationship between TCFD compliance and two important corporate outcomes: investment efficiency and CEO power. The negative association between TCFD compliance and investment inefficiency, documented in Chapter 2, is observed only among firms with environmental board committees, suggesting that governance structures are a necessary condition for climate disclosure to translate into economic outcomes. This finding bridges the disclosure and governance literatures by demonstrating that the economic benefits of climate

transparency depend on the strength of internal oversight mechanisms. In addition, the study provides evidence on the interaction between environmental governance and CEO power. The results suggest that the positive association between environmental board committees and TCFD compliance weakens in firms with higher CEO power, while environmental expertise plays a complementary enabling role, mitigating the constraining effect of CEO power on disclosure decisions. This distinction between structural and knowledge-based governance mechanisms represents a key theoretical contribution of the study.

This study makes three contributions to the literature. First, it extends the emerging literature on TCFD compliance by providing cross-country evidence on internal governance determinants of voluntary climate disclosure, specifically the roles of environmental board committees and director expertise, which have received limited attention in prior TCFD research. Second, it contributes to the corporate governance literature by demonstrating that environmental governance mechanisms condition both the CEO power-disclosure relationship and the economic consequences of climate disclosure for investment efficiency, providing new evidence on how board structures moderate these associations. Third, by focusing on the voluntary compliance period, this study contributes to the voluntary disclosure literature by identifying the governance conditions under which climate disclosure translates into real economic outcomes, offering insights relevant to the ongoing transition to mandatory reporting regimes.

This study also offers important implications for policymakers and practitioners. For regulators, the results suggest that encouraging or mandating environmental governance mechanisms such as environmental board committees and climate expertise on boards may enhance the effectiveness of climate disclosure frameworks. From a corporate perspective, strengthening internal climate governance can improve transparency and reduce information asymmetry, thereby supporting more efficient capital allocation. From a broader societal perspective, credible climate disclosure plays a critical role in addressing the climate crisis. By institutionalising the identification and management of climate-related risks and opportunities, environmental board committees can help bridge the gap between firms and societal expectations, strengthening the legitimacy of sustainability reporting and supporting global climate transition efforts.

Despite these contributions, this study is subject to some limitations that provide avenues for future research. First, the analysis focuses on a period characterised by voluntary climate

disclosure, which may influence firms' reporting incentives. As regulatory requirements continue to evolve and TCFD compliance becomes mandatory in some jurisdictions, the observed associations may differ in more regulated settings. Future research could examine whether the role of environmental governance mechanisms changes under mandatory disclosure regimes. Second, although the study adopts a cross-country perspective, institutional differences are captured at an aggregate level and may not fully reflect the complexity of country-specific regulatory, cultural, and governance environments. Future studies may incorporate more granular institutional measures or focus on specific country settings to better capture these contextual differences.

Third, climate disclosure is measured using the TCFD using CCI. Future research could employ alternative measures of climate disclosure or develop more refined proxies that distinguish between symbolic and substantive reporting practices. Fourth, environmental expertise is measured using keyword-based classification of directors' career histories and educational backgrounds. While this approach follows established practice (Homroy & Slechten, 2019), it may not fully capture the depth or relevance of directors' environmental knowledge. Future research could develop more refined measures of environmental expertise, such as distinguishing between operational, regulatory, and scientific expertise, to better understand which types of knowledge most effectively promote climate disclosure.

Overall, this study provides cross-country evidence on how internal environmental governance structures are associated with firms' voluntary climate disclosure decisions.

Appendices to Chapter Four

4.A Variable Definition

This table presents the definitions of variables used in the current study. The sources and data items used from each source are also provided.

Variable	Definition	Proxy for	Source
Dependent Variable Measures:			
TCFD	Measured using the Climate Compliance Index (CCI) developed by Demaria & Rigot (2021). The variable equals 0 if the firm does not disclose climate-related financial information aligned with the TCFD recommendations and equals the CCI score if the firm complies with the TCFD framework.	TCFD compliance	ESG and Sustainability Reports
Independent Variable			
EnvComm	Equals 1 if the company has an environmental board committee and 0 otherwise.	Environmental Board Committee	BoardEx
EnvExpert	Total number of environmental experts on the company's board.	Environmental Expert Directors	BoardEx
Power	A composite index constructed based on three indicators: CEO duality (1 if the CEO is also board chair, 0 otherwise), CEO tenure (1 if CEO tenure exceeds the sample median, 0 otherwise), and CEO ownership (1 if CEO share ownership exceeds the sample median, 0 otherwise). The index is calculated as the sum of the three indicators, scaled by the total number of components, ranging from 0 to 1, with higher values indicating greater CEO power.	CEO Power	BoardEx
Inv_Ineff	Absolute value of residuals estimated from firm-specific investment inefficiency (Biddle et al., 2009). Larger absolute residuals indicate greater investment inefficiency. $Investment_{i,t} = \beta_0 + \beta_1 SalesGrowth_{i,t-1} + \epsilon_{i,t}$ Investment equals the ratio of the net increase in tangible and intangible assets to	Investment Inefficiency	LSEG (formerly Refinitiv)

	lagged total assets. Sales growth is the rate of change in sales from year t-1 to year t.		
Control Variables			
Bsize	Natural logarithm of the total number of board members	Board Size	LSEG (formerly Refinitiv)
Bindep	Ratio of independent directors on a board	Board Independence	LSEG (formerly Refinitiv)
Size	Natural logarithm of the firm's market capitalisation	Firm Size	LSEG (formerly Refinitiv)
Leverage	Total debt divided by total assets.	Leverage	LSEG (formerly Refinitiv)
Tangibility	Ratio of property, plant, and equipment (PPE) to total assets.	Asset Tangibility	LSEG (formerly Refinitiv)
Loss	Dummy variable equal to 1 if net income before extraordinary items is negative, and 0 otherwise.	Loss	LSEG (formerly Refinitiv)
Cash	Ratio of cash and cash equivalents to total assets.	Cash holding	LSEG (formerly Refinitiv)
CAPEX	Ratio of capital expenditures to total assets.	Capital Expenditures	LSEG (formerly Refinitiv)
Dividend	Dummy variable that equals 1 if the firm pays dividends in the year and 0 otherwise	Firm Earning	LSEG (formerly Refinitiv)

4.B Descriptive Statistics of Sub-Sample after Entropy Balance Analysis

The Table reports the summary statistics for treated (firm-year observations where the board maintains an environmental committee) and control firms (firm-year observations where no such environmental committee exists) after Entropy Balancing Analysis. The table reports the mean and variance of the covariates for 2,895 firm-year observations. Board size (Bsize) is defined as the natural logarithm of the total number of board members. Board independence (Bindep) is defined as the ratio of independent directors to the total number of directors on a board. Firm size (Size) is measured as the natural logarithm of the firm's market capitalisation. Leverage is measured as total debt divided by total assets. Tangibility is measured as the ratio of PPE to the firm's total assets. Cash is calculated as the ratio of cash to total assets. CAPEX is defined as the ratio of capital expenditures to total assets. Loss is a dummy variable that equals 1 if the net income before the extraordinary item is negative and 0 otherwise. Dividend is a dummy variable that equals 1 if the firm paid dividends and 0 otherwise.

	Treatment		Control	
	With the Environmental Committee)		Without the Environmental Committee	
	Mean	Variance	Mean	Variance
Bsize	2.310	0.007	2.310	0.008
Bindep	0.691	0.005	.691	0.006
Size	9.221	0.051	9.221	0.048
Leverage	0.284	0.005	0.284	0.004
Tangibility	0.338	0.008	0.338	0.007
Cash	0.120	0.003	0.120	0.004
CAPEX	0.442	0.001	0.442	0.001
Loss	0.201	0.012	0.201	0.012
Dividend	0.465	0.015	0.465	0.011
Observations	1,054		1,841	

Appendix 4.C Geographical Distribution of the sample

This table presents the country-level distribution of the sample. The sample includes firms from 36 countries, providing a geographically diverse research setting. However, the distribution of observations is not uniform across countries and is relatively concentrated in a few markets, particularly Canada, China, and the United Kingdom. This concentration may reflect differences in market size and data availability.

Country	Firms	Observations	% of Observations
Argentina	14	69	2.38
Australia	8	30	1.04
Belgium	8	38	1.31
Bermuda	25	112	3.87
Brazil	30	133	4.59
Canada	129	588	20.31
Cayman Islands	11	44	1.52
Chile	12	56	1.93
China	85	344	11.88
Colombia	4	20	0.69
Denmark	6	30	1.04
France	13	57	1.97
Germany	18	71	2.45
Greece	10	49	1.69
Hong Kong	12	53	1.83
India	9	45	1.55
Ireland	23	111	3.83
Italy	7	29	1.02
Japan	13	63	2.18
Luxembourg	14	66	2.28
Mexico	8	40	1.38
Monaco	4	20	0.69
Netherlands	19	82	2.83
Norway	2	9	0.31
Panama	2	8	0.28
Peru	5	25	0.86
Singapore	18	73	2.52
South Africa	10	47	1.62
South Korea	10	50	1.73
Spain	5	25	0.86
Sweden	11	50	1.73
Switzerland	19	87	3.01
Taiwan	12	59	2.04
Turkey	4	17	0.59
United Kingdom	66	295	10.19
Total	646	2,895	100.00

Appendix 4.D Robustness Analysis Excluding Canadian Firms

This table reports the results of the baseline regression after excluding Canadian firms to ensure that the findings are not driven by sample concentration. The results indicate that both environmental governance structures and board-level expertise play a significant role in promoting climate-related disclosure. Overall, these findings confirm that the main results are robust to the exclusion of Canadian firms and are not driven by sample concentration.

VARIABLES	(1) TCFD	(2) TCFD
EnvComm	0.073*** (3.320)	
EnvExpert		0.016** (2.042)
Bsize	0.111*** (5.081)	0.120*** (7.327)
Bindep	0.025 (1.073)	0.048*** (2.844)
Size	0.037*** (8.297)	0.041*** (13.362)
Leverage	0.012 (0.343)	0.014 (0.528)
Tangibility	0.055 (1.287)	0.065** (2.199)
Cash	-0.051 (-1.631)	-0.079*** (-3.550)
Capex	-0.202 (-1.408)	-0.247** (-2.237)
Loss	-0.022* (-1.754)	-0.025** (-2.202)
Dividend	0.032** (2.054)	0.035*** (3.056)
Intercept	-0.422*** (-7.090)	-0.448*** (-11.535)
Observations	2,307	2,307
Adj. R ²	0.436	0.429
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes

Appendix 4.E Figures

Figure 4.1: Marginal Effect Plot of the Association between the Environmental Board Committee and TCFD compliance

Figure 4.1 presents the marginal effect of environmental board committee presence on predicted TCFD compliance scores over the period 2017–2021. The figure plots predicted TCFD scores for firms with ($\text{EnvComm} = 1$) and without ($\text{EnvComm} = 0$) an environmental board committee, holding all other covariates at their mean values. The error bars represent 95% confidence intervals. The non-overlapping confidence intervals confirm a statistically significant positive association between environmental committee presence and TCFD compliance, consistent with H1.

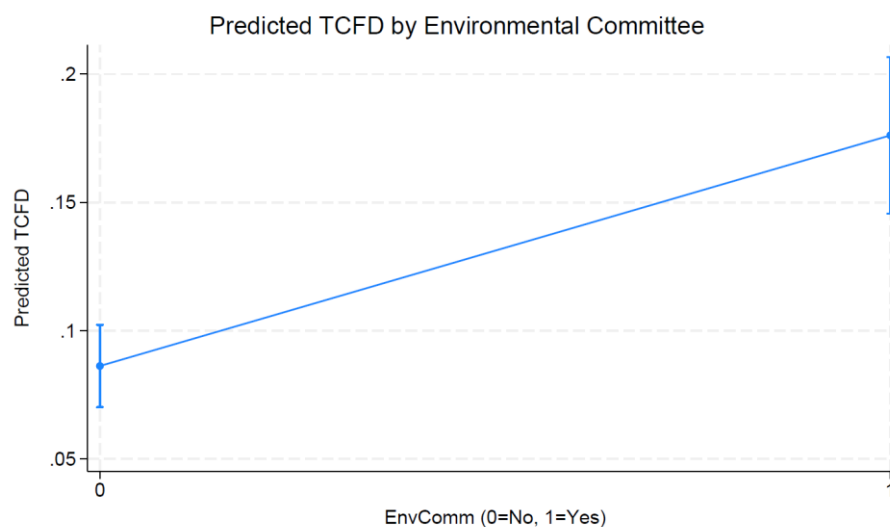
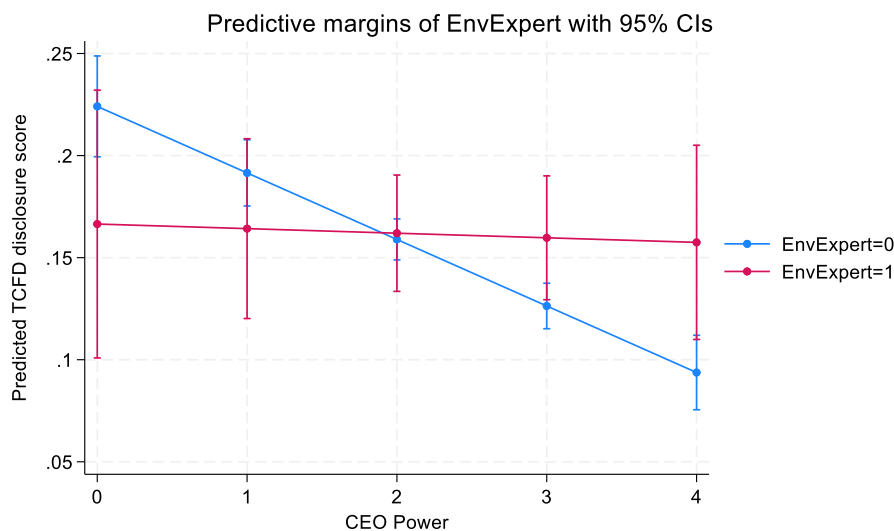


Figure 4.2: The Effect of Environmental Expert Director on the Association between CEO Power and TCFD compliance

Figure 4.2 presents the predictive margins of environmental expertise on TCFD compliance across different levels of CEO power, with 95% confidence intervals. The blue line represents firms without environmental expert directors (EnvExpert = 0), while the pink line represents firms with at least one environmental expert director (EnvExpert = 1). For firms without environmental expertise, predicted TCFD compliance declines sharply as CEO power increases, from approximately 0.225 at the lowest power level to 0.095 at the highest, indicating that concentrated CEO authority significantly constrains climate disclosure in the absence of specialised board knowledge. In contrast, for firms with environmental expertise, predicted TCFD compliance remains relatively stable across all levels of CEO power at approximately 0.160, suggesting that board-level expertise effectively buffers the negative influence of CEO power on voluntary climate disclosure. This pattern provides visual support for H3b.



Chapter Five Conclusion

5.1 Introduction

As global concerns about climate change intensify, addressing its economic and environmental consequences has become a central focus for researchers, policymakers, and financial market participants. Corporations play a critical role in responding to these challenges, as their operations significantly influence environmental outcomes and their strategic decisions shape how climate-related risks are managed (Ilhan et al., 2023). Climate-related risks can have substantial adverse effects on firms' operations, financial performance, and long-term sustainability (Sautner et al., 2023). As the economic impacts of climate change become more apparent, stakeholders are increasingly demanding greater corporate accountability and transparency regarding companies' exposure to climate-related risks and the strategies they employ to manage them (Ngo et al., 2022). In this context, climate-related financial disclosure has become a crucial tool for companies to communicate their environmental strategies and demonstrate responsible business practices. Greater transparency in climate reporting enables stakeholders to better assess corporate exposure to climate risks, strengthens investor confidence, and facilitates more efficient capital allocation in financial markets (TCFD, 2017).

Recognising the importance of enhancing climate transparency, the Financial Stability Board established the TCFD in 2015 to provide a structured framework for reporting climate-related financial information (TCFD, 2017). The TCFD framework is established to improve the quality, consistency, and comparability of climate disclosures and to increase transparency in corporate reporting (Lombardi et al., 2022). Nevertheless, the 2019 TCFD report indicates that global compliance with its recommendations remains limited, underscoring the need for further research into the factors influencing climate-related disclosures and companies' participation in voluntary reporting frameworks.

Previous accounting research shows inconsistent results regarding whether firms are willing to voluntarily disclose environmental information. Some studies, aligned with the resource-based view, suggest that transparency about environmental efforts can provide a competitive advantage, boost stakeholder trust, and increase firm value (Johnston et al., 2005; Lai et al., 2014). Conversely, other research indicates that firms may hesitate to engage in voluntary

environmental disclosures due to costs, organisational adjustments, and uncertainties linked to environmental initiatives and reporting (Oberndorfer et al., 2013; Wright & Nyberg, 2017). These opposing viewpoints reveal a significant gap in understanding the motivations behind compliance with TCFD and the financial impacts of climate-related disclosures, which this thesis aims to explore.

Hence, this thesis provides an empirical investigation of the determinants and consequences of firms' compliance with the TCFD framework. Specifically, it examines how environmental board committees, environmental expertise and CEO power are associated with TCFD compliance and explores whether such transparency affects firms' economic outcomes, particularly investment efficiency. Part of these tests, this thesis also includes analysing the effect of the regulatory environment and the political role. This would provide a deeper understanding of how climate disclosure practices can enhance corporate accountability and improve decision-making in capital markets.

This thesis comprises three well-linked research studies that primarily examine the voluntary compliance with the TCFD framework. The first study investigates the association between TCFD compliance and firm-level investment efficiency, with a particular focus on overinvestment and underinvestment. The second study investigates the association between CEO power and TCFD compliance, and whether CEO support for climate initiatives is associated with this relationship. Finally, the third study investigates the association between environmental board committees, the presence of environmental expert directors, and voluntary TCFD compliance. These studies highlighted the possible effects of a firm's climate governance, industry's climate risk sensitivity, the national governance index, and the regional climate regulatory framework on a firm's decision-making process regarding these issues. The following three sections provide a brief conclusion for each empirical chapter included in the current thesis.

5.2 Summary of Findings

5.2.1 The Association between Voluntary Compliance with TCFD and Corporate Investment Efficiency

This chapter examines the association between voluntary TCFD compliance and corporate investment efficiency. Specifically, it explores the association between TCFD compliance and

investment inefficiency, including overinvestment and underinvestment. The findings provide consistent evidence that firms complying TCFD-aligned disclosure exhibit significantly lower levels of investment inefficiency. In particular, TCFD compliance is associated with reductions in both overinvestment and underinvestment, suggesting that climate-related financial disclosure contributes to more disciplined and efficient capital allocation.

These results indicate that enhanced climate transparency improves the firm's information environment by providing investors with more comprehensive insights into firms' exposure to climate-related risks and opportunities. In line with voluntary disclosure theory, improved transparency reduces information asymmetry and strengthens external monitoring of managerial decisions, thereby supporting more efficient investment behaviour (Chen et al., 2022).

Further analyses suggest that the association between TCFD compliance and investment efficiency operates partly through improvements in capital market conditions. Specifically, TCFD compliance is associated with higher stock liquidity, which partially mediates the relationship between climate disclosure and investment efficiency. This finding highlights the role of financial markets in transmitting the benefits of enhanced climate transparency into more efficient corporate investment decisions. The effectiveness of TCFD disclosure also appears to depend on the broader institutional environment. The results indicate that the positive impact of TCFD compliance on investment efficiency is stronger in countries with more stringent climate policy frameworks, suggesting that national climate policies complement firm-level disclosure practices. Importantly, the association between TCFD compliance and improved investment efficiency remains robust after controlling for ESG disclosure, indicating that the effect is driven by the specific informational value of climate-related financial disclosure.

Overall, the findings provide strong evidence that voluntary TCFD compliance has meaningful economic consequences by improving the transparency of climate-related risks and enhancing the efficiency of corporate investment decisions.

5.2.2 The Association Between CEO Power, CEO Climate Support and Voluntary Climate Change-Related Disclosure

This chapter investigates the association between CEO power and TCFD compliance, and whether CEO support for climate initiatives is associated with this relationship. The findings

indicate that CEO power is negatively associated with the likelihood of voluntary TCFD compliance, suggesting that firms led by more powerful CEOs are less inclined to engage in climate-related financial disclosure. This result is consistent with the managerial power perspective, which argues that executives with greater authority may resist transparency when disclosure increases external scrutiny or constrains managerial discretion. It also aligns with the findings of Bose et al. (2025). In contrast, the results show that CEO climate support is positively associated with TCFD compliance, indicating that firms whose leaders express a stronger commitment to climate initiatives are more likely to voluntarily report on climate. This finding supports the predictions of upper echelons theory, highlighting the importance of managerial values and environmental awareness in shaping corporate disclosure decisions (Neely et al., 2020).

Further analysis reveals that while CEO power reduces the likelihood of TCFD framework compliance, it is positively associated with the quality of climate-related disclosure among firms that have already adopted the framework. This suggests that powerful CEOs may exercise discretion in deciding whether to comply with voluntary climate reporting but may enhance the depth and credibility of disclosure once such reporting is undertaken. The results also highlight the importance of institutional environments. Stronger climate policy frameworks partially mitigate the negative influence of CEO power on TCFD compliance, indicating that regulatory pressures can constrain managerial discretion and encourage greater transparency. However, the political environment appears less effective in offsetting the influence of CEO power on disclosure decisions.

Overall, these findings demonstrate that both managerial characteristics and institutional contexts play a critical role in shaping firms' engagement with voluntary climate disclosure frameworks.

5.2.3 The Association between Environmental Board Committees, Environmental Experts and Voluntary Climate Disclosure

This chapter examines the association between environmental board committees, the presence of environmental expert directors, and voluntary TCFD compliance. The findings show that firms with environmental governance structures, specifically environmental board committees and directors with environmental expertise, are more likely to comply with TCFD reporting. These results suggest that specialised governance structures enhance firms' capacity to

understand climate-related risks and support the implementation of climate disclosure practices, aligning with the upper echelons theory and with Driss et al. (2024).

The results indicate that environmental board committees generally promote climate disclosures; however, their effectiveness is limited in firms where CEOs hold significant decision-making power. In contrast, directors with environmental expertise are more successful at reducing the negative impact of CEO authority on compliance with TCFD guidelines. This finding suggests that specialised knowledge within the board can improve oversight and facilitate more meaningful engagement with climate reporting.

The study also highlights the role of environmental governance in shaping the economic consequences of climate disclosure. The results show that TCFD compliance is associated with improved investment efficiency among firms with environmental governance mechanisms in place, particularly through reducing underinvestment. This suggests that environmental oversight structures help firms translate climate-related information into more effective investment decisions.

Finally, the findings indicate that the effectiveness of environmental governance mechanisms is reinforced by institutional contexts. Environmental committees appear more effective at promoting TCFD compliance in countries with stronger climate policy frameworks, suggesting that internal governance structures and external regulatory environments jointly influence firms' climate disclosure practices.

Overall, the results demonstrate that specialised environmental governance structures play a critical role in promoting credible climate disclosure and strengthening the link between climate transparency and corporate decision-making.

5.3 Thesis Contribution

This thesis makes several important contributions to the literature on climate-related financial disclosure, corporate governance, and corporate decision-making, while also providing practical insights for policymakers, regulators, and corporate leaders.

First, the thesis contributes to the growing literature on climate-related financial disclosure by providing new evidence on the economic consequences of TCFD reporting. While previous studies have largely focused on the determinants of climate disclosure or the financial risks

associated with climate change (Bingler et al., 2022; Di Marco et al., 2023; Ding et al., 2023), this thesis demonstrates that compliance with TCFD recommendations has meaningful implications for corporate behaviour. The findings specifically indicate that companies following TCFD-aligned disclosures demonstrate improved investment efficiency, marked by decreases in both overinvestment and underinvestment. This suggests that climate-related financial reporting improves the information environment of firms, diminishes information asymmetry between management and investors, and promotes better capital allocation decisions.

Second, the thesis extends the literature on managerial power and corporate disclosure by examining how CEO characteristics influence firms' engagement with voluntary climate reporting frameworks. The findings reveal that CEO power reduces the likelihood of voluntary TCFD compliance, suggesting that powerful executives may resist transparency when disclosure increases external monitoring or constrains managerial discretion. At the same time, CEO climate support significantly increases the likelihood of climate disclosure, highlighting the importance of managerial values and leadership attitudes in shaping firms' responses to climate-related risks. These findings contribute to the corporate governance literature by demonstrating how managerial authority and leadership characteristics jointly influence firms' transparency decisions in emerging sustainability reporting contexts.

Third, the thesis contributes to the corporate governance and sustainability literature by highlighting the critical role of specialised governance structures in overseeing climate-related disclosure practices. The results show that board-level environmental governance mechanisms, including environmental committees and directors with environmental expertise, significantly increase firms' compliance with TCFD reporting. Moreover, these governance mechanisms enhance the effectiveness of climate disclosure by strengthening its relationship with corporate investment efficiency and mitigating the negative influence of CEO power on disclosure decisions. These findings emphasise the importance of board expertise and oversight in ensuring that climate-related information is effectively integrated into corporate strategy and investment decisions.

Beyond its academic contributions, the thesis also provides important implications for practice and policy. For corporate leaders, the findings highlight the importance of strengthening board-level environmental expertise and governance structures to support credible and effective climate disclosure. Firms seeking to improve transparency and investment decision-making

may benefit from establishing environmental committees and appointing directors with relevant environmental expertise.

For policymakers and regulators, the findings provide evidence that climate-related financial disclosure frameworks such as the TCFD can generate meaningful economic benefits by improving corporate transparency and investment efficiency. However, the results also suggest that the effectiveness of voluntary climate disclosure depends on internal governance structures and leadership incentives. These insights are particularly relevant in the context of the global transition toward mandatory climate disclosure regimes, including the ISSB's development of sustainability standards and the implementation of IFRS S2 climate-related disclosures. By identifying the organisational factors that influence firms' engagement with climate reporting, this thesis offers insights that can inform the design of more effective climate disclosure policies and governance frameworks.

Finally, the thesis provides valuable insights for investors and other stakeholders by demonstrating that climate-related financial disclosure can improve firms' information environment and enhance the efficiency of capital markets. By increasing transparency regarding climate-related risks and opportunities, TCFD reporting enables investors to better assess firms' long-term risk exposures and strategic responses to climate change. Collectively, the findings across the three studies provide evidence consistent with substantive rather than purely symbolic TCFD compliance, climate disclosure improves investment efficiency (Chapter 2), is shaped by genuine governance mechanisms (Chapters 3 and 4), and its economic benefits depend on the strength of internal oversight structures (Chapter 4), contributing to the ongoing debate regarding whether voluntary climate disclosure frameworks generate genuine corporate change (Rodrigue et al., 2013).

5.4 Research Limitations and Future Research Directions

While this thesis provides important contributions and robust empirical evidence, it also has some limitations. First, this thesis focuses on the voluntary compliance period of the TCFD framework. During the sample period, firms voluntarily complied with TCFD recommendations, which may have influenced both the motivations for disclosure and the characteristics of complying firms. As global regulatory environments continue to evolve and climate-related reporting becomes mandatory in many countries, the determinants and

consequences of climate disclosure may change. In particular, the ISSB's introduction of IFRS S2 climate-related disclosures represents an important shift toward mandatory climate-related financial disclosure. Consequently, future research could examine whether the relationships identified in this thesis persist under mandatory disclosure regimes by comparing firms' behaviour before and after the transition to IFRS S2-aligned reporting.

Second, although this thesis investigates several important internal governance mechanisms such as CEO power, CEO climate support, and board-level environmental governance structures, other potentially relevant organisational factors were beyond the scope of the analysis. Future research could extend this work by examining additional governance and organisational characteristics, including ownership structure, the role of institutional investors, board diversity, or organisational culture, which may also influence firms' engagement with climate-related disclosure frameworks.

Third, the measurement of CEO power in this thesis is based on three commonly used indicators: CEO duality, CEO tenure, and CEO ownership. Due to data limitations, CEO compensation was excluded from the CEO power index. Future research could incorporate additional dimensions of managerial power, particularly compensation-based measures, to provide a more comprehensive assessment of executive influence on climate disclosure decisions.

Finally, the proxy used to capture CEO climate support may not fully reflect the CEO's genuine environmental beliefs or strategic commitment to climate action. While the measure captures observable signals of climate support, it may not fully capture underlying managerial attitudes or strategic intentions. Future research could employ alternative approaches, such as textual analysis of CEO communications, including earnings call transcripts, shareholder letters, or public speeches, to provide a more nuanced measure of CEOs' climate-related attitudes and their influence on corporate climate disclosure practices.

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