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Three essays on the impact of climate change on firm's valuation and policies

Nicolas Baelen

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THÈSE DE DOCTORAT DE L'UNIVERSITÉ CLERMONT AUVERGNE

IAE Clermont Auvergne

Ecole Doctorale des Sciences Economiques Juridiques, Politiques et de Gestion

Clermont Recherche Management (CleRMa)

Présentée par

Nicolas BAELEN

Sujet de la thèse :

Three Essays on the Impact of Climate Change on Firms' Valuation and Policies

Pour obtenir le titre de

DOCTEUR EN SCIENCES DE GESTION

Soutenue le 27 novembre 2023

Devant le jury composé de :

Directeur de thèse	Sylvain MARSAT Professeur, Université Clermont Auvergne
Directeur de thèse	Guillaume PIJOURLET Maitre de conférences, Université Clermont Auvergne
Rapporteur	Fabrice HERVE Professeur, Université de Bourgogne
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Et présidée par la Professeur **Sophie SPRING** (Professeur, Université de Montpellier)

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L'université n'entend donner aucune approbation ni improbation aux opinions émises dans les thèses. Ces opinions doivent être considérées comme propres à leurs auteurs.

« *Labor improbus omnia vincit* »* Virgile, *Géorgiques*, livre I, v. 145.

* Un travail acharné vient à bout de tout.

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Abstract

This thesis consists of three empirical studies (chapter 2, chapter 3, and chapter 4, respectively) investigating the impact of climate change on firm value and policies. We aim to contribute to the growing literature on climate finance by analyzing the implications of climate risk on firm valuation and decision-making, through investment policy and environmental strategies.

In chapter 1, we define climate risks and discuss their financial implications on firms from the theoretical and empirical literature. We then present the avenues of research on the impact of climate change on firms that we investigate in the following chapters.

In chapter 2, we analyze the impact of mitigation and adaptation to climate change strategies on corporate financial performance. Using an international sample of 3,544 firms from 42 countries in the 2012-2016 period, we disentangle corporate environmental strategy into two categories defined by the IPCC (Houghton et al., 2001): the mitigation and the adaptation to climate change strategies. We find evidence that mitigation has a positive and significant impact on both accounting and market-based financial performance. However, we show that adaptation to climate change strategy is only associated with greater market-based financial performance. Moreover, we find evidence of complementarity between mitigation and adaptation strategies on return on assets, while mitigation and adaptation simultaneously implemented have a significant impact on corporate financial performance.

In chapter 3, we investigate the effect of physical risk related to climate future change on firm value. Drawing on an international dataset of 1,294 firms over the 2009-2020 period, we measure physical risks using a unique specific-firm rating developed by Carbon4 Finance. In line with Dessaint and Matray (2017), we find that acute physical risk has a negative and significant effect on firm value, whereas chronic physical risk is not significantly related to firm value. This indicates that physical risk should not be considered only as a global issue since

acute and chronic risks are priced differently by investors. By investigating the channels of the effect of chronic and acute risks on firm value, we find that acute risks imply less sales growth and lower dividends. We then note a more material impact of acute risk on sales growth and dividends that explains the difference in impact compared to chronic risk.

In chapter 4, we study the influence of physical climate risk on corporate investment. Using a US sample of 4,008 firm-years observations over the 2009-2020 period, our regression results first show that physical climate risk is positively associated with R&D and long-term investments. These results suggest that physical climate risk impacts the type and nature of corporate investments. We show that the interaction between physical risk and R&D has a significant and positive effect on corporate risk-taking. Moreover, we find that firms use their excess to invest more in R&D. While a strand of the literature suggests that climate risk leads to less risky decisions (Ginglinger & Moreau, 2019; Huang et al., 2018; Noth & Rehbein, 2019), our challenging results show that firms with high physical risk tend to take more risk through R&D to adapt to climate change.

Overall, our results suggest that climate risk is a significant driver of firm value and decision-making, especially through investment policy and environmental strategies.

Keywords: *Climate change; climate risk; environmental strategy; firm value; financial performance; corporate investment; decision-making.*

Résumé

Ce travail doctoral, s'articulant autour de trois études empiriques (chapitre 2, chapitre 3 et chapitre 4), s'intéresse à l'impact du changement climatique sur la valeur et les politiques menées par les entreprises. Notre objectif est de contribuer à une littérature grandissante sur la finance climatique en analysant les implications du risque climatique sur l'évaluation et la prise de décisions des entreprises, par le biais de la politique d'investissement et des stratégies environnementales.

Dans le chapitre 1, nous définissons les risques climatiques et stratégies environnementales et discutons de leurs implications financières sur les entreprises, d'un point de vue théorique et empirique. Nous présentons ensuite les pistes de recherche sur l'impact du changement climatique sur les entreprises que nous étudions dans les chapitres suivants.

Dans le chapitre 2, nous analysons l'impact des stratégies d'atténuation et d'adaptation au changement climatique sur la performance financière des entreprises. Basé sur un échantillon international de 3544 entreprises de 42 pays sur la période 2012-2016, nous distinguons la stratégie environnementale en deux concepts définis par le IPCC (Houghton et al., 2001) : la mitigation et l'adaptation au changement climatique. Les résultats montrent que la mitigation a un impact positif et significatif sur la performance comptable et financière des entreprises. Cependant, l'adaptation est seulement associée à un Q de Tobin plus élevé. De plus, nous montrons une complémentarité entre la mitigation et l'adaptation sur le ROA, tandis que ces deux stratégies ont un impact positif lorsqu'elles sont menées simultanément.

Dans le chapitre 3, nous étudions l'effet du risque physique lié au changement climatique futur sur la valeur des firmes. Basé sur un échantillon international de 1294 firmes sur la période 2009-2020, nous mesurons le risque physique à l'aide d'une notation unique par entreprise développée par Carbon4 Finance. En phase avec Dessaint et Matray (2017), nous trouvons que le risque aigu a un effet négatif et significatif sur la valeur des firmes, alors que le risque chronique n'a pas d'impact significatif. Nos résultats suggèrent que le risque physique ne doit pas être considéré comme un problème global étant donné les différences d'évaluation des risques aigus et chroniques par les investisseurs. En étudiant les canaux de transmissions des risques physiques sur la valeur des firmes, nous trouvons que les risques aigus impliquent une réduction de la croissance des ventes et des dividendes. Nous montrons donc un impact matériel plus important du risque aigu qui peut expliquer la différence d'impact par rapport au risque chronique.

Dans le chapitre 4, nous étudions l'influence du risque physique sur la politique d'investissement des entreprises. Basé sur un échantillon américain de 4008 observations en firme-années sur la période 2009-2020, les résultats montrent que le risque climatique physique est positivement et significativement associé au niveau de R&D ainsi qu'aux investissements long-terme des firmes. Ces résultats suggèrent que le risque physique a un impact sur le type et la nature des investissements des entreprises. Nous montrons également que l'interaction entre le risque physique et la R&D a un effet significatif et positif sur la prise de risque des entreprises. De plus, nous observons que les entreprises utilisent leurs liquidités excédentaires pour investir davantage dans des projets de R&D. Alors qu'un courant de la littérature suggère que le risque climatique conduit à prendre des décisions moins risquées (Ginglinger & Moreau, 2019 ; Huang et al., 2018 ; Noth & Rehbein, 2019), nos résultats montrent que les entreprises avec un risque physique élevé ont tendance à prendre plus de risques à travers des investissements en R&D pour s'adapter au changement climatique.

Dans l'ensemble, nos résultats suggèrent que le risque climatique est un déterminant significatif de la valeur et de la prise de décisions des entreprises, en particulier par le biais de la politique d'investissement et des stratégies environnementales.

Mots clés : *Changement climatique ; risque climatique ; stratégie environnementale ; valeur des entreprises ; performance financière ; politique d'investissement ; perception du risque.*

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Abbreviations

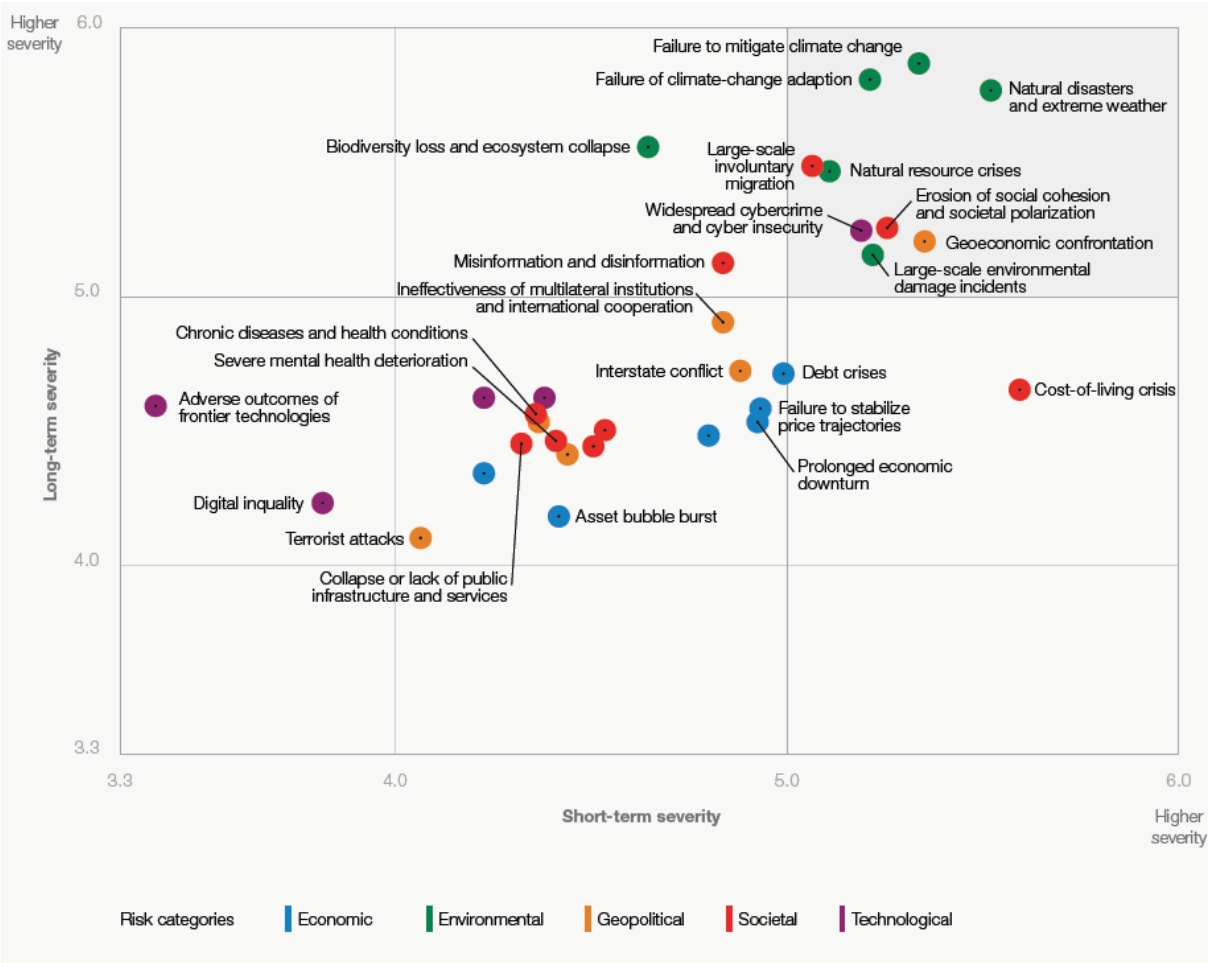
IPCC	Intergovernmental Panel on Climate Change
GRPS	Global Risks Perceptions Survey
TCFD	Task Force on Climate-Related Financial Disclosures
NRBV	Natural Resource Based View
CDP	Carbon Disclosure Project
R&D	Research and Development
ROA	Return On Assets
ROE	Return On Equity
CRIS	Climate Risk Impact Screening
OECD	Organisation for Economic Cooperation and Development
GHG	Greenhouse Gas
NGFS	Network for Greening the Financial System
CEO	Chief Executive Officer
CSR	Corporate Social Responsibility
ESG	Environmental, Social and Governance
OLS	Ordinary Least Square
GDP	Gross Domestic Product
CAPEX	Capital Expenditures
COP	Conference of the Parties
VIF	Variance Inflation Factor

General introduction

One of the most notable trends of the last decades has been the rise of climate awareness. These concerns are driven by the fact that climate change affects climate patterns that influence the intensity and, in some cases, the frequency of climate-related events, such as hurricanes, heatwaves, storms, or droughts. Scientists are now warning people and policymakers of the results if the world reaches average temperatures of 1.5 ° C above pre-industrial levels (IPCC 2022). However, the IPCC estimates that only drastic reductions in carbon emissions could mitigate future climate disasters. Climate change is then a major issue for all economic actors, and especially for firms that contribute to greenhouse gas emissions.

This increased focus on climate change issues raises questions about climate risk. Figure 1 shows the relative severity of risks survey from the World Economic Forum Report (2023). Respondents were asked to assess the severity of global risks that may become future shocks or crises over the next two and ten years on a Likert scale of 1 to 7. Based on the Global Risks Perceptions Survey (GRPS), the long-term global risks landscape is dominated by environmental risks. In fact, climate action failure (from mitigation and adaptation) and extreme weather events are considered the most critical social risk to the world over the next 10 years (World Economic Forum Global Risk Report, 2023). Furthermore, most of the respondents to the World Economic Forum survey are critical of what policymakers do to mitigate climate change.

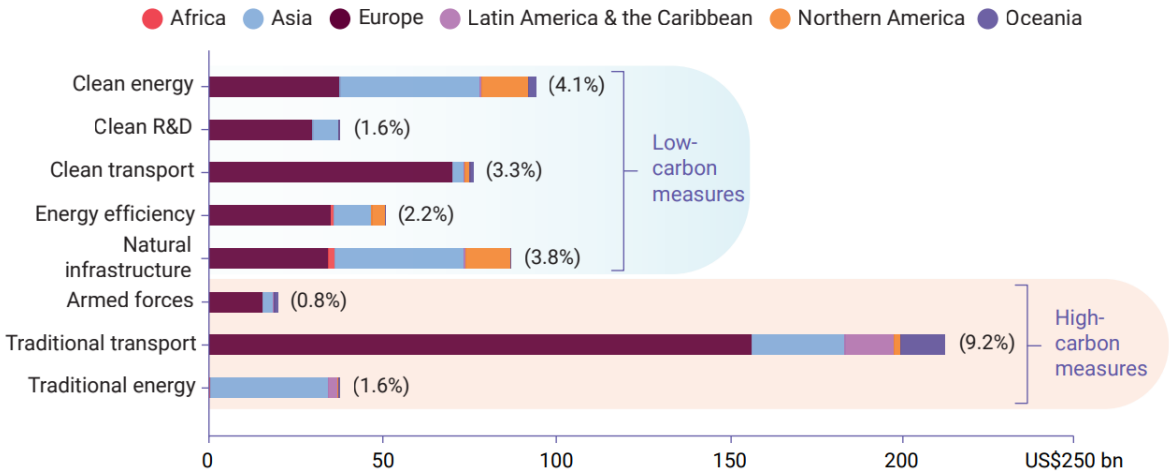
Figure 1. Relative severity of risks over a 2 and 10-year period (World Economic Forum Global Risks Perception Survey, 2022-2023)



Source: Relative severity of risks over a 2 and 10-year period (World Economic Forum Global Risks Perception Survey, 2022-2023). Survey respondents were asked to assess the relative severity of risks on a Likert scale of 1 to 7, 1 representing a risk with a low severity, and 7 a risk with very high severity. We note 5 risk categories: economic, environmental, geopolitical, societal, and technological.

Despite the growing environmental concerns, the low-carbon transition is not anchored firmly enough. Indeed, the COVID-19 pandemic period has stimulated public and private expenditures. We note an acceleration of the low-carbon transition through global recovery spending. However, most countries have forgotten the idea of using low-carbon strategies as a means of economic recovery. As shown in Figure 2, only around 18% of recovery spending is likely to reduce carbon emissions.

Figure 2. Global recovery spending as of May 2021 across sectors by region (UNEP Emissions Gap Report, 2021)

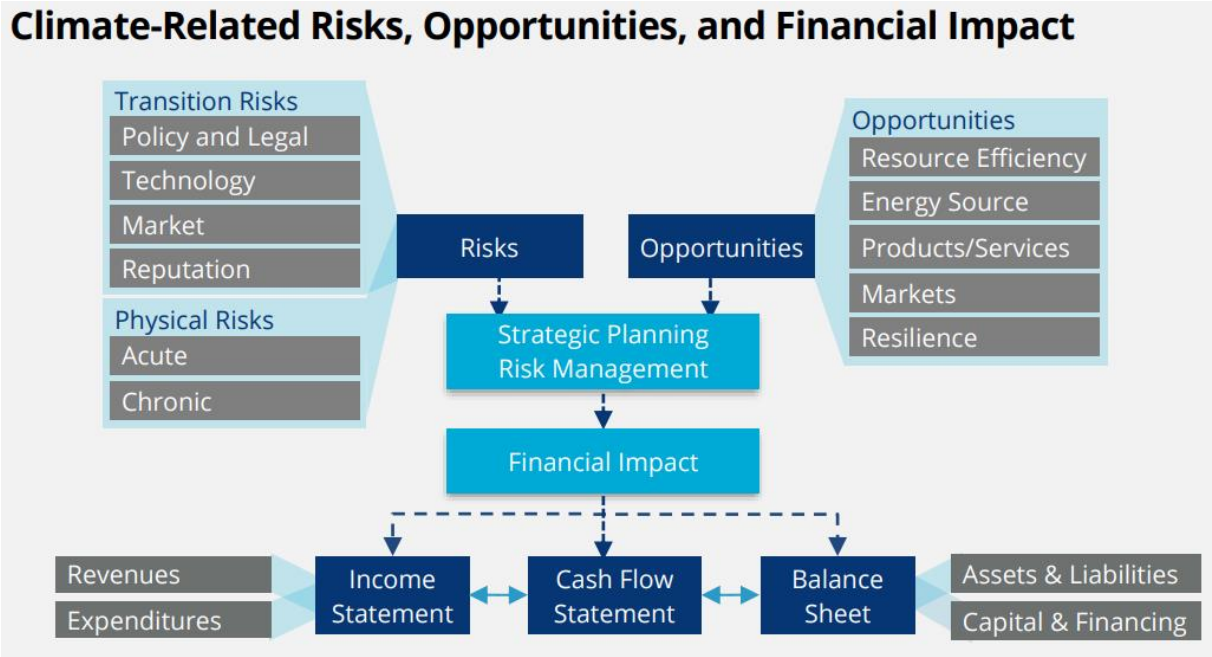


Source: Emissions Gap Report: The heat is on (UNEP-CCC 2021). Global recovery spending as of May 2021 across sectors by region (US\$ billion). Low-carbon initiatives are on top. High-carbon initiatives are at the bottom.

The growing demand from investors, corporate managers, policymakers, and other stakeholders increases the need for climate disclosure. As a result, the TCFD provides an improved classification of climate-related risks. The TCFD assumes that climate change can result in climate-related risks but also opportunities, as evidenced in Figure 3. First, the Task Force categorizes climate risks into two main types of risks: risks related to the transition to a lower carbon economy and risks related to the physical impacts of climate change. The climate transition may result in various risks such as policy and legal, technology, market, and reputation risk. In other words, a lower carbon economy requires a global environmental strategy that can cause market changes and transition risks. Second, climate change may result in physical risks. The TCFD notes that physical risks can be acute or chronic. Acute risk is defined as event-driven risk, including increased severity of extreme weather events (cyclones, hurricanes, or floods). Chronic risk refers to longer-term changes in climate patterns that may cause sea level rise, chronic heatwaves, and changes in rainfall patterns. Physical risks may

then have financial impacts on firms as climate change could result in direct damage to assets or indirect impacts from the supply chain.

Figure 3. Climate-related risks, opportunities, and financial impact (TCFD, 2017)



Source: Final Report: Recommendations of the Climate-Related Financial Disclosure Task Force, 2017

This classification reveals interesting facts. First, we learn that climate-related risks consist of transition and physical risks that can affect risk management and therefore have a financial impact. Second, climate change could represent opportunities for companies. In fact, environmental strategies can lead to opportunities for companies. The IPCC defines two main categories of environmental strategy: mitigation and adaptation to climate change strategies. Mitigation is defined as an intervention to reduce the sources or enhance the sinks of greenhouse gases, while adaptation is the adjustment in response to actual or expected climate change effects to exploit beneficial opportunities (Houghton et al., 2001). In general, we see a growing awareness of the contribution that climate change influences firm value and decision-making.

. Despite the growing academic literature on climate finance in recent years, Diaz-Rainey et al. (2017) showed that until 2015 there were only a few articles in the main finance journals. The literature has first focused on the relationship between environmental performance and financial performance at the firm level (Delmas et al., 2015; Lee & Min, 2015; Matsumura et al., 2014). A new stream of literature investigates the effects of natural disasters on firm value (Huang et al., 2018; Noth & Rehbein, 2019), corporate investment (Kanagaretnam et al., 2022), debt and dividend policy (Huang et al., 2018). While the literature has mainly focused on the financial historical physical risk, there is yet little work investigating the impact of increased physical risk due to climate change on a firm's decisions and value. We thus aim to fill this gap in our doctoral work.

Specifically, we aim to answer the following main question in our doctoral thesis:

Does climate change have an impact on firm decisions and value?

We precisely investigate the financial impact of climate change from various perspectives. Indeed, we study the impact of physical risk on firm value to better understand how investors price acute and physical risks. We then investigate how investors price physical risk studying the link between physical risk and firm value. Last, we focus on the influence of climate risk on firms' decisions through investment policy.

We propose a view to explain the possible relationship between environmental strategies and corporate financial performance. We first build on the natural resource-based view theory (NRBV) to conceptualize the relation between environmental performance and financial performance. Hart (1995) extends the resource-based view theory (Barney, 1991; Wernerfelt, 1984) and introduces the constraint of natural resources. The NRBV theory includes three strategic capabilities that are pollution prevention, product stewardship, and sustainable

development. We differentiate those capabilities due to their different mobilized resources and expected goals. We then disentangle mitigation and adaptation strategies. While Porter & Van der Linde (1995) define pollution as an economic waste, Hart (1995) suggests that a pollution mitigation strategy moves from an internal process to an external legitimacy-based activity. A firm mitigating its environmental damages may enhance the firm's image (Davis, 1976), reputation (Russo & Fouts, 1997), and legitimacy. In contrast, the risk of reputation is a real issue, and companies tend to implement an environmental strategy to prevent reputational scandals. Alleviating its environmental damages also shows a capacity to comply with new regulations. As the mitigation strategy is led as a legitimacy-based strategy, reducing environmental damages can generate a higher reputation and enhance short-term financial performance.

Sustainable development involves structural changes (Russo and Fouts, 1997) and a long-term commitment to obtain a competitive advantage (Hart, 1995). Indeed, the results of innovation are not immediately apparent (Porter & Linde, 1995). The adaptation strategy can lead to a firm's competitive advantage through the new green technology and costly-to-copy firm resources and capabilities of the firm to copy. The main issue is to adapt to climate change at acceptable costs. However, Porter's theory (Porter, 1991; Porter & Linde, 1995) suggests that early green investments offset operational costs that could enhance financial performance in the long term. Environmental innovation may lead to a differentiation advantage, generate a first-mover effect from exploiting new markets (Hart, 1995), and be an opportunity to increase product or service prices. Furthermore, firms that implement environmental strategies in the long term should be considered more prepared for future crises by investors (Orlitzky et al., 2003).

Furthermore, we propose contrasting arguments to explain the impact of climate risk on firm value and firm decisions. On the one hand, climate risk may have financial implications for firms, resulting from direct and indirect asset damages. The first argument is that climate risk may hurt firm value through the negative effects of climate change. As a result, investors may demand a risk premium as compensation for climate risk exposure (Bansal et al., 2016; Sautner et al., 2023). A recent strand of literature highlights that the perception of physical risk is a determinant in the valuation process (Alok et al., 2020; Choi et al., 2020). Individuals also use heuristics to assess risk. One heuristic is to infer the frequency of an event from its availability, the ease with which occurrences of the event come to mind (Tversky and Kahneman, 1974; Dessaint and Matray, 2017). In other words, risk assessment may be driven by the salience of the event. It will create a discrepancy between perceived risk and actual risk. When a climate disaster has been recently observed, the availability is high and its probability is overestimated (Dessaint & Matray, 2017). Investors may overestimate climate risk due to high media coverage and time proximity that enhance the salience of an event. The salience hypothesis implies that investors are affected by risks that are more extreme and attention-grabbing. Because saliency is experienced-based, high saliency could influence investors' risk perception and, therefore, be detrimental to firm value.

To better understand the financial impact of climate risk, we must ask the firm value drivers, such as investment policy (Shao et al., 2013), dividend policy (Baker & Wurgler, 2004; Breuer et al., 2014), or debt level of debt (Ginglinger & Moreau, 2019). In fact, climate risk can indirectly reduce firm value through the impact on the decision-making of corporate managers. Indeed, the precautionary motive may lead to more cash holding and less investments (Bates et al., 2009; Feng & Johansson, 2018; Huang et al., 2018) to increase resilience. To reduce the risk of bankruptcy and preserve acceptable financial health, companies can reduce their level

of debt (Ginglinger & Moreau, 2019; Noth & Rehbein, 2019). The main argument is that firms want to build a financial slack to adapt to climate change and increase resilience.

However, the CDP report (2019) highlights the paradox that the potential value of climate-related opportunities for the biggest global firms is almost seven times higher than the cost of achieving them. Thus, climate change can stimulate innovation and bring new opportunities for companies to develop new products and processes. Considering investment policy as a determinant of firm value, green R&D could be implemented to increase firm value (Lee & Min, 2015). One might therefore imagine that climate risk may trigger new opportunities to generate future benefits by being the first mover of a new market, having a competitive advantage, and developing new products. In this context, corporate managers must consider physical risk due to climate change and adjust their investment policy accordingly. Although emerging literature documents mixed results on the consequences of climate risk on risk perception (Bernile et al., 2017; Brown et al., 2018; Cameron & Shah, 2015; Gallagher, 2014; Gao et al., 2020), corporate managers could implement investment strategies and take more risk to adapt to climate change and counteract the negative effects of future climate change.

Based on these arguments, it follows that environmental strategies should impact corporate financial performance, while climate risk should influence firm value and corporate investment.

In particular, in our doctoral thesis the following three research questions:

Research Question 1: Do mitigation and adaptation strategies impact corporate financial performance?

Research Question 2: Does physical climate risk impact firm value?

Research Question 3: Does physical climate risk influence corporate investment policy?

To answer these research questions, this work is divided into four chapters. The first chapter reviews the theoretical and empirical literature background on climate change and corporate value and policy. We then provide avenues of research on climate finance as called by Giglio et al. (2021). Building on this chapter, we investigate three gaps in the literature, (1) the link between mitigation and adaptation strategies and financial performance, (2) the influence of climate risk on firm value, and (3) on investment policy in the following chapters.

Chapter 2 investigates whether the type of environmental strategies implemented impacts corporate financial performance. While numerous studies have been dedicated to the relationship between environmental performance and financial performance, meta-analyses show mixed results (Busch & Lewandowski, 2018; Dixon-Fowler et al., 2013; Horváthová, 2010). Following the IPCC classification (Houghton et al., 2001) and Linnenluecke et al. (2016), we mobilize two distinct environmental strategies: mitigation and adaptation to climate change strategies. Mitigation and adaptation strategies have different objectives and are implemented by firms for various reasons. Mitigation is defined as an intervention to reduce sources or enhance the sinks of greenhouse gases (Houghton et al., 2001), while adaptation is the adjustment in response to actual or expected effects of climate change to exploit beneficial opportunities (Linnenluecke et al., 2016; Tol, 2005). We measure mitigation and adaptation by the total environmental damages by firms developed by Trucost and the environmental innovation score developed by the Refinitiv Asset4 database, respectively. A total sample of 12,852 companies/years worldwide was used in the analysis for the period from 2012 to 2016. We test our model using accounting- and market-based financial performance measures, using the return on assets and Tobin's q . The regression results reveal that mitigation is positively related to both indicators. However, the adaptation strategy prevails only on market-based measures. In summary, mitigation appears to be a reactive strategy to maintain or restore the

firm's image from a short-term perspective. On the contrary, adaptation is a proactive strategy that positively influences future financial performance. To complement our investigation, we show that mitigation and adaptation are complementary and non-substitutable inputs of ROA. It then underlines the benefits of disentangling environmental strategies. Surprisingly, we do not find statistically significant differences in Tobin's q , whether a firm implements mitigation or adaptation strategies alone or simultaneously. It suggests that investors reward mitigation and adaptation strategies in the long term, regardless of their nature.

Chapter 3 analyses the impact of physical climate risk on firm value. While a nascent stream of literature studies the impact of physical risks (Bansal et al., 2016; Ginglinger & Moreau, 2019; Hong et al., 2019; Sautner et al., 2023), we still know very little about how firm-specific physical risk influences firm value. We measure physical risk using the CRIS data from Carbon4 Finance, which provides an original forward-looking climate risk proxy. We distinguish acute risks related to natural disasters and chronic risks that refer to long-term shifts in climate patterns (Basel Committee on Banking Supervision, 2021). We investigate the effects of acute and chronic physical risks on firm valuation. Based on an international dataset of 1,294 firms over the 2009-2020 period, we find that acute physical risk has a negative and significant association with firm value, whereas chronic physical risk is not significantly linked. We then highlight that acute and chronic risks are priced differently by investors. Investigating the channels that drive the relationship between physical risk and firm value, we find that both physical risks have similar results on ROA, leverage, and R&D. In contrast, we note that acute risk indirectly and significantly impacts Tobin's q by reducing sales growth and cash dividends. Our findings then underline the importance of not taking physical risk as a global issue and the need to differentiate between acute and chronic risks. Finally, we show that investor attention

to physical risks has evolved over time. Acute and overall physical risks are only significantly associated with firm value in the most recent study period.

The aim of Chapter 4 is to study the influence of physical climate risk on corporate investment. Even if we note a growing literature on the financial impact of historical climate risk and natural disasters (Huang et al., 2018; Kanagaretnam et al., 2022; Noth & Rehbein, 2019), few articles investigate the impact of physical risk due to climate change on firm decisions (Ginglinger & Moreau, 2019). We confront two different streams of research that could explain the financial implications of physical risk. While one might imagine a precautionary strategy to cover the potential direct and indirect asset damage due to climate change, corporate managers can adapt to climate change and increase resilience through more R&D investment. We use CRIS climate risk developed by Carbon4 Finance as a proxy for physical risk by firm. The Carbon4 database offers a unique measure that captures the increased physical risk in the future due to global warming. Based on a US dataset of 4,008 firm-year observations over the 2009-2020 period, we find that physical risk is positively and significantly associated with corporate investments, as measured by R&D and long-term investments. Our results show that firms facing high climate risk invest more in R&D than physical assets. We also show that when they have excess cash, risky climate firms are more likely to use it to increase R&D. Furthermore, further tests reveal that physical risk is associated with corporate risk-taking that pushes firms to invest more in risky R&D projects. We then complement the literature by investigating the role of physical risk in firm decisions through investment policy. Faced with future climate change, companies tend to implement new processes and products through R&D to adapt to climate change and increase resilience.

Chapter 1. Environmental strategies, climate risk, and firm implications

Abstract

Given the growing climate awareness and the contradictory results in the literature, the impact of climate change on companies seems to be a major topic in research in finance. In this chapter, we first introduce the increasing financial concerns of firms due to climate change. We define climate risks and environmental strategies implemented as a response to climate change. We then provide an overview of the theoretical foundations and state of the empirical debate on the impact of climate risk on firm value. From this literature, we try to better understand the implications of climate risk on decision-making. We then review the literature investigating the impact of climate change on risk-taking, risk aversion, and therefore corporate policies. We then present the theoretical and empirical backgrounds on the impact of environmental strategies on firm valuation. After identifying the gaps in the literature that may be of interest, we finally present the challenging research questions that we address throughout the three essays of this doctoral thesis. More precisely, we investigate the literature backgrounds and how we contribute to the literature dealing with the impact of climate risk on firm value, on investment policy, and the link between environmental strategies and corporate financial performance.

Keywords: Climate change, climate risk; corporate financial performance; firm value; investment policy.

Résumé

Du fait de la prise de conscience croissante du changement climatique et des résultats contradictoires dans la littérature académique sur le sujet, l'impact du changement climatique sur les entreprises semble être un sujet majeur de la recherche en finance. Dans un premier temps, nous introduisons dans ce chapitre, l'importance de la prise en compte des enjeux environnementaux pour les entreprises. Nous définissons les risques climatiques et stratégies environnementales implémentées en réponse au changement climatique. Nous recensons ensuite les fondements théoriques et l'état du débat empirique sur l'impact du risque climatique sur la valeur des entreprises. A partir de cette littérature, nous essayons de mieux comprendre les implications du risque climatique sur la prise de décisions des dirigeants. Nous présentons la littérature s'intéressant à l'impact du risque climatique sur la prise de risque, l'aversion au risque, et ainsi sur les politiques menées par les entreprises. Enfin, nous présentons la littérature théorique et empirique traitant de l'impact des stratégies environnementales sur la valorisation des firmes. Après avoir identifié des voies de recherche, nous présentons les questions auxquelles nous tenterons de répondre tout au long des trois essais de notre thèse. Plus particulièrement, nous étudions les limites des principales études et nos contributions à la littérature sur l'impact du risque climatique sur la valeur des firmes, sur leur politique d'investissement et sur l'impact financier des stratégies environnementales.

Mots clés : Changement climatique, risque climatique, performance financière, valeur des entreprises, politique d'investissement.

In this chapter, we first introduce the financial implications of climate change for firms. We present the increasing importance of climate change, define climate risks and environmental strategies, and question the influence of physical risks on firms in Section 1.1. We provide an overview of the theoretical and empirical debate on the influence of climate risk on firm value in Section 1.2. In Section 1.3, we discuss the impact of climate risk on decision-making and how firms lead financial policies in reaction to climate-related events or to adapt to future climate change. In Section 1.4, we provide an overview of the theoretical foundations and empirical debate on the financial impact of environmental strategies. Finally, Section 1.5 discusses the identified gaps in the climate finance literature. We present the challenging research questions that we address in the three essays of this doctoral thesis.

1.1. The increasing importance of climate change

As one of the most significant issues for all economic actors, climate change has been the subject of large media coverage and a growing stream of academic literature over the past decades. In this section, we first document the growing environmental concerns and climate awareness. We define climate risks and environmental strategies led by firms. We then investigate how physical may be a major issue for companies.

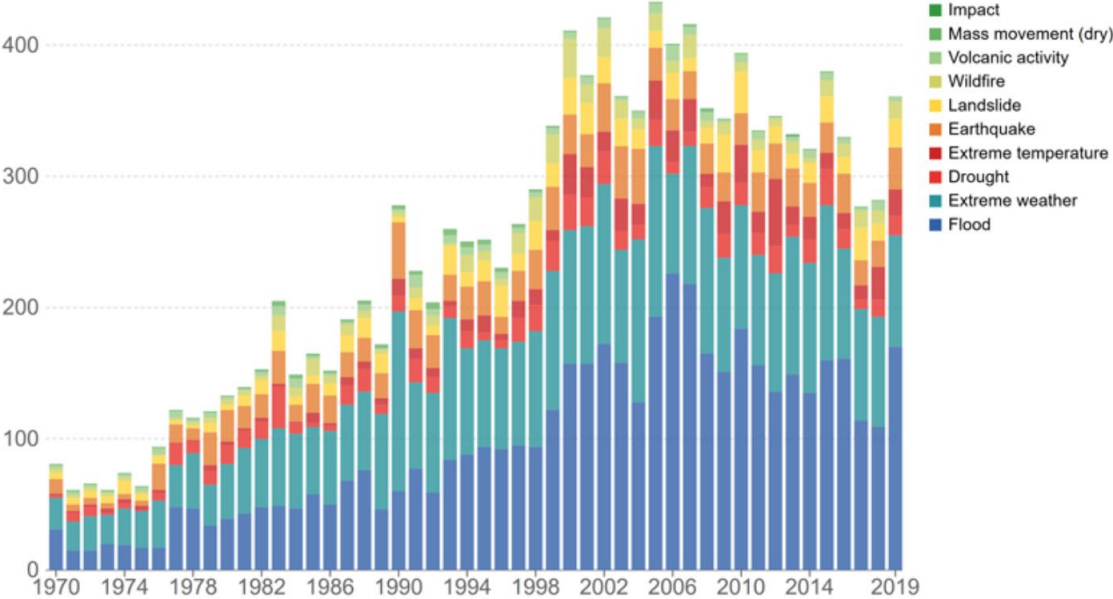
1.1.1. The growing environmental concerns and climate awareness

The debate about climate change has been intensified by direct asset destruction due to natural disasters, media coverage, and environmental regulation. Moreover, as evidenced in Figure 1.1, the number of some annual reported natural disasters has increased in recent decades. The EMDAT graph includes both weather-related and nonweather-related disasters. Floods and extreme weather events are the main reported disasters, and we note a significant increase from

1970 to 2019. Thus, the Figure 1.1 shows that the annual number of some natural disasters has increased. While the link between climate change and natural disasters has not been clearly established, the occurrence of climate-related events has made economic actors more aware of environmental issues. If the impact of climate change is well documented, the impacts of climate change cannot be reduced without the development of sustainable strategies (OECD, 2021). However, the global economic output will increase significantly by 2050, suggesting a rise in greenhouse gas emissions (GHG) over the next decades.

The economic impacts of climate change could be defined as “an externality that is unprecedentedly large, complex, and uncertain” (Tol, 2009). At first, physical risks may have implications for firms, such as direct assets damages and indirect impacts from supply chain disruptions. We then could easily imagine that physical risks may have an impact on current and future economic growth through changes in revenues and increased operating costs. As a major contributor to greenhouse gas emissions, climate change is then a real issue for companies. Indeed, we note a snowball effect of climate awareness on all stakeholders. Investors demand more environmental strategies (Flammer, 2013) and include climate risk in their portfolios. Policymakers lead more and more strict environmental regulations (OECD, 2021). Corporate managers can also develop a climate risk aversion after a natural disaster (Dessaint & Matray, 2017). For all these reasons, firms implement sustainability measures through environmental strategies, even if it implies significant changes.

Figure 1.1. Global reported natural disasters by type, 1970 to 2019

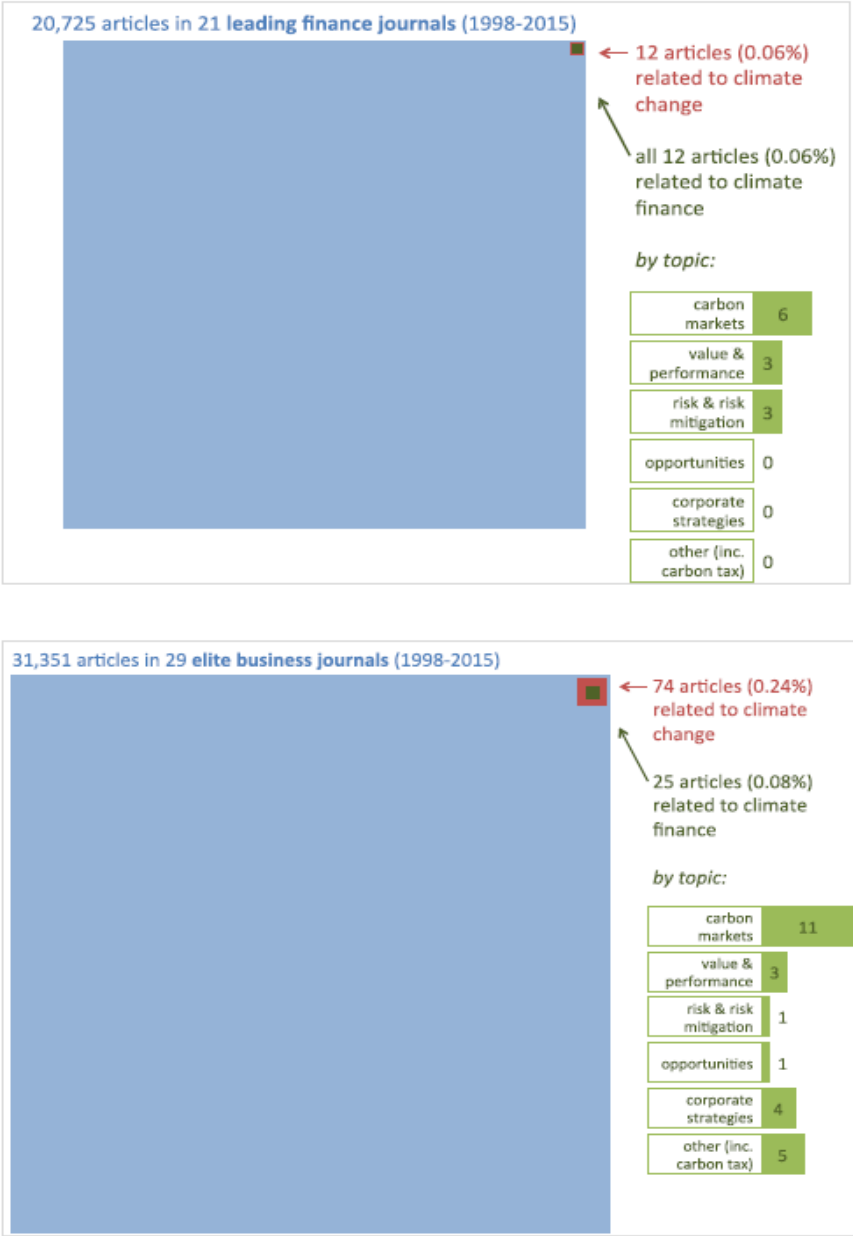


This figure displays the annual reported number of natural disasters, by type. This includes both weather and non-weather-related disasters. Source: EMDAT (2020): OFDA/CRED International Disaster Database, Université Catholique de Louvain – Brussels – Belgium OurWorldInData.org/natural-disasters.

We then note the increasing importance of climate change for investors, policymakers, and corporate managers. This tendency has been reflected in academic debate in recent years (Minx et al., 2017). Based on the Web of Science publications, (Callaghan et al., 2020) confirm this trend by showing that the number of climate change documents increased from 134,413 from 2007-2013 to 201,606 from 2014-2018. However, Diaz-Rainey et al. (2017) show that until 2015 there were only a few articles in main finance journals. Figure 1.2 reports the number of climate change and climate finance articles in leading finance journals and elite business journals. The figure highlights that only 0.24% of research articles in 29 elite business journals from 1998 to 2015 are related to climate change. This observation is even more acute in leading finance journals where only 12 articles in 20,725 are related to climate change over the 1998-2015 period. Hence, we note a growing stream of literature on climate finance that begins with

corporate environmental strategies and their impact on value and performance (Clarkson et al., 2011; Delmas et al., 2015; Konar & Cohen, 2001; Lee & Min, 2015; Matsumura et al., 2014).

Figure 1.2. Number of climate change-related and climate finance-related articles in leading finance journals and elite business journals (Diaz-Rainey et al., 2017)



This figure reports the number of climate change-related and climate finance-related articles in leading finance journals (top panel) and elite business journals (bottom panel). Shaded areas are proportional to number of articles. Source: Figure 1 from Diaz-Rainey et al. (2017) article.

1.1.2. Climate risks definitions

The TCFD defines climate-related risk as the potential negative impacts of climate change on an organization. Regarding taxonomy, the TCFD divides climate-related risks into two main categories: transition risks and physical risks due to climate change. On the one hand, transition risks are defined as risks related to the transition to a lower-carbon economy that may entail extensive policy, legal, technology, and market changes. Organizations need to address mitigation and adaptation solutions to deal with climate change, and transition risks may deepen the financial and reputational risks. Indeed, the TCFD includes policy and legal risks, technology, market, and reputation risks in transition risks.

Physical risks are defined as risks resulting from climate change that can be event-driven or longer-term shifts in climate patterns. Physical risks may have financial implications for companies, such as direct asset damages and indirect impacts from supply chain disruption. The Network for Greening the Financial System (NGFS), launched by central banks to accelerate green finance development, also distinguishes two types of physical risks. We then note acute physical risks that refer to those that are event-driven, including increased severity of extreme weather events, such as cyclones, and hurricanes (Ranger et al., 2022). The second main category of physical risk is chronic risks that “refer to longer-term shifts in climate patterns”, such as increased temperatures, sea level rise, or chronic heatwaves. Such risks may have financial implications for organizations, such as direct asset damages or indirect damages from supply chain disruption. In addition, a firm’s financial performance can be affected by shifts in water availability, sourcing, and quality, food security, and extreme temperature changes that affect firm operations, transport, and employees’ safety (TCFD).

1.1.3. Environmental strategies

To meet the challenges of climate change, firms may implement environmental strategies. Indeed, several constraints arise from climate transition. Firms should consider the new environmental regulations, the reputation risk, and the market consequences. Therefore, firms can develop green strategies, such as mitigating greenhouse gas emissions or leading the adaptation to climate change strategy (Linnenluecke et al., 2016). The IPCC defines those two main types of environmental strategies: mitigation and adaptation. Mitigation is defined as the ‘anthropogenic intervention to reduce the sources or improve greenhouse gases’, while adaptation is defined as ‘adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities’. In summary, mitigation is the reduction of environmental damage and adaptation represents a response to climate change to exploit future beneficial opportunities.

Hart (1995) explains that a pollution-prevention strategy moves from an internal process to an external activity. In fact, a pollution-prevention strategy becomes a legitimacy-based activity. A mitigation strategy may then enhance the image, reputation, and legitimacy of the firm. In contrast, firms lead adaptation strategies for different reasons. An adaptation strategy can lead to a firm’s competitive advantage through the rare, costly-to-copy, and immovable resources and capabilities of the firm but requires a long-term vision to have a sustainable development.

A key challenge in integrating mitigation and adaptation strategies is to understand the costs and benefits of these strategies. Mitigation benefits are more global by reducing environmental damage, whereas adaptation benefits are more localized (Denton et al., 2014). Integrating mitigation and/or adaptation strategies can represent a climate change response at the firm level.

1.1.4. Climate risk: a major risk for firms?

Most of the literature has focused on the relationship between environmental performance and corporate financial performance (Delmas et al., 2015; Konar & Cohen, 2001; Matsumura et al., 2014). Matsumura et al. (2014) find that for each additional thousand metric tons of carbon emissions, the firm value decreases by \$212,000. Overall, their results show that investors penalize firms for their carbon footprint and also firms that do not disclose their emissions. It underlines the growing concerns about climate change of investors but also the need for transparency. If we observe a consequent number of articles since the publication of Matsumura et al. (2014), no attention has been precisely dedicated to the financial effects of environmental mitigation and adaptation strategies.

Academic progress in the assessment of environmental strategies and climate risk measures improves empirical studies. Recent studies have focused on the impact of natural disasters on firm value (Noth & Rehbein, 2019), corporate investment (Kanagaretnam et al., 2022), cash holding, and dividend policy (Huang et al., 2018). Berkman et al. (2021) contribute to the literature by using a useful measure of firm-specific climate risk based on firm disclosures. They use a forward-looking measure of climate risk and document the implications on market value. This paper is subject to some future research. First, the climate risk measure based on firm disclosures opens some potential bias. For example, disclosure of climate risk is mandatory rather than voluntary. Although they demonstrate that climate risk disclosures are value-relevant, their climate risk measure will not capture the impact of increased physical climate risk due to climate change.

The paper of Huang et al. (2018) has been fundamental in understanding the financial implications of climate risk. They examine the link between climate risk and financing choices.

Specifically, they investigate the consequences of country climate risk on firm performance and policy worldwide. They measure climate risk using the Global Climate Risk Index developed by Germanwatch. They find that firms in high-climate-risk countries tend to hold more cash, issue lower dividends, and have less short-term debt but more long-term debt. Their results suggest that firms use financing policies to try to counteract the potential negative effects of climate risk. Firms in countries characterized by higher climate risk may want to constitute a financial slack to cope with climate change. The main limitation of this article is the use of a climate risk measure at the country level that could lead to a potential misestimation of firm climate risk. They do not account for how a company can be affected by climate risk from its overseas activity. Since the paper by Huang et al. (2018), we note improvements in the assessment of climate risk. However, we note that studies on the financial impact of physical climate risk are still scarce.

As summarized in Table 1.1, some empirical studies mobilized in our dissertation paved the way for the climate finance literature. Overall, the literature tends to identify climate risk as a major issue for companies. Therefore, we document in the following sections the impact of climate risk on firms in various ways.

Table 1.1. Main studies mobilized on climate risk impacts of firms.

Research article	Research question	Variable of interest	Main proxy	Main results	Rationale
Matsumura et al. (2014)	The link between carbon emissions and firm	Carbon emissions	Carbon emissions data and the act of voluntarily disclosing carbon emissions.	Carbon emissions and carbon emissions disclosure are negatively and significantly associated with firm value, as measured by Tobin's q.	Financial markets penalize carbon emissions and the non-disclosure of this environmental information.
Lee & Min (2015)	The link between green R&D and firm value	Green R&D for eco-innovation	Environmental performance data comes from the Environmental Report Plaza	Their results report a negative relationship between green R&D and carbon emissions and a positive relationship between green R&D and financial performance.	The findings underline that firms need to implement proactive green strategies to manage environmental and financial performance.
Dessaint & Matray (2017)	Investigate the corporate managers' reaction to hurricane events	The managers' response to hurricane events	Hurricanes' information comes from the Spatial Hazard Events and Losses database for the US.	They find that hurricane events lead managers to increase cash holding and express more concerns about climate risk. However, they show that the effects are temporary.	The paper highlights that managers exhibit biases when assessing risk. The results are consistent with salience theories of choice.
Huang et al. (2018)	The impact of country climate risk on firm performance and financing decisions.	Climate-related risk	Global Climate Risk Index developed by Germanwatch (country-level climate risk variable).	Climate risk is associated with lower and more volatile earnings. Firms in risky countries tend to hold more cash, have less short-term debt, and distribute less dividends.	Firms integrate climate risk by implementing new policies to moderate the negative effects of climate risk. They constitute a financial slack to cover future climate threats.
Noth & Rehbein (2019)	The impact of a major flood in Germany in 2013 on	The impact of a natural disaster	Regionally aggregated information about flood damages from the	They found that firms located in the disaster regions had higher turnover, lower	The paper documents a positive effect on firm performance after a natural disaster. While firms may cut back

	firm turnover, leverage, and cash.		German Insurance Association	leverage, and higher cash after 2013.	investment, governments and insurance companies may compensate the affected firms to counteract the negative effects.
Berkman et al. (2021)	The impact of climate risk exposure on market value.	Climate risk exposure	A firm-specific measure of climate risk exposure from Ceres (based on a textual analysis of climate disclosures).	They find a negative and significant relationship between climate risk and market valuation.	The market considers climate risk exposure as value-reducing. Due to potential damages, climate risk increases the risk premium requested by investors.
Ginglinger & Moreau (2019)	The link between climate risk and capital structure	Physical climate risk	CRIS rating developed Carbon 4 Finance (a firm-specific measure of increased physical risk due to climate change)	They find that greater physical risk leads to lower leverage in the post-2015 period.	Their results show that the reduction in leverage could be explained by a firm's optimal leverage decrease and a lender's spread increase.
Kanagaretnam et al. (2022)	The link between climate risk and corporate investment	Climate-related risk	Global Climate Risk Index developed by Germanwatch (country-level climate risk variable).	They show that climate-related risk at the country level is positively associated with physical capital and negatively associated with organizational capital.	They show that when climate risk increases, firms in climate-vulnerable industries that are more susceptible to climate risk experience a significant decrease in capital investment relative to firms in climate-non-vulnerable industries.

1.2. Climate risk, a new determinant in the assessment of firm value?

As called by Giglio et al. (2021), there are emerging avenues of research in climate finance. The empirical literature investigates the pricing of climate risks across assets such as real estate, equities, or fixed-income securities (Giglio et al., 2021). As climate risk is documented as one of the major risks by corporate managers (Ilhan et al., 2021; Krueger et al., 2020), we try to better understand in this section the influence of climate risk on firm value. If the primary theoretical background explains that investors demand a risk premium as compensation for their exposure to climate risk (Bansal et al., 2016) that could mechanically decrease firm value (Campiglio et al., 2023). Other theories and empirical results may contradict this hypothesis.

1.2.1. Theoretical background

Given the financial implications of climate change, we may postulate that physical climate risk is a determinant in the assessment of firm valuation. First, physical risk may impact firm value through direct asset damage and supply chain disruptions. Bansal et al. (2016) demonstrate that investors may demand a risk premium to compensate for their exposure to climate risk. Therefore, an argument is that physical risk can hurt firm value. Moreover, climate risk may indirectly be linked with firm value if determinants of firm value are influenced by climate risk. Among the determinants of firm value, the financial literature has identified corporate policies as channels, such as the investment policy (Shao et al., 2013), dividend policy (Baker & Wurgler, 2004; Breuer et al., 2014), the level of debt (Ginglinger & Moreau, 2019). Thus, if corporate managers want to protect themselves against climate risk, the firm value could be affected.

On the other hand, climate change may provide new opportunities for firms by developing new products or processes. While asset damages and supply chain disruption due to natural hazards are well documented, the CDP report (2019) underlines that the potential value of climate-related opportunities for the biggest global firms is almost seven times higher than the cost of achieving them. We may explain the potential opportunity by being the first mover of a new market, resulting in a competitive advantage. Therefore, firms may benefit from future climate change by implementing adaptation strategies to counteract the negative effects of climate risk.

1.2.2. The empirical debate

A body of the literature has focused on the market responses to a specific natural hazard, such as vulnerability to droughts (Hong et al., 2019; Huynh et al., 2020), rising temperatures (Addoum et al., 2023; Bansal et al., 2016) or the sea-level rise (Bernstein et al., 2019) at the country level. However, studies on the impact of firm-specific physical climate risk on firm value are still scarce (Berkman et al., 2021; Huang et al., 2018; Sautner et al., 2023). One main attempt is the study of Berkman et al. (2021) which shows an overall negative impact of climate risk on market price. However, as mentioned by the authors, the measure of climate risk is based on textual analysis and may lead to some bias. The few empirical results on the link between climate risk and firm value are so far inconclusive (Sautner et al., 2023). Sautner et al. (2023) find that while regulatory risk is significantly associated with firm valuation, the physical risk is not clearly linked with it. However, they used earnings conference calls to assess firm climate change exposure which may also be subject to bias.

One of the issues at stake in the empirical debate could be the distinction between climate risks. The Basel Committee on Banking Supervision (2021) defines the distinction to be made

between acute and chronic physical risks. By nature, we may consider acute risks more salient to investors as their direct impact is more striking compared to long-term shifts of chronic risks that are less attention-grabbing (Ginglinger, 2020). Because of salience and investment horizon motives, we may expect differences in the impact of physical risks on firm value. On the one hand, the literature has documented that investors use heuristics to assess risk. Dessaint & Matray (2017) underline the importance of the salience. Some climate-related events may come easier to mind due to proximity, media coverage, or past experiences, for example. All these factors may increase the salience of an event. On the other hand, we assume that chronic risks would only be tangible for firms over decades. Thus, it is rational for an investor to be more sensitive to acute risks than chronic risks. Although existing studies deal with the impact of climate risks on firm value without disentangling them (Berkman et al., 2021; Krueger et al., 2020), to the best of our knowledge, no study unravels the impacts of acute and chronic risks on firm value. Further analysis may try to better understand the transmission channels of the relationship between, physical risks and firm valuation.

1.3. Does climate risk influence decision-making?

From the debate investigating the influence of climate risk on firm valuation, a growing body of literature focuses on the impact of climate issues on the determinants of financial value (Ginglinger & Moreau, 2019; Huang et al., 2018). The empirical limits of climate risk calculation have been a factor in the evolution of the literature on this topic. The majority of articles deal more with reactions to natural disasters than with taking future climate risk into account. After reviewing the literature, we investigate in this section how climate risk could influence corporate managers' decision-making.

1.3.1. The impact on risk-taking and risk aversion

The literature shows that economic actors use heuristics to assess risks. One heuristic is to consider the frequency of an event from its availability (Tversky & Kahneman, 1974). Dessaint & Matray (2017) document the importance of the salience of an event that affects that availability. Depending on the context, some events may come easier to mind. Some factors can influence risk aversion and decision-making, such as proximity, media coverage, and past experiences that increase the salience of an event.

A strand of the literature investigates the consequences of natural disasters on risk perceptions (Bernile et al., 2017, 2021; Brown et al., 2018; Cameron & Shah, 2015; Choi et al., 2020; Gallagher, 2014; Gao et al., 2020). Natural disasters affect managers' perceptions of risk. Experiencing a climate disaster can increase risk aversion (Cameron & Shah, 2015). In the same vein, Choi et al. (2020) report that exceptionally high temperatures capture the attention of investors and lead carbon-intensive firms to underperform. However, Bernile et al. (2017) show a nonlinear relation between the intensity of CEO early life exposure to fatal disasters and corporate risk-taking. Corporate managers who experience disasters without severe negative destruction tend to have more aggressive corporate policies. Corporate managers may underestimate the change of climate risk and feel less at risk for physical damage. This could lead to influencing corporate policies.

1.3.2. The impact on firm policies

The previous subsection underlines the fact that natural disasters and climate risks. If we assume that corporate managers' risk aversion influences decision-making, we can imagine that climate risk has a significant impact on corporate policies. Firms can adopt a conservative strategy and

thus build financial slack in anticipation of the future negative impacts of climate change. In many cases, this takes the form of more cash, lower dividends, and lower leverage (Ginglinger & Moreau, 2019; Huang et al., 2018; Noth & Rehbein, 2019).

Huang et al. (2018) show that firms in high-climate-risk countries are more likely to maintain financial slack by holding more cash, distributing fewer dividends, and adjusting short- and long-term debt levels. Firms with a high level of climate risk are faced with increasing operating costs, changes in production processes, and higher insurance premia and bankruptcy costs. Indeed, the empirical literature shows that firms tend to reduce their level of debt (Ginglinger & Moreau, 2019; Noth & Rehbein, 2019). We could explain these results by the risk of willingness to reduce the bankruptcy and preserve a good financial health. Thus, we observe an influence on firm choices to be more resilient and counteract the potential negative effects of climate change.

Overall, climate risk can lead to direct financial loss through asset destruction, and indirect through certain corporate managers' decisions. Consequently, it seems worthwhile to discuss the influence of climate risk on investment policy, which is essential to understanding corporate financial value (Shao et al., 2013). A strand of the empirical literature documents a negative impact of natural disasters on corporate investment (Feng et al., 2022; Huang et al., 2018; Kanagaretnam et al., 2022), a negative effect of physical risk due to future climate change on corporate investment might exist. Corporate managers may be risk averse and the precautionary motive may lead to more cash holding and less corporate investment (Bates et al., 2009; Feng & Johansson, 2018; Huang et al., 2018). The only attempts to specifically study the link between climate risk and investment policy come from Huang et al. (2018) and Kanagaretnam

et al. (2022). In their research work, both papers use a country-level measure of climate-related risk based on historical climate-risk exposure. Therefore, the use of a country-specific measure to study the impact of corporate investment may limit the interpretation of its findings. Although studies do not show a consensus on the link between physical risk due to climate change and investment policy, it would be interesting to investigate the effects on corporate investment. Further studies may attempt to better understand the relationship by studying the impact of different components of corporate investment policy.

1.3.3. R&D, a way to adapt to climate change

While empirical literature mainly shows that firms with a high climate risk tend to adopt conservative strategies (Ginglinger & Moreau, 2019; Huang et al., 2018; Noth & Rehbein, 2019), one might wonder whether physical climate risk may stimulate corporate investment policy. Companies are facing physical and transition risks that are leading them to change their business strategy. One way of adapting to climate change could be through proactive environmental strategies. The NRBV provides an appropriate theoretical foundation for discussing the impact of eco-innovation. A firm sustainable competitive advantage can be achieved through valuable, costly to imitate, and non-substitutable resources and capabilities (Hart, 1995). However, firms need to think beyond the short term and manage with a long-term focus. As eco-innovation is related to corporate investment in R&D, firms could benefit from future climate change by implementing green R&D investments. As evidenced by Lee & Min (2015), green R&D therefore may be positively and significantly associated with corporate financial performance. We can explain those results by the fact that adapting to climate change strategies through R&D investments may increase firm resilience in the long term. Thus, environmental strategies could be a catalyst for the physical risk–firm value link and a response to adapt to future climate change.

1.4. Environmental strategies, a response to climate change?

In this section, we look at the extent to which environmental strategies can be a way for companies to respond to climate issues. Moreover, the primary concern of firms is to implement environmental strategies at an acceptable cost (Porter & Linde, 1995). We therefore turn our attention to the financial impact of environmental strategies. First, we review the theoretical underpinnings of the relationship between environmental performance and firm valuation. We detail the main empirical findings. We then turn to a line of research looking at the impact of mitigation and adaptation strategies.

1.4.1. Environmental strategies and firm valuation: Theoretical background

Regarding the theories that may explain the link between environmental performance and financial performance, two major views are opposed regarding this relationship. On the one hand, neoclassical theory argues that improved environmental performance leads to additional costs for firms (Friedman, 1970). If referring to Friedman's sentence, "the social responsibility of business is to increase its profits". It suggests that corporate social responsibility has a direct cost in terms of time and resources. Moreover, driven by the agency theory (Jensen & Meckling, 1976), CSR engagement may lead to a conflict between managers and shareholders (Barnea & Rubin, 2010). They explain that corporate managers may have an interest in over-investing in CSR to gain personal reputation at a cost to shareholders. On the other hand, pollution may be defined as a form of economic waste (Porter & Linde, 1995). Thus, it suggests that pollution prevention can result in cost savings. We could mobilize the resource-based view theory to conceptualize the relationship between environmental performance and financial performance (Branco & Rodrigues, 2006). Hart (1995) extends the resource-based theory by introducing the constraint of natural resources. Hart (1995) proposes that a pollution-prevention strategy moves

from an exclusively internal process to an external activity. In other words, a pollution prevention strategy based on mitigating environmental damage becomes a legitimacy-based activity (Barney, 1991; Russo & Fouts, 1997). In contrast, sustainable development requires a long-term vision that may lead to a firm's competitive advantage through the rare, costly-to-copy, and immovable resources and capabilities of the firm.

Sustainable development strategies imply substantial investment and a long-term commitment to gain a competitive advantage (Hart, 1995). Firms need a long-term perspective on innovation and outcomes are not immediately apparent (Porter & Linde, 1995). Integrating environmental issues into products and processes can create a 'first-mover' effect in emerging green market products (Hart, 1995). This competitive advantage could result from environmental research and development expenses (Lee & Min, 2015). Firms will have a technological advantage and be the leading light of the market for stakeholders.

As a result of implementing environmental strategies, a firm's financial performance may increase (Clarkson et al., 2011). A proactive environmental strategy can enhance firm performance, nevertheless, a strand of the literature tends to suggest that the link only prevails in a long-term perspective (Horváthová, 2012). Moreover, firms may underestimate the economic benefits from pollution reduction (Hart, 1995; King & Lenox, 2002). The eco-innovation implementation costs may be a barrier for some firms that do not have the financial capacity to wait for long-term profits.

As a result, the theoretical debate on corporate social responsibility and specifically environmental performance is not new. Still, there is no consensus on the possible link between

environmental performance and financial performance. We focus on the two main streams of literature that claim that there is a negative or positive relationship. However, one can argue that there are so many variables engaged that there is no reason to expect a significant relationship (Aupperle et al., 1985; McWilliams & Siegel, 2000). A large theoretical debate that has extended into the empirical field.

1.4.2. Does it pay to be green: mixed evidence from empirical studies

A large stream of research has investigated the “Does it pay to be green?” debate (Ambec & Lanoie, 2008; Dixon-Fowler et al., 2013). Most studies suggest a positive relationship between environmental performance and corporate financial performance. However, some empirical works have shown contradictory results. Some meta-analyses examine factors that could influence the relationship between environmental and financial performance, specifically the choice of environmental performance proxy (Busch & Lewandowski, 2018; Galama & Scholtens, 2021; Horváthová, 2010), the moderators of the relationship (Dixon-Fowler et al., 2013), the sample size (Konar & Cohen, 2001), or the geographical area.

Literature background mostly uses emission reduction proxies such as the emission of toxic chemicals or greenhouse gas emissions (Delmas et al., 2015; Konar & Cohen, 2001; Matsumura et al., 2014). Konar and Cohen (2001) show that poor environmental performance is negatively correlated with intangible assets' value. Firms that mitigate their environmental damages gain a competitive advantage and positively impact their firm valuation (Derwall et al., 2005). Matsumura et al. (2014) find that, on average, for every additional thousand metric tons of carbon emissions, the firm value decreases by \$212,000, where the median emissions are 1.07 million metric tons.

Other empirical studies investigate the relationship between innovative environmental strategies and financial performance (Clarkson et al., 2011; Lee & Min, 2015; Xie et al., 2019). Lee and Min (2015) used green research and development investments as a proxy for eco-innovation. They show that green R&D is positively related to financial performance at the firm level. These findings support the hypothesis that early green investments offset operational costs and increase financial performance in the long term (Horváthová, 2012; Lee and Min, 2015).

To summarize, the literature background has identified numerous studies investigating the relationship between environmental performance and financial performance (Derwall et al., 2005; Matsumura et al., 2014). However, the results remain inconclusive, and the recent literature rather focuses on addressing the question “When does it pay to be green?” (Busch & Lewandowski, 2018). The literature has then identified moderators of the link between environmental performance and financial performance (Busch & Lewandowski, 2018; Dixon-Fowler et al., 2013), such as environmental performance measures, firm size, and methodology.

1.4.3. The impact of mitigation and adaptation strategies

Hart (1995) distinguishes pollution prevention, product stewardship, and sustainable development due to their different mobilized resources and expected goals. This classification underscores the need to disentangle mitigation and adaptation strategies in the debate about environmental performance. Mitigating its environmental damages may enhance the firm’s image (Davis, 1976), reputation (Russo & Fouts, 1997), and legitimacy. Reducing its environmental damage can improve the firm reputation and indirectly increase its financial performance. In contrast, sustainable development requires a long-term vision to develop an

environmentally conscious strategy (Hart, 1995; Russo & Fouts, 1997). Therefore, an adaptation strategy can lead to a firm's competitive advantage through the rare, costly-to-copy, and immovable resources and capabilities of the firm. Moreover, a sustainable development strategy is not necessarily a synonym for less environmental pollution but rather as a production process that can be maintained in the long term (Hart, 1995). The main issue is adapting to climate change at acceptable costs (Porter & Linde, 1995).

Although the literature on environmental performance literature is vast but remains inclusive (Busch & Lewandowski, 2018; Galama & Scholtens, 2021), we could then imagine that these differences may be reflected in their impact on corporate financial performance. To our knowledge, no study has tackled the differences between mitigation and adaptation environmental strategies on corporate financial performance. Most studies examine the link between carbon reduction and financial performance (Matsumura et al., 2014; Delmas et al., 2015), while some research articles study the relationship between green innovation and financial performance (Lee and Min, 2015; Clarkson et al., 2011).

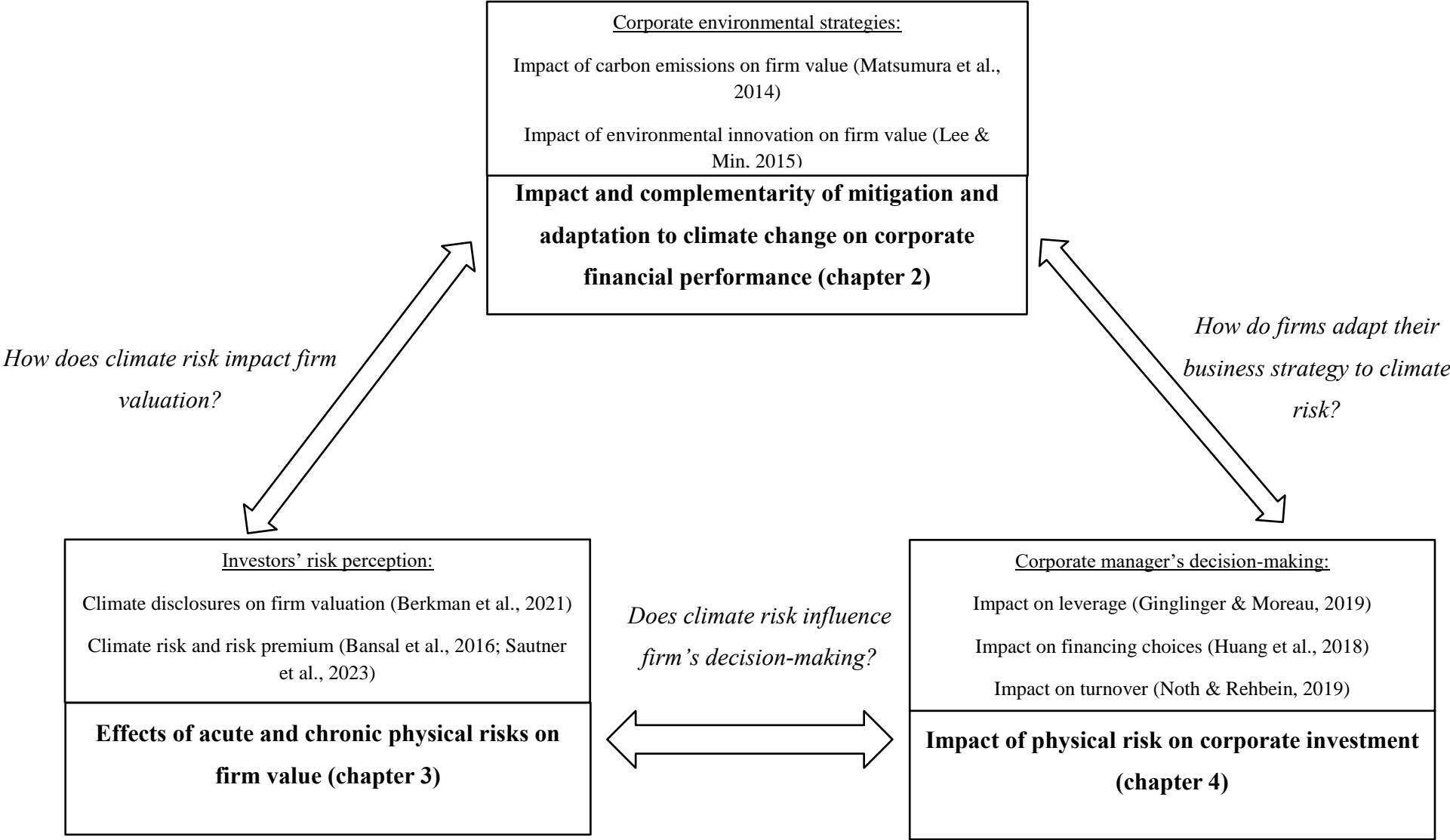
Furthermore, the IPCC explains that mitigation and adaptation strategies must be implemented to be climate resilient. However, those actions may create trade-offs. An adaptation strategy may increase greenhouse gas emissions and therefore reduce the mitigation performance of a company. It could be interesting to investigate the complementarity and substitutability of mitigation and adaptation strategies and their financial impact on firms worldwide.

1.5. Conclusion: avenues of research

Despite the growing literature focusing on climate change's financial implications, we try in this chapter to bridge the literature gaps to introduce the research questions that we address all along in the remainder of this thesis. We first introduced the concept of climate risk and environmental strategies. We present their definitions and classifications. We highlight the types of climate risk and the firms' environmental responses. At a time when the literature on climate finance is still expanding, we are more specifically interested in the impact of climate risk on firm value and decision-making.

Studies focusing on the financial impact of climate risk are still at an early stage. Despite their quality, the lack of climate risk measures, the unsophisticated methodology, or the focus on a particular climate risk do not allow the empirical literature to close the debate on the influence of physical risk on firm value. Finally, very few studies investigate the effect of physical risk on corporate investment. The first attempt comes from Huang et al. (2018). Even if their study opened the debate, they used a country-level climate risk proxy in an international data set that can raise statistical issues to investigate the impact of physical risk on firm decisions. Regarding the impact of environmental performance on corporate financial performance, the vast literature presents some limits, and the subject is still debated. We hypothesize that the lack of consensus comes from the various environmental variables used in the empirical literature. As highlighted by Dam & Scholtens (2015), environmental and financial proxies may influence the empirical results.

Figure 1.3. Climate change financial implications, extant literature, and contributions.



Considering the limits of existing studies and the raised avenues of research, we conduct in the following chapters three empirical studies to investigate the impact of climate change on firm decisions and firm value. In Figure 1.3, we present how we contribute to the literature through three empirical studies. Specifically, we try to contribute to the literature by studying the influence of physical risk on firm value and decision-making. Then we study the differences in the financial impact of environmental responses considering climate change. Overall, we contribute to a main research question that guides all our doctoral work:

Does climate change have an impact on firm decisions and value?

In Chapter 2, we examine the importance of disentangling mitigation and adaptation to climate change environmental strategies in the relationship between environmental strategies and corporate financial performance. We then used mitigation and adaptation proxies from Trucost and Refinitiv Asset4, respectively, to measure the environmental strategies that the companies lead. In doing so, we contribute to the literature by being the first, to our knowledge, to study the impact and complementarity of mitigation and adaptation strategies on firm financial performance.

In Chapter 3, we investigate the financial impact of climate risk. Specifically, we focus on the impact of the physical climate risk due to future climate change on firm value. The very few studies that focus on the impact of climate risk on firms mainly use country-level climate risk proxy (Huang et al., 2018) or climate variables based on textual analysis (Berkman et al., 2021). Using a unique firm-specific physical risk variable developed by the Carbone4 Finance database, we complement the empirical literature on climate risk's impact on firm value. Furthermore, we take an international perspective to investigate the differences in impact

between acute and chronic physical risks. Thus, we contribute to previous studies by highlighting the influence of acute and chronic risks on investors' perception through the long-term perspective of firm value.

Finally, in Chapter 4, we capitalize on Huang et al. (2018) to study the influence of physical risk due to climate change on corporate investment policy. While the investigation on the subject focuses on the impact of natural disasters on corporate policies (Dessaint & Matray, 2017; Gao et al., 2020; Huang et al., 2018; Kanagaretnam et al., 2022), we introduce the future climate risk aversion by using an increased physical risk due to future climate change proxy developed by Carbon4 Finance database. Specifically, we investigate the impact of physical risk on corporate investment and try to understand the drivers of this relationship. To the best of our knowledge, we are the first to analyze the impact of firm-specific physical risk on corporate investment and investigate the drivers of the relationship. We contribute to the literature by empirically showing the role of physical risk in firm decisions. Specifically, we document that physical risk fosters risk-taking and long-term investments.

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Chapter 2. Environmental and Corporate Financial Performance: Disentangling Mitigation and Adaptation Strategies

Abstract

Using a unique dataset of 3,554 firms from 42 countries during 2012-2016, we examine the impact of mitigation and adaptation to climate change strategies on firm financial performance. Measuring financial performance by accounting and market-based indicators, we find evidence that mitigation is positively related to both indicators. In contrast, adaptation to climate change strategy is only associated with greater market-based financial performance. Building on these results, we attempt to explore complementarity or substitutability between the different strategies. Mitigation and adaptation strategies appear as complementary inputs of accounting-based financial performance. Conversely, mitigation and adaptation strategies positively impact market-based financial performance, whether they are independently or simultaneously implemented. Our results suggest that investors reward environmental strategies in a period of increasing climate concerns without drawing any distinction between mitigation and adaptation processes.

Keywords: Adaptation; complementarity; environmental performance; financial performance; mitigation.

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Résumé

A l'aide d'une base de données unique de 3554 entreprises de 42 pays au cours de la période 2012-2016, nous examinons l'impact des stratégies de mitigation et d'adaptation au changement climatique sur la performance financière des entreprises. En mesurant la performance par des indicateurs comptables et de marché, nous constatons que la stratégie de mitigation est positivement liée à ces 2 indicateurs. En revanche, la stratégie d'adaptation au changement climatique n'est associée qu'à une meilleure performance financière orientée marché. Sur la base de ces résultats, nous tentons d'étudier la complémentarité ou la substituabilité de ces stratégies environnementales. Les stratégies de mitigation et d'adaptation apparaissent comme des éléments complémentaires de la performance comptable. A l'inverse, les stratégies ont un impact positif sur la performance financière ; qu'elles soient mises en œuvre indépendamment ou simultanément. Nos résultats suggèrent que les investisseurs récompensent les stratégies environnementales dans une période de prise de conscience climatique croissante, sans faire de distinction entre l'implémentation de stratégies de mitigation et d'adaptation.

Mots clés : Adaptation, complémentarité ; performance environnementale ; performance financière ; mitigation.

2.1. Introduction

\$970 Billion in five years – The estimated amount of the potential financial impact for a proportion of 215 of the world’s largest companies reported risks (CDP, 2019). Meanwhile, 225 firms included in the CDP study estimate that they could gain \$2.1 trillion thanks to climate-related opportunities. Environmental concerns have become a core issue for investors due to increasing climate awareness (Flammer, 2013). Environmental concerns and climate change push firms to change their business practices (Russo and Fouts, 1997; Guenster et al., 2011). Then, firms have been encouraged to implement environmental strategies such as mitigating environmental damages and leading adaptation to climate change strategies (Linnenluecke et al., 2016). Houghton et al. (2001) define mitigation of climate change as ‘anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases’. An alternative is reducing vulnerability by adapting to global warming. Adaptation to climate change is defined as ‘adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities’ (Houghton et al., 2001). In other words, mitigation consists of reducing environmental damages. Adaptation represents a response to climate change to exploit beneficial opportunities (Tol, 2005; Linnenluecke et al., 2016).

The relationship between environmental performance and financial is still debated despite extensive literature (Lioui and Sharma, 2012; Endrikat et al., 2014; Busch and Lewandowski, 2018; Galama and Scholtens, 2021). The literature background examines numerous factors that could influence the results of environmental performance and financial performance studies. The environmental performance – corporate financial performance may be influenced by the measure of greenhouse gas emissions with absolute or relative indicators (Clarkson et al. 2015).

Some studies also examine the influence of sectors in the relationship (King and Lenox, 2001) or countries' climate policy stringency (Galama and Scholtens, 2021). We hypothesize the large variety of environmental measures explains the lack of consensus (Guenther et al., 2012; Albertini, 2013; Dam and Scholtens, 2015). While the literature mainly focuses on the effect of greenhouse gas emissions on corporate financial performance, we disentangle environmental performance into two concepts to properly represent climate change responses: mitigation and adaptation strategies. To the best of our knowledge, no study has tackled the differences between mitigation and adaptation on corporate financial performance.

According to Hart (1995), "a sustainable development strategy does not merely seek to do less environmental damages but, rather, to produce in a way that can be maintained indefinitely into the future" (p. 1466). This quotation leads us to investigate differences between mitigating its environmental damages and adapting its strategy to climate change. A firm that mitigates its environmental damages shows a coping capacity to institutional pressure to comply with new regulations. Moreover, it may lead to improvements in the firm's image (Davis, 1976) and a short-term way for corporate managers to repair its reputation. The alternative to responding to climate change is adaptation. The main issue is to adapt to climate change at acceptable costs. Adaptation will require structural changes. Firms have to restructure their business strategy (Russo and Fouts, 1997; Guenster et al., 2011). It involves the implementation of new technologies to lead to a competitive advantage. Nevertheless, outcomes from innovation are not immediately apparent (Porter and Van der Linde, 1995). Thus, the environmental performance – financial performance needs empirical investigation disentangling mitigation and adaptation strategies.

A total sample of 12,852 firm/years worldwide for the period from 2012 to 2016 was used in the analysis. We test our model using both accounting- and market-based financial performance measures, using return on assets and Tobin's q. Our results are robust, even taking into consideration control variables and different financial performance indicators. As a robustness check, our results find further support after employing instrumental variables regressions. We find a positive and significant relationship between mitigation of environmental damages and financial performance. However, adaptation strategy is more likely to prevail in the long term. Our results reveal that environmental innovation is positively and statistically associated with market-based financial performance and long-term perspective. Additional tests reveal challenging results for the literature. On the one hand, we show that mitigation and adaptation practices are complementary and non-substitutable strategies. These complementary processes are positively associated with accounting-based financial performance indicators, underlining the importance of disentangling environmental strategies. On the other hand, mitigation and adaptation strategies positively impact market-based financial performance, whether they are independently or simultaneously implemented.

Our contribution to the literature is threefold. First, this study aims to contribute to the literature on environmental performance assessment. We disentangle mitigation and adaptation strategies as two different types of environmental strategies led by firms. Corporate managers face increasing environmental concerns and have to find solutions in mitigation and adaptation (Linnenluecke et al., 2016). We address the problem of choosing an appropriate proxy to measure environmental performance, which can trigger different outcomes.

Second, our results show differences in impact between firms that limit their environmental damages and firms that adapt their strategies to climate change. Even if the environmental performance – financial performance relationship has been widely discussed, our study could explain some inconclusive results by distinguishing mitigation and adaptation. It helps us to identify the reactive and proactive strategies. It shows that mitigating environmental damages increases a firm's financial performance. A mitigation strategy represents the best option to maintain or restore the firm's image. From a short-term perspective, a mitigation strategy can be seen as a reactive strategy for firms. In contrast, adaptation represents a proactive strategy and positively impacts a firm's future financial performance from a long-term perspective.

Third, we study the complementarity and substitutability of mitigation and adaptation strategies. Testing our hypotheses on both accounting-based and market-based financial performance indicators, we find that mitigation and adaptation have to be simultaneously implemented by a firm to positively and significantly affect the return on assets. Mitigation and adaptation appear as complementary and non-substitutable inputs of accounting-based financial performance indicators. It underlines the differences in strategies on asset efficiency and the benefits of disentangling them. Surprisingly, there is the same impact on Tobin's q , whether the firm carries out a mitigation or adaptation policy alone or both simultaneously. These challenging results show that investors reward environmental initiatives in the long-term regardless of their nature.

The rest of the paper proceeds as follows. The second section presents the literature background and the hypotheses. We describe the data and method used in the third section. The fourth section is dedicated to empirical results. The last section provides concluding remarks.

2.2. Related literature and hypotheses

The literature background has identified numerous studies investigating the relationship between environmental performance and financial performance (Matsumura et al., 2014; Delmas et al., 2015). However, the results remain inconclusive (Horváthová, 2010). The literature results' inconsistency can be attributed to the different proxies in empirical studies to measure environmental performance. The stakeholder theory (Freeman, 1984; Donaldson and Preston, 1995) offers a way of understanding how firms create value. Porter and Van der Linde (1995) define pollution as a form of economic waste. It suggests that pollution prevention can result in cost savings. Some research articles have built on the resource-based view theory to conceptualize the relationship between environmental performance and financial performance (Branco and Rodrigues, 2006).

Hart (1995) extends the resource-based theory by introducing the constraint of natural resources. The natural resource-based view theory contains three strategic capabilities: pollution prevention, product stewardship, and sustainable development. Strategic capabilities have different environmental driving forces. They also have different goals through the key resources mobilized and the expected competitive advantage. Sustained competitive advantage can be internal (competitive advantage) or external (social legitimacy). Hart (1995) proposes that a pollution-prevention strategy moves from an exclusively internal process to an external activity. In other words, a pollution-prevention strategy based on mitigating environmental damages becomes a legitimacy-based activity. Mitigation may enhance the image, reputation, and legitimacy of the firm. In contrast, sustainable development requires a long-term vision to develop an environmentally conscious strategy, including new green technology. Thus, an adaptation strategy can lead to a firm's competitive advantage through the rare, costly-to-copy,

and immovable resources and capabilities of the firm. Literature background mobilizes the natural resource-based view theory (Hart, 1995) to conceptualize the relationship between environmental performance and financial performance.

Some meta-analyses examine factors that could influence the environmental – financial performance relationship, and specifically the choice of environmental performance proxy (Horváthová, 2010; Busch and Lewandowski, 2018; Galama and Scholtens, 2021). Corporate managers face growing environmental concerns and must rethink their business strategy implementing mitigation and adaptation strategies (Linnenluecke et al., 2016). These two strategies have different costs and expected benefits. Nevertheless, previous studies do not disentangle strategic environmental capabilities. Most studies examine the link between carbon reduction and financial performance (Matsumura et al., 2014; Delmas et al., 2015). Some research articles study the green innovation – financial performance relationship (Lee and Min, 2015; Clarkson et al., 2011). This paper aims to disentangle mitigation and adaptation strategies assessing environmental performance. Thus, we examine the relationship between both practices and financial performance. We want to understand better the differences between firms that limit environmental damages and firms that adapt their strategies to climate change. To identify mitigation-related and adaptation-related research articles, we split our literature review into two environmental strategies. Then, we present the third hypothesis on the complementarity between both strategies.

2.2.1. Mitigation and financial performance

Environmental performance is associated with reputational benefits. Davis (1976) suggests that CSR policies may lead to improvements in the firm's image. Environmental-friendly firms gain

a competitive advantage by improving their reputation. Mitigation may help build a good reputation with customers, investors, or regulators (Russo and Fouts, 1997). In the reverse case, reputational risk is a real threat that can occur in many ways. Firms need to be socially and environmentally responsible for minimizing reputational risk. They show investors they can be more competitive in a market environment facing climate change. A firm that mitigates its environmental damages also shows a coping capacity to institutional pressure to comply with new regulations. Capitalizing on the idea that mitigation strategies are led as a legitimacy-based strategy, reducing environmental damages may generate a higher reputation and enhance the short-term financial performance. Investments in greenhouse performance will be converted into better accounting-based performance (Ambec and Lanoie, 2008).

On the empirical side, research articles do not identify environmental performance as a result of mitigation and adaptation strategies. We find most articles and meta-analyses dealing with the effect of corporate carbon performance on financial performance (King and Lenox, 2001; Busch and Lewandowski, 2017; Galama and Scholtens, 2021). Literature background mobilizes mitigation proxies such as the emission of toxic chemicals or greenhouse gas emissions (Konar and Cohen, 2001; Kuo et al., 2010; Matsumura et al., 2014; Delmas et al., 2015). Konar and Cohen (2001) show that poor environmental performance is negatively correlated with intangible assets' value. Firms that mitigate their environmental damages gain a competitive advantage and positively impact their firm valuation (Derwall et al., 2005). Matsumura et al. (2014) find that, on average, for every additional thousand metric tons of carbon emissions, the firm value decreases by \$212,000, where the median emissions are 1.07 million metric tons. Moreover, the effect of greenhouse gas emissions differs from short- and long-term measures of financial performance (Delmas et al., 2015). Orlitzky et al. (2003) and Albertini (2013) show

that accounting-based indicators are more closely related to environmental performance, while Dixon-Fowler et al. (2013) find that market-based performance is more relevant.

By disentangling mitigation and adaptation strategies, questions then arise about the only effect of mitigating its environmental damages on financial performance considering the environmental innovation activities. Thus, we formulate the following hypothesis:

Hypothesis 1 The more a firm mitigates its environmental damages, the higher its short-term perspective of financial performance.

2.2.2. Adaptation to climate change and financial performance

The alternative to responding to global climate change is adaptation. Beyond mitigation strategies, corporate managers have to think differently with increasing societal concerns about climate change. Firms are pushed to change their business practices and develop innovative products and processes. Sustainable development strategies imply substantial investment and a long-term commitment to gain a competitive advantage (Hart, 1995). Firms need a long-term perspective on innovation, and outcomes are not immediately apparent (Porter and Van der Linde, 1995). A proactive environmental strategy can then enhance firm performance (Clarkson et al., 2011) but only in a long-term perspective (Horváthová, 2012).

The natural resource-based view theory can be mobilized to discuss the impact of adaptation on financial performance. Firms have to adapt themselves to climate change to increase their revenues through two different channels. At first, innovation will lead to a differentiation

advantage (Srinivasan et al., 2020). It will create an opportunity to increase product-selling prices, and this will cause revenues to soar (Hart & Ahuja, 1996). Environmental innovation practices are considered as a way to optimize operations and product characteristics. Green products or services can allow firms to exploit new markets. Even if green products are more expensive to produce, consumers will pay more for eco-products or services. Second, innovation strategies could lead to a first-mover advantage. Integrating environmental matters into products and processes can create a ‘first-mover’ effect in emerging green market products (Hart, 1995). This competitive advantage could result from environmental research and development expenses (Lee and Min, 2015). Firms will have a technological advantage and will be the leading light of the market for stakeholders. They will also be considered more prepared for future crises (Orlitzky et al., 2003; Osiyevskyy et al., 2020).

Empirical studies provide evidence of the positive association between green strategies and financial performance (Clarkson et al., 2011; Lee and Min, 2015; Xie et al., 2019). Results are consistent with the natural resource-based view theory (Clarkson et al., 2011). Lee and Min (2015) used green research and development investments as a proxy for eco-innovation. They show that green R&D is positively related to financial performance at the firm level. These findings support Porter’s theory (Porter, 1991; Porter and Van der Linde; 1995) that considers that early green investments offset operational costs and enhance financial returns in the long term (Horváthová, 2012; Lee and Min, 2015). Rennings and Rammer (2011) study the effects of regulation-driven environmental innovation on firm-level innovation and firm performance. Using a German firm sample, they find that both product and process innovations driven by environmental regulation create more sales with new products and cost savings.

We identify adaptation as a proactive environmental strategy that requires a long-term commitment to gain a competitive advantage and increase financial performance. Considering the mitigation strategies practicable in the short term and the substantial costs, adapting its strategy to climate change may only increase the firm's financial performance in the long term. Thus, we postulate the following hypothesis:

Hypothesis 2 The more a firm adapts to climate change, the higher its long-term perspective of financial performance.

2.2.3. Complementarity between mitigation and adaptation

Resource-based view theory (Wernerfelt, 1984; Barney, 1991) explains that CSR improves firm-stakeholder relationships and enhances a firm reputation among all stakeholders. In this way, companies lead environmental strategies to reduce interest between corporate managers and stakeholders. One critical issue is the different demands among stakeholders. Firms will have to adapt themselves to all stakeholders. We mobilize the concept of Stakeholder Salience (Mitchell et al. 1997), which defines salience as 'the degree to which managers prioritize competing stakeholder claims' (Mitchell et al., 1997). Mitchell et al. (1997) noted that all stakeholder definitions ignore urgency, defined as the degree to which stakeholder claims call for immediate attention. They propose a new stakeholder classification based on the power to influence the firm, the legitimacy, and the urgency of the stakeholders' claim on the firm. Stakeholders have different visions of the firm's environmental performance. Some stakeholders will demand short-term profitability, while others want the firm to differentiate from the market and accept longer-term financial performance. Therefore, we postulate that simultaneously implementing mitigation and adaptation strategies may help a firm resolve

conflict between stakeholders. It will reduce problems among stakeholders and increase the firm's financial performance (Harjoto and Jo, 2011).

We do not find empirical studies testing the complementarity of environmental strategies. Cavaco and Crifo (2014) investigate the complementarity and substitutability between corporate social responsibility dimensions that mediate the relationship between corporate social responsibility and financial performance. They show that human resource and business behavior dimensions are complementary inputs of financial performance, indicating mutual benefits and fewer conflicts among stakeholders. Customers are more attracted to products and services from socially responsible firms (Luo and Bhattacharya, 2006). Investors also perceive sustainable initiatives as a positive signal of a firm's future profitability (Ioannou and Serafeim, 2015). CSR firms can also be considered more prepared for future crises (Orlitzky et al., 2003). All these findings demonstrate that corporate managers could lead environmental strategies satisfying many stakeholders.

Considering the importance of environmental issues, implementing mitigation and adaptation strategies may increase a firm's financial performance in the short-term and long-term perspective. Thus, we formulate the following hypothesis:

Hypothesis 3 Mitigation and Adaptation strategies are complementary environmental practices positively associated with financial performance when they are combined.

2.3. Data and research Design

We start our sample with international listed firms in the 2012-2016 period appearing in the Worldscope database. Our study period was driven by data availability and represents a period of considerable debate on energy transition worldwide. This period was also marked by the Doha Amendment to the Kyoto Protocol, which established new environmental commitments for 2013-2020. Measuring mitigation strategies, we obtain total environmental damages from the Trucost database. From 8,239 firms, the total environmental damages of 558 firms are missing in Trucost. To explain adaptation to climate change, we use the environmental innovation score from Thomson Reuters ESG – Asset4. Non-available environmental innovation scores from Asset4 also consequently reduce our sample by 3,541. Then, we collect financial variables from the Worldscope database. All variables are defined in Table 2.1. After balancing for unavailable observations of financial controls, 3,554 firms in 42 countries are remaining in our final sample, totalling 12,852 firm-year observations.

[Insert Table 2.1 here]

Table 2.2 provides sample distributions by year, by industry, and by country. We have observations 2,465 in 2012, 2,406 in 2013, 2,565 in 2014, 2,569 in 2015, and 2,847 in 2016. The United States represents 27.33% of our sample. Moreover, the most represented sectors are Industrials and Consumer Discretionary. They represent 18.15% and 16.40% of our sample, respectively.

[Insert Table 2.2 here]

2.3.1. Firm's financial performance

We consider two types of measures to assess corporate financial performance: an accounting-based indicator and a market-based indicator. Both represent different perspectives of financial performance. Using both indicators, Delmas et al. (2015) show that a decrease in greenhouse gas emissions decreases a company's short-term financial performance. Nonetheless, they observe that a reduction of carbon emissions increases a firm's potential long-term value. Accounting measures evaluate the historical aspect of financial performance and are used to capture the firm's initiatives in the short term. We use the return on assets in our study as the accounting-based indicator. Return on assets shows how profitable a firm is relative to its total assets and is calculated by dividing earnings before interest by total assets. Higher return on assets indicates more asset efficiency.

We incorporate Tobin's q as a market-based measure, which is defined as the ratio of a firm's market value to its assets' replacement cost (Chung and Pruitt, 1994). Climate change has attracted investors' attention, and Tobin's q represents a well-founded indicator for the market perception of a firm's long-term perspective of financial performance. Tobin's q captures the investors' evaluation of a firm's ability to generate future economic earnings and thus represents the value of long-term investments (Dowell et al., 2000). A Tobin's q value greater than 1 indicates that the forward-looking market value is higher than the current value of its assets. In short, we use return on assets and Tobin's q to approximate short- and long-term perspectives of financial performance. We test our model using accounting and market-based measures but not interchangeably. To shed light on the robustness of results, we use both the return on equity (ROE) and the market-to-book (MB) as the dependent variable, instead of return on assets and Tobin's q.

2.3.2. Measuring Mitigation strategies

In this section, we describe the environmental data we used. We acquired a mitigation proxy from Trucost. Used in numerous academic research articles (Delmas et al., 2015; Bolton and Kacperczyk, 2021), Trucost compiles carbon and environmental footprint measures for more than 6000 firms. Trucost quantifies the environmental impacts and associated damage costs from extraction and resource use, and sinks. The data generated by Trucost offer the environmental impacts of a firm's direct and indirect environmental damages. The variable combines environmental costs from the direct operations and those from the selected firm's supply chain broken down by impact category. The variables are distributed within seven broad categories of environmental issues: GHGs, general waste, heavy metals, natural resources, volatile organic compounds, water abstraction, and other emissions. We choose to capture a firm's mitigation strategy the total environmental damages. Table 2.3 presents the total environmental damages by firm distribution by sector and region. Standardized between 0 and 1, the mean of total environmental damages is 0.434. Materials and Utilities are the most polluting sectors (0.675 and 0.699 respectively). Surprisingly, the average environmental damages from North America are under our sample's mean (0.420).

[Insert Table 2.3 here]

2.3.3. Measuring Adaptation to climate change strategies

Adaptation to climate change strategy is measured by the environmental innovation score of Thomson Reuters – Asset4, one of the major ESG rating agencies. Asset4 analyses most publicly traded firms on the basis of three dimensions (environmental, social, and governance),

on a scale from 0 to 100 relative to peers in their respective industries. Asset4 classifies the environmental dimension into three scores: emission score, environmental innovation score, and resource use score. The environmental innovation score “reflects a company’s capacity to reduce the environmental costs and burdens for its customers, thereby creating new market opportunities through new environmental technologies and processes or eco-designed products”. The Asset4 proxy well-captures the opportunities developed through new green processes and products induced in the definition of adaptation (Houghton et al., 2001). The Thomson Reuters – Asset4 is also well-known in the literature background (Gupta, 2018; Marsat et al., 2020). Table 2.3 shows the distribution of environmental innovation scores by region and industry. The calculated mean is 0.525. We observe that Europa is the region with the highest average environmental innovation score, consistent with European environmental concerns and green policies led by governments.

2.4. Methodology

We use unbalanced panel data to estimate the effects of mitigation and adaptation on climate change on firms' financial performance. First, we investigate whether mitigation and adaptation are associated with financial performance after controlling for firms' characteristics. We perform our test on two different indicators of financial performance. Considering the diversity of financial performance, we use the return on assets and Tobin's q to proxy the accounting measure and the market-based measure of financial performance, respectively. To conduct our study, we use the following model:

Financial Performance $_{i,t}$

$$\begin{aligned}
 &= \beta_0 + \beta_1 \text{Environmental Damages}_{i,t-1} + \beta_2 \text{Innovation Score}_{i,t-1} \\
 &+ \beta_3 \text{ROA}_{i,t-1} + \beta_4 \text{Leverage}_{i,t-1} + \beta_5 \text{Sales Growth}_{i,t-1} + \beta_6 \text{Size}_{i,t-1} \\
 &+ \beta_7 \text{R\&D}_{i,t-1} + \beta_8 \text{R\&D dummy}_{i,t-1} + \beta_9 \text{GDP}_{i,t-1} + \beta_{10} \text{GDP Growth}_{i,t-1} \\
 &+ \text{Industry} + \text{Year} + \text{Region} + \varepsilon_{i,t}.
 \end{aligned}$$

Using return on assets as the dependent variable, $\text{ROA}_{i,t-1}$ is not included in the model. In both models, panel data include observations on N cross-section units (firms) over T time-periods. β_0 represents the unobserved firm-level modeled by the constant of the model. β_n are the estimated regression coefficients for each of the independent variables. We include industry, year, and country fixed-effects.

We use several controls that explain corporate financial performance. In step with previous studies (Delmas et al., 2015), we control for firm specifications, including the financial performance by return on assets, the firm leverage, the natural logarithm of a firm's total assets (SIZE), and the sales growth. As R&D is highly correlated to corporate social responsibility (McWilliams and Siegel, 2000; Elsayed and Paton, 2005), we introduce the research and development ratio (RD). To deal with the R&D missing data issue, we set non-available data to zero, following Barnett and Salomon (2012). Moreover, we control for the presence of data with an R&D dummy named RDD that is equal to one if data is missing (Marsat & Williams, 2016; Aouadi and Marsat, 2018). Leverage is the ratio between the book value of total debt and total assets. Sales growth represents total sales divided by sales in the previous year. R&D is calculated by research and development expenditures divided by total sales. Environmental performance can take time to improve financial performance, and results can differ with or without lagged environmental variables (Konar and Cohen, 2001). We use lagged independent

variables in our model consistent with previous studies. All variables are winsorized at the 1 and 99% levels to counteract any potential effect of outliers. The standard errors are also clustered by firm.

2.4.1. Descriptive statistics and correlation matrix

Table 2.4 provides descriptive statistics for our study. Our sample has an averaged Tobin's q of 1.701. The mean and standard deviation of Total Environmental Damages are 0.436 and 0.217. Environment Innovation Score has a mean of 0.525 and a standard deviation of 0.264. Our sample firms have a mean return on assets and firm leverage of 5.356 and 24.773, respectively. The mean of the natural log of their assets (SIZE) is 15.756.

[Insert Table 2.4 here]

Table 2.5 provides the correlation coefficients among variables of the model. Correlations between explanatory variables do not display a multicollinearity bias. It allows us to regress our mitigation and adaptation proxies in the same model¹.

[Insert Table 2.5 here]

¹ Beyond the correlation matrix, we perform the VIFs test as an indicator for multicollinearity. It should be note that no VIF exceeds 3 and the mean stays close to 1. It underlines the absence of significant multicollinearity.

2.5. Empirical Results

We proceed in two steps to present our results. First, we show a significant relationship between mitigation and adaptation strategies and corporate financial performance. Second, we test the complementarity and substitutability between mitigation and adaptation strategies.

Table 2.6 reports the ordinary least square (OLS) regression results using year-fixed effects, industry, and country dummies. Columns (1) and (2) report the results using a 1-year lag between the independent variables and firm financial performance. Column (1) presents the results with return on assets as a dependent variable. Column (2) shows results with Tobin's q as the dependent variable. Our results show that total environmental damages are negatively associated with return on assets and Tobin's q. The environmental innovation score has only a significant and positive impact on Tobin's q ($p < 0.01$).

Observing the financial control variables, Firm Size is statistically significant across both models. This result is consistent with the literature background (Elsayed & Paton, 2005; Delmas and al., 2015). Regarding the results, from a market-based perspective, return on assets and R&D have a positive and significant effect on Tobin's q. Surprisingly, sales growth does not significantly impact Tobin's q, whereas it has a positive association with return on assets. Findings suggest that GDP growth has a significant and positive effect on return on assets and Tobin's q. The explanatory of our model (1) is 15% (R-squared = 0.150). With Tobin's q as the dependent variable, we find that the model's explanatory power is relatively significant in explaining the investors' long-term perspective of a firm (R-squared = 0.443).

[Insert Table 2.6 here]

2.5.1. Mitigation and financial performance

Regarding the mitigation effect on financial performance, we find that total environmental damages' coefficients are negative and significant on return on assets and Tobin's q. Our results are consistent with prior literature (Matsumura et al., 2014; Galama and Scholtens, 2021). In other words, a firm that mitigates its environmental damages has a higher accounting- and market-based financial performance. Mitigation strategies signal the market about good environmental performance and are positively associated with financial performance. The latter finding is confirmed on both accounting- and market-based measures. As a robustness check, we use alternative dependent variables (return on equity and market-to-book). Our findings are consistent with the baseline model results. In light of the results, we accept Hypothesis H1. However, the relationship between total environmental damages and financial performance is positive for both accounting- and market-based indicators. Galama and Scholtens (2021) show that greenhouse gas performance is more positively related to market-based than accounting-market financial performance. Our results highlight that mitigation strategy is positively associated with the firm's internal capabilities to generate value and the external perceptions of performance.

2.5.2. Adaptation and financial performance

In this section, we discuss findings on the effect of adaptation on financial performance. Column (1) in Table 2.6 shows the effect of adaptation on return on assets. The results indicate that firms' environmental innovation does not significantly impact return on assets at the 5% level. Column (2) presents the effects of estimates using Tobin's q as a dependent variable to materialize financial performance's long-term perspective. The environmental innovation score coefficient is positive and significant ($p < 0.01$). In line with Hypothesis 2, our results indicate

that higher adaptation to climate change increases financial performance, but only from a market-based perspective. Environmental innovation requires higher initial investments than mitigation. Consequently, the positive association between adaptation and financial performance is more likely to prevail in the long-term. Our results are consistent with the literature (Horváthová, 2012). To adopt eco-innovation at a firm level, companies need to make a long-term commitment. While Lee and Min (2015) show that a firm's green R&D investment is associated with greater financial performance, as measured by Tobin's q, we provide additional findings on the environmental innovation – financial performance relationship. We show that a firm adaptation to climate change is only positively and significantly related to market-based corporate financial performance.

2.5.3. Complementarity between Mitigation and Adaptation strategies

To better understand the differences across strategies on financial performance, we explore the existence of complementarity or substitutability between mitigation and adaptation. We have two environmental dimensions (mitigation and adaptation). We create four environmental states, which are dummy variables. These variables are equal to 1 when the firm does better than the industry average. Table 2.7 presents the definition and distribution of our environmental states. Because environmental damages are our proxy for mitigation, STATE00 is defined using ranking above the industry average on mitigation and below the industry average on adaptation. We can see that states are uniformly distributed, and the most frequent state is STATE10, representing firms that only perform a mitigation strategy. The distribution reinforces the fact that mitigation and adaptation are quite different. Thus, a firm can implement both strategies simultaneously or not.

[Insert Table 2.7 here]

We can perform regression analysis using environmental states dummy variables. The regressions are composed of the dependent variable, the four environmental states, and the baseline model's controls. We consider STATE00 as the reference environmental state. Columns (3) and (4) in Table 2.6 present the regression analysis for return on assets and Tobin's q on environmental strategies states and other selected control variables. Regarding the control variables, coefficients are consistent with previous results in Table 2.6. Regarding the environmental states, Tobin's q is positively affected by all environmental states (STATE10, STATE01, and STATE11). Mitigation strategy individually conducted has a positive and significant effect on Tobin's q. Similarly, the environmental innovation score is positively and statistically associated with Tobin's q. Results are consistent with our baseline model results, and Table 2.6 provides evidence that mitigation and adaptation strategies can be matched and positively affect firm financial performance. For the ROA, only STATE11 (strong mitigation and strong adaptation to climate change) is significantly positive. It suggests mitigation and adaptation processes must be simultaneously implemented to positively affect firm ROA.

Nevertheless, environmental state coefficients do not directly reveal the complementarity or substitutability between strategies (Mohnen and Röller, 2005; Cavaco and Crifo, 2014). In other words, we have to test the joint distribution of coefficients to test the complementarity. The concept of supermodularity has been implemented by Kodde and Palm (1986). It permits to test for complementarity among environmental strategies. We follow Mohnen and Röller (2005) and Cavaco and Crifo (2014) method to test for complementarity and substitutability between environmental states. We test for complementarity and substitutability using joint one-sided Wald tests. We start with testing the significant difference between environmental states

running in Stata, a two-sided Wald test. We note β_{ij} the estimates of the coefficients of the environmental states.

First, we test the significant difference between environmental states:

$$H_0 : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) = 0 \text{ against}$$

$$H_\alpha : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) \neq 0$$

β_{00} represents the estimate of the coefficient of the environmental state when mitigation and adaptation are weak. β_{10} represents the estimate of the coefficient of environmental state when mitigation is strong, and adaptation is weak. β_{01} represents the estimate of the coefficient of environmental state when mitigation is weak and adaptation strong. β_{11} represents the estimate of the coefficient of environmental state when mitigation and adaptation are strong. Two-sided Wald tests results on Tobin's q show a non-significant difference between environmental states. We accept the null hypothesis and conclude no statistical difference between environmental states on Tobin's q. With return on assets as the dependent variable, we observe a statistically significant difference between environmental states ($p < 0.05$). Thus, we can explore the existence of complementarity or substitutability practices on firm asset efficiency. We perform one-sided Wald tests to understand the sign of the relationship better.

Environmental states complementarity:

$$H_0 : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) \geq 0 \text{ against}$$

$$H_\alpha : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) < 0$$

Environmental states substitutability:

$$H_0 : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) \leq 0 \text{ against}$$

$$H_\alpha : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) > 0$$

Table 2.8 reports a summary of one-sided Wald tests. We find evidence of the complementarity between mitigation and adaptation strategies ($p < 0.05$). Moreover, these strategies are non-substitutable. These results are only confirmed on return on assets. The desire for a firm to improve environmental performance through different processes can lead to over-investment issues (Buchanan et al., 2018). For example, corporate managers can overinvest in green strategies to better personal reputation (Barnea and Rubin, 2010). In this case, green strategies are substitutable. Our results show no overinvestment issue implementing mitigation and adaptation processes simultaneously.

Our findings underline the differences between testing on return on assets and Tobin's q . Tobin's q reflects intangible performance measures, like confidence or reputation, not captured by return on assets. In contrast, return on assets only acknowledges a firm's GHG emissions indirectly via the efficiency of its use in production earnings (Busch & Hoffman, 2011).

[Insert Table 2.8 here]

We validate our Hypothesis 3, only measured on accounting-based financial performance. Results show that mitigation and adaptation practices are positively associated with market-based financial performance when implemented in isolation and positively associated when adopted simultaneously. Then, we find no significant difference between mitigation and

adaptation on Tobin's q . Tobin's q captures the investors' evaluation of the firm's ability to generate future earnings. In short, firms face increasing pressure to be environmental-friendly, and investors reward green practices, whatever the type and the implementation. Previous studies examine the impact of greenhouse gases on financial performance (Dixon-Fowler et al., 2013; Endrikat et al., 2014) and the impact of environmental innovation on corporate financial performance (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013; Lee and Min, 2015). Our paper provides additional insights in the literature examining the impact of mitigation and adaptation strategies when implemented independently or simultaneously on accounting and market-based corporate financial performance.

2.5.4. Evidence from high polluting sectors

Given the public pressure to improve environmental performance, how firms in high-polluting sectors can become socially responsible remains unanswered. Using a US sample from 1995 to 2009, Cai et al. (2012) show that firms' corporate social responsibility engagement in controversial sectors positively affects firm value. Then, we investigate the influence of polluting sectors in our main results. We split our sample into two subsets based on the most polluting sectors. We use three sectors to represent high polluting sectors: Energy, Materials, and Utilities. As displayed in Table 2.9, we test the relationship between environmental states and corporate financial performance (ROA and Q) when firms are in high polluting sectors compared to the rest of the sample. High polluting sectors represent 23.46% of our total sample. Columns (1) and (2) in Table 2.9 present results on return on assets. We note that mitigation and adaptation simultaneously implemented only have a significant effect on firms from polluting sectors. In other sectors, the relationship is not statistically significant. It underlines that, environmental strategies positively affect a firm asset efficiency in high polluting sectors.

Columns (3) and (4) present regression results on Tobin's q. The coefficients are positive and significant whether the firm is in a polluting sector or not. This result reinforces our previous results showing that investors reward environmental policies regardless of the nature of the strategy and the sector.

[Insert Table 2.9 here]

2.5.5. Mitigation and Adaptation strategies and financial performance: the role of the institutional and legal environment

The origin of a country's laws shapes its legal rules and the firm-level contracting environment (Porta et al., 2008). Thus, country's legal origin can impact governance structures and the decision-making process. A civil law country is characterized by state intervention in economic life through regulations and a stakeholder view (Porta et al., 2008). A common law country is a more discretion-oriented system supporting private market outcomes. As the firm's CSR rating and its country's legal origin are strongly correlated (Liang and Renneboog, 2017), we provide further information testing the legal environment's role on the environmental performance – financial performance relationship. For this purpose, we split our sample into two groups based on the country's legal environment, i.e., civil law countries and common law countries.

Examining our sample, we find that the average total environmental damages from firms from civil law countries and those from common law countries are similar. In contrast, firms from civil law countries are more likely to develop environmental innovation (the mean of environmental innovation is 0.56 when located in civil law countries, and 0.49 in common law

countries). This first observation is consistent with Liang and Renneboog (2017), explaining that firms from common law countries have lower CSR than companies from civil law countries.

Table 2.10 reports OLS regressions results for each group. We find that legal origin does not fundamentally change our results. Environmental innovation score on return on assets is not significant, whereas the firms' legal origin. Compared with our baseline model regressions results, total environmental damages are still negatively associated with return on assets and Tobin's q. We find that total environmental damages have a greater impact on return on assets for firms' in common law countries than in civil law countries. Moreover, mitigating its environmental damages has a positive impact on Tobin's q for firms in civil law countries. To summarize, our results remain stable, whereas the country's legal origin. However, our results show that in civil law countries, firms are more penalized by investors, whereas the impact on asset efficiency is less significant than in common law countries.

[Insert Table 2.10 here]

2.6. Robustness tests

In this section, we present the robustness tests. We provide three main robustness tests. First, we check if our results continue to hold for two alternative measures of firm financial performance. Second, we test the robustness of results with alternative measures of mitigation

strategies. Then, we present instrumental variables estimations addressing endogeneity concerns.

Addressing endogeneity, we add three fixed-effects in our baseline model: industry, country and, year. Moreover, we have lagged all explanatory variables in our analysis. Table 2.11 reports robustness checks removing fixed-effects of our baseline model and using alternative firm financial performance measures. First, Column (1) and Column (2) present regression analysis without fixed effects. As evidenced by Table 2.11, results are not affected by adding fixed effects. Second, Column (3) and Column (4) in Table 2.11 display regression analysis when employing other accounting-based and market-based performance measures. We use the return on equity as a proxy for accounting-based financial performance. Return on equity is calculated as the net income on average shareholder's equity. We use the market to book as a proxy for Tobin's q following the literature background (Galema et al., 2008; Edmans, 2011). Market to book is calculated as the market value of equity divided by its book value of equity. It represents the market's perception of a particular stock's value. Results remain qualitatively the same using other financial performance measures.

[Insert Table 2.11 here]

Addressing the measurement bias, we use an alternative measure of mitigation strategy. Evaluating environmental performance could be a problem in studying the environmental performance – financial performance relationship (Horváthová, 2010). We ran a robustness test presented in Table 2.12 with a new mitigation score to address this issue. Using the Thomson

Reuters – Asset4 database, we created the mitigation score. We summed the resource use score and the emission score and divided it by 2. Then, we replaced our total environmental damages variable with the mitigation score. Mitigation score is significant and positively associated with the return on assets and Tobin's q ($p < 0.01$). Our results remain unaffected by the change of our mitigation proxy. Hypothesis 1 is still supported. The result is robust in that the relationship persists regardless of the proxy.

[Insert Table 2.12 here]

As evidenced by our empirical results, mitigation and adaptation strategies significantly impact Tobin's q . However, our results may be subject to endogeneity issues. We estimate instrumental variable regressions in order to mitigate endogeneity concerns. A focal firm's CSR performance could be influenced by the CSR performance of the firms within the same industry-country pair, and by the CSR performance of other firms in the same country over time (Ioannou and Serafeim, 2012; Cheng et al., 2014; Arouri and Pijourlet, 2017). We instrument the total environmental damages by the mean country-industry and the mean country-year total environmental damages while excluding the focal firm (Cheng et al., 2014). We follow the same process for the environmental innovation score and create the mean country-industry and the mean country-year as instruments.

Table 2.13 reports two-stages least squares regressions. In Column (1), we estimate the first-stage OLS regressions to predict the value of the total environmental damages. We regress total environmental damages on all exogenous independent variables, fixed effects, and the instruments (mean country-industry and the mean country-year total environmental damages

excluding the focal firm). Column (2) displays the second-stage regression results, which use the predicted values of the total environmental damages from the first-stage regressions. In Columns (3) and (4), we repeat the same procedure for environmental innovation score. These tests show that the instruments satisfy the conditions of exogeneity and relevance². The coefficient on the total environmental damages is negative and significant (p-value < 0.01), and the coefficient on the environmental innovation score is positive and significant (p-value < 0.01). As evidenced by results in Table 2.13, results remain qualitatively the same.

[Insert Table 2.13 here]

2.7. Conclusion

Despite a vast literature background dealing with the relationship between environmental performance and financial performance, the debate is still ongoing. In this paper, we disentangle mitigation and adaptation processes in the assessment of environmental performance. This way, we examine the relationship between mitigation and adaptation and financial performance. Investors increasingly require firms to align their business objectives with environmental issues. We highlight the financial impact of two environmental strategies.

Using an unbalanced panel data with environmental data from Thomson Reuters's - Asset4 and Trucost on an international sample of 12,852 observations, we find differences between firms that limit environmental damages and those that adapt their strategies to climate change. To

² Additional endogeneity tests do not show endogeneity issues. Durbin and Wu-Hausman statistics are not significant. Then, we do not reject the null hypothesis and conclude that variables are exogenous.

summarize the empirical results, mitigate its environmental damages will positively and significantly affect financial performance. Regarding the adaptation to climate change effect, the time horizon conditioned the impact of firm adaptation on financial performance, and adaptation strategy is positively associated with market-based financial performance.

This study provides new empirical findings on the complementarity between mitigation and adaptation. We show that mitigation and adaptation strategies simultaneously implemented are positively associated with asset efficiency from an accounting-based perspective. Moreover, we find that green strategies are complementary and non-substitutable. In contrast, from a market-based perspective, mitigation and adaptation strategies positively and significantly impact Tobin's q , whereas they are independently or simultaneously implemented. We explain these challenging results because investors reward any environmental practices in a growing environmental awareness context.

Our results have interesting managerial implications. While firms face mounting pressure to be environmentally conscious, there are many ways to improve firm environmental performance. Our results highlight how mitigation and adaptation strategies are valued. Corporate managers should design their environmental strategies. Running mitigation and adaptation strategies simultaneously has a significant impact on asset efficiency and is rewarded by the market in the long term. Our study also has implications for policymakers, which can better understand companies' environmental strategies and their impact on corporate financial performance.

As a future research question, it would be interesting to examine the effect of physical climate risks on the environmental performance – financial performance relationship. Linnenluecke et al. (2016) underline the negative consequences of climate change. Physical risks could moderate our results.

Table 2.1. Variables definition and source

Variable	Definition	Description	Source
ENV DAMAGES	Total environmental damages	The natural log of the total environmental damages by firm (direct and indirect).	Trucost
INNOV SCORE	Environmental innovation score	“Environmental innovation category score reflects a company's capacity to reduce the environmental costs and burdens for its customers, and thereby creating new market opportunities through new environmental technologies and processes or eco-designed products” (Thomson Reuters – Asset4 definition).	Asset4
MITIG SCORE	Mitigation Score	$(\text{Emission Score} + \text{Resource Use Score}) / 2$	Asset4
Q	Tobin's q	$(\text{Market value of equity} + \text{book value of assets} - \text{book value of equity} - \text{balance sheet deferred taxes}) / \text{book value of assets}$	Worldscope
MB	Market-to-book	$\text{Market value of equity} / \text{book value of equity}$	Worldscope
SIZE	Firm size	$\text{Ln}(\text{book value of total assets})$	Worldscope
ROA	Return on assets	$\text{EBITDA} / \text{book value of assets}$	Worldscope
SG	Firm sales growth	$(\text{Sales in year } t / \text{sales in year } (t-1))$	Worldscope
RD	R&D expenses	$\text{R\&D expenditures} / \text{sales}$	Worldscope
RDD	R&D dummy	Equals 1 if R&D is missing, zero otherwise	Worldscope
LEV	Firm leverage	$\text{Book value of debt} / \text{book value of assets}$	Worldscope
ROE	Return on equity	$\text{Net Income} / \text{Average Shareholders' Equity}$	Worldscope

Table 2.2. Sample distribution

Panel A: Distribution by GICS sector			Panel B: Distribution per year		
	N	%		N	%
Consumer Discretionary	2,108	16.40	2012	2,465	19.18
Consumer Staples	947	7.37	2013	2,406	18.72
Energy	839	6.53	2014	2,565	19.96
Financials	1,711	13.31	2015	2,569	19.99
Health Care	754	5.87	2016	2,847	22.15
Industrials	2,332	18.15	Total	12,852	100.00
Information Technology	1,051	8.18			
Materials	1,503	11.69			
Real Estate	557	4.33			
Telecommunication Services	377	2.93			
Utilities	673	5.24			
Total	12,852	100.00			

Panel C: Distribution per country						
			N	%		
Australia	919	7.15	Mexico	80	0.62	
Austria	68	0.53	Morocco	13	0.10	
Belgium	101	0.79	Netherlands	147	1.14	
Brazil	317	2.47	New Zealand	39	0.30	
Canada	647	5.03	Norway	72	0.56	

China	387	3.01	Poland	116	0.90
Cyprus	4	0.03	Portugal	36	0.28
Czech Republic	15	0.12	Republic of Korea	421	3.28
Denmark	108	0.84	Russian Federation	87	0.68
Egypt	40	0.31	Saudi Arabia	2	0.02
Finland	106	0.82	Singapore	152	1.18
France	397	3.09	South Africa	458	3.56
Germany	370	2.88	Spain	189	1.47
Greece	47	0.37	Sweden	175	1.36
Hungary	9	0.07	Switzerland	271	2.11
India	315	2.45	Thailand	93	0.72
Indonesia	118	0.92	Turkey	94	0.73
Ireland	59	0.46	Ukraine	4	0.03
Italy	147	1.14	United Kingdom	897	6.98
Japan	1,596	12.42	United States of America	3,512	27.33
Luxembourg	28	0.22			
Malaysia	196	1.53	Total	12,852	100.00

These tables show the industry, year, and country distributions for our sample during the period 2012-2016. We use the GICS structure of 11 sectors: Consumer Discretionary, Consumer Staples, Energy, Financials, Health Care, Industrials, Information Technology, Materials, Real Estate, Telecommunications, and Utilities.

Table 2.3. Total environmental damages and environmental innovation score by firm distribution by sector and region

	ENV DAMAGES Mean	INNOV SCORE Mean
<u>Sector</u>		
Consumer Discret.	0.387	0.497
Consumer Staples	0.621	0.538
Energy	0.559	0.538
Financials	0.157	0.528
Health Care	0.380	0.456
Industrials	0.452	0.553
Information Technology	0.326	0.548
Materials	0.675	0.524
Real Estate	0.354	0.528
Telecommunications	0.275	0.541
Utilities	0.699	0.512
<u>Region</u>		
East Asia	0.455	0.516
Europa	0.426	0.576
Latin America	0.466	0.469
MENA	0.338	0.361
North America	0.420	0.508
South Asia	0.481	0.504
Sub-Saharan Africa	0.468	0.450
Total	0.434	0.525

This table reports the mean of total environmental damages and environmental innovation score by sector and region. We use the GICS structure of 11 sectors: Consumer Discretionary, consumer staples, energy, financials, health care, industrials, information technology, materials, real estate, telecommunications, and utilities. Based on the OECD classification, we define 7 regions in our sample: East Asia, Europa, Latin America, MENA, North America, South Asia, and Sub-Saharan Africa. We standardized our environmental variables to have values between 0 and 1.

Table 2.4. Descriptive statistics

Variables	Mean	Median	Standard Deviation	Minimum	Maximum	Q1	Q3
Q	1.701	1.280	1.199	0.568	7.893	1.014	1.891
ROA	5.356	4.790	7.764	-35.650	31.610	1.910	8.570
ROE	11.076	10.69	21.375	-94.350	84.910	4.820	18.180
MB	2.713	1.710	3.105	0.000	19.970	1.030	3.140
ENV DAMAGES	0.436	0.426	0.217	0.000	1.000	0.274	0.572
INNOV SCORE	0.525	0.459	0.264	0.000	1.000	0.312	0.772
MITIG SCORE	0.555	0.582	0.261	0.000	1.000	0.327	0.781
ROA	5.806	5.040	7.552	-35.65	31.61	2.110	8.915
LEV	24.772	23.285	17.634	0.000	83.187	10.670	35.815
SIZE	15.756	15.630	1.588	10.677	19.697	14.703	16.691
SG	1.053	1.030	0.252	0.443	3.047	0.939	1.120
RD	1.756	0.000	4.698	0.000	34.280	0.000	1.010

This table reports the descriptive statistics of the ROA and Tobin's q variables and explanatory variables. This table includes the mean, the median, the standard deviation, the minimum, the maximum, Q1 and Q3 of the variables. The sample consists of 12,852 observations. All variables are defined in Table 2.1.

Table 2.5. Correlation matrix

	Q	ROA	ROE	MB	ENV DAMAGES	INNOV SCORE	MITIG SCORE	STATE00	STATE10	STATE01	STATE11	LEV	SIZE	SG	RD	RDD
Q	1															
ROA	0.559***	1														
ROE	0.415***	0.808***	1													
MB	0.772***	0.423***	0.479***	1												
ENV DAMAGES	-0.079***	-0.044***	-0.117***	-0.068***	1											
INNOV SCORE	-0.065***	-0.061***	-0.017	-0.037***	0.007	1										
MITIG SCORE	-0.031***	0.001	0.044***	0.020*	0.056***	0.392***	1									
STATE00	-0.001	0.023**	-0.027**	-0.018*	0.344***	-0.484***	-0.133***	1								
STATE10	0.043***	-0.000	-0.005	0.028**	-0.303***	-0.501***	-0.260***	-0.367***	1							
STATE01	-0.051***	-0.015	-0.016	-0.035***	0.235***	0.524***	0.212***	-0.329***	-0.347***	1						
STATE11	0.007	-0.009	0.050***	0.025**	-0.274***	0.511***	0.202***	-0.319***	-0.336***	-0.301***	1					
LEV	-0.165***	-0.095***	-0.061***	-0.002	0.154***	0.034***	0.023**	0.005	-0.052***	0.058***	-0.008	1				
SIZE	-0.326***	-0.194***	-0.041***	-0.202***	-0.115***	0.295***	0.353***	-0.130***	-0.196***	0.164***	0.179***	0.133***	1			
SG	0.085***	0.093***	0.065***	0.062***	0.015	-0.079***	-0.082***	0.045***	0.032***	-0.019*	-0.063***	-0.038***	-0.061***	1		
RD	0.232***	0.011	-0.019*	0.137***	-0.056***	0.025**	0.030***	-0.023**	-0.071***	0.089***	0.009	-0.144***	-0.079***	0.018*	1	
RDD	0.112***	0.057***	0.023*	0.076***	0.226***	0.117***	0.119***	0.018	-0.172***	0.183***	-0.018*	-0.065***	-0.029**	-0.016	0.433***	1

This table reports correlations between variables of interest from 2012 to 2016. All variables are defined in Table 2.1. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 2.6. Mitigation and Adaptation strategies and financial performance

Variables	(1)	(2)	(3)	(4)
	ROA	Q	ROA	Q
ENV DAMAGES	-2.589*** (0.001)	-0.561*** (0.000)		
INNOV SCORE	0.241 (0.509)	0.204*** (0.000)		
STATE10			-0.011 (0.950)	0.094*** (0.000)
STATE01			0.257 (0.173)	0.084*** (0.000)
STATE11			0.695*** (0.000)	0.199*** (0.000)
ROA		0.069*** (0.000)		0.069*** (0.000)
LEV	-0.037*** (0.000)	-0.001 (0.123)	-0.038*** (0.000)	-0.002*** (0.002)
SIZE	-0.820*** (0.000)	-0.186*** (0.000)	-0.861*** (0.000)	-0.184*** (0.000)
SG	2.163*** (0.000)	0.002 (0.968)	2.197*** (0.000)	-0.002 (0.943)
RD	-0.190*** (0.000)	0.043*** (0.000)	-0.192*** (0.000)	0.043*** (0.000)
RDD	-1.386*** (0.000)	-0.001 (0.981)	-1.270*** (0.000)	0.007 (0.751)
Country, Industry, Year fixed effects	Yes	Yes	Yes	Yes
Constant	16.525*** (0.000)	4.049*** (0.000)	16.123*** (0.000)	3.831*** (0.000)
Observations	12,852	12,852	12,852	12,852
R-squared	0.150	0.443	0.149	0.441
Adjusted R-squared	0.145	0.441	0.145	0.438

This table reports the results of OLS regressions for accounting and market-based firm financial performance as measured by ROA and Tobin's q on total environmental damages, environmental innovation score and other selected control variables. All variables are defined in Table 2.1. Columns (3) and (4) report the regression results for financial performance on environmental strategies states. STATE10 is a dummy equal to 1 if ranking below industry average on Mitigation and below industry average on Adaptation. STATE01 is a dummy equal to 1 if ranking above industry average on Mitigation and above industry average on Adaptation. STATE11 is a dummy equal to 1 if ranking below industry average on Mitigation and above industry average on Adaptation. All regressors are one year lagged to account for endogenous interdependence. All variables are winsorized at the 1 and 99% level. The models include year, industry, and country fixed effects. Our sample spans from 2012 to 2016. P-values are in parentheses. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 2.7. Environmental strategies states

Environmental States	State	Observations	%
Ranking above industry average on Mitigation and below industry average on Adaptation	STATE00	3,319	25.82
Ranking below industry average on Mitigation and below industry average on Adaptation	STATE10	3,587	27.91
Ranking above industry average on Adaptation and above industry average on Mitigation	STATE01	3,046	23.70
Ranking below industry average on Mitigation and above industry average on Adaptation	STATE11	2,900	22.56

This table reports the environmental strategies states definition and distribution.

Table 2.8. Summary of results on complementarity/substitutability tests

Hypothesis	ROA	Q
Complementarity	Yes**	No
Substitutability	No	No

This table reports the results of complementarity and substitutability tests. We perform one-sided Wald tests to test the complementarity and substitutability between mitigation and adaptation strategies. We test the following hypotheses for environmental states complementarity: $H_0 : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) \geq 0$ against $H_\alpha : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) < 0$ and $H_0 : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) \leq 0$ against $H_\alpha : \beta_{11} + \beta_{00} - (\beta_{10} + \beta_{01}) > 0$ for environmental states substitutability. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 2.9. Mitigation and adaptation strategies and financial performance: the role of polluting sectors

Variables	(1)	(2)	(3)	(4)
	ROA	ROA	Q	Q
	Polluting sectors	Rest of the sample	Polluting sectors	Rest of the sample
STATE10	0.692 (0.100)	-0.028 (0.890)	0.122*** (0.000)	0.108*** (0.000)
STATE01	1.145** (0.015)	0.178 (0.377)	0.062* (0.092)	0.064** (0.022)
STATE11	2.179*** (0.000)	0.290 (0.181)	0.141*** (0.000)	0.216*** (0.000)
ROA			0.032*** (0.000)	0.088*** (0.000)
LEV	-0.008 (0.466)	-0.040*** (0.000)	0.002** (0.029)	-0.004*** (0.000)
SIZE	-0.305** (0.023)	-1.185*** (0.000)	-0.155*** (0.000)	-0.161*** (0.000)
SG	2.067*** (0.000)	2.489*** (0.000)	-0.084* (0.059)	0.105** (0.016)
RD	0.264** (0.026)	-0.161*** (0.000)	0.064*** (0.000)	0.047*** (0.000)
RDD	-1.169*** (0.002)	-1.132*** (0.000)	-0.105*** (0.000)	0.019 (0.444)
Country, Industry, Year fixed-effects	Yes	Yes	Yes	Yes
Constant	1.869 (0.397)	20.439*** (0.000)	3.269*** (0.000)	3.208*** (0.000)
Observations	3,015	9,837	3,015	9,837
R-squared	0.112	0.139	0.328	0.454
Adjusted R-squared	0.097	0.135	0.317	0.451

This table reports OLS regression analysis for firm financial performance over the period of 2012-2016. Our sample is split with respect to most polluting sectors and the rest of the sample. We use three sectors to represent high polluting sectors: Energy, Materials and Utilities. The main variables of interest are environmental strategies states. STATE10 is a dummy equal to 1 if ranking below industry average on Mitigation and below industry average on Adaptation. STATE01 is a dummy equal to 1 if ranking above industry average on Mitigation and above industry average on Adaptation. STATE11 is a dummy equal to 1 if ranking below industry average on Mitigation and above industry average on Adaptation. All variables are defined in Table 2.1. All regressors are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1 and 99% level. The models include year, industry, and country fixed effects. Our sample spans from 2012 to 2016. P-values are in parentheses. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 2.10. Mitigation and adaptation strategies and financial performance: the role of legal environment

Variables	(1)	(2)	(3)	(4)
	ROA	ROA	Q	Q
	Civil law countries	Common law countries	Civil law countries	Common law countries
ENV DAMAGES	-1.829*	-2.713**	-0.647***	-0.489***
	(0.061)	(0.012)	(0.000)	(0.001)
INNOV SCORE	-0.189	0.483	0.211***	0.204**
	(0.695)	(0.366)	(0.004)	(0.015)
ROA			0.081***	0.065***
			(0.000)	(0.000)
LEV	-0.060***	-0.023**	0.000	-0.003**
	(0.000)	(0.011)	(0.769)	(0.028)
SIZE	-0.809***	-0.829***	-0.160***	-0.203***
	(0.000)	(0.000)	(0.000)	(0.000)
SG	2.744***	2.032***	0.171**	-0.089
	(0.000)	(0.001)	(0.010)	(0.163)
RD	-0.113*	-0.227***	0.025**	0.048***
	(0.076)	(0.000)	(0.018)	(0.000)
RDD	-0.127	-1.873***	0.017	-0.040
	(0.689)	(0.000)	(0.727)	(0.383)
Year-fixed effects	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Constant	17.956***	17.073***	3.432***	4.445***
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	5,654	7,198	5,654	7,198
R-squared	0.195	0.145	0.499	0.410
Adjusted R-squared	0.188	0.142	0.494	0.407

This table reports the results of regression analysis for firm financial performance over the period of 2012-2016. Our sample is split between civil law countries and common law countries. The dependent variable is proxied by the return on assets in Column (1) and (2) and by Tobin's q in Column (3) and (4). The main variables of interest are total environmental damages and environmental innovation score. All variables are defined in Table 2.1. All regressors are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1 and 99% level. The models include year, industry, and country fixed effects. Our sample spans from 2012 to 2016. P-values are in parentheses. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 2.11. Mitigation and adaptation strategies and financial performance: Robustness tests and evidence from different financial performance measures

	(1)	(2)	(3)	(4)
Variables	ROA	Q	ROE	MB
ENV DAMAGES	-2.973*** (0.000)	-0.453*** (0.000)	-15.015*** (0.000)	-2.055*** (0.000)
INNOV SCORE	-0.154 (0.684)	0.145** (0.010)	1.039 (0.340)	0.444** (0.011)
ROA		0.077*** (0.000)		0.135*** (0.000)
LEV	-0.025*** (0.000)	-0.001 (0.140)	-0.053** (0.014)	0.019*** (0.000)
SIZE	-0.934*** (0.000)	-0.167*** (0.000)	-0.589** (0.021)	-0.278*** (0.000)
SG	2.534*** (0.000)	-0.073 (0.129)	4.999*** (0.000)	0.028 (0.814)
RD	-0.098*** (0.007)	0.052*** (0.000)	-0.463*** (0.000)	0.068*** (0.000)
RDD	-1.481*** (0.000)	-0.006 (0.845)	-3.802*** (0.000)	-0.178* (0.068)
Country, Industry, Year-fixed effects	No	No	Yes	Yes
Constant	18.939*** (0.000)	4.023*** (0.000)	17.775*** (0.000)	5.774*** (0.000)
Observations	12,852	12,852	12,852	12,852
R-squared	0.059	0.384	0.102	0.282
Adjusted R-squared	0.058	0.384	0.097	0.279

This table reports robustness checks regression analysis over the period of 2012-2016. Columns (1) and (2) display the results of regression for firm financial performance on total environmental damages, environmental innovation score and other selected control variables without including fixed effects. Columns (3) and (4) present the results of regression for firm financial performance as measured by return on equity and market to book. All variables are defined in Table 2.1. All regressors are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1 and 99% level. The Columns (3) and (4) include year, industry, and country fixed effects. Our sample spans from 2012 to 2016. P-values are in parentheses. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 2.12. Environmental performance and financial performance: evidence from an alternative measure of mitigation

Variables	(1) ROA	(2) Q
MITIG SCORE	2.673*** (0.000)	0.294*** (0.000)
INNOV SCORE	-0.391 (0.295)	0.134** (0.022)
ROA		0.069*** (0.000)
LEV	-0.037*** (0.000)	-0.002* (0.094)
SIZE	-1.007*** (0.000)	-0.207*** (0.000)
SG	2.287*** (0.000)	0.020 (0.685)
RD	-0.190*** (0.000)	0.043*** (0.000)
RDD	-1.230*** (0.000)	0.027 (0.408)
Country, Industry, Year-fixed effects	Yes	Yes
Constant	17.034*** (0.000)	4.008*** (0.000)
Observations	12,852	12,852
R-squared	0.153	0.443
Adjusted R-squared	0.149	0.440

This table reports regression results for firm financial performance as measured by ROA and Tobin's q on Mitigation Score, environmental innovation score and other selected control variables. All regressors are one-year lagged to account for endogenous interdependence. All interdependent variables are winsorized at the 1 and 99% level. MITIG SCORE is calculated as (Resource use score + Emission score)/2 developed by Asset4. INNOV SCORE is firm's environmental innovation score computed by Asset4. ROA is return on assets. LEV represents firm's leverage. SIZE is firm's size. SG represents sales growth. RD is R&D expenses scaled by sales. RDD is a dummy variable equals to 1 if R&D expenses are non-available. All variables are defined in Table 2.1. All regressors are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1 and 99% level. The models include year, industry and country fixed effects. Our sample spans from 2012 to 2016. P-values are in parentheses. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 2.13. Environmental Performance and Tobin's q: Instrumental variables and alternative estimation method

Variables	(1)	(2)	(3)	(4)
	First stage	Second stage	First stage	Second stage
ENV DAMAGES		-0.685*** (0.001)		-0.561*** (0.000)
INNOV SCORE		0.204*** (0.000)		0.515*** (0.000)
Country Year Mean of ENV DAMAGES	-0.506*** (0.000)			
Country Industry Mean of ENV DAMAGES	0.912*** (0.000)			
Country Year Mean of INNOV SCORE			-1.136*** (0.000)	
Country Industry Mean of INNOV SCORE			0.882*** (0.000)	
Year-fixed effects	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Constant	0.288*** (0.000)	4.638*** (0.000)	-0.194*** (0.001)	4.734*** (0.000)
Observations	12,847	12,847	12,845	12,845
R-squared	0.702	0.443	0.217	0.439
Adjusted R-squared	0.700	0.440	0.213	0.437

This table reports results exploring the relationship between Tobin's q, total environmental damages, environmental innovation score and other selected control variables. We address endogeneity issues using an alternative estimation method. Column (1) presents the first stage OLS regressions to predict the value of the total environmental damages. We regress total environmental damages on all exogenous independent variables, fixed effects, and the instruments (mean country-industry and the mean country-year total environmental damages excluding the focal firm). Column (2) presents the second-stage regression results using the predicted values of the total environmental damages from the first-stage regressions. Column (3) and Column (4), we repeat the same procedure for environmental innovation score. For brevity, we do not report control variables coefficients in this table. Results are similar of those reported in Table 2.6 and are available upon request. All variables are defined in Table 2.1. All regressors are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1 and 99% level. The models include year, industry and country fixed effects. Our sample spans from 2012 to 2016. P-values are in parentheses. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

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Chapter 3. Acute vs Chronic Physical Climate Risk and Firm Value

Abstract

This chapter investigates the effects of physical climate risk on firm valuation, introducing the distinction between acute and chronic physical risks. Since acute risks are more salient and already experienced compared to chronic risks, we expect them to be more priced by investors. Drawing on an international dataset of 1,293 firms during the 2009-2020 period, we empirically find that acute physical risk has a negative and significant direct association with firm value, while chronic physical risk is not significant on the 2050 horizon. When considering the transmission channels that may explain the influence of physical risks on firm value, both acute and chronic risks have similar effects on ROA, leverage, R&D, and capex. However, compared to chronic risk, the acute risk is shown to indirectly significantly impact more firm value by reducing sales growth and dividends. Finally, we find that acute and overall physical risks are only linked in the most recent period of the sample, showing that investor attention on these issues has evolved over time. Overall, we document that physical risk should not be taken only as a global issue, since acute and chronic risks are considered and priced differently by investors.

Keywords: Climate risk, physical risk, acute risk, chronic risk, firm value, salience

A paper based on this chapter co-written with Sylvain MARSAT and Guillaume PIJOURLET has been presented in the CIGE 2022 and CREBF 2023 conferences.

Résumé

Ce chapitre étudie les effets du risque climatique physique sur la valeur des entreprises, en introduisant la distinction entre les risques physiques aigus et chroniques. Considérant les risques aigus comme plus saillants et déjà vécus par les acteurs économiques comparés aux risques chroniques, nous nous attendons à ce qu'ils soient mieux évalués par les investisseurs. A partir d'un ensemble de données internationales portant sur 1293 entreprises au cours de la période 2009-2020, nous montrons empiriquement que le risque physique aigu est lié négativement et significativement avec la valeur des entreprises, alors que le risque physique chronique n'a pas d'impact significatif à l'horizon 2050. Si l'on considère les canaux de transmission susceptibles d'expliquer l'influence des risques physiques sur la valeur, les risques aigus et chroniques ont des effets similaires sur le ROA, l'effet levier, la R&D et les CAPEX. Cependant, par rapport au risque chronique, le risque aigu a un impact indirect significatif sur la valeur des entreprises en réduisant la croissance des ventes et les dividendes. Enfin, nous observons que les risques physiques aigus et globaux ne sont liés que dans la période la plus récente de l'échantillon, ce qui montre que l'attention des investisseurs sur ces questions a évolué avec le temps. Ainsi, nous montrons que le risque physique ne doit pas être seulement considéré comme un risque global, puisque les risques aigus et chroniques sont pris en compte et évalués différemment par les investisseurs.

Mots clés : Risque climatique, risque physique, risque aigu, risque chronique, valeur des firmes, saillance

3.1. Introduction

Climate change is increasingly an economic issue, and firms have to adjust their strategy to deal with the related risks (Linnenluecke et al., 2016, Bui et al., 2017, Hummel et al., 2021). Two hundred and fifteen of the biggest global companies report almost US\$1 trillion at risk from climate impacts, with many likely to hit within the next five years (Bartlett & Coleman, 2019). In addition, while the economic impact of global warming is “unknowable” (Pindyck, 2013), investors increasingly consider climate change and now consider climate risk as a major risk for their portfolios (Ilhan et al., 2021; Krueger et al., 2020). Based on a survey of 439 institutional investors, Krueger et al. (2020) show that 21% of the respondents started incorporating climate risk into their investment strategy more than ten years ago, whereas 65% started doing it in the last five years.

Although most of the literature is focused on the influence of regulatory climate risk on firm value (Brooks et al., 2021, Giglio et al., 2021), a nascent and growing stream of academic literature investigates more precisely the impact of physical risks (Bansal et al., 2016; Ginglinger & Moreau, 2019; Hong et al., 2019; Sautner et al., 2023). Physical risks are physical damage to assets and disruption of flow of goods caused by increased natural disasters attributed to climate change (Field et al., 2012). Investors require a risk premium to compensate for the risk of holding assets exposed to physical climate risks (Bansal et al., 2016). Some studies find evidence that several physical risks such as droughts (Hong et al., 2019; Huynh et al., 2020) or rising temperatures (Addoum et al., 2023; Bansal et al., 2016) are priced in stock markets. However, if the impact of physical risks is a real issue (Engle et al., 2020), studies on the financial impact of climate risk are often limited to examining the influence of very specific climate risks, such as droughts (Hong et al. 2019; Huynh et al. 2020), temperature changes

(Bansal et al. 2016) or hurricanes (Shelor et al. 1992; Lamb 1995). We aim to fill this gap by examining the impact of different types of firm-level physical climate risks on firm value.

In this paper, we use Carbon4 Finance CRIS data as an original forward-looking climate risk proxy to assess firm-related physical climate risk at the firm level. This measure proves to be significantly and positively correlated with other measures of physical risks (Hain et al., 2022) and also allows us to contribute to the existing literature by making the distinction between acute physical risk and chronic physical risk (Basel Committee on Banking Supervision, 2021). Acute risks are related to natural disasters (extreme drought, heatwaves, storms, floods), whereas chronic risks refer to long-term changes in climate patterns (increasing temperature, sea-level rise, rainfall patterns)³. In essence, acute risks are more salient to investors as their impact is more striking, while the gradual changes of chronic risks are less attention-grabbing (Ginglinger, 2020). In addition, acute risks are event-driven and more material for investors, but chronic risks such as sea level rise and long-term changes will only be tangible for companies in decades⁴. Therefore, it can be rational for a limited-horizon investor to be more sensitive to acute risks since these risks have already impacted and/or has a probability to concretely impact companies within this horizon. On the contrary, chronic risks may occur beyond this investment horizon, and long-term environmental risks are largely financially discounted from the investors' point of view. Thus, because of salience and investment horizon reasons, we expect acute climate risks to have a higher negative impact on firm valuation than chronic risks.

³ <https://www.oecd.org/corporate/ca/TCFD-Climate-Report.pdf>

⁴ Idem

Although existing studies treat the impact of climate risks on firm value without disentangling them (Berkman et al., 2021; Krueger et al., 2020), our paper aims to complement the literature by capitalizing on the forward-looking measure CRIS of physical climate risk to unravel the impacts of acute and chronic risks (Ginglinger & Moreau 2019). First, using a sample of 1,293 firms from 24 countries over the 2009-2020 period, we show that physical risk has an overall negative and significant effect on firm value. Second, we find that this effect is driven by acute risks, whereas chronic risks have no significant relation to firm value. In other words, investors, all else equal, seem to price only physical acute risks exposure. Based on these results, we investigate the indirect effects of physical risk on firm value and show that sales growth and dividends seem to be the negative indirect drivers of this relationship. By disentangling the direct and indirect effects of chronic and acute risks, we reveal the economic significance of physical risk on firm value and find that the effect is only significant in the most recent period. Finally, we find that chronic risk has a negative and significant impact on firm value when a more long-term horizon is considered.

We thus contribute to the existing literature on climate risk valuation by disentangling for the first time chronic and acute physical risk effects and documenting their asymmetric effect on firm value. We specifically shed light on the effect of acute physical risks on investors' stock valuation processes, whereas chronic risk is not considered. Acute physical climate risks may trigger investors' attention, while chronic risks are less attention-grabbing and largely affected by discounting. We expect that these findings can be of interest to both managers and investors who are concerned with the value of firms facing future physical climate risks. The remainder of the paper is structured as follows: the next section reviews the related literature and presents the hypotheses. The third section is dedicated to the data and the sample. We then present the main empirical results and further analyses. The last section concludes the paper.

3.2. Hypotheses

Physical climate risks may affect current and future economic growth due to physical damages, increased operating costs, supply chain disruptions, and changes in revenues. As a result, investors may require a risk premium to compensate for these risks (Bansal et al., 2016; Sautner et al., 2023), either chronic or acute, and then decrease firm value. In addition, recent studies show that investors' perception of physical risk by investors plays a major role in the valuation process. Following this reasoning, physical risk due to future climate change may reduce the firm value (Campiglio et al., 2023). However, empirical findings are so far not conclusive (Sautner et al., 2023). Sautner et al. (2023) use earnings conference calls to assess firm climate change exposure through a machine learning process. While regulatory risk is significantly linked with firm valuation, the physical dimension proves to be not clearly related to it. The measure used for physical climate change exposure, however, relies on conference calls and may be subject to bias that may be mitigated with an external assessment like Carbon4 CRIS methodology. Thus, we expect, all else being equal, the following hypothesis:

H₁: Physical climate risk is negatively linked with firm value.

Beyond this, we propose to investigate the differences in effects among physical risks. Climate hazards do not have the same financial costs, depending on direct asset destruction and long-term effects. Hence, we propose to unravel the impacts of acute and chronic risks. Two different perspectives may support the need to disentangle acute and chronic risks. On the one hand, the literature shows that individuals and economic actors use heuristics to assess risk. For instance, one heuristic is to consider the frequency of an event from its availability (Tversky & Kahneman, 1974). Dessaint & Matray (2017) document the importance of the salience of an

event that affects that availability. Depending on the context, some events may easier come to mind. In summary, some factors can influence the investment decisions, such as proximity, media coverage, and past experiences that increase the salience of an event. Because acute risks may be more salient to investors and their impact are more striking and grab the investors' attention (Ginglinger, 2020), the type of physical risks should be considered.

Besides, the investment horizon has to be considered in determining the effects of physical risks on firm value. Acute risks refer to event-driven physical climate risks. They may be more material for investors due to direct asset destruction, whereas chronic risks will only be tangible for firms in decades. Therefore, we observe a body of literature investigating the reactions of corporate managers and people's reactions after a natural disaster (Bernile et al., 2017; Brown et al., 2018; Cameron & Shah, 2015; Feng et al., 2022; Gao et al., 2020). We assume that chronic risks, such as long-term changes, may impact investors' decisions. However, investors have a limited investment horizon that should not exceed the time for chronic risks to impact companies. For instance, Addoum et al. (2023) find no significant relationship between temperature exposures and U.S. firms' sales. In summary, investors may be more sensitive to acute risk, given the probability of impacting firms within their investment horizon. In contrast, chronic risks can materialize beyond their investment horizon or would be highly discounted. Therefore, chronic risks refer to long-term risks that could be less valued by investors.

We then hypothesize that acute and chronic risks are priced differently by investors due to salience and investment horizon. We expect acute risks to have a higher negative impact on firm valuation than chronic risks. Therefore, we can hypothesize:

H₂: Acute risks have a higher negative impact on firm valuation than chronic risks.

3.3. Data and methodology

3.3.1. Climate risk measure

To measure climate risk, we draw on Climate Risk Impact Screening (CRIS) data provided by Carbon4 Finance, a leading data provider and independent agency in adaptation to climate change. CRIS climate risk is related to location-specific climate hazards and industry-specific vulnerabilities. It is a combination of climate projections for specific geographic locations and vulnerability based on an issuer's sector. Carbon4 Finance developed climate risk measures for three intensity scenarios (low, medium, and high) and two time horizons (2050 and 2100). The CRIS methodology includes physical risk for each hazard, disentangling acute risks (heatwaves, droughts, extreme rainfall, and storms) and chronic risks (increases in average temperature, changes in rainfall patterns, and rise of sea level).

Risk ratings are attributed on a scale between 1 to 99, 1 being the lowest risk and 99 the highest. The aggregated multi-hazard is then based on the weighted geometric mean of all the risk ratings for each hazard. We note three main steps to perform climate risk analysis for a listed company. Carbon4 Finance first collects the geographical and sector distribution of the firm's operations. They then build the risk ratings for each hazard, time horizon, and scenario. Each hazard risk is calculated as an average of the risk rating of all business segments, weighted by the proportion of each segment in the overall activities of the firm. The last step is to build the aggregated risk rating, which represents a synthetic risk rating based on hazard risk ratings. The main interest of CRIS measures is that the ratings capture the increased physical risk in the future due to global warming compared to historical reference climate hazards. While there is still debate on the coherence of the methodologies used to assess physical risks, Hain et al.

(2022) show that language-based models are largely not consistent, while this precise measure is significantly and positively correlated with the two other model-based approaches of Trucost and Southpole.

[Insert Table 3.1 here]

Table 3.1 describes all variables used in our study. In our empirical estimation, we use three distinct proxies for climate risk. We first use PHYSICAL CLIMATE RISK, defined as CRIS global risk grade at a firm level. We also calculate CHRONIC (ACUTE) RISK as the mean of chronic (acute) risk ratings at a firm level. We combine the CRIS risk ratings for each physical risk: acute (changes in the intensity or frequency of heatwaves, changes in rainfall extremes, changes in drought extremes, changes in the intensity or frequency of storms) and chronic (increase in average temperature, changes in rainfall patterns, sea level rise). Following Ginglinger & Moreau (2019), we consider the scores for the medium-intensity scenario and the 2050-time horizon⁵.

[Insert Table 3.2 here]

Table 3.2 presents the physical risk ratings by industry for each climate hazard. Physical climate risk ratings are scaled from 0 (the lowest) to 100 (the highest) relative to peers in their industries. We observe that physical risks vary across industries. For instance, firms in polluting industries have high climate risks and associated sub-risks. The PHYSICAL CLIMATE RISK means are indeed 34.06 and 37.12 for firms in the Energy and Utilities sectors, respectively. The sector of

⁵ We performed robustness checks for all scenarios and time horizons, results are not affected. These tables are available on request.

utilities represents the sector with the highest physical climate risk, chronic and acute risks mean, whereas Financials and Telecommunications firms have unsurprisingly a mean climate risk under the global mean.

3.3.2. Firm value measure

We use Tobin's Q to measure firm value, calculated as (market value of equity + book value of assets - book value of equity - balance sheet deferred taxes)/book value of assets. Tobin's Q has the main advantage of being a forward-looking financial measure and is largely used in the literature (Aouadi & Marsat, 2018; Delmas et al., 2015). Thus, Tobin's Q represents an indicator of the market perception of a firm's long-term financial performance expectations that may well capture the potential effect of future climate change. We also use market-to-book (MB) as a robustness check.

3.3.3. Control variables

In line with previous studies (Berkman et al., 2021; Delmas et al., 2015; Huang et al., 2018; Matsumura et al., 2014), we control for firms' characteristics, including: return on assets (ROA), the natural logarithm of a firm's total assets (SIZE), firm leverage (LEV), sales growth (SG), research and development expenditures (R&D), dividends (DIV) and capex (CAPEX). We also include country-level macroeconomic control variables and control for GDP per capita (GDP) and GDP growth (GDP GROWTH) from the World Bank database. Moreover, we control for industry, year, and industry fixed-effects. We use the ICB classification of 11 sectors: Consumer discretionary, consumer staples, energy, financials, healthcare, industrials,

information technology, materials, real estate, telecommunications, and utilities. We also define four regions: East Asia, Europa, Middle East, North Africa, and North America.

3.3.4. Sample

We collect climate ratings for all listed firms covered by the Carbon4 Finance database. Our sample is obviously limited by the availability of CRIS climate risk data. We match it with financial Worldscope data from the Refinitiv Thomson Reuters database for 2009-2020. After balancing unavailable observations of control variables, our sample entails 1,293 firms from 24 countries. Companies from the United States of America represent 36.14% of the sample, and the most represented industries are Industrials and Consumer Discretionary, respectively 19.29% and 16.52% of our sample. The remaining countries and sectors included in our sample are depicted in Table 3.3.

[Insert Table 3.3 here]

Table 3.4 presents the descriptive statistics of our variables. Our main physical risk measure, PHYSICAL CLIMATE RISK has an overall average of 30.47, while the average CHRONIC RISK and ACUTE RISK ratings are 23.95 and 25.41, respectively. For our sample, Tobin's Q has a mean of 1.42. ROA has a mean of 5.82 percent, while the average sales growth is 5.52 percent. Average size, leverage, and R&D are respectively 9.72, 59.84 percent, and 2.04 percent of the assets. The average dividend (DIV) and capital expenditures (CAPEX) over total assets

are 2.13 and 3.81. The macroeconomic control variables GDP and GDP GROWTH have a mean of 10.79 and 0.69, respectively.

[Insert Table 3.4 here]

To gain insight into our research question, we conducted correlation tests between the variables used in our analysis. The correlation table is presented in Table 3.5. In line with H_1 , we find a negative and significant correlation between climate risk measures and Tobin's q . The reported correlations are -0.138, -0.070, and -0.110 between Q and CLIMATE RISK CHRONIC RISK, and ACUTE RISK, respectively. We observe that correlations between control variables and climate risk proxies can be statistically significant but do not raise major multicollinearity issues.

[Insert Table 3.5 here]

3.4. Results

In this section, we first examine the direct effect of physical climate risks on firm value. We then explore the transmission channels through which chronic and acute physical risks may affect firm value. We finally study how the evolution of climate risk perception may influence the impact of physical climate risk on firm value.

3.4.1. The direct effect of physical risk on firm value

To explore the relationship between physical climate risk and firm value, we regress Tobin's q on physical risk and control variables. We then estimate the effect of climate risk on firm value using the following specification:

$$Firm\ Value_{i,t} = \beta_0 + \beta_1 Physical\ Climate\ Risk_i + \sum_k \beta_k CONTROLS_{i,t-1}^k + \sum_t \alpha_t Year_i^t + \sum_p \gamma_p Industry_i^p + \sum_r \delta_r Region_i^r + \varepsilon_{i,t}$$

Where $Firm\ Value_{i,t}$ is our firm value measure (Tobin's Q or market-to-book ratio) for the firm i in year t . Climate Risk is our variable of interest, which can be measured by PHYSICAL CLIMATE RISK, CHRONIC RISK, and ACUTE RISK. Our model includes the control variables, as defined previously. Financial variables are winsorized at 1% and 99% to counteract any potential effect of outliers. All control variables are one-year lagged to mitigate endogenous interdependence. We also include p industry, t year, and r region fixed effects. The standard errors are clustered by firm.

[Insert Table 3.6 here]

Table 3.6 depicts our estimations of the effect of physical risks on Tobin's Q (columns 1, 2, and 3) and Market-to-book (columns 4, 5, and 6). We find in Column (1) that the physical climate risk has a significant and negative coefficient of -0.010 (p-value <0.05). Consistent with our H_1 , our findings reveal that investors value less firms that are vulnerable to increased physical risks due to future climate change. Besides, for all specifications, firm size is negatively related

to Tobin's q and market-to-book. ROA, leverage, sales growth, research and development expenditures, and GDP growth are positively and significantly linked to firm value ($p < 0.01$).

We analyze more precisely the impact of chronic and acute risks on Tobin's Q in Columns (2) and (3) in Table 3.6. In line with H_2 , our results indicate that acute risks are negatively associated with Tobin's Q . The estimated effect of chronic risk on firm value is, however, non-significant. Our results are robust using market-to-book as the dependent variable in Columns (4), (5), and (6). We checked collinearity among variables for our models and do not find any variance inflation factor exceeding 2, meaning that this issue is not a problem for our model (Table 3.7).

[Insert Table 3.7 here]

Overall, our findings support H_1 : Global physical risk significantly impacts firm value. These findings, compared to Sautner et al. (2023), highlight that the measure of physical risk may significantly impact the results. We expect our measure, however, to be the most correlated to other measures of physical risk, which is not the case of language-based methodologies (Hain et al., 2021). Moreover, regression results disentangling acute and chronic risks are in line with H_2 . Our results show that the effect of physical risk on firm value is mostly driven by acute risks, which underlines the importance of differentiating acute and chronic risks when assessing the impact of physical risk on firm value.

The findings highlight that physical risks are considered by investors that, all else being equal, value companies exposed to these risks less. This study extends but differs from the literature by disentangling acute and chronic risks effects on firm value. We find evidence in line with the salience hypothesis, implying that investors are mainly affected by risks that are more extreme and attention-grabbing (Alok et al., 2020; Choi et al., 2020). Following Tversky & Kahneman (1974) and Dessaint & Matray (2017), salience may trigger an availability heuristic and overreaction that leads to a significant stock price decrease (Huynh & Xia, 2021). Besides, investors may also value more risks that are more impactful in the short term, whereas chronic risks will only materialize in decades, implying that the negative cash-flow impact will be largely discounted so that their impact will eventually be not significant for them.

3.4.2. Transmission channels of the effect of physical risks on firm value

We then investigate the transmission channels of the effect of chronic and acute physical risks on firm value. We first estimate the effect of both CHRONIC RISK and ACUTE RISK on firm's financial characteristics (ROA, LEV, SG, R&D, DIV and CAPEX). Table 3.8 displays our results. We find that physical risk is negatively and significantly related to ROA and leverage while it positively and significantly affects R&D and CAPEX. This effect is documented for both chronic and acute risks, even if CAPEX is significantly more positively impacted in the case of chronic risks. In addition, we investigate more precisely the indirect impact of physical climate risks on firm value by estimating the product of the effect of the physical risks on each mediator time the effect of the mediator on Tobin's Q. We show that chronic risks indirectly mitigate the value throughout the impact on ROA, but this effect may be counterbalanced by R&D and capex. Meanwhile, we find a clear difference in the indirect effects on two major dimensions: sales growth and dividends. Acute risks imply for firms both significantly less sales growth and lower dividends, which, in turn, negatively impact firm

Tobin's Q ⁶. These findings highlight that salience bias may not be the only difference in the acute/chronic market valuation asymmetry but may also be rooted in real reasons linked to lower sales growth and lower dividends that impact firm value.

[Insert Table 3.8 about here]

3.4.3. The direct and indirect economic significance of physical climate risks

To assess the direct, indirect, and total effects of climate risk, we examine the consequences of a change in climate risk on firm value following the methodology used by Li et al. (2013). We first calculate the change in climate variables from the 25th percentile to the 75th percentile. The change in global physical risk (PHYSICAL CLIMATE RISK) from the 25th percentile to the 75th percentile from our sample is $\Delta\text{PHYSICAL CLIMATE RISK} = 9.310$. Similarly, we compute the change in chronic and acute physical risk (CHRONIC RISK and ACUTE RISK) from the 25th percentile to the 75th percentile and find $\Delta\text{CHRONIC RISK} = 4.624$ and $\Delta\text{ACUTE RISK} = 6.658$, respectively.

[Insert Table 3.9 here]

Table 3.9 presents the economic significance of climate risk on firm value. Following Li et al. (2013), we decompose the total effects into direct and indirect effects of physical risk. Row (1)

⁶ Results with Market-to-Book are not displayed for the sake of brevity but are similar.

presents the coefficients from the regressions (see Table 3.8 for acute and chronic risks). Row (2) displays the product of the Row (1) coefficients from indirect effect regressions and the change in physical risks (Δ PHYSICAL CLIMATE RISK, Δ CHRONIC RISK, and Δ ACUTE RISK). Row (3) reports the coefficients from the direct effect presented in Table 3.6. Row (4) represents the product of the Row (2) and Row (3) coefficients. The sum of indirect effects is the sum of coefficients in Row (4). The direct effect is the product of the direct effect in Table 3.6 and the percentile change in physical climate risks. The total effect is calculated as the sum of the indirect and direct effects.

Our findings show that when global physical risk is increased from the 25th percentile to the 75th percentile, the direct effect is to decrease Tobin's q by -0,092. The indirect effect is to reduce Tobin's q by -0,018. The total effect of PHYSICAL CLIMATE RISK is to decrease Tobin's q by -0,110. Given Tobin's q mean of 1.422, the total effect of physical risk is significant from an economic point of view. While the indirect effects are quite similar for acute and chronic risks (respectively -0.019 and -0.020), their total effect is largely different (-0.017 for chronic risks versus -0.087 for acute risks), confirming the asymmetry between these two risks for investors. Moreover, interestingly, we find that the negative economic effect is partly mitigated by the indirect effect on corporate investment (R&D and CAPEX). While the sum of the indirect effects of PHYSICAL CLIMATE RISK is negative, the indirect effect on R&D (CAPEX) is 0.021 (0.007). Hence, firms facing physical climate risks may be incited to increase their R&D and capital budgeting to prevent and adapt, which has an indirect positive effect on firm value.

3.4.4. Physical climate risk and time

Flammer (2013) documents that the sensitivity of stakeholders towards the environment has changed significantly over time. As a matter of fact, she pinpoints, for example, that environmental regulation, media attention to environmental news, or the rise of shareholders' proposals related to environmental issues has increased as time passes. In our sample, we may then expect more attention to the impacts of physical climate risk in the most recent period of our sample.

[Insert Table 3.10 here]

We split the sample according to the year 2015, which is both the middle of the period and the year of the Paris COP 21 that attracted particular attention to climate and environmental issues. Interestingly, we do not find any significant effect of any physical climate risk on the firm value before 2015. However, after 2015, the effect is in line with our baseline results, i.e., for both overall physical and acute climate risk but not significant for chronic risks. We then find that the effect is only significant for 2015-20, which means that investors' perception of physical risks has changed substantially over time, being more sensitive to physical risks in the recent period.

In addition, we investigate whether the time horizon of scenarios also affects the perception of physical risks for investors. While chronic risks are less likely in the short-term horizon, one may expect to have more long-term impacts. Since the database distinguishes three climate

change intensities (low, medium, and high) and two time horizons, we test the impact on firm value for all the possible scenarios.

[Insert Table 3.11 here]

Table 3.11 presents the results. Our findings are robust for 2050 horizon scenarios, since only acute risk has a negative and significant impact on firm value. However, interestingly, both chronic and acute risks are significantly related to firm value in the scenario of 2100. This implies that investors are concerned about the impact of physical risks, but this effect is mediated by the horizon considered. For the 2050 scenarios, chronic risks are less likely to impact firms and are not significantly related. Taking into account 2100 scenarios, the picture is different. At this horizon, investors expect firms to be substantially affected by chronic risks such as increased temperature risk, changes in rainfall patterns, or sea-level rise risk, and firm value is therefore significantly impacted. Meanwhile, regardless of the horizon, acute risks are always negatively and significantly related to firm value.

3.5. Conclusion

This study contributes to a growing literature on the impact of climate risk on firm value by examining the influence of acute and chronic physical risk related to climate change on firm value. Using a physical risk related to future climate change measure CRIS developed by Carbon4 Finance and based on an international dataset from 24 countries over the 2009-2020 period, we show that physical risk significantly decreases firm value as measured by Tobin's Q

and Market-to-Book. More importantly, we uncover that this effect is driven by acute risks, while the direct effects of chronic risks on firm value remain nonsignificant.

Our findings pinpoint the importance of not taking physical risks as a monolithic concept and the need to differentiate between acute and chronic risks. In fact, investors perceive acute and chronic risks differently, and this has implications for the valuation of the firm. Additional tests reveal that this difference is also related to the more material impact of acute risk on sales growth and dividends. Furthermore, we document the direct, indirect, and total effects of physical risks on firm value. Thus, we shed light on the economic significance of physical risk in firm value and the need to consider physical risks as a significant factor in firm valuation, especially in the most recent period. Finally, while acute risk is related to firm value, whatever the horizon, chronic risks only materialize for long terms horizon forecasts (2100).

This paper takes additional steps toward an improved understanding of the influence of physical climate risk on firm value. We hope that these findings may interest investors and corporate managers, providing a better understanding of the type of climate risk that has an impact on a company. Additionally, one of the conclusions that can be drawn from this study is that a positive indirect effect on corporate investment mitigates the negative effect of physical risk on firm value. Studying corporate managers' policies to alleviate the potential impacts of physical risks might be interesting as a future research question.

Table 3.1. Variables definition and source

Variable	Definition	Description	Source
PHYSICAL CLIMATE RISK	CRIS Climate Risk	CRIS global risk grade at a firm level for median scenario and 2050 time-horizon.	Carbon4 Finance
CHRONIC RISK	Physical Chronic Risk	The mean of chronic risk ratings at a firm level defined by the CRIS methodology (increase temperature risk, changes in rainfall patterns, and sea-level rise risk) for median scenario and 2050 time-horizon.	Carbon4 Finance
ACUTE RISK	Physical Acute Risk	The mean of acute risk ratings at a firm level defined by the CRIS methodology (heatwave risk, changes drought risk, rainfall extremes risk, and storms risk) for median scenario and 2050 time-horizon.	Carbon4 Finance
Q	Tobin's Q	$(\text{Market value of equity} + \text{book value of assets} - \text{book value of equity} - \text{balance sheet deferred taxes}) / \text{book value of assets}$	Worldscope
SIZE	Firm size	$\text{Ln}(\text{book value of total assets})$	Worldscope
ROA	Return on assets	$\text{EBITDA} / \text{book value of assets}$	Worldscope
SG	Firm sales growth	$(\text{Sales in year } t / \text{sales in year } (t-1)) - 1$	Worldscope
RD	R&D expenses	$\text{R\&D expenditures} / \text{total sales}$	Worldscope
LEV	Firm leverage	$\text{Total debt} / \text{Total assets}$	Worldscope
DIV	Dividend	$\text{Cash dividends scaled by total assets}$	Worldscope
CAPEX	Capital expenditure	$\text{Capital expenditure divided by total assets}$	Worldscope
GDP	GDP per capita	Natural logarithm of GDP per capita	World Bank database
GDP GROWTH	GDP growth	Annual percentage change in GDP	World Bank database

Table 3.2. Physical risk distribution by industry

ICB Industry	PHYSICAL CLIMATE RISK	CHRONIC RISK	ACUTE RISK
Basic Materials	32.520	25.467	27.431
Consumer Discret	31.018	23.894	25.671
Consumer Staples	31.251	24.745	26.485
Energy	34.062	28.799	28.332
Financials	27.512	21.936	22.688
Health Care	30.167	23.839	25.825
Industrials	31.213	24.019	26.141
Real Estate	24.284	18.129	19.611
Technology	29.981	23.796	25.092
Telecommunications	26.428	21.191	21.762
Utilities	37.119	29.847	30.424
Total	30.467	23.952	25.410

Note: This table reports the mean of CRIS climate risk rating and each climate hazard risk developed by Carbon4 by sector. We use the GICS structure of 11 sectors: Consumer Discretionary, consumer staples, energy, financials, health care, industrials, information technology, materials, real estate, telecommunications, and utilities.

Table 3.3. Sample distribution

Country	Freq.	Percent	Cumul.	ICB Industry	Freq.	Percent	Cumul.
Australia	372	2.88	2.88	Basic Materials	881	6.82	6.82
Austria	55	0.43	3.30	Consumer Discretionary	2,135	16.52	23.34
Belgium	90	0.70	4.00	Consumer Staples	876	6.78	30.12
Canada	469	3.63	7.63	Energy	569	4.40	34.53
Denmark	146	1.13	8.76	Financials	2,001	15.49	50.01
Finland	105	0.81	9.57	Health Care	1,217	9.42	59.53
France	671	5.19	14.77	Industrials	2,492	19.29	78.72
Germany	527	4.08	18.85	Real Estate	548	4.24	82.96
Hong Kong	363	2.81	21.65	Technology	1,067	8.26	91.22
Ireland	43	0.33	21.99	Telecommunications	462	3.58	94.79
Israel	87	0.67	22.66	Utilities	673	5.21	100.00
Italy	131	1.01	23.67	Total	12,921	100.00	
Japan	3,250	25.15	48.83				
Luxembourg	12	0.09	48.92				
Netherlands	115	0.89	49.81				
New Zealand	13	0.10	49.91				
Norway	75	0.58	50.49				
Portugal	33	0.26	50.75				
Singapore	155	1.20	51.95				
Spain	199	1.54	53.49				
Sweden	216	1.67	55.16				
Switzerland	313	2.42	57.58				
United Kingdom	811	6.28	63.86				
United States	4,670	36.14	100.00				
Total	12,921	100.00					

Note: These tables show our sample's industry and country distributions from 2009 to 2020. We use the ICB structure of 11 sectors: Consumer Discretionary, Consumer Staples, Energy, Financials, Health Care, Industrials, Information Technology, Materials, Real Estate, Telecommunications, and Utilities.

Table 3.4. Descriptive statistics

Variables	Mean	S.D.	P25	P75	N
Q	1.424	1.256	0.680	1.738	12,921
MB	2.861	3.908	1.120	3.320	12,921
PHYSICAL CLIMATE RISK	30.467	6.375	26.133	35.415	12,921
CHRONIC RISK	23.951	4.156	21.579	26.203	12,921
ACUTE RISK	25.410	4.816	22.313	28.971	12,921
ROA	5.824	6.160	1.930	8.600	12,921
SIZE	9.723	1.487	8.834	10.764	12,921
LEV	59.842	22.112	44.719	76.028	12,921
SG	5.516	15.513	-1.820	10.660	12,921
R&D	2.037	3.495	0.000	2.619	12,921
DIV	2.131	2.618	0.400	2.834	12,921
CAPEX	3.813	3.513	1.234	5.432	12,921
GDP	10.786	0.156	10.704	10.873	12,921
GDP GROWTH	0.691	2.208	0.487	1.716	12,921

Note: Table 3.4 presents the descriptive statistics of all variables. This table includes the mean, the standard deviation, the number of observations, and the Q1 and Q3 of the variables. The sample consists of 12,921 observations. All variables are defined in Table 3.1.

Table 3.5. Correlation matrix

	Q	MB	PHYSICAL CLIMATE RISK	CHRONIC RISK	ACUTE RISK	ROA	SIZE	LEV	SG	R&D	DIV	CAPEX	GDP	GDP GROWTH
Q	1													
MB	0.579***	1												
PHYSICAL CLIMATE RISK	-0.138***	-0.155***	1											
CHRONIC RISK	-0.070***	-0.077***	0.760***	1										
ACUTE RISK	-0.110***	-0.142***	0.944***	0.730***	1									
ROA	0.601***	0.339***	-0.148***	-0.072***	-0.134***	1								
SIZE	-0.186***	-0.039***	0.004	0.045***	0.082***	-0.068***	1							
LEV	-0.314***	-0.016	-0.195***	-0.142***	-0.183***	-0.308***	0.228***	1						
SG	0.217***	0.143***	-0.103***	-0.077***	-0.103***	0.191***	-0.115***	-0.084***	1					
R&D	0.415***	0.252***	0.011	0.033***	0.057***	0.154***	-0.023**	-0.279***	0.097***	1				
DIV	0.468***	0.330***	-0.112***	-0.015	-0.116***	0.522***	-0.055***	-0.173***	-0.046***	0.084***	1			
CAPEX	0.131***	0.039***	0.182***	0.249***	0.179***	0.099***	-0.037***	-0.191***	0.036***	-0.026**	0.129***	1		
GDP	0.185***	0.124***	-0.141***	-0.090***	-0.144***	0.089***	-0.060***	-0.011	0.029***	0.084***	0.081***	0.003	1	
GDP GROWTH	0.034***	0.025**	0.030***	0.024**	0.013	0.096***	-0.036***	-0.019*	0.204***	-0.030***	0.003	0.023**	0.099***	1

Note: This table reports the correlation coefficients among variables of interest from 2009 to 2020. All variables are defined in Table 3.1. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 3.6. Physical risks and firm value

	(1)	(2)	(3)	(4)	(5)	(6)
	Q	Q	Q	MB	MB	MB
PHYSICAL CLIMATE RISK	-0.009** (-2.12)			-0.040** (-2.56)		
CHRONIC RISK		-0.008 (-1.43)			-0.024 (-1.21)	
ACUTE RISK			-0.010** (-2.00)			-0.061*** (-3.51)
ROA	0.035*** (28.90)	0.035*** (28.93)	0.035*** (28.90)	0.056*** (8.86)	0.057*** (8.92)	0.056*** (8.82)
SIZE	-0.132*** (-12.66)	-0.131*** (-12.58)	-0.130*** (-12.48)	-0.105*** (-2.58)	-0.102** (-2.51)	-0.092** (-2.27)
LEV	0.004*** (6.16)	0.004*** (6.14)	0.004*** (6.15)	0.019*** (7.15)	0.019*** (7.14)	0.019*** (7.11)
SG	0.003*** (8.05)	0.003*** (8.06)	0.003*** (8.04)	0.009*** (5.12)	0.009*** (5.16)	0.009*** (5.09)
R&D	0.0532*** (11.80)	0.0531*** (11.77)	0.0534*** (11.83)	0.215*** (11.41)	0.213*** (11.34)	0.217*** (11.55)
DIV	0.074*** (21.26)	0.075*** (21.38)	0.074*** (21.21)	0.243*** (14.18)	0.246*** (14.36)	0.241*** (14.03)
CAPEX	0.013*** (4.66)	0.013*** (4.66)	0.013*** (4.64)	0.037*** (2.84)	0.037*** (2.79)	0.037*** (2.82)
GDP	0.239** (2.01)	0.249** (2.11)	0.234** (1.97)	0.250 (0.59)	0.293 (0.70)	0.199 (0.47)
GDP GROWTH	0.013*** (3.16)	0.013*** (3.13)	0.013*** (3.16)	0.057*** (2.59)	0.056** (2.57)	0.057*** (2.61)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.997 (-0.77)	-1.261 (-0.98)	-1.025 (-0.79)	-1.909 (-0.41)	-3.269 (-0.71)	-1.124 (-0.24)
Observations	12,921	12,921	12,921	12,921	12,921	12,921
R ²	0.525	0.525	0.524	0.233	0.232	0.234

Note: Table 3.6 presents the results of OLS regressions for Tobin's Q and Market-to-Book on physical climate risks (PHYSICAL CLIMATE RISK, CHRONIC RISK and ACUTE RISK) at 2050 time horizon, and other selected control variables. All variables are defined in Table 3.1. All regressors are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1% and 99% level. The models include year, industry, and region fixed-effects. Our sample spans from 2009 to 2020. Standard errors are clustered at firm level. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 3.7. Variance Inflation Factors (VIF) from Table 3.6 regressions

Variables	(1)	(2)	(3)	(4)	(5)	(6)
PHYSICAL CLIMATE RISK	1.16			1.16		
CHRONIC RISK		1.12			1.12	
ACUTE RISK			1.16			1.16
ROA	1.57	1.55	1.56	1.57	1.55	1.56
LEV	1.36	1.31	1.35	1.36	1.31	1.35
SIZE	1.08	1.08	1.09	1.08	1.08	1.09
R&D	1.11	1.11	1.11	1.11	1.11	1.11
SG	1.08	1.08	1.08	1.08	1.08	1.08
GDP	1.05	1.04	1.05	1.05	1.04	1.05
GDP GROWTH	1.02	1.02	1.02	1.02	1.02	1.02
DIV	1.43	1.42	1.44	1.43	1.42	1.44
CAPEX	1.09	1.12	1.09	1.09	1.12	1.09
MEAN VIF	1.19	1.19	1.20	1.19	1.19	1.20

Note: This table reports the variance inflation factors from the models tested in Table 3.6. All variables are defined in Table 3.1.

Table 3.8. The effects of chronic and acute physical risks on firm's financial characteristics

	(1) ROA	(2) LEV	(3) SG	(4) R&D	(5) DIV	(6) CAPEX
CHRONIC RISK	-0.048*** (-3.19)	-0.324*** (-6.41)	-0.068 (-1.55)	0.074*** (9.23)	0.034*** (5.39)	0.095*** (11.19)
ACUTE RISK	-0.065*** (-4.82)	-0.235*** (-5.11)	-0.221*** (-5.56)	0.075*** (10.31)	-0.048*** (-8.29)	0.054*** (6.92)
$\beta_{CHRONIC RISK}$ - $\beta_{ACUTE RISK}$	0.017 (1.49)	-0.089* (-1.79)	0.153*** (3.53)	-0.001 (-0.16)	0.082*** (11.33)	0.041*** (4.16)
Indirect effects on Tobins' Q						
CHRONIC RISK	-0.169*** (-3.44)	-0.097*** (-2.04)	-0.018 (-1.08)	0.394*** (-8.87)	0.254 (-5.17)	0.119*** (-5.67)
ACUTE RISK	-0.229*** (-4.87)	-0.084*** (-1.83)	-0.058*** (-5.05)	0.401*** (-9.89)	-0.357*** (-7.84)	0.067*** (-4.88)
Difference of indirect effects	0.060 (-1.47)	-0.013 (-0.19)	0.040*** (3.26)	-0.007 (-0.17)	0.611** (2.1)	0.052 (0.31)

Note: Table 3.8 presents the results of OLS regressions of firm characteristics (ROA, LEV, SG, R&D, DIV, and CAPEX) on physical climate risks at 2050 time horizon and other selected control variables. We tested the significance of the difference of the coefficients of CHRONIC RISK and ACUTE RISK. This table also reports the indirect effects on Tobin's Q. The indirect effects are computed as the product of the effect of the physical risks on the mediators time the effect of the mediator on Tobin's Q. Coefficients of indirect effects on Tobin's Q are multiplied by 100 for readability. All variables are defined in Table 3.1. All regressors are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1% and 99% levels. The models include control variables used in Table 3.6 and year, industry, and region fixed-effects. Our sample spans from 2009 to 2020. Standard errors are clustered at firm level. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 3.9. The economic significance of physical risks

	ROA	LEV	SG	R&D	DIV	CAPEX	Sum of indirect effects	Direct effects	Total effects
PHYSICAL CLIMATE RISK									
(1)	-0.052	-0.141	-0.172	0.042	-0.027	0.061			
(2) = (1) * Δ PHYSICAL CLIMATE RISK	-0.482	-1.313	-1.601	0.393	-0.251	0.564			
(3)	0.035	0.004	0.003	0.053	0.074	0.013		-0.010	
(4) = (2) * (3)	-0.017	-0.005	-0.005	0.021	-0.019	0.007	-0.018	-0.092	-0.110
CHRONIC RISK									
(1)	-0.048	-0.324	-0.068	0.074	0.034	0.095			
(2) = (1) * Δ CHRONIC RISK	-0.222	-1.498	-0.314	0.342	0.157	0.439			
(3)	0.035	0.004	0.003	0.053	0.074	0.013		-0.008	
(4) = (2) * (3)	-0.008	-0.006	-0.001	0.018	0.012	0.005	-0.020	-0.036	-0.056
ACUTE RISK									
(1)	-0.065	-0.235	-0.221	0.075	-0.048	0.054			
(2) = (1) * Δ ACUTE RISK	-0.435	-1.565	-1.471	0.498	-0.318	0.359			
(3)	0.035	0.004	0.003	0.053	0.074	0.013		-0.010	
(4) = (2) * (3)	-0.015	-0.006	-0.004	0.026	-0.024	0.004	-0.019	-0.069	-0.088

Note: Table 3.9 reports the economic significance of physical risks on Tobin's q . We compute the change in climate variables from the 25th percentile to the 75th percentile of each climate variable (Δ PHYSICAL CLIMATE RISK = 9.310, Δ CHRONIC RISK = 4.624, Δ ACUTE RISK = 6.658). Row (1) displays the coefficients from the regression results of the effects of physical risks on firm's financial characteristics. Row (2) presents the product of Row (1) and the change in physical risk variables from the 25th percentile to the 75th percentile. Row (3) reports the coefficients from the direct effect regression in Table 3.6. Row (4) presents the product of Row (2) and Row (3) and represents the indirect effect due to changes in physical risk. We then compute the sum of indirect effects. The direct effect is calculated as the result of the coefficient on physical risk in Table 3.6 and the percentile change. The total effect is the sum of indirect and direct effects.

Table 3.10. Physical risk and firm value over time

	(1)	(2)	(3)	(4)	(5)	(6)
	2009-2014	2015-2020	2009-2014	2015-2020	2009-2014	2015-2020
	Q	Q	Q	Q	Q	Q
PHYSICAL CLIMATE RISK	-0.008 (-1.45)	-0.013** (-2.27)				
CHRONIC RISK			-0.006 (-0.93)	-0.011 (-1.55)		
ACUTE RISK					-0.008 (-1.38)	-0.014** (-2.14)
ROA	0.022*** (14.40)	0.027*** (15.86)	0.022*** (14.45)	0.027*** (15.90)	0.022*** (14.40)	0.027*** (15.86)
SIZE	-0.117*** (-8.95)	-0.164*** (-10.98)	-0.116*** (-8.86)	-0.163*** (-10.89)	-0.116*** (-8.82)	-0.161*** (-10.73)
LEV	-0.006*** (-6.76)	0.002*** (2.79)	-0.006*** (-6.78)	0.002*** (2.78)	-0.006*** (-6.77)	0.002*** (2.77)
SG	0.002*** (6.35)	0.002*** (5.48)	0.002*** (6.36)	0.002*** (5.50)	0.002*** (6.35)	0.002*** (5.48)
R&D	0.036*** (6.57)	0.085*** (12.77)	0.036*** (6.55)	0.085*** (12.77)	0.036*** (6.59)	0.085*** (12.81)
DIV	0.070*** (15.99)	0.060*** (11.84)	0.071*** (16.08)	0.061*** (11.99)	0.070*** (15.97)	0.060*** (11.79)
CAPEX	-0.003 (-0.99)	0.009** (2.29)	-0.003 (-0.98)	0.009** (2.25)	-0.003 (-1.01)	0.009** (2.27)
GDP	1.116*** (8.67)	0.428*** (3.14)	1.118*** (8.68)	0.438*** (3.22)	1.113*** (8.64)	0.419*** (3.07)
GDP GROWTH	0.026*** (9.52)	0.010*** (3.81)	0.026*** (9.53)	0.009*** (3.79)	0.026*** (9.52)	0.010*** (3.84)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-9.631*** (-6.83)	-2.089 (-1.39)	-9.779*** (-6.96)	-2.411 (-1.62)	-9.652*** (-6.86)	-2.097 (-1.39)
Observations	6,131	6,790	6,131	6,790	6,131	6,790
R ²	0.480	0.527	0.480	0.527	0.480	0.527

Note: This table presents the results of OLS regressions for Tobin's Q on physical climate risks (PHYSICAL CLIMATE RISK, CHRONIC RISK and ACUTE RISK), and other selected control variables. We replicate the analysis in Table 3.6 on two subsamples over time. All variables are defined in Table 3.1. All regressors are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1% and 99% level. The models include industry and region fixed-effects. Our sample spans from 2009 to 2020. Standard errors are clustered at firm level. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 3.11. Acute and chronic physical risks and firm value by scenario

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Low 2050 CHRONIC Q	Low 2050 ACUTE Q	Med 2050 CHRONIC Q	Med 2050 ACUTE Q	High 2050 CHRONIC Q	High 2050 ACUTE Q	Low 2100 CHRONIC Q	Low 2100 ACUTE Q	Med 2100 CHRONIC Q	Med 2100 ACUTE Q	High 2100 CHRONIC Q	High 2100 ACUTE Q
PHYSICAL_RISK	-0.008 (-1.37)	-0.014** (-2.83)	-0.008 (-1.43)	-0.010** (-2.00)	-0.008 (-1.41)	-0.008** (-2.08)	-0.011** (-2.26)	-0.010** (-2.48)	-0.011** (-2.26)	-0.009*** (-2.61)	-0.008* (-1.83)	-0.009*** (-2.63)
ROA	0.035*** (28.93)	0.035*** (28.90)	0.035*** (28.93)	0.035*** (28.90)	0.035*** (28.93)	0.035*** (28.90)	0.035*** (28.91)	0.035*** (28.90)	0.035*** (28.91)	0.035*** (28.87)	0.035*** (28.93)	0.035*** (28.87)
SIZE	-0.131*** (-12.58)	-0.130*** (-12.50)	-0.131*** (-12.58)	-0.130*** (-12.48)	-0.131*** (-12.57)	-0.132*** (-12.67)	-0.131*** (-12.61)	-0.131*** (-12.56)	-0.131*** (-12.56)	-0.132*** (-12.67)	-0.131*** (-12.56)	-0.132*** (-12.68)
LEV	0.004*** (6.13)	0.004*** (6.10)	0.004*** (6.14)	0.004*** (6.15)	0.004*** (6.13)	0.004*** (6.16)	0.004*** (6.10)	0.004*** (6.09)	0.004*** (6.10)	0.004*** (6.15)	0.004*** (6.10)	0.004*** (6.18)
SG	0.003*** (8.06)	0.003*** (8.05)	0.003*** (8.06)	0.003*** (8.04)	0.003*** (8.06)	0.003*** (8.04)	0.003*** (8.07)	0.003*** (8.05)	0.003*** (8.06)	0.003*** (8.04)	0.003*** (8.06)	0.003*** (8.04)
R&D	0.053*** (11.77)	0.053*** (11.85)	0.053*** (11.77)	0.053*** (11.83)	0.053*** (11.78)	0.053*** (11.80)	0.053*** (11.82)	0.053*** (11.83)	0.053*** (11.83)	0.053*** (11.83)	0.053*** (11.81)	0.053*** (11.82)
DIV	0.075*** (21.37)	0.074*** (21.23)	0.075*** (21.38)	0.074*** (21.21)	0.075*** (21.37)	0.074*** (21.21)	0.075*** (21.38)	0.074*** (21.25)	0.075*** (21.37)	0.074*** (21.15)	0.075*** (21.38)	0.074*** (21.11)
CAPEX	0.013*** (4.66)	0.013*** (4.67)	0.013*** (4.66)	0.013*** (4.64)	0.013*** (4.65)	0.013*** (4.64)	0.013*** (4.70)	0.013*** (4.66)	0.013*** (4.69)	0.013*** (4.66)	0.013*** (4.67)	0.013*** (4.67)
GDP	0.243** (2.05)	0.224* (1.88)	0.249** (2.11)	0.234* (1.97)	0.242** (2.04)	0.243** (2.05)	0.253** (2.13)	0.235** (1.98)	0.249** (2.10)	0.233** (1.96)	0.235** (1.98)	0.237** (2.00)
GDP GROWTH	0.013*** (3.15)	0.013*** (3.18)	0.013*** (3.13)	0.013*** (3.16)	0.013*** (3.15)	0.013*** (3.14)	0.013*** (3.13)	0.013*** (3.16)	0.013*** (3.14)	0.013*** (3.18)	0.013*** (3.15)	0.013*** (3.17)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-1.194 (-0.92)	-0.781 (-0.60)	-1.261 (-0.98)	-1.025 (-0.79)	-1.168 (-0.90)	-1.104 (-0.85)	-1.118 (-0.87)	-0.949 (-0.73)	-1.079 (-0.84)	-0.875 (-0.67)	-1.010 (-0.77)	-0.902 (-0.69)
Observations	12,921	12,921	12,921	12,921	12,921	12,921	12,921	12,921	12,921	12,921	12,921	12,921
R2	0.525	0.525	0.525	0.524	0.525	0.524	0.525	0.525	0.525	0.525	0.525	0.524

Note: This table presents the results of OLS regressions for Tobin's Q on chronic and acute physical risks depending on time horizon and intensity, and other selected control variables. 2050 and 2100 refer to climate ratings for 2050 and 2100 time horizon respectively. Carbon4 distinguishes 3 climate change intensities (low, medium, and high). All variables are defined in Table 3.1. All controls are one-year lagged to account for endogenous interdependence. All variables are winsorized at the 1% and 99% level. The models include year, industry, and region fixed-effects. Our sample spans from 2009 to 2020. Standard errors are clustered at firm level. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

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Chapter 4. Physical Climate Risk and Corporate Investment Policy

Abstract

Using a US sample, we examine whether physical climate risk has an impact on the horizons and types of corporate investment. We find that physical risk positively and significantly impacts firm investment, as measured by R&D and long-term investment. Conversely, physical risk and capital expenditures are not significantly linked. We show that corporate managers invest more in the long term to adapt to climate change and counteract the future negative effects of physical risk. Testing whether risk-taking is a channel explaining the relation, further tests reveal that climate risk is associated with corporate risk-taking that pushes firms to invest more in risky R&D projects. Moreover, our results highlight that risky climate firms are more likely to use excess cash to implement R&D projects and long-term investments. Our findings are consistent with the idea that investment policy helps firms to adapt to climate change and enhance resilience.

Keywords: Climate risk; corporate investment; R&D; risk-taking

Résumé

A partir d'un échantillon américain, nous examinons dans quelle mesure le risque climatique physique a un impact sur l'horizon et le type d'investissements des entreprises. Nous observons que le risque physique a un impact positif et significatif sur le niveau d'investissement des entreprises, mesuré par la R&D et les investissements à long-terme. En revanche, le risque physique et les CAPEX ne sont pas significativement liés. Nous montrons que les dirigeants d'entreprise investissent davantage à long terme pour s'adapter au changement climatique et réduire les effets négatifs futurs du risque physique. Nous testons ensuite si la prise de risque est un canal de transmission de la relation. Les résultats additionnels montrent que le risque climatique est associé à la prise de risque des entreprises au travers d'investissements en R&D. De plus, nos résultats soulignent que les entreprises à risque tendent à utiliser leurs liquidités excédentaires pour mettre en œuvre des projets de R&D et des investissements à long terme. Nos résultats sont cohérents avec l'idée que la politique d'investissement est un moyen pour les entreprises de s'adapter au changement climatique et de renforcer leur résilience.

Mots clés : Risque climatique, investissement, R&D, prise de risque

4.1. Introduction

While regulatory risk is considered to be the most important climate risk facing investors (Krueger et al., 2020; Stroebel & Wurgler, 2021), a recent survey shows that physical climate risks are considered to be the main climate risks in the long run (Stroebel & Wurgler, 2021). However, the financial consequences of physical risks have received little empirical investigation. Physical risks are physical damages to assets and disruption of flow of goods caused by increased natural disasters attributed to climate change (Field et al., 2012). A growing literature has begun to investigate how firms adapt their financial policies to cope with physical climate risks. Hence, the impact of physical climate risks on leverage (Ginglinger & Moreau, 2019; Noth & Rehbein, 2019), cash holding (Huang et al., 2018; Noth & Rehbein, 2019), cash holding (Huang et al., 2018; Noth & Rehbein, 2019), and dividend policy (Huang et al., 2018) have already been studied. These results may be of particular interest in understanding the impact of physical climate risks on company value. It indeed has been shown that financial decisions such as dividend policy (Baker & Wurgler, 2004; Breuer et al., 2014; Brockman & Unlu, 2009), financial structure (Fama & French, 1998) or investment policy (Fama & French, 2015; Shao et al., 2013) may have an influence on firms' market value. However, little is yet known about how such risks influence firms' investment policies. In this, we aim to fill this gap in the literature by exploring the impact of physical climate risks on corporate investment policies.

The existing literature has already studied the impact of the occurrence of natural disasters on investment policy (Feng et al., 2022; Kanagaretnam et al., 2022). It has been shown, for example, that US firms reduce their capital expenditure following the occurrence of a natural disaster (Feng et al., 2022). These results underline the fact that managers tend to adopt more conservative financial policies in the wake of such events. However, a recent study based on an

international sample of firms from 39 different countries seems to show the opposite (Kanagaretnam et al. 2022). These authors put forward the idea that companies would increase their investment in physical capital following natural disasters in order to limit their impact, and, according to the precautionary principle, to protect themselves from the potential consequences of future events.

As we can see, the question of the impact of climate risk is not yet empirically settled and requires further investigation. Existing research has focused on understanding the impact of past events on corporate investment policies. Feng et al. (2022) analyzed the evolution of US firms' investment policies following 33 US hurricanes and 4 tropical cyclones. Kanagaretnam et al. (2022) assess climate risk using the Annual Climate Risk Index, a country-level climate risk measure provided by Germanwatch. This rating assesses how different countries have been impacted by natural disasters over the past year. We aim to contribute to the existing literature by analyzing how future climate risk is likely to influence corporate investment policies. This allows us to understand how firms adjust their investment policies to anticipated climate risks.

We also want to contribute to the literature exploring the determinants of corporate investment (Hillier et al., 2011; Kang et al., 2014; Lai et al., 2015; Shao et al., 2013) by investigating for the first time whether and how future physical climate risks influence both horizons and types of corporate investment. Corporate managers' decisions should be influenced by uncertain future consequences of climate change. Thus, they may tend to lead more conservative and less risky strategies to cope with any future natural disasters. Some empirical articles support this hypothesis (Ginglinger & Moreau, 2019; Huang et al., 2018; Kanagaretnam et al., 2022; Noth & Rehbein, 2019). We can thus expect that firms highly exposed to climate risk increase their cash holdings (Huang et al., 2018; Noth & Rehbein, 2019) but decrease their long-term

investments such as capital expenditures or R&D expenditures. However, it is also possible to postulate that future climate risk could lead to an increase in long-term investment to implement adaptation strategies to climate change. These strategies indeed require the development of new products and processes through R&D projects (Lee & Min, 2015; Oliva et al., 2022).

To test these two competing hypotheses, we choose the CRIS climate risk developed by Carbon4 Finance as a proxy for physical climate risk by firm. The CRIS methodology measures climate risk by the physical risk related to future climate change. CRIS climate risk is a function of location-specific climate hazards and industry-specific vulnerabilities. Carbon4 Finance developed climate risk measures for three intensity scenarios (low, medium, and high) and two-time horizons (2050 and 2100). The main interest of CRIS measures is that the ratings capture the increased physical risk in the future due to global warming compared to historical reference climate hazards. Based on a U.S. sample of 427 firms over the 2009-2020 period, we show that physical climate risks due to future climate change have a positive and significant effect on corporate long-term investment.

We also observe that this influence is positive and significant for R&D expenditures, but not for capital expenditures. This interesting result suggests that exposure to physical climate risks may lead firms to take greater risks by investing more in R&D projects, which are riskier investments (Bhagat & Welch, 1995; Coles et al., 2006; Kothari et al., 2002; Shao et al., 2013). We empirically confirm this hypothesis by revealing that exposure to physical climate risks magnifies the effect of R&D expenditures on corporate risk-taking. In doing so, we also contribute to the literature on the effect of climate risks on corporate risk-taking (Bernile et al., 2017; Dessaint & Matray, 2017; Gao et al., 2020).

The remainder of the paper is structured as follows. The next section reviews the related literature and presents the hypotheses. The third section describes the data and sample. The fourth section is dedicated to the empirical results and robustness checks. The last section concludes the paper.

4.2. Literature review and hypotheses

Since firms may hold more cash to cope with adverse shocks (Opler et al., 1999), firms tend to hold more cash when exposed to high climate risk and to distribute fewer dividends to cope with the consequences of extreme climatic events (Huang et al., 2018; Noth & Rehbein, 2019). For instance, the most exposed firms may face above-average costs, such as operational costs or increased insurance premia after a natural disaster. To reduce the risk of bankruptcy and preserve an acceptable financial health, the empirical literature also shows that firms tend to reduce their level of debt (Ginglinger & Moreau, 2019; Noth & Rehbein, 2019). Thus, firms adapt their decisions to be more resilient and mitigate the potential negative effects of climate change. Firms may adopt a conservative strategy by reducing their investments and thus build financial slack in anticipation of future negative impacts of climate change (Kanagaretnam et al., 2022). Based on the above discussion, we present the following hypothesis, all else being equal:

Hypothesis 1: Physical climate risk is negatively associated with corporate investment.

On the other hand, it is also possible to postulate that firms may increase their capital and R&D expenditure to enhance their resilience to natural disasters and implement climate change adaptation strategies requiring innovation in production processes as well as products (Denton et al., 2014; Oliva et al., 2022). The CDP report (2019) underlines that the potential value of climate-related opportunities for the biggest global firms is almost seven times higher than the cost of achieving them. It is in corporate managers' interest to consider these conclusions and lead an investment policy by integrating the physical climate risk. Therefore, we can postulate that:

Hypothesis 2: Physical climate risk is positively associated with corporate investment.

4.3. Data and sample

4.3.1. Sample selection

Our variable of interest is physical climate risk. To measure this variable, we use the CRIS ratings provided by Carbon4. The Carbon4 database covers the MSCI World Index. In this study, and contrary to Kanagaretnam et al. (2022), we consider US firms to mitigate concerns regarding institutional and cultural heterogeneity among countries that may influence corporate investment policies (Shao et al., 2013), and thus may induce endogeneity issues. We collected financial variables from the Worldscope database from 2009 to 2020 and matched them with Carbon4 data. To be included in the sample, we require the financial variables to be available over five years. We have also removed firms with negative total assets, net sales, capex, or market-to-book ratio. Our final sample comprises 4,008 firm-year observations from 2009 to 2020. Appendix 4.A provides definitions and data sources for the variables used in this paper. All variables are winsorized at the 1 and 99% levels to mitigate any potential effect of outliers.

Table 4.1 presents the industry and year distributions for our sample. We use the ICB classification. Our sample distribution shows that industrials, financials, and technology are the most represented industries. They represent 18.59%, 15.32% and 14.25% of our sample, respectively. We have 327 observations in 2009, 336 in 2010, 349 in 2011, 361 in 2012, 331 in 2013, 335 in 2014, 335 in 2015, 332 in 2016, 332 in 2017, 333 in 2018, 324 in 2019, and 313 in 2020.

[Insert Table 4.1 here]

Table 4.2 depicts the descriptive statistics for variables used in our work. Physical climate risk measure (PHYSICAL_RISK) has a Q1 of 24.675 and a Q3 of 28.420 with an average of 27.029. We observe that our corporate investment variables RD/TA and CAPEX/TA have an average of 2.720 and 3.412, respectively. For our sample, CASH/TA has a mean of 13.691. Our sample firms have a mean market-to-book value (MTBV) of 4.435, the natural logarithm of their assets (SIZE) is 16.658, leverage (LEV) of 0.604, intangible assets (INT_ASSETS) of 0.268. The average value of PPE/TA is 0.213, the mean value of CFO/TA is 10.645, and 0.020 for DIV/TA. Finally, the climate change performance index (CCPI) has a mean of 42.662.

[Insert Table 4.2 here]

Appendix 4.B reports the correlation matrix among variables used in our study. We observe that physical risk and corporate investment variables (R&D/TA and CAPEX/TA) are significantly and positively correlated. The correlation coefficients reported in the correlation table are relatively small, excluding a multicollinearity bias.

4.3.2. Physical climate risk measure

Many climate proxies have been used in the empirical literature. Some studies use temperatures (Bansal et al., 2016; Dell et al., 2012), sea level rise (Baldauf et al., 2020), and vulnerability to droughts (Hong et al., 2019). Huang et al. (2018) investigate the impact of climate risk on firm performance using a country climate risk variable. Some recent studies have used new firm-specific climate risk variables (Berkman et al., 2021; Ginglinger & Moreau, 2019). In this paper, we use the Climate Risk Impact Screening (CRIS) developed by Carbon4 Finance, a leading independent agency in adaptation to climate change and data provider. CRIS climate risk is a function of location-specific climate hazards and industry-specific vulnerabilities. Carbon4 developed climate risk measures for each climate hazard, three intensity scenarios (low, medium, and high), and two-time horizons (2050 and 2100). Climate risk ratings are determined on a scale from 1 to 99. Climate risks are calculated as an average of the risk rating of all business segments, weighted by the proportion of each segment in the overall activities of the firm. The aggregated multi-hazard is based on the weighted geometric mean of all risk ratings. The CRIS ratings are determined on the basis of a 2050 horizon. We then assume that the physical risk remains stable over the study period.

The main interest of CRIS measures is that the ratings capture the increased physical risk in the future due to global warming compared to historical reference climate hazards. Appendix 4.A reports the definitions of variables and data sources used in our study. PHYSICAL_RISK is scaled from 1 (the lowest) to 100 (the highest) relative to industry peers. We use CRIS risk ratings for medium scenario and 2050-time horizon in our study, as previously done by Ginglinger & Moreau (2019). As a robustness check, we also use low emissions scenario 2050-

time horizon and high emissions scenario 2050-time horizon ratings as alternative physical risk measures.

4.3.3. Measures of corporate investment

We have explained that physical climate risk may influence corporate investment policy. Motivated by prior works (Huang et al., 2018; Shao et al., 2013), we employ different variables to measure corporate investment policies. We consider the level of cash as short-term corporate investment and R&D and CAPEX as components of long-term investment (Anderson et al., 2012; Barger et al., 2010; Shao et al., 2013). We scale corporate investment measures with total assets to construct our dependent variables. Thus, CASH/TA is computed as the level of cash divided by total assets. R&D/TA is calculated as the firm R&D expenses scaled by total assets. CAPEX/TA is calculated as the firm capital expenditures scaled by total assets. LT INVEST/TA is calculated as the sum of R&D and CAPEX, scaled by total assets. The details of calculations and data sources are provided in Appendix 4.A.

4.4. Empirical results

4.4.1. Impact of physical climate risk on corporate investment policy

In this section, we first estimate the impact of physical climate risk on corporate investment policy. We then perform ordinary least squares (OLS) using the following specification:

$$\text{Eq.(1): } \text{CORPORATE_INV}_{i,t} = \beta_0 + \beta_1 (\text{PHYSICAL_RISK})_i + \beta_2 (\text{CONTROLS})_{i,t-1} + \beta_3 (\text{INDUSTRY})_i + \beta_4 (\text{YEAR})_t + \varepsilon_{i,t}$$

CORPORATE_INV is our corporate investment proxies (CASH/TA, R&D/TA CAPEX/TA OR LT INVEST/TA) of a firm i in year t . We control for firm characteristics, including the market to book value (MTBV), the natural logarithm of a firm's total assets (SIZE), firm leverage (LEV), intangible assets (INT_ASSETS), property plant and equipment (PPE/TA), cash flow operations (CFO/TA), and dividend (DIV/TA). Previous studies have demonstrated that some firm characteristics are related to corporate investment. A higher market-to-book value is associated with more investment. Firms with more leverage and intangible assets tend to less invest. However, as evidenced by Shao et al. (2013), firms' total assets and dividends are associated with lower financial constraints and a lack of investment opportunities. We also include the Climate Change Performance Index (CCPI). Developed by Germanwatch, the CCPI evaluates the countries' climate efforts comparing 57 countries and the European Union annually. We also control for industries and year-fixed effects. The standard errors are also clustered by firm.

[Insert Table 4.3 here]

Table 4.3 summarizes our regression results testing the effect of physical risk on investment policy. In Column (1), where CASH/TA is the dependent variable, the regression results show that PHYSICAL RISK is not significantly associated with short-term investment. In Columns (2), (3), and (4), the regression results present the impact of physical risk on long-term corporate investment. In Column (2) and Column (4), where R&D/TA and LT INVEST/TA are the dependent variables, the regression results show that PHYSICAL RISK has a significant and positive coefficient of 0.238 ($p < 0.001$) and 0.267 ($p < 0.001$), respectively. However, we observe that in Column (3), PHYSICAL RISK is not significantly associated with capital expenditures. The regression results in Table 4.3 thus partially support H2. We find a positive and significant

association between physical risk and corporate investment, as measured by R&D and long-term investment. Our results also suggest that firms with high climate risk invest more in R&D projects but not significantly more in capital expenditures. Under the threat of long-term future risk of climate disasters, corporate managers may lead to more aggressive investment policy and invest more in R&D than capital expenditures to implement adaptation to climate change strategies and increase firm financial resilience. Our results could be explained by the need to innovate and develop new processes and products through R&D projects (Lee & Min, 2015; Oliva et al., 2022).

We then test the robustness of our results by considering alternative proxies of physical climate risk. As previously explained, the Carbon4 Finance database provides CRIS climate risk ratings based on three scenarios (low, medium, and high). In our study, we use the medium scenario for a 2050-time horizon. We then investigate the impact of physical risks related to low- and high-intensity climate change scenarios on corporate investment. Table 4.4 shows the regression results using the low emissions scenario (LS_RISK) in Columns (1) to (4) and the high scenario (HS_RISK) in Columns (5) to (8) as variables of interest. The results displayed in Columns (2) and (6) show that R&D is positively and statistically associated with both low- and high scenarios. Similarly, using LT INVEST/TA as the dependent variable, the climate measure remains positive and statistically significant at the 1% level (Columns (4) and (8)). We find support for our previous results. Physical risk is positively and significantly associated with R&D and long-term investment. The relationship remains non-significant on CASH/TA (Columns (1) and (5)) and CAPEX/TA (Columns (3) and (7)). Our results confirm our previous results and suggest that the intensity of climate scenarios does not seem to drive the relationship physical risk-corporate investment.

[Insert Table 4.4 here]

4.4.2. Historical vs future physical climate risk and corporate investment

Beyond the robustness checks using alternative physical climate risk measures, we investigate in this section the influence of historical physical climate risk on corporate investment. Most of the literature has focused on corporate managers’ reactions to natural disasters related to historical physical risk (Bernile et al., 2017; Feng et al., 2022; Gao et al., 2020). Our variable of interest PHYSICAL_RISK has the specific characteristics to catch the increased future physical risk related to climate change. To better understand why our main results differ from the literature, we study the differences in the effects of historical and future physical risk on corporate investment.

[Insert Table 4.5 here]

Table 4.5 documents the effects of historical and future physical climate risks on corporate investment measures. We report the results of OLS regressions of corporate investment on physical risk and historical physical risk, and other selected control variables. We then test the significance of the difference between the coefficients of PHYSICAL_RISK and H0_RISK. First, we observe that the coefficient of H0_RISK in Column (1) is negative and statistically significant. It means that historical physical risk is negatively and significantly associated with cash. Historical physical risk coefficients are lower and only significant at the 10% level than future physical risk coefficients. Then, the regression results using the historical physical risk diverge from those reported in Table 4.3. We observe a negative and statistically significant association with cash, whereas the impact on R&D and long-term investment is undermined and less statistically significant. Those results are insightful to demonstrate the importance of

choosing relevant climate proxies. Even if we use historical climate variables, our results differ from Huang et al. (2018). In fact, previous studies use climate proxies based on historical natural disasters at the country level (Huang et al., 2018; Kanagaretnam et al., 2022). We use an historical climate risk proxy developed by Carbon4. This climate variable measures the past climate risk per company, based on the risks of 7 climate hazards over the period 1976-2005. It therefore provides more detailed data, covering both acute and chronic risks. Conversely, the variable used by Huang et al. (2018) is calculated on the basis of human and financial losses resulting from past natural disasters at the country-level.

The second part of Table 4.5 is dedicated to the significance of the difference of the physical and historical risk coefficients. Using the regressions results, we test the significance of the following equation, $\beta_{PHYSICAL\ RISK} - \beta_{HO_RISK} = 0$. We find a clear difference in the impact of historical and physical risk. Specifically, using R&D/TA and LT INVEST/TA as dependent variables, Columns (2) and (4) report a positive and significant coefficient of 0.173 and 0.184 at the 1% level. Then, we find a clear difference in the effects of historical and physical risks on corporate investment. Latter findings highlight the importance of studying the influence of physical risk due to future climate change. To summarize, we underline the differences in the impact of historical and future physical risk on corporate investment. Thus, we better understand why our main empirical results could differ from Huang et al. (2018). We can attribute the increase in R&D and long-term investments to the desire to develop new processes and products to adapt to future climate change.

4.4.3. Impact of physical climate risk on corporate risk-taking

Our findings that exposure to physical climate risk positively influences R&D expenditures seem to validate H2 postulating that potential confrontation with the future consequences of climate change leads firms to engage in long-run and more risky projects. However, it could also be argued that this positive impact of physical climate risk on R&D spending stems from the fact that highly exposed firms invest in less risky R&D projects, enabling them to invest more in R&D (Shao et al., 2013). In order to decide between these two hypotheses, it is therefore essential to test empirically how exposure to physical climate risk impacts the sensitivity of corporate risk-taking to R&D expenditure. We then estimate the following model:

$$\text{Eq.(2): } SD(ROA)_{i,t} = \beta_0 + \beta_1 (PHYSICAL\ RISK)_t + \beta_2 (CORPORATE_INV)_{i,t-1} + \beta_3 (CORPORATE_INV * R\&D/TA)_{i,t} + \beta_4 (CONTROLS)_{i,t-1} + \beta_5 (INDUSTRY)_i + \beta_6 (YEAR)_t + \varepsilon_{i,t}$$

The dependent variable is SD(ROA), measured by the firms' standard deviation of the ROA over 5-year overlapping periods. Our model includes PHYSICAL RISK as independent variable in all our specifications. CORPORATE_INV can be CASH/TA, R&D/TA CAPEX/TA OR LT INVEST/TA) of a firm *i* in year *t*. We also use the same control variables as in our base model, Eq. (1).

[Insert Table 4.6 here]

Our estimation results are presented in Table 4.6. For the sake of brevity, we only report coefficients for our variables of interest. These results are available upon request. The positive

and significant coefficient of `PHYSICAL_RISK` in Columns (1), (2) and (3) confirms that physical climate risk exposure leads firms to take more risks. In Column (1), we observe that corporate risk-taking is significantly and positively correlated with `R&D/TA`. In line with previous literature, this corroborates that high `R&D` expenditures are related to a risky investment policy and thus higher risk-taking (Bhagat et al., 1995; Coles et al., 2006; Kothari et al., 2002; Shao et al., 2013). In addition, in Column (2), the interaction between physical risk and `R&D` level has a positive and significant coefficient. This supports that firms with a high level of physical risk invest in riskier `R&D` projects. We find similar results in Columns (5) and (6) with long-term investment instead of `R&D`. However, in Column (3), capital expenditures are not significantly linked with corporate risk-taking, without the interaction variable in the regression model. In Column (4), we find that the interaction between physical risk and `Capex` has a positive and significant coefficient, while capital expenditures are strongly negatively correlated with corporate risk-taking (coefficient of -0.377).

Furthermore, we re-run our regressions by using alternative proxies for corporate risk-taking (denoted `CRT2` and `CRT3`), following previous literature (Boubakri et al., 2013; Faccio et al., 2011). We measure `CRT2` as the standard deviation for each company over the entire sample period with a minimum of five observations. `CRT3` is calculated as the difference between the maximum and minimum `ROA` for each sample firm. Our results are depicted in Table 4.7. `PHYSICAL_RISK` is positively and significantly associated with `RISK2` but only at the 10% level. The interaction between physical risk and `R&D` has a significant and positive coefficient (p -value < 0.01). Column (2) and Column (3) results follow the same tendencies as displayed in Table 4.8, with `SD(ROA)` as the dependent variable. However, we observe some differences in `PHYSICAL_RISK` coefficients. Columns (4), (5), and (6) report the regression results using `CRT3` as the dependent variable. Overall, we observe similar results that highlight the

robustness of our findings. The results support our findings in Table 4.6 and confirm that firms with high physical risk are more likely to invest in risky R&D projects to adapt to climate change.

[Insert Table 4.7 here]

4.4.4. Physical risk and the use of excess cash

Finally, to better understand the extent to which firms' physical climate risk exposure influences their investment decisions, we examine whether our variable of interest impacts the use of excess cash (Harford et al., 2008; Shao et al., 2013). Indeed, excess cash is a financial resource at the discretion of managers that is held in excess of an optimal level, depending on traditional determinants for cash holdings. We previously showed that climate risk pushes firms to implement more R&D expenses and long-term investment. We thus should find that firms with a high exposure to physical climate risk use their excess cash more to invest in R&D and long-term projects than in CAPEX.

We define excess cash as cash that is not needed for firm operations or investments (Dittmar & Mahrt-Smith, 2007). To measure excess cash, we calculate the residuals from regressing the level of cash by industry on MTBV, SIZE, LEV, R&D/TA, CFO/TA. We also include a year-fixed effect in our regression model. Following the literature (Arouri & Pijourlet, 2017; Dittmar & Mahrt-Smith, 2007; Drobetz et al., 2010; Frésard & Salva, 2010), we restrict our sample to firms that have positive excess cash. To examine how physical climate risk influences the way firms use their excess cash in order to adapt their financial decisions, we estimate the following model:

$$\text{Eq.(3): } \Delta \text{CORPORATE_INV}_{i,t} = \beta_0 + \beta_1 (\text{PHYSICAL RISK})_i + \beta_2 (\text{XCASH})_{i,t-1} + \beta_3 (\text{XCASH}_{i,t-1} * \text{PHYSICAL RISK}_{i,t}) + \beta_4 (\text{CONTROLS})_{i,t-1} + \beta_5 (\text{INDUSTRY})_i + \varepsilon_{i,t}$$

[Insert Table 4.8 here]

Table 4.8 displays the regression results investigating the role of physical risk in the use of excess cash. Following previous literature (Shao et al., 2013), we use the variation of corporate investment measures as dependent variable ($\Delta \text{R\&D/TA}$, $\Delta \text{CAPEX/TA}$, and $\Delta \text{LT INVEST/TA}$). XCASH variable represents the lagged excess cash of each firm. The main variable of interest is the interaction between physical risk and excess cash ($\text{PHYSICAL RISK} * \text{XCASH}$). Columns (1), (3), and (5) present the results of OLS regressions without the interaction variable. Columns (2), (4), and (6) present the results of OLS regressions, including the interaction of physical risk and excess cash. In Column (2) and Column (6), we find that the coefficient of the interaction is positive and statistically significant. Thus, this indicates that the excess cash is used by US firms to develop more R&D and long-term investments. However, there is no significant association between the interaction between physical risk and excess cash on capital expenditures and dividend variation. Our findings highlight that U.S. firms facing physical risk tend to use excess cash to implement R&D projects and not in capital expenditures.

4.5. Conclusion

Using an original physical climate risk measure developed by Carbon4 Finance, we find that U.S. firms facing high physical risk invest more in R&D and long-term investment but not in cash and CAPEX. Our challenging findings are robust to alternative physical risk proxies. Further tests show that the interaction between physical risk and R&D has a significant and positive effect on corporate risk-taking. It suggests that climate risk is associated with corporate risk-taking, enhancing firms to invest more in risky R&D projects than capital expenditures or cash. Moreover, we show that, when having excess cash, firms with high physical risk are more likely to use it to implement R&D projects and long-term investments.

While previous empirical studies suggest that firms behave more conservatively after experiencing climate disasters (Feng et al., 2022; Huang et al., 2018), we complement the literature investigating the effect of increased physical risk related to future climate change on corporate investment policy. We shed light on the differences in impacts between historical physical risk and future physical risk on R&D. Our paper highlights that physical risk influences investment policy feeding the debate on corporate investment determinants. Finally, our findings have managerial implications, providing a better understanding of the impact of climate risk on corporate investment. The corporate managers' perception of physical risk due to future climate change enhances long-term investment and affects risk-taking behavior through risky R&D projects.

Table 4.1. Sample distribution

ICB Sector	N	%	Year	N	%
Sample distribution across sectors			Sample distribution across years		
Basic Materials	190	4.74	2009	327	8.16
Consumer Discretionary	480	11.98	2010	336	8.38
Consumer Staples	249	6.21	2011	349	8.71
Energy	180	4.49	2012	361	9.01
Financials	614	15.32	2013	331	8.26
Health Care	505	12.60	2014	335	8.36
Industrials	745	18.59	2015	335	8.36
Real Estate	138	3.44	2016	332	8.28
Technology	571	14.25	2017	332	8.28
Telecommunications	88	2.20	2018	333	8.31
Utilities	248	6.19	2019	324	8.08
			2020	313	7.81
Total	4,008	100.00	Total	4,008	100.00

This table presents the sample distribution across ICB sectors and years. The sample consists of 4,008 observations.

Table 4.2. Summary statistics

VARIABLES	Mean	S.D.	Q1	Q3	N
R&D/TA	2.720	4.236	0.000	4.008	4,008
CASH/TA	13.691	14.420	3.139	19.145	4,008
CAPEX/TA	3.412	3.451	1.076	4.727	4,008
SD(ROA)	2.680	2.797	0.814	3.497	4,008
CRT2	3.658	2.789	1.528	5.030	4,008
CRT3	12.484	9.391	5.390	17.010	4,008
PHYSICAL_RISK	27.029	3.192	24.675	28.420	4,008
LS_RISK	24.861	3.072	22.605	25.927	4,008
HS_RISK	27.650	3.220	25.343	28.946	4,008
MTBV	4.435	5.908	1.650	4.715	4,008
SIZE	16.658	1.441	15.593	17.560	4,008
LEV	0.604	0.200	0.469	0.751	4,008
INT_ASSETS	0.268	0.230	0.056	0.437	4,008
PPE/TA	0.213	0.228	0.050	0.282	4,008
CFO/TA	10.645	6.276	6.182	14.351	4,008
DIV/TA	0.020	0.024	0.001	0.029	4,008
CCPI	42.662	12.860	39.800	52.330	4,008

This table presents the descriptive statistics of all variables. This table includes the mean, the standard deviation, the Q1, the Q3, and the number of observations. The sample consists of 4,008 observations.

Table 4.3. Physical climate risk and investment policy

	(1)	(2)	(3)	(4)
	CASH/TA	R&D/TA	CAPEX/TA	LT INVEST/TA
PHYSICAL_RISK	0.093 (0.55)	0.238*** (4.42)	0.023 (0.66)	0.267*** (3.79)
MTBV	0.418*** (5.35)	0.123*** (3.63)	0.006 (0.41)	0.128*** (3.00)
SIZE	-0.755* (-1.93)	-0.362*** (-2.64)	0.014 (0.20)	-0.376** (-2.20)
LEV	-22.610*** (-7.35)	-2.468** (-2.21)	-0.037 (-0.08)	-2.319* (-1.76)
INT_ASSETS	-29.820*** (-13.24)	-4.516*** (-6.20)	-0.575* (-1.87)	-5.112*** (-6.02)
PPE/TA	-30.230*** (-9.80)	-4.446*** (-5.82)	11.300*** (15.27)	6.944*** (6.31)
CFO/TA	0.191** (2.41)	0.000 (-0.01)	0.134*** (6.48)	0.139*** (3.64)
DIV/TA	7.853 (0.37)	-0.144 (-0.02)	-20.240*** (-4.78)	-21.760** (-2.31)
CCPI	-0.074** (-2.13)	-0.024** (-2.50)	0.014* (1.93)	-0.011 (-0.88)
Constant	47.900*** (5.67)	4.958* (1.73)	-1.862 (-1.14)	3.259 (0.88)
Year & Industry FE	Yes	Yes	Yes	Yes
<i>N</i>	4,008	4,008	4,008	4,008
adj. <i>R</i> ²	0.554	0.500	0.675	0.526

This table presents the results of OLS regressions for corporate investment (CASH/TA, R&D/TA, CAPEX/TA, and LT INVEST/TA) on physical climate risk and other selected control variables. All variables are defined in Appendix 4.A. All control variables are one-year lagged to account for endogenous interdependence. We winsorize variables at the 1% and 99% level. The models include year and industry fixed effects. Our sample spans from 2009 to 2020. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 4.4. High/low scenarios physical climate risk and corporate investment

	Low intensity scenario				High intensity scenario			
	(1) CASH/TA	(2) R&D/TA	(3) CAPEX/TA	(4) LT INVEST/TA	(5) CASH/TA	(6) R&D/TA	(7) CAPEX/TA	(8) LT INVEST/TA
LS_RISK	0.006 (0.03)	0.236*** (4.01)	0.026 (0.68)	0.268*** (3.48)				
HS_RISK					0.058 (0.33)	0.235*** (4.34)	0.024 (0.68)	0.264*** (3.78)
MTBV	0.417*** (5.34)	0.125*** (3.69)	0.0064 (0.43)	0.131*** (3.06)	0.418*** (5.35)	0.124*** (3.67)	0.006 (0.42)	0.130*** (3.03)
SIZE	-0.742* (-1.90)	-0.351** (-2.55)	0.014 (0.21)	-0.363** (-2.12)	-0.750* (-1.92)	-0.360*** (-2.62)	0.014 (0.20)	-0.373** (-2.18)
LEV	-22.680*** (-7.41)	-2.594** (-2.32)	-0.048 (-0.10)	-2.459* (-1.87)	-22.660*** (-7.36)	-2.525** (-2.26)	-0.042 (-0.09)	-2.382* (-1.81)
INT_ASSETS	-29.840*** (-13.24)	-4.528*** (-6.20)	-0.576* (-1.88)	-5.125*** (-6.02)	-29.830*** (-13.25)	-4.545*** (-6.25)	-0.578* (-1.88)	-5.144*** (-6.06)
PPE/TA	-29.970*** (-9.58)	-4.518*** (-5.85)	11.280*** (15.30)	6.855*** (6.21)	-30.140*** (-9.71)	-4.481*** (-5.84)	11.290*** (15.28)	6.902*** (6.26)
CFO/TA	0.191** (2.42)	0.000 (-0.01)	0.134*** (6.49)	0.139*** (3.63)	0.191** (2.41)	0.000 (-0.02)	0.134*** (6.49)	0.138*** (3.63)
DIV/TA	8.709 (0.41)	0.057 (0.01)	-20.250*** (-4.78)	-21.550** (-2.28)	8.238 (0.39)	0.0592 (0.01)	-20.220*** (-4.78)	-21.540** (-2.29)
CCPI	-0.074** (-2.14)	-0.024** (-2.48)	0.014* (1.93)	-0.011 (-0.86)	-0.074** (-2.14)	-0.024** (-2.49)	0.014* (1.93)	-0.0110 (-0.87)
Constant	50.120*** (5.92)	5.479* (1.91)	-1.890 (-1.15)	3.780 (1.03)	48.760*** (5.67)	4.920* (1.71)	-1.883 (-1.15)	3.192 (0.87)
Year & Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	4,008	4,008	4,008	4,008	4,008	4,008	4,008	4,008
adj. <i>R</i> ²	0.553	0.498	0.675	0.525	0.553	0.499	0.675	0.526

This table presents the results of OLS regressions for corporate investment (CASH/TA, R&D/TA and CAPEX/TA) on high/low scenarios physical climate risk. Columns (1) to (4) present the regression results using LS_RISK as independent variable. Columns (5) to (8) refer to HS_RISK. All variables are defined in Appendix 4.A. All control variables are one-year lagged to account for endogenous interdependence. We winsorize variables at the 1% and 99% level. The models include year and industry fixed effects. Our sample spans from 2009 to 2020. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 4.5. Historical vs future physical climate risk and investment policy

	(1) CASH/TA	(2) R&D/TA	(3) CAPEX/TA	(4) LTINVEST/TA
PHYSICAL_RISK	0.093 (0.55)	0.238*** (4.42)	0.023 (0.66)	0.267*** (3.79)
H0_RISK	-0.258*** (-2.62)	0.065* (1.79)	0.012 (0.47)	0.083* (1.74)
$\beta_{PHYSICAL_RISK} - \beta_{H0_RISK}$	0.351** (2.38)	0.173*** (3.44)	0.011 (0.36)	0.184*** (2.91)

This table displays the effects of historical and future physical climate risks on corporate investment measures. We report the results of OLS regressions of corporate investment on physical risk and historical physical risk and other selected control variables. We tested the significance of the difference of the coefficients of PHYSICAL_RISK and H0_RISK. All variables are defined in Appendix 4.A. We winsorize variables at the 1% and 99% levels. The models include control variables used in Table 4.3 and year and industry fixed-effects. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 4.6. Physical climate risk and corporate risk-taking

	(1)	(2)	(3)	(4)	(5)	(6)
	SD(ROA)	SD(ROA)	SD(ROA)	SD(ROA)	SD(ROA)	SD(ROA)
R&D/TA	0.086** (6.56)	-0.181* (-1.77)				
PHYSICAL_RISK	0.085** (4.76)	0.057*** (2.76)	0.104*** (6.03)	0.030 (1.25)	0.087*** (4.92)	-0.031 (-1.14)
R&D/TA*PHYSICAL_RISK		0.010*** (2.63)				
CAPEX/TA			0.027 (1.33)	-0.377*** (-4.13)		
CAPEX/TA*PHYSICAL_RISK				0.014*** (4.55)		
LT INVEST/TA					0.072*** (6.79)	-0.334*** (-4.73)
LT INVEST/TA*PHYSICAL_RISK						0.015*** (5.81)
Constant	5.398*** (6.16)	6.299*** (6.70)	5.993*** (6.99)	8.175*** (8.33)	5.552*** (6.35)	9.109*** (8.56)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year & Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	3,874	3,874	4,006	4,006	3,872	3,872
adj. <i>R</i> ²	0.222	0.223	0.214	0.218	0.223	0.229

This table presents the results of OLS regressions for standard deviation of ROA on physical climate risk, corporate investment (R&D/TA, CAPEX/TA and LT INVEST), the interaction of physical risk and corporate investment, and other selected control variables. Columns (1), (3), and (5) present the results of OLS regressions without the interaction variable. Columns (2), (4), and (6) present the results of OLS regressions including the interaction of physical risk and corporate investment proxies. All variables are defined in Appendix 4.A. All control variables are one-year lagged to account for endogenous interdependence. We winsorize variables at the 1% and 99% level. The models include year and industry fixed effects. Our sample spans from 2009 to 2020. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 4.7. Physical climate risk and corporate risk-taking: robustness checks

	(1)	(2)	(3)	(4)	(5)	(6)
	CRT2	CRT2	CRT2	CRT3	CRT3	CRT3
R&D/TA	-0.186** (-2.11)			-0.620** (-2.02)		
PHYSICAL_RISK	0.031* (1.73)	0.023 (1.11)	-0.059*** (-2.59)	0.087 (1.40)	0.064 (0.90)	-0.173** (-2.15)
R&D/TA*PHYSICAL_RISK	0.012*** (3.60)			0.037*** (3.30)		
CAPEX/TA		-0.287*** (-3.63)			-1.033*** (-3.74)	
CAPEX/TA*PHYSICAL_RISK		0.014*** (5.11)			0.044*** (4.59)	
LT INVEST/TA			-0.298*** (-4.94)			-0.944*** (-4.46)
LT INVEST/TA*PHYSICAL_RISK			0.015*** (7.05)			0.047*** (6.11)
Constant	8.758*** (10.82)	10.500*** (12.38)	11.560*** (12.71)	28.390*** (10.05)	33.520*** (11.31)	36.860*** (11.53)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year & Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	3,874	4,006	3,872	3,874	4,006	3,872
adj. <i>R</i> ²	0.420	0.411	0.433	0.376	0.367	0.383

This table reports the results of OLS regressions for alternative measure of corporate risk-taking (CRT2 and CRT3) on physical climate risk, corporate investment (R&D/TA and CAPEX/TA), the interaction of physical risk and corporate investment, and other selected control variables. All variables are defined in Appendix 4.A. All control variables are one-year lagged to account for endogenous interdependence. We winsorize variables at the 1% and 99% level. The models include year and industry fixed effects. Our sample spans from 2009 to 2020. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Table 4.8. Physical risk and the use of excess cash

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta R\&D/TA$	$\Delta R\&D/TA$	$\Delta CAPEX/TA$	$\Delta CAPEX/TA$	$\Delta LT\ INVEST/TA$	$\Delta LT\ INVEST/TA$
XCASH	0.705*** (3.05)	-5.366** (-2.45)	0.872** (2.23)	-5.142 (-1.38)	1.589*** (3.21)	-10.070** (-2.15)
PHYSICAL_RISK	-0.001 (-0.11)	-0.007 (-0.98)	0.010 (0.86)	0.004 (0.30)	0.009 (0.60)	-0.003 (-0.22)
XCASH*PHYSICAL_RISK		0.233*** (2.78)		0.231 (1.63)		0.447** (2.50)
MTBV	-0.007* (-1.82)	-0.006* (-1.65)	-0.012** (-1.98)	-0.012* (-1.88)	-0.020** (-2.51)	-0.019** (-2.37)
SIZE	0.028* (1.92)	0.030** (2.06)	0.037 (1.51)	0.039 (1.59)	0.066** (2.13)	0.070** (2.26)
LEV	0.138 (1.16)	0.117 (0.99)	-0.099 (-0.49)	-0.119 (-0.59)	0.036 (0.14)	-0.004 (-0.02)
INT_ASSETS	0.395*** (4.13)	0.408*** (4.26)	0.124 (0.76)	0.136 (0.84)	0.547*** (2.67)	0.571*** (2.78)
PPE/TA	0.111 (0.88)	0.113 (0.90)	-0.720*** (-3.37)	-0.717*** (-3.36)	-0.636** (-2.35)	-0.631** (-2.34)
CFO/TA	-0.006 (-1.52)	-0.006 (-1.55)	-0.003 (-0.44)	-0.003 (-0.46)	-0.008 (-0.99)	-0.008 (-1.02)
DIV/TA	0.467 (0.60)	0.340 (0.44)	0.921 (0.70)	0.795 (0.60)	1.556 (0.93)	1.312 (0.78)
CCPI	-0.004 (-1.16)	-0.003 (-1.09)	0.012** (2.36)	0.013** (2.40)	0.008 (1.19)	0.008 (1.26)
Constant	-0.631* (-1.87)	-0.495 (-1.45)	-1.269** (-2.22)	-1.134* (-1.96)	-1.909*** (-2.64)	-1.646** (-2.25)
Year & Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	3,445	3,445	3,445	3,445	3,443	3,443
adj. <i>R</i> ²	0.012	0.014	0.027	0.027	0.028	0.030

This table presents the results of OLS regressions for the use of cash proxies ($\Delta R\&D/TA$, $\Delta CAPEX/TA$ and $\Delta LT\ INVEST/TA$). Columns (1), (3) and (5) ((2), (4), and (6)) present the results of OLS regressions without (with) the interaction variable. All variables are defined in Appendix 4.A. XCASH is the positive residuals from regressing the level of cash by industry on MTBV, SIZE, LEV, R&D/TA and CFO/TA. We winsorize variables at the 1% and 99% level. The models include year and industry fixed effects. t-statistics are reported in parenthesis. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

Appendix 4.1. Variables definition and sources

Variable	Definition	Description	Source
PHYSICAL_RISK	CRIS Climate Risk	CRIS global risk grade for median scenario and 2050 time-horizon.	Carbon4 Finance
CASH/TA	Level of cash	Level of cash scaled by total assets	Worldscope
R&D/TA	Research and development expenses	R&D expenses scaled by total assets	Worldscope
CAPEX/TA	CAPEX	Capital expenditures scaled by total assets	Worldscope
LT INVEST/TA	Long term investment	The sum of R&D and capital expenditures scaled by total assets	Worldscope
SD(ROA)	Standard deviation of ROA	The volatility of firms' ROA over 5-year overlapping periods	Worldscope
XCASH	Excess cash	The positive residuals from regressing the level of cash by industry on MTBV, SIZE, LEV, R&D/TA, CFO/TA	Worldscope
MTBV	Market to book value	Market value divided by book value	Worldscope
SIZE	Firm size	Ln(book value of total assets)	Worldscope
LEV	Firm leverage	Book value of debt / book value of assets	Worldscope
INT_ASSETS	Intangible assets	The amount of firm's intangible assets	Worldscope
PPE/TA	Property plant and equipment	The level of property, plant and equipment divided by total assets	Worldscope
CFO/TA	Cash flow operations	The level of cash flow operations scaled by total assets	Worldscope
DIV/TA	Dividend	Cash dividend scaled by firm total assets	Worldscope
CCPI	Climate Change Performance Index	The Climate Change Performance Index is an independent tool for tracking and comparing the climate efforts of individual countries	Germanwatch
HS_RISK	High scenario physical risk	CRIS physical risk ratings by firm for high emissions scenario	Carbon4 Finance
LS_RISK	Low scenario physical risk	CRIS physical risk ratings by firm for low emissions scenario	Carbon4 Finance
H0_RISK	Historical physical risk	The historical physical climate risk by firm	Carbon4 Finance
CRT2	Corporate risk-taking 2	The alternative measure of corporate risk-taking calculated as the standard deviation of ROA for each firm over the entire period	Worldscope
CRT3	Corporate risk-taking 3	The difference between the maximum and minimum ROA for each firm of the sample	Worldscope

This table provides definitions and data sources for the variables used in this study. Our sample spans from 2009 to 2020.

Appendix 4.2. Correlation matrix

	R&D/TA	CASH/TA	CAPEX/TA	LT INVEST/TA	SD(ROA)	PHYSICAL _RISK	MTBV	SIZE	LEV	INT_AS SETS	PPE/TA	CFO/TA	DIV/T A	CCPI
R&D/TA	1													
CASH/TA	0.579***	1												
CAPEX/TA	-0.026	-0.094***	1											
LT INVEST/TA	0.769***	0.392***	0.615***	1										
SD(ROA)	0.296***	0.275***	0.158***	0.336***	1									
PHYSICAL_RISK	0.111***	-0.027	0.354***	0.310***	0.180***	1								
MTBV	0.236***	0.207***	0.018	0.194***	0.070***	-0.038*	1							
SIZE	-0.284***	-0.282***	-0.097***	-0.285***	-0.214***	0.001	-0.211***	1						
LEV	-0.321***	-0.387***	-0.166***	-0.354***	-0.260***	-0.104***	0.168***	0.472***	1					
INT_ASSETS	0.044**	-0.153***	-0.274***	-0.140***	0.037*	-0.059***	0.068***	-0.236***	-0.216***	1				
PPE/TA	-0.193***	-0.270***	0.774***	0.340***	0.058***	0.376***	-0.077***	-0.011	-0.063***	-0.326***	1			
CFO/TA	0.360***	0.407***	0.290***	0.464***	0.257***	0.166***	0.375***	-0.443***	-0.468***	0.070***	0.069***	1		
DIV/TA	0.058***	0.097***	0.110***	0.110***	0.041**	0.092***	0.287***	-0.096***	-0.111***	-0.016	0.168***	0.433***	1	
CCPI	-0.016	0.038*	0.043**	0.013	-0.072***	0.005	-0.069***	-0.093***	-0.042**	-0.048**	-0.009	0.003	-0.021	1

This table provides the correlation matrix for the key variables of our sample. Our sample spans from 2009 to 2020. ***, **, * denote statistical significance at the 1, 5, and 10% levels.

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General conclusion

Research on climate change and its impact on business has increased tremendously in recent years (Giglio et al., 2021). A strand of the literature has first focused on the impact of environmental performance on corporate financial performance (Busch & Lewandowski, 2018; Delmas et al., 2015; Galama & Scholtens, 2021; Matsumura et al., 2014), whose conclusions are still mixed. Furthermore, a nascent literature investigates the impact of natural disasters on firm value (Huang et al., 2018; Noth & Rehbein, 2019), corporate investment (Kanagaretnam et al., 2022), debt and dividend policy (Huang et al., 2018), or risk aversion (Bernile et al., 2017; Dessaint & Matray, 2017; Gao et al., 2020). In general, the literature has focused on historical physical risk, and empirical results tend to pinpoint a conservative strategy after a natural disaster (Huang et al., 2018; Kanagaretnam et al., 2022; Noth & Rehbein, 2019).

Responding to the call of Engle et al. (2020), the literature made some progress in measuring climate risk. We observe climate risk measures based on firm climate disclosures (Berkman et al., 2021), earnings calls (Sautner et al., 2023), and historical natural disasters (Huang et al., 2018; Kanagaretnam et al., 2022). The paper of Ginglinger & Moreau (2019) introduces a firm-specific measure of increased climate risk related to climate change in the empirical debate. However, to date, very few studies have investigated the impact of physical risk due to future climate change on firm value and decisions. The growing environmental concerns (Krueger et al., 2020) underline the importance of studying the impact of physical risk due to climate change beyond the already addressed natural disasters' reaction.

The main subject of this thesis is to contribute to the literature on climate finance. Our doctoral thesis provides evidence on the impact of climate change on firms' valuation and financial decisions. We expand the literature on environmental strategies by disentangling mitigation and adaptation to climate change strategies and studying their impact on corporate financial performance. Our research also investigates the impact of physical climate risk on firm value. In addition, we focus on the influence of physical risk on one of the key determinants of firm value, that is, investment policy. Therefore, in our dissertation, we address the following main question: **'Does climate change influence firm decisions and affect firm value?'** Specifically, we raise the following three questions in this thesis:

- **Do mitigation and adaptation strategies impact corporate financial performance?**
- **Does physical climate risk impact firm value?**
- **Does physical climate risk influence corporate investment policy?**

Building on the first chapter that examines the avenues of research illustrated above, we investigate each question in three empirical essays, presented in chapters 2, 3, and 4, respectively.

Research findings

In Chapter 1, we synthesize the literature on the links between climate change and firm value and financial decisions. Despite an extensive literature on the relationship between corporate environmental performance and financial performance, empirical results do not permit one to reach a consensus (Busch & Lewandowski, 2018; Galama & Scholtens, 2021; Horváthová, 2010). Therefore, we introduce the distinction between mitigation and adaptation strategies in

the debate. Furthermore, we propose two contrasting views to explain the influence of climate change on firm value and decision-making. On the one hand, an argument is that physical risk can harm the value of the firm. Direct asset damage and supply chain disruptions caused by climate change can increase aversion to climate risk and force firms to maintain financial slack by adjusting financial policy (Feng et al., 2022; Huang et al., 2018; Kanagaretnam et al., 2022). On the other hand, climate change can also provide new opportunities and some firms can benefit from future climate change by implementing an innovative investment policy. Building on this chapter, we highlight research avenues that we explore in the following chapters.

In Chapter 2, we investigate the relationship between mitigation and adaptation strategies on corporate financial performance. First, we disentangle environmental strategies into two categories defined by the TCFD: mitigation and adaptation strategies. We measure the total mitigation strategy as the corporate emissions developed by Trucost. Adaptation is measured by the firm innovation score developed by Refinitiv Asset4. Based on an international dataset of 3,554 firms from 42 countries in the 2012-2016 period, we find evidence that mitigation is positively and significantly associated with accounting and market-based financial performance. However, adaptation to the climate change strategy is only associated with better market-based financial performance, as measured by Tobin's q . To better understand these results, we study the complementarity between mitigation and adaptation. We show that both environmental strategies have a significant and positive effect on ROA and Tobin's q . To our knowledge, the first to disentangle mitigation and adaptation strategies to climate change and to analyze their impact on corporate financial performance.

In Chapter 3, we measure the physical climate risk related to future climate change using the Carbon4 Finance database. Drawing on an international dataset of 1,294 firms over the 2009-2020 period, we investigate the impact of physical climate risks on firm value. We make the distinction between acute physical risk and chronic physical risk (Basel Committee on Banking Supervision, 2021). Acute risks are related to natural disasters, whereas chronic risks refer to long-term changes in climate patterns. We find in Chapter 3 that climate acute physical risk has a negative and significant link with firm value, whereas chronic physical risk is not significantly associated with firm value. We then show that physical risk should not be considered only as a global issue since investors price acute and chronic physical risks differently. We also investigate the channels through which chronic and acute risks influence firm value. We find that acute and chronic risks have similar effects on ROA, leverage, R&D, and capital expenditures. However, we find a clear difference for sales growth and dividends. In fact, acute risks imply less sales growth and lower dividends. In other words, we note a more material impact of acute risk on sales growth and dividends that explains the difference in financial impact compared to chronic risk.

Finally, in Chapter 4, we investigate the influence of physical risk on firm decisions through corporate investment. Based on a US sample of 4,008 firm-year observations over the 2009-2020 period, we find that physical risk related to future climate change significantly and positively affects R&D and long-term investments. Moreover, we show that when they have excess cash, firms are more likely to invest in R&D rather than capex or distribute more dividends. To better understand these challenging results, we show that the interaction between physical risk and R&D has a significant and positive effect on corporate risk-taking. It suggests that, in a context of climate change, corporate managers tend to invest in risky R&D projects to adapt to climate change and counteract the future negative effects of climate change. Finally,

we show that when they have excess cash, firms with high physical risk are more likely to use it to increase R&D and long-term investments.

Contributions and practical implications

In general, our doctoral thesis contributes to the climate change and firm valuation literature in several ways. First, using a unique database based on Carbon4 ratings, our findings contribute to the financial impact of climate risk and support theories that emphasize the idea that physical risk reduces firm value (Bansal et al., 2016). We show that investors seem to price only acute physical risks that are event-driven and more material, contrary to chronic risks that will be tangible to firms in decades. Our findings pinpoint the importance of not taking physical risks as a monolithic concept. Although some studies so far treat the influence of physical risks on firm value (Berkman et al., 2021; Krueger et al., 2020), we complement the literature by disentangling precisely the impacts of acute and chronic risks on firm value. Our results reinforce the fact that climate risk can negatively affect firm value through direct asset damage and supply chain disruptions.

Second, we complement the literature linking climate risk with firm characteristics. We document the indirect effects of physical risk on firm value. We show that sales growth and dividends are the main drivers of the negative relationship between physical risk and firm value. Specifically, we focus on the impact of physical risk on firms' decisions. Our findings confirm that corporate managers adjust their strategy considering climate risk. Showing a negative relationship between climate risk and firm leverage, we document the idea that firms under the threat of climate change want to reduce the risk of bankruptcy (Ginglinger & Moreau, 2019; Noth & Rehbein, 2019). However, contrary to a strand of literature that documents a

precautionary strategy leading to more cash holding and less corporate investment (Huang et al., 2018; Kanagaretnam et al., 2022), we demonstrate that physical risk could lead to more corporate investments. Our challenging results show that physical risk influences firm decisions through corporate investment. Firms invest in R&D as a vector of environmental innovation and new process/product development to adapt to climate change and enhance resilience.

Third, by exploring the firms' potential responses to climate risk, we contribute to the vast literature on the environmental performance – financial performance relationship (Delmas et al., 2015; Lee & Min, 2015; Matsumura et al., 2014). Although meta-analyses pinpoint issues in assessing environmental performance (Busch & Lewandowski, 2018; Galama & Scholtens, 2021; Horváthová, 2010), we disentangle mitigation and adaptation strategies in evaluating environmental performance. In the context of climate change, we highlight the responses through environmental strategies and their financial impact. We study the different effects of mitigation and adaptation strategies on financial performance. We also provide new empirical findings on the complementarity between environmental strategies. Moreover, we show that investors reward environmental initiatives in the long term regardless of their nature.

Our doctoral thesis has also some interesting practical implications for corporate managers, investors, and policymakers. Our findings highlight the financial impact of the responses of some companies to climate change. We investigate to what extent investors price environmental strategies. Although mitigation strategies have a positive effect on financial performance, adaptation to climate change strategies seems to only have a positive impact on corporate financial performance in the long term. Consequently, developing mitigation or adaptation strategies could be a way for managers to increase the value of the company.

Second, our thesis highlights that physical risk due to climate change reduces the value of the firm. Taking into account the increasing environmental considerations, corporate managers could adjust their policies to counteract the negative effect of climate risk.

Finally, our work provides guidance on the effect of physical risk on corporate investment. Although the literature mostly documents that corporate managers lead conservative strategies after a natural disaster (Huang et al., 2018), we show that the increased risk due to future climate change is positively related to R&D investments. Thus, this approach to adapting to climate change may offer companies a way to increase firm value.

Limitations and directions for future research

Even if the results presented in our thesis are robust in the context of our settings, our work still has various limitations that open future research opportunities. First, our analysis relies on environmental and climate data provided by three main databases: Refinitiv Thomson Reuters ASSET4 ESG, Trucost, and Carbon4 Finance. The measurement of climate data is still progressing (Berkman et al., 2021; Ginglinger & Moreau, 2019; Huang et al., 2018; Sautner et al., 2023) and it would be interesting to use alternative measures of environmental strategies and physical climate risk to ensure that alternative proxies do not provide different results.

Our sample size is driven by the availability of climate data. Carbon4 Finance database used to measure firm-specific physical risk due to future climate change only covers major companies around the world. Other studies should be conducted to better understand the influence of climate change on smaller-capitalisation companies. Moreover, the Carbon4 Finance database

also provides firm physical climate risk for 7 hazards. If we consider acute and chronic risks in Chapter 2, future research could further unravel physical risk to better understand the impact of each physical risk on firm decisions. Other work should study the impact of climate risk on market reaction, portfolio management, and policymakers.

In our doctoral thesis, we focus our attention on the environmental strategies – corporate financial performance relationship, and physical climate risk on firm value and investment policy, but not on both. In fact, it could be interesting to investigate the influence of physical risk on environmental strategies. We could then investigate the impact of climate risk on divestment.

Finally, we document that investor attention to physical risks has evolved over time. Climate change will be a major issue for all stakeholders for many years to come. In general, we focus our work on firm valuation. Future research may focus on how climate risk will be priced in financial markets in the future (Giglio et al., 2021). Thus, new opportunities will lead to a better understanding of climate exposure, such as the impact of new environmental regulations, the growing concerns about stranded assets, and the social pressure exerted by investors. All of these avenues pave the way for future research on climate finance.

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