

Impact of Climate Transition Risk on Banks:
Regulatory Frameworks, Carbon Pricing and Credit Risk

by

Adeboye Oyegunle

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Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

External Examiner	Prof. Jan Mahrt-Smith Associate Professor, Finance Joseph L. Rotman School of Management University of Toronto
Supervisor/Co-Supervisor:	Prof. Olaf Weber Professor Schulich School of Business York University
Co-Supervisor:	Prof. Michael Wood Associate Professor School of Environment, Enterprise and Development University of Waterloo
Internal/External Member:	Prof. Vanessa Schweizer Associate Professor Department of Knowledge Integration University of Waterloo
Internal Member:	Prof. Jason Thistlethwaite Associate Professor School of Environment, Enterprise and Development University of Waterloo
Other Member:	Prof. Amr ElAlfy Assistant Professor School of Environment, Enterprise and Development University of Waterloo

Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Statement of Contributions

Adeboye Oyegunle is the sole author of Chapters 1, 2, and 6, written under Dr. Olaf Weber's supervision. Chapters 1 and 6 were not written for publication. Chapter 2 is adapted from one of the author's publications during the PhD program, but sections are included to reflect current updates in research and future outlook. This thesis comprises three manuscripts prepared for publication. One manuscript has already been published, while the other two have undergone initial peer review at reputable journals, receiving a “revise and resubmit” decision. Both manuscripts have been revised accordingly, with all reviewers’ comments addressed and resubmitted for final approval and publication. The chapters in this thesis represent the final revised version that was submitted to the journals.

Exceptions to sole authorship of material are as follows:

Chapter 3: Adeboye Oyegunle: Conceptualization, Methodology, Data Curation, Writing-Original draft preparation, Formal analysis, Writing- Reviewing and Editing, Investigation, Project administration. Olaf Weber: Methodology, Validation, Formal Analysis, Writing - Review & Editing, Supervision. Amr ElAlfy: Conceptualization, Resources, Data Curation.

Chapter 4: Adeboye Oyegunle: Conceptualization, Methodology, Data Curation, Writing-Original draft preparation, Formal analysis, Writing- Reviewing and Editing, Investigation, Project administration. Olaf Weber: Methodology, Validation, Formal Analysis, Writing - Review & Editing, Supervision. Sara Aghakazemjourabbaf: Methodology, Formal analysis

Amr ElAlfy: Conceptualization, Data Curation.

Chapter 5: Adeboye Oyegunle: Conceptualization, Methodology, Data collection, Writing-Original draft preparation, Formal analysis, Writing- Reviewing and Editing, Investigation,

Project administration, drafting, editing and submitting manuscripts. Olaf Weber: Supervision, Validation, Writing - Review & Editing, Supervision, Conceptualization, Formal analysis.

Pelumioluwa Abiola: Methodology, Data Curation, Model Development and Assessment.

Throughout the research process, as the lead author, I led the research work and contributed to conceptualizing the study design, ensuring that our approach and methods aligned with my research objectives. I also took the lead in managing the project, data collection and analysis, ensuring the studies were well-structured. My coauthors played a crucial role by offering their expertise and guidance at each research stage. They provided insightful feedback on draft manuscripts, contributed to analysis where required, and significantly enhanced our final work's overall quality and clarity.

Abstract

As the risk associated with climate change intensify, there is an observed trend of increased government and regulatory intervention targeted at mitigating the economic impacts of climate risk and facilitating the decarbonization process. These interventions primarily manifest in two ways. First is through government-imposed market-based instruments, such as carbon pricing, which apply a cost on carbon emissions to discourage pollution and ensure that emitters pay for their environmental impact. The other is through regulatory disclosure requirements that mandate specific sectors to disclose their climate-related actions, with regulatory authorities overseeing compliance within their respective jurisdictions. This research addresses these interrelated yet distinct approaches to managing climate transition risks by examining how market-driven policies, such as carbon pricing, influence bank lending practices and identifying gaps between emerging climate risk regulations and scientific research. It achieves this by assessing the impact of market-based tools, like carbon pricing, on key economies, especially those with high carbon emissions and substantial GDP reliance on carbon-intensive sectors and the impacts on various economic sectors across regions. It also evaluates how emerging regulations align with these policies by synthesizing and analyzing academic evidence on their effectiveness. Theoretically, this research contributes to the theories of credit risk, financial stability and adaptive governance, particularly in strengthening the economic resilience of critical sectors exposed to climate transition risk and enhancing the capacity of regulators and financial institutions to adapt and align their operations with the evolving climate risk regulatory landscape. This analysis provides insights into how lenders to critical sectors can improve their operational frameworks and how regulators can enhance climate regulations in response to the dynamic challenges posed by climate change.

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To the University of Waterloo, I am deeply rooted here and look forward to contributing in meaningful ways to this great institution that has shaped and supported me. The memories I made here are forever imprinted in my heart. Thank you for everything.

Above all, to God Almighty be all thanks, honor, and glory.

Adeboye Oyegunle

Dedication

This work is dedicated to the memory of my mother, Mrs. Comfort Adunni Oyegunle. You were here when this journey began, your faith in me unwavering, but you departed before its completion. This is for you.

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Chapter 1

1.1 Background and Rationale

Climate change has emerged as one of the most significant global challenges of the 21st century.

With the ratification of the Paris Agreement in 2015, the international community committed to addressing climate change through Nationally Determined Contributions (NDCs) (UNFCCC, 2015; Vogt-Schilb & Hallegatte, 2017). This spurred the development of regulatory efforts and climate legislation across various sectors to mitigate climate-related risks (Ghosh, 2023).

Financial regulators, especially central banks, were also not left out of this effort and have increasingly recognized climate change as a threat to the economy (Battiston et al., 2021; Ens & Johnston, 2020).

Bank regulators, in particular, have acknowledged that climate change poses systemic risks (Schult et al., 2024) with the potential to cause ecosystem collapse, infrastructure failure, and asset devaluation, all of which will ultimately threaten the overall financial system stability (Ruzzenenti et al., 2023). Climate risk manifests in physical risks from climate events and transition risks associated with the shift to a low-carbon economy (Benedetti et al., 2019).

Physical risks include event-based impacts like natural disasters (Gambhir et al., 2022; Woetzel et al., 2020), while transition risks involve economic and financial losses stemming from policy changes, new technologies, market shifts, and changing investor sentiments (Batten et al., 2016; Gros et al., 2016; Scott, 1995). Considering the role of banks as the mainstay of the economy, their exposure to these risks is particularly concerning (Nieto, 2019).

Despite these risks, banks' investment in carbon-intensive industries is still significant, thus increasing their susceptibility to climate impacts and efforts being taken to transition to low

carbon economy (Gelzinis, 2019; Rainforest Action Network, 2023). Three key factors drive this continued exposure. First, many asset owners lack the full extent of their portfolios' exposure to climate risks (Campiglio et al., 2018), due to limited data and the inability to predict the tail risk of climate impact (Morris & Collins, 2023). Though solutions such as scenario analysis have been proffered (BoC & OSFI, 2022; Steinberg et al., 2019), evidence shows that even the world's largest banks, despite their resources, struggle to fully articulate and evaluate the potential impacts of hypothetical climate scenarios due to insufficient data and immature climate-risk models (Board of Governors of the Federal Reserve System, 2024).

Second, the evolving nature of climate risk research reflects ongoing uncertainty about the magnitude of financial risk of climate impact (Campiglio et al., 2023) and limited time horizon. Significant gaps remain in climate risk assessment for banks, primarily because the tools used are traditionally based on financial economics and have not adequately accounted for or quantified climate risks (Taylor, 2023), due to the nascent stage of climate risk research in the financial sector.

Third, banks' deep financial ties to the fossil fuel industry, complicates divestment efforts (Cojoianu et al., 2023; Nguyen et al., 2023). Between 2010 and 2021, research shows that banks extended over \$7.1 trillion in syndicated loans and bonds to fossil fuel companies (Rickman et al., 2024), with most being long-term in nature, representing significant economic obligations for banks. This makes divestment from these sectors particularly complex and costly, thus creating a "lock-in" effect, where the financial and economic dependencies on fossil fuel investments directly impact transition efforts (Ruzzenenti et al., 2023).

Having an ongoing exposure to carbon intensive sectors is also not without risk for banks. Despite the continued financial returns these investments may offer, they present a clear

contradiction to global efforts aimed at achieving net-zero carbon emissions by mid-century, but more importantly, they become unnecessarily exposed to a fast-evolving climate policy risks which substantially increases their chance of loss and investment becoming stranded (Nkwaira & Poll, 2023; Weber et al., 2020). Banks' ongoing investments in fossil fuels not only undermines the global objective on fossil fuel, but also delays the transition to renewable energy systems. This presents a direct threat to efforts aimed at meeting global climate targets, which exposes financial institutions to long-term risks associated with the inevitable shift towards greener, low-carbon economies, creating a dual threat of environmental harm and financial risk for banks.

Compounding these issues are the post-COVID economic impact and global political unrest in Europe and the Middle East, both of which threatened global energy security. Banks face the significant dilemma of supporting the economy amid these geo-political challenges and managing the exposure to financial risks from the transition to a low-carbon economy. This enhances the regulatory role helping banks navigate these challenges of addressing the climate threat and ensuring that banks play their economic role.

Central to this is the acknowledgement that climate risk threaten financial system stability (Carney, 2015; Dafermos et al., 2018; Ferreira et al., 2022). To address this, regulators have explored various methods to manage the financial risks associated with climate change. Central banks have led the way by introducing macroprudential measures, such as the introduction of regulatory or policy measures to help safeguard the stability of the entire financial system from risks related to climate change, as well as to curb the impact of climate risk on banking sector investments (Nkwaira & Poll, 2023). This has led to the development of climate risk regulations in different jurisdictions, such as the introduction of Climate Risk Management Guideline B-15 by the Office of the Superintendent of Financial Institutions (OSFI) in Canada (Generally

referred to as OSFI B-15) (NGFS, 2019) and the Bank of England's Supervisory Statement on climate-related financial risks, popularly called S-19/21 (Bank of England (BoE), 2022), with the objective of reducing banks' exposure to climate risks and easing the transition to a low-carbon economy (UNEP F. I., 2018).

Understanding this background is crucial for this research, as it explores how emerging climate policies influence banking sector climate risk exposure and the impact of this on credit risk. The banking sector's historical reliance on fossil fuels and other high emitting sectors presents a challenge, where efforts to align with climate goals may jeopardize short-term revenue.

Likewise, since regulations influence the banking system's response to climate efforts, inconsistent regulatory implementation across jurisdictions further complicates banks' responses to climate-related risks, as examined in Chapters 2 and 5. Specifically, Chapter 5 assesses whether emerging regulations in this field align with research, thus laying the groundwork on regulatory approach to climate risk framework upon which the banks depend on for guidance.

This study highlights the interplay between climate change and credit risk. Chapters 3 and 4 of this paper highlight this conversation in detail by addressing the effect of carbon pricing on credit risk for a carbon-dependent economy like Canada and across multiple scenarios in different regions. The findings suggest that higher carbon prices lead to lower Z-Scores (using the Altman Z-Score formula, which is a formula used to predict the likelihood of a company defaulting because of insolvency). These results underscore the need for banks to integrate climate risk into credit assessments, aligning with the broader shift toward sustainable finance (Capasso et al., 2020).

Overall, this PhD research provides additional insights into how climate-related financial risks may directly impact critical sectors of the economy that banks are exposed to under different

policies. The research discusses the need to redirect focus from traditional financial metrics to include environmental policy impacts, thus helping to enrich the theoretical framework of credit risk. This research is pivotal for academics and practitioners in finance, as it provides empirical evidence and theoretical insights into the complex interactions between climate policy and credit risk, paving the way for more resilient and sustainable financial systems.

1.2 An emerging but complex landscape

The role of banks in driving economic growth has made them vulnerable to climate change risks (Huang et al., 2022). Banks face heightened exposure to climate risk due to their investment and lending activities, which may be impacted by climate-related events such as extreme weather, policy changes, and the transition to a low-carbon economy (S. Batten et al., 2016). Regulatory bodies are stepping in by introducing various guidelines, policies, and standards to guide financial institutions in managing climate risk (Eceiza et al., 2020; Gourdel et al., 2024; NGFS, 2019; Roncoroni et al., 2021). However, this regulatory landscape is complex and evolving, with differing approaches and methodologies across regions and institutions.

Though research indicates the negative impact of climate risk on financial stability (Allen et al., 2020; Phan et al., 2021), the timing and accuracy of its financial effects are still debated (Hiebert & Monnin, 2023), and there is still a degree of uncertainty on the overall outcome of climate impacts (Trinh, 2024). This is despite multiple studies on climate impact and financial stability. Financial regulators and actors are also testing many approaches to understand better the extent of risk, including applying approaches such as stress testing and climate scenario analysis.

Central banks and other banking and economic regulators understand that climate change poses systemic financial risks that require a macroprudential response. This includes using systemic

risk buffers and measures to limit exposure concentrations despite challenges in modelling and data (Hiebert & Monnin, 2023). This explains the introduction of multiple policies, guidelines, and regulations for the financial industry to address the climate crisis. This study focuses on how these policies, particularly the introduction of carbon pricing, affect banks' exposure to critical industries, especially carbon-intensive ones (Kölbel et al., 2024; Othman & Haron, 2024).

Specifically, this research addresses the evolving climate regulatory actions aimed at driving the economic transition to a low-carbon economy and the uncertainty about how these largely untested regulatory actions will influence banks' credit risk exposure (Redondo & Aracil, 2024), to carbon-exposed industries when implemented. This challenge is compounded by the lack of sufficient data to thoroughly analyze or more accurately predict the full extent of climate risk issues in the financial sector and has even led to a more precautionary policy approach to addressing the climate question.

The lack of comprehensive data hampers the ability to assess climate risks in the banking sector and predict the sector (Battiston et al., 2017). Some studies propose market-based solutions such as GHG market share and exposure disclosures (Monasterolo et al., 2017). Understanding these risks is crucial for banks as they need to assess the risks associated with lending to high-emission sectors, which could lead to higher risk premiums and borrowing costs and necessitate hedging against higher default probabilities.

Unfortunately, the evolving regulatory landscape, while well-intentioned, remains largely untested, amplifying uncertainties for banks striving to balance compliance with financial stability. This underscores the need for improved data collection and market-based solutions, such as enhanced GHG disclosures and exposure reporting, though these measures still fall short of fully capturing the complexities of transition climate risks. As carbon pricing policies expand

globally, understanding these risks becomes imperative for banks to recalibrate lending strategies, manage risk premiums, and hedge against rising default probabilities in high-emission sectors. The convergence of these factors marks a decisive moment that will shape the financial sector's ability to navigate the climate crisis effectively.

1.3 Research Objectives

The primary objective of this study is to evaluate how climate transition risk affects credit risk exposure in the banking sector and how regulators are responding to managing these risks. Specifically, this research focuses on two critical but similar climate transition risk areas: the effects of government-announced carbon pricing on banks' credit and emerging regulatory disclosure efforts targeted at helping banks manage these climate-related risks. This study connects these critical aspects of climate transition risk and explores potential solutions for analyzing their effects on banks' financial stability. The study achieves this by examining how emerging carbon pricing policies affect individual commercial credit in different sectors and regions under various scenarios, emphasizing the need for banks to incorporate carbon emissions into their credit risk assessment practices.

Also, the urgency of mitigating climate change has led to a surge in regulatory measures targeted at reducing carbon emissions and fostering sustainable finance. These regulations, especially carbon pricing and climate risk disclosure requirements, are designed to integrate climate risks into the financial system and encourage banks to align their operations with global climate goals. By examining the development and implementation of these regulations and considering the inherent gaps within the literature and the impact of carbon pricing on loan exposures, this study aims to assess the effectiveness of proposed transition risk tools while highlighting the gaps in

climate regulations and policies in their quest to addressing the climate question within the banking sector.

To address the issues above, Chapters 3 and 4 analyzed the impact of policy decisions, specifically carbon pricing, on bank credit. We consider how announced carbon price policies will impact different economies using scenario analysis to project future likely transition climate risks impacts on banks' loan portfolios. The objective is to understand how climate risks may affect banks' investments over time, their exposures across different regions, what regulations need to be in place to help mitigate these risks and what opportunities lie ahead in the coming years.

Chapter 5 focuses on two main approaches to addressing the climate-financial nexus. First, it analyzes the current regulatory landscape, examining key policies and frameworks introduced by major financial regulators and international bodies. This includes an evaluation of systemic risk buffers, exposure limits, and other macroprudential tools designed to enhance the financial system's resilience to climate-related shocks. Second, leveraging Artificial Intelligence, it compares regulatory outputs with academic research findings, identifying key gaps, inconsistencies, and discrepancies across jurisdictions, inadequate data for climate risk assessment, and the difficulty of integrating long-term climate risks into traditional financial risk models. This critical analysis highlights where existing regulations fall short and underscores the need for more cohesive and robust global regulatory approaches.

The outcomes of these assessments enhance our understanding of how emerging climate policies affect banks' financial exposures. By evaluating the impact of regulations on bank portfolios and risk management strategies, particularly for institutions heavily exposed to carbon-intensive industries, the study addresses core challenges of the climate transition, including implications

for lending practices, asset valuations, and risk appetite. It also assesses the potential for increased borrowing and capital costs due to regulatory compliance and the need to hedge against climate-related risks. Ultimately, this research offers a comprehensive perspective on how climate risk regulations are reshaping the banking sector's financial landscape and provides recommendations to strengthen regulatory frameworks in support of climate goals.

1.4 Why is this important?

The manuscripts in this thesis are interconnected by exploring how climate transition risks, particularly regulatory actions such as climate disclosure guidelines and carbon pricing, impact financial stability and drive the credit risk exposure of financial institutions, especially banks. The research shows how carbon pricing as a regulatory tool can expose banks to increased credit risks due to the financial pressures faced by these sectors. By analyzing the impact of such regulations on banks' loan portfolios, the paper highlights the importance of addressing the regulatory frameworks that mitigate these risks. As climate regulatory actions continue to emerge and mature, aligning this with research expectations and developments is necessary. It utilizes artificial intelligence to bridge gaps in climate risk disclosure and highlight where policy and academic perspectives diverge. Together, these chapters form a comprehensive analysis of the evolving role of climate risk regulations in shaping the credit risk landscape of financial institutions.

1.5 Climate Policies and Regulatory Rules – What is the Connection?

This research focuses on a critical aspect of climate transition risk: policies and how they influence banks' management of climate risks. In this context, climate risk policies manifest primarily in two ways. The first is through government policies that have broad implications for various sectors of the economy, which indirectly impact the banks lending to those sectors.

Second, regulatory bodies establish rules and guidelines for banks, outlining how they should manage and mitigate climate risks. While these two mechanisms serve distinct purposes, they are aligned in their overall goals, as both directly impact banks' risk exposure (through government policy expectations) and operational constraints (due to regulatory requirements). The combined effect of government policies and regulatory actions represents the most significant influence on banks' climate transition risk exposure and decision-making process as banks navigate their core function of providing credit to critical economic sectors while being compelled to comply with regulatory mandates such as disclosure requirements (See Fig 1.1). Therefore, this research centers on addressing these inherent climate risks faced by banks, the strategies to address them, and an evaluation of the maturity of the relevant regulatory frameworks that help drive the process.

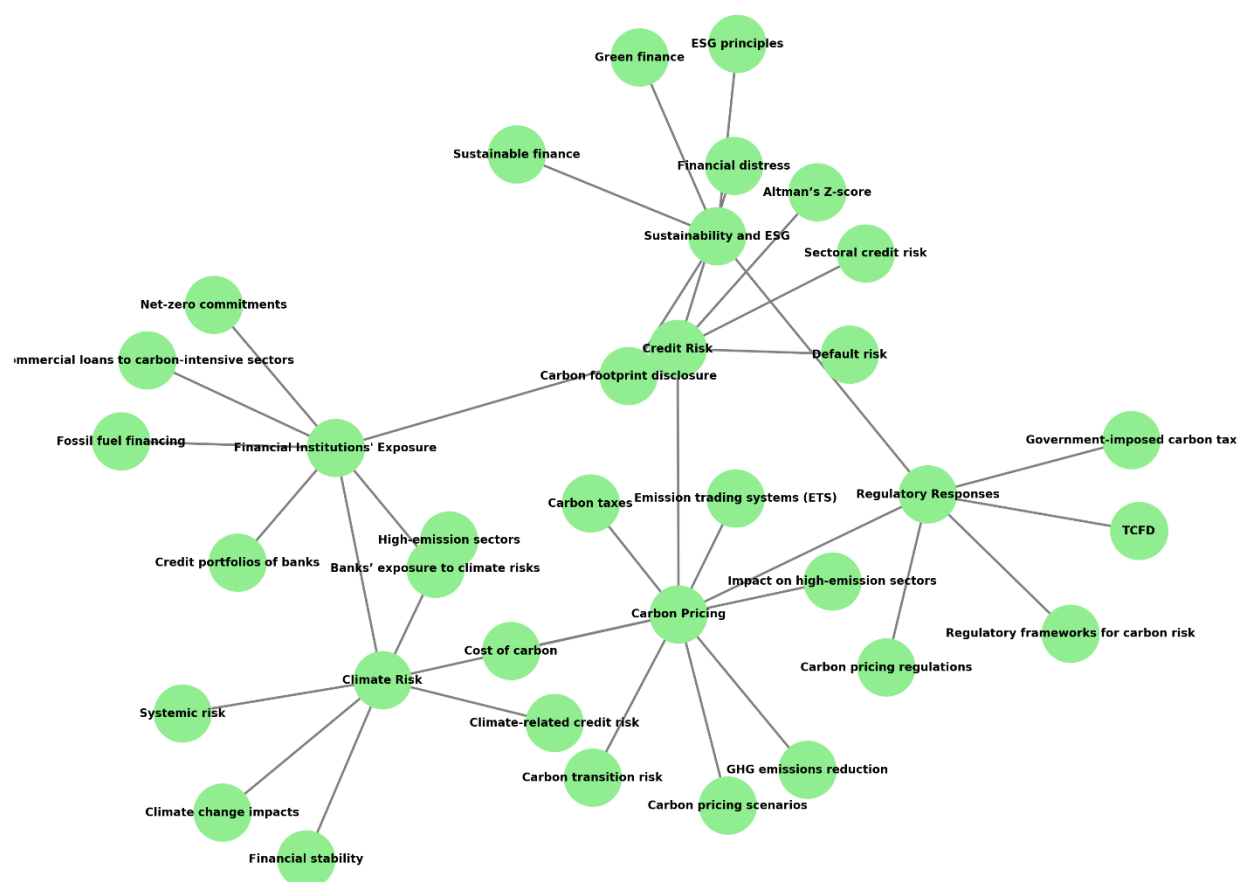


Figure 1-1: Descriptive Representation of Research Themes

1.6 Research Questions

Building on the research objectives outlined earlier in this chapter, this study examines the impact of inconsistencies in climate regulations and the introduction of climate-related risks on banks' financial stability and risk management practices. To this end, this research will address the following questions:

- How do different carbon pricing policies across various jurisdictions impact the credit risk exposure of banks, particularly those heavily invested in carbon-intensive industries?
- How effective are current macroprudential tools, such as scenario analysis and climate risk regulations, in enhancing financial stability?

- What are the potential impacts of carbon pricing policies on banks' lending practices and credit risk exposures to critical economic sectors?
- Is there an alignment between emerging climate risk regulations and research expectations?

These questions will help evaluate the existing challenges in current climate risk assessment methodologies and tools and discuss gaps, such as the need for improved data and scenario modelling techniques. It will also assess the adequacy and impact of existing regulatory measures and macroprudential tools in enhancing the resilience of banks against climate-related financial shocks by analyzing the implications of carbon pricing on banks' lending behaviours, asset valuations, and overall risk management strategies, providing insights into future regulatory needs and adjustments.

1.7 Contributions to Knowledge

This research aims to complement existing studies on climate-related risks and opportunities within the financial sector, highlighting how different countries and economies are exposed to climate change policy risks and the impact of those risks on the financial sector's credit portfolio. By focusing on scenario analysis and climate disclosures, it seeks to strengthen the adoption and use of scenarios for climate impact evaluation, which is increasingly relevant as the financial sector grapples with managing future climate-related risks (Steinberg et al., 2019) and its impact on credit risk (Capasso et al., 2020). In doing this, this study contributes to an important objective of this PhD research by offering practical insights into the impact of climate transition risk mechanisms, such as carbon pricing, on the real sector of the economy. It also highlights the need for banks to develop effective transition plans to manage the effects of these risks on their credit portfolios. The study enhances academic knowledge by improving climate credit risk

methodologies and providing analytical insights into improving policy development for managing systemic risks like climate change.

Specifically, this dissertation contributes to existing theories on credit risk by looking beyond traditional credit risk models, which focus on financial metrics such as profitability, leverage and liquidity (Altman, 1968; Altman & Saunders, 1998), but expands into how other factors such as how climate change may impact credit risk (Capasso et al., 2020). It also addresses the need to bridge the gap between emerging climate risk regulation (Carè, 2023; Hidalgo-Oñate et al., 2024) and research. By comparing regulatory expectations with peer-reviewed studies, this research identifies discrepancies across jurisdictions and the challenges in proposing solutions and future pathways for climate regulations disclosure requirements. It also explores how these regulatory inconsistencies affect banks' disclosure capabilities and risk profiles, emphasizing the need for harmonized global regulatory frameworks. This was achieved through a detailed analysis of the current regulatory landscape, focusing on current regulations and frameworks as introduced by major financial regulators and international bodies, addressing a critical aspect of climate policy approach to a fast-evolving governance function (Bank of England (BoE), 2022; BoC & OSFI, 2022; Ens & Johnston, 2020; M. Scott et al., 2017), which continues to challenge regulators and financial institutions alike.

1.8 Conclusion

The study contributes to existing theories on credit risk management (Thakor, 2016) by incorporating the climate transition risk consideration into credit risk, financial stability (Goodhart & Tsomocos, 2007; Schinasi, 2005); by highlighting the criticality of climate risk impact on credit and adaptive governance theories (Hatfield-Dodds et al., 2007; Hurlbert & Gupta, 2016); by exploring opportunities and identifying inherent gaps in implementing climate

risk regulation; and how adoption of a polycentric approach to governance could help enhance a positive drive in the climate transition application (Marshall, 2015; Tobin et al., 2024).

Overall, this thesis expands the scope and potential application of climate transition risk impacts on credit by incorporating carbon costs to demonstrate how regulatory climate transition measures can affect credit risk. This approach contributes to the ongoing conversation on the link between climate change and credit risk by introducing policy considerations such as carbon pricing into credit risk assessment (Aiello & Angelico, 2023). By applying an alternative approach to climate risk impact on credit, our research derives insights into using well-established credit default models for analyzing the impact of a company/sector climate risk on a bank's portfolio. It also highlights the need for dynamic and comprehensive credit risk management approaches that integrate financial and non-financial risk factors to enhance the resilience and sustainability of the banking system.

Chapter 2: Scenario Analysis and Climate Disclosure

This chapter addresses the importance of climate risk disclosure and scenario analysis as essential tools for understanding and mitigating the climate risk of banks' lending exposures. It is critical to this research as it helps lay the groundwork for regulatory emergence and is essential to the core of our research. As financial institutions grapple with the unpredictable impacts of climate change, the need for robust climate accountability and realistic scenario assessments has become even more important. Being the critical bulk of the model applied for my research and across this thesis, scenario analysis, to a large extent, and its main driver, regulatory disclosure and guidelines, highlight a critical part of the climate risk mitigation effort in the banking sector. This chapter highlights scenario analysis and regulatory policies' critical role in providing a clearer picture of banks and the financial sector's credit exposure to climate risks and supporting efforts to mitigate these impacts.

This paper plays a vital role in highlighting the importance of two parts of my research: scenario analysis and climate risk disclosure policies and guidelines. It analyses the increased interest and importance of scenarios in understanding climate risk impact and why this plays a significant role in addressing the financial risk of climate change. It also lays a transparent background on the evolving nature of these approaches as the core of analysis and output for credit risk climate models. By taking this approach, the study provides insight into the evolving nature and focus of the real-world financial sector's regulatory effort to ensure accountability and standardization of climate disclosures in line with scientific research expectations (discussed in Chapter 5).

Scenario analysis is a forward-looking tool banks and other financial institutions use to evaluate the likely impacts of risks on their portfolios (Baer, 2024). The adoption of scenario analysis in the financial sector has grown significantly since the Financial Stability Board's Task Force on

Climate-related Financial Disclosures (TCFD) recommendations in 2017 (TCFD, 2017). By projecting different future scenarios, financial institutions can better understand various plausible outcomes and develop strategies to mitigate adverse climate risk effects. The increasing use of scenario-based assessments reflects the financial sector's recognition of the need for precise and actionable insights into climate risks.

However, more data access and regulatory guidance are needed to ensure effective climate risk management. The lack of comprehensive data on the financial impacts of climate change complicates efforts to develop accurate scenario analyses and disclose relevant information (Semieniuk et al., 2021). Regulatory leadership and standardized climate disclosures ensure that financial institutions provide the necessary data to accurately account for and assess climate risks (Yébenes, 2024). Collaborative efforts between financial institutions, regulators, and the research community are essential to enhance climate risk disclosures and scenario analysis frameworks.

At the core of this study is the assessment of climate transition risk and its overall impact on credit. Transition risks arise from the shift to a low-carbon economy, which can negatively affect critical economic drivers such as market conditions, policy frameworks, and technology.

Anticipating and managing these risks is crucial for maintaining financial system stability and enabling financial institutions to adapt to changing conditions. By projecting plausible outcomes for their financial obligations and exposure, institutions can develop strategies to mitigate such risks. This chapter is critical because it lays the foundation for using scenario analysis to evaluate the likely impact of credit on financial institutions and explores how this approach can help navigate the uncertainties of transition risk within the broader context of climate risk management and credit risk.

The paper was published as a precursor to this study. This chapter provides the necessary background and introduction to the climate risk impact on credit focus of my thesis. The result is still very relevant to ongoing discussions in this field. The paper highlights the study's critical importance of climate risk disclosure and scenario analysis. By exploring the challenges and opportunities associated with these tools, the chapter provides a comprehensive overview of their role in mitigating the impacts of climate change on credit risk. The rest of the chapter is an excerpt from the paper - *The Politics of Climate Change: Embedding Regulatory Guidance for Scenario Analysis and Climate Risks Disclosure in the Financial Sector* (Oyegunle, 2020).

The Politics of Climate Change: Embedding Regulatory Guidance for Scenario Analysis and Climate Risks Disclosure in the Financial Sector

- Adeboye Oyegunle

This rest of this chapter was published in the *Queen's Policy Review: The Politics of Climate Change*, 11(11), 57–65.

2.1 Introduction

The increasing risk of climate change on the financial sector's investment and assets threatens financial stability and the economy. This challenge is exacerbated by inadequate climate accountability, especially the “answerability” and “enforceability” of climate commitments (Newell, 2008; Newell & Mulvaney, 2013) and inadequate data on the possible impact of climate change on the financial system. This situation has created the need for a more transparent and robust climate disclosure commitment, requiring financial institutions to clearly disclose the

climate risks they are exposed to, backed by realistic scenario assessments of financial assets and investments to help support the mitigation of climate impact on the financial system. Such transparency not only enhances the capacity of regulators and stakeholders to assess vulnerabilities but also fosters the development of targeted strategies to mitigate climate impacts on the financial system. For instance, the Task Force on Climate-Related Financial Disclosures (TCFD) has established frameworks for companies to integrate climate-related risks into their financial reporting, enabling investors to make more informed decisions and prompting companies to adopt more sustainable practices to mitigate systemic risks to the broader economy (Moody's, 2021; TCFD, 2020).

The ability to project a probable future is why scenario analysis is important to financial institutions' climate risk impact. Climate change risks threaten the ability of economies to thrive and may negatively impact critical sectors of the economy. This will be detrimental to firms' financial assets, investments and the financial institutions that finance them (Dafermos et al., 2018). It may also result in serious risk to financial stability, since efforts to control the negative impacts of climate may necessitate the development of climate policies or other transitions to low-carbon economy efforts that are targeted at mitigating climate change effects instigated by rising temperature and weather unpredictability. These challenges and threats of climate change to financial stability and critical sectors will threaten the global economy and financial systems and impede banks' and other financial institutions' ability to meet their financial objectives (S. Batten et al., 2016).

At the heart of understanding the financial risk of climate change is the need to identify and mitigate its impact on financial assets and investments. This calls for collaborative input from financial institutions and central banks since climate risks have macroeconomic implications

which threaten the financial system (Batten et al., 2020) and may require a prudential guidance approach to managing it. Unfortunately, achieving this goal is not straightforward as there is no clear understanding or data to show the extent of the financial impact of climate risk exposure and its inherent risks and opportunities (Battiston et al., 2017).

To address this, the Financial Stability Board's (FSB) Financial Task Force on Climate-related Financial Disclosures (TCFD) recommended the use of scenario analysis to help provide forward-looking assessments of climate-related risks while highlighting climate risks and opportunities upon which strategic decisions on climate change risks can be made (TCFD, 2017). Since the introduction of TCFD, a growing number of stakeholders in the financial sector have begun to adopt scenario-based assessments on a voluntary basis as its recommendations become more critical to bridging the unknown impact of climate risk on their assets and investments. This paper aims to review the growing relevance of scenario analysis and climate disclosure in the financial sector, especially in helping to determine the plausible impact of climate risk on financial assets and investment and how regulatory guidance can help steer the financial sector towards averting worse-case climate scenarios.

2.2 Climate Risk Disclosures and Scenario Analysis

Climate risks can be categorized into two groups: physical risks, which refer to the risk of physical damages on investment, such as severe weather, and transition risks, which occur as a result of a shift to a low-carbon economy, such as changes in technology, market, reputational or policy conditions (Gros et al., 2016; M. Scott et al., 2017; UNEP F. I., 2018). Physical risks can be classified either as chronic – referring to gradual changes in weather patterns, or acute, which refers to hazardous impacts of extreme weather events such as hurricanes (Mazzacurati et al., 2018; TCFD, 2017). These risks can have macroeconomic impacts such as inflation and/or price

instability or losses due to extreme weather, leading to a growing interest in understanding their nature and effects.

The need to understand the impacts of climate risks and potential opportunities is one of the reasons the call for climate disclosure is becoming mainstream in the financial industry's efforts to manage physical and transition risks. For example, financial analysts may ask what the impact of a new policy directing the zero-carbon goal in Canada in the next decade will be. Considering the Canadian banking industry's current high exposure to oil sands and other carbon-intensive investments such as mining, it begs the question of what the future of this industry will be and the ability of banks to recoup investments if such policies take effect.

This is why the interest in scenario analysis as a forward-looking tool to assess plausible future realities of climate change risks and opportunities for financial sector portfolios is on the rise, since it can help bridge the gap by providing realistic insight into likely outcomes even with the lack of historical precedent on the impact of climate-related financial risk. Understanding these risks and opportunities and how they may impact financial portfolios will help the financial sector take necessary mitigating actions against these risks and adequately position itself for the opportunities that scenarios may present.

2.3 Carving the Financial Sector's Scenario Pathway

Climate scenarios have been utilized in strategic decision-making, risk mitigation, and to determine future scenarios. It has also been helpful for climate modelling efforts developed in response to specific temperature change or aerosol concentration scenarios, whose results were achieved by manipulating model output and climate data (Mearns et al., 2001). Likewise, scenario modelling was adopted by the IPCC and other reports to determine plausible climate

and emission pathways for the future (IPCC, 2014; Masson-Delmotte et al., 2018; Mearns et al., 2001; Tol, 2016) and has been used to assess energy and GHG pathways (Vuuren et al., 2017). Despite its relative usefulness in crafting plausible, consistent descriptions of possible futures, its use is relatively new and in its infancy in the financial sector (Battiston et al., 2017). However, there has been increased interest in its use by the sector since the TCFD recommendations were released, with different recent studies and reports defining what and how this will be practiced, considering that most scenario models were not initially designed for the financial sector (UNEP FI, 2018; UNEP FI, 2019).

As there is a need to assess the likelihood of climate impact, there has been an uptick in the use of scenario analysis to help assess the likely impact of climate risk on financial institutions' portfolios and the operations of industries to which they are exposed. The increasing interest in climate scenarios and adoption by financial institutions has been encouraged mainly by three significant factors. First, the unpredictability of climate affects financial sectors' portfolios, and there is a need to develop applicable mitigation and adaptation processes to help manage these impacts. Second, the lack of an adequate historical model upon which decisions can be patterned makes decision-making for future impact almost impossible due to limited research on climate change impact in the financial sector. While we have an idea of the impacts of climate change, it is complex to predict the extent of these impacts on financial investments. Third, there is a need to create a climate disclosure approach that will help meet diverse stakeholders' expectations while bridging the unknown gap of the future state of assets and investments in financial systems portfolios and their exposure to different climate risks and opportunities.

The argument for scenario analysis is that it is very useful for determining future probable states for medium-to-long-term models that are often uncertain, hence its suitability for understanding

possible future outcomes of climate risks (TCFD, 2017). The fact that there has yet to be an antecedent to follow or a specific methodology to address financial risk exposure makes this more critical, as it means the industry will either formulate its process or adopt established scenario analysis models that may not have any correlation with the financial industry. The latter has been the most common approach, with recent studies showing the adaptation of various scenario models from other sectors. There are also a series of ongoing efforts to help develop diverse climate-related risk scenario analyses, which regulators and industry actors lead for the financial sector (Ens & Johnston, 2020; NGFS, 2019; UNEP FI, 2018; UNEP FI, 2019).

2.4 Scenario Relevance and the Evolving Regulatory Involvement

Scenario analysis is not to forecast or predict (Schoemaker, 1991) but to frame differing and complex hypotheses about the future (Coreau et al., 2009). Scenario analysis is best applicable in uncertain situations where human ability is lacking to control outcomes (Bohensky et al., 2011). By using scenario analysis as part of climate disclosure measures, financial institutions can determine the effectiveness of their future climate strategy. This will allow them to take advantage of opportunities that may arise or mitigate risks that may occur through climate change (Scott et al., 2017). Addressing this will help ensure necessary steps are taken to avert the impact of emerging climate risk policies even as financial institutions continue to better understand how these risks impair the financial system.

Globally, there is increasing interest in the impacts of climate risks on financial systems (Battiston et al., 2017). For example, the French Energy Transition law expects companies to provide extensive disclosures on climate-related risks of their portfolios and the mitigating steps to address them (Ameli et al., 2019). It also requires that banks conduct climate-related stress testing of their portfolio of loans and disclose the results. In December 2017, eight central banks

and financial regulators in high-income and emerging economies formed a Network for Greening the Financial System (NGFS) to tackle climate exposure and other similar risk issues in surrounding financial risks (Campiglio et al., 2018). By September 2020, the NGFS membership had risen to 73 members and 13 observers comprised of central banks, settlement houses, financial supervisory authorities, and other multilateral organizations.

The Bank of Canada (BoC) is also part of this effort. It has already taken steps to encourage climate disclosures and scenario analysis at the financial institution level. At the same time, it published its first paper on climate scenario analysis for the Canadian banking sector in May 2020, though it has yet to commit to taking regulatory action. However, the Bank of England is leading this effort (Batten et al., 2016). In June 2020, it released the first climate-related financial disclosure, laying out its approach to managing climate risks across its operations and how it intends to tackle future climate challenges. The Bank has also supported NGFS and plans to develop a biennial exploratory scenario on financial risks from climate change by 2021, which will test the financial industry's current business model climate resilience to physical and transition climate risks in the United Kingdom and beyond. However, despite these efforts, most central banks have implemented this as a voluntary rather than required process, with most regulators arguing that they are not in the business of policing banks and other financial players (Ens & Johnston, 2020), which technically leaves financial institutions to act at their discretion.

2.5 Need for Regulatory Input and Guidance

As the use of scenario analysis for assessing climate risk becomes more mainstream in the financial sector, there is a need for regulatory direction to help guide climate disclosure and scenario analysis models. This is important for two reasons – understanding and appraising climate risk needs to be premised on scenario models that provide realistic insights into probable

climate solutions and realistic future projections that are reliable. Within the context of this research, the scenarios being “realistic” implies that these models must accurately reflect plausible pathways based on current scientific knowledge, technological trends, and socio-economic realities, while their being “reliable” ensures that the outputs are robust, reproducible, and can be trusted to guide critical financial and policy decisions (TCFD, 2017; UNEP FI, 2019). Second is the challenge with data and relevant disclosures, which speaks to the need for regulatory-led disclosure requirements. This is significant as financial data is not often readily available, and financial institutions do not often share their data beyond the required regulatory information, which makes it challenging to determine the extent of climate impact on their portfolio and other investments.

The systemic nature of climate risk is another reason regulatory input is necessary. Managing the systemic risk of climate change requires a different approach because of its externalities (NGFS, 2019) and the unpredictable nature of its risks (Batten et al., 2020). Current trend data and scientific evidence point to the fact that there is a need to act, since failure to prepare for or late transition to a low-carbon economy may come at a considerable cost to the financial system (Gros et al., 2016). As global temperatures rise, climate damages escalate disproportionately, driven by feedback mechanisms such as ice sheet collapse, permafrost thaw releasing greenhouse gases, and the loss of biodiversity through ecosystem breakdown, which together intensify global warming and disrupt ecological balance, further amplifying risks to both natural systems, such as water and food security, and the economic systems, including infrastructure stability and market dynamics (IPCC, 2021), with significant impact on the financial system.

Some papers and academic studies have already reviewed the need for central banks' involvement in climate risk efforts, especially regarding the roles central banks should play in

climate change efforts (Campiglio et al., 2017). However, the question of regulatory enforcement and the best approach still needs to be answered. Also, the suggestion that central banks should aid best practices through information sharing on scenario analysis modelling (Campiglio et al., 2018) will not be enough because we need to catch up on climate action. The argument has been that enforcing regulatory standards and climate disclosure on financial institutions may hurt the financial system. Also, despite having regulatory and supervisory authority, central banks are unwilling to assume a position that may be perceived as policing the financial system. However, these stances are not without fault, considering the economic and environmental impact of inaction, which may result in sudden shifts in market demand, technological shifts or policy changes that may expose financial institutions to transition risk impacts.

Despite these realities, this paper does not advocate for direct regulatory enforcement. Instead, it seeks to recommend a more involved approach by central banks and provide guidance on the way forward. One area in which central banks can start getting involved is charting a path forward for scenario analysis modelling in the finance industry. Very few central banks are doing this currently, but more needs to be done regarding oversight and leadership.

There is also the need for collaboration and standardization of scenario analysis methodologies in the financial sector. There are too many scenario model methods with often conflicting approaches, which makes existing studies incomparable and results inconsistent for valid research conclusions. There are a few reasons for this – first, the available scenario analysis models utilize different methodologies and are mainly developed for purposes other than the use of the finance industry; the industry, being late to the game, is only adopting these available standards for its use. Second, there are inconsistencies in approaches and results due to the proliferation of methods and diverse objectives, most of which are driven by profit motives, with

each business and consultant trying to outdo one another on the best method and approach. Likewise, there is the evolving nature of scenarios and inaccessibility of financial data, which cannot be effectively tackled without adequate policy direction on expectations. Unfortunately, there may be no immediate end due to the largely voluntary nature of climate regulations, since voluntary reporting is susceptible to greenwashing and has often proven ineffective. However, this can be addressed through a policy guide approach that will support financial institutions in using the appropriate models, methods, and technical inputs where necessary.

Through the NGFS, there is now an increased awareness and interest in understanding the financial risk of climate change by central banks. There are also ongoing efforts by multilateral organizations, such as the United Nations Environment Programme Finance Initiative (UNEP FI) and Principles for Responsible Investment (PRI), to help their members develop scenario methodologies and how to manage climate risks in their portfolios using scenario analysis. However, despite these efforts, there is still the need for more guidance on the development and application of scenarios frameworks in the financial sector. Specifically, regulators need to help enhance methodologies and develop solutions for assessing climate physical and transition risks.

Some of the ways that have been suggested for central banks to act in addition to disclosure requirements include discouraging investment in fossil fuel through green financial assets purchase, changing the regulatory weight for financial assets to reflect the asset's climate risks exposure, and utilizing credit allocation mechanisms that will help influence increased lending to green investment and businesses (Vaze et al., 2019). The regulatory direction in these areas will enable banks to make coping decisions that will ensure that regardless of the impact of the transition to a carbon-free economy or physical damages to assets, they will avoid resultant financial effects (Campiglio et al., 2019). Also, considering the threat to the financial system and

financial stability, it is expedient that a regulatory directive is in place to guide scenario development at the financial sector level and help manage the stability of the economy.

2.6 What Next? Policy Direction and Recommendations

The nature of the financial sector and investors, such as banks, puts them at risk of the unpredictability of climate change. This has necessitated the development and coordination of policymakers and regulators to address the concerns of climate-related financial risks (Campiglio et al., 2017). Lack of action now may lead to a need to take abrupt actions in the near to medium term, such as rapid introduction of carbon taxes to meet emissions targets, stricter regulatory mandates with stringent emission reduction standards and sudden ban or restriction on fossil fuel which could destabilize energy markets and may have consequences that may be detrimental to the economy (Ens & Johnston, 2020). This is a possibility if we consider the IPCC warning and the need to act now by reducing emissions to net zero by the middle of the century (IPCC, 2019).

This paper has established that there is a need for regulatory action to achieve this goal, particularly considering that the present voluntary corporate action approach by financial regulators is ineffective. While this paper does not advocate for the complete enforcement of a climate risk regulatory mandate or the complete overhaul of the current approach, it proposes the development of policy guidelines that will help financial institutions navigate the scenario assessment path and provide an industry-relevant climate disclosure approach that has relevant indicators, which can help drive efforts toward climate risk mitigation. The following actions need to be taken to mitigate climate risk and implement regulatory-driven climate disclosure expectations based on scenario pathway expectations.

2.6.1 Need for prudential guidance

It is necessary to embed regulatory expectations for financial institutions by guiding climate disclosure with scenario assessment as its crucial component. This guideline will serve three purposes: It will show the central bank's commitment to climate risks while providing a path for climate reporting and relevant disclosures to help stakeholders make informed decisions on probable and obvious climate risks. Central banks' leadership in this area will compel financial institutions to act, especially towards a low-carbon economy. This is necessary as it will enable financial institutions to plan and understand the nature and extent of risks they may be faced with. It will also give the regulator a fair understanding of the possible macroeconomic impact and the nature of systemic risk in the financial sector. This disclosure must include but should not be limited to declaring the probable and realistic climate impact of financial institutions' loan exposure, investment and assets and providing necessary information that will be relevant to the financial sector's ability to develop a resilient system based on the knowledge of possible scenario pathways for economic and climatic realities.

2.6.2 Climate disclosure measurement and reporting

One of the critical challenges with climate risk impact measurement is the lack of available data to measure climate risk impact, which is critical to understanding climate effects. It is also necessary to know this to accurately undertake a scenario assessment and other quantifiable calculations of future climate projections. The reality is that data is sparse and not readily available in the financial sector, which impedes researchers from accurately studying and estimating what climate risk impact may look like for the financial system. This challenge can be largely resolved if clear, deliberate and detailed climate disclosure is required from financial institutions. The goal is to collect data and publicly report to provide investors and other

stakeholders access to make informed decisions on the climate exposures of financial institutions.

2.6.3 Taking the lead: making climate disclosure a regulatory deliverable

The Bank of England has already taken the lead by releasing its disclosure report. However, central banks need to do more by making it standard for the industry they regulate to be more open and disclose their ongoing climate change exposures. In doing this, central banks need to ensure that climate disclosure becomes a key regulatory expectation without necessarily introducing a punitive mandate; developing a reporting standard alone for financial institutions will go a long way in ensuring compliance. As part of this, central banks must develop their disclosure approaches and overarching scenario models that are locally or regionally applicable. It could also create incentives to encourage involvement while taking deliberate proactive measures to protect the economy and ensure financial stability.

2.7 Conclusion

With a growing regulatory interest, there needs to be a concerted effort on policy guidance and direction since one of the major challenges with implementing climate risk mitigation efforts is the need for more strategic policy guidance. Although there is no immediate solution to climate risk challenges, implementing some or all of these measures is important to successfully mitigate the impact of physical and transition risks on the financial sector.

The need to act is further established by scenario analysis used in the financial sector, which is in its infancy and can be supported by financial regulators' action on standardization, guidance, and collaboration. The extent of action the central banks take for their respective economies will go a

long way in the climate fight. It may help define the outlook and relevance of scenario assessment in the financial sector in the near future.

Chapter 3

Carbon Costs and Credit Risk in a Resource-Based Economy – Carbon Cost Impact on the Z-Score of Canadian TSX 260 Companies

Adeboye Oyegunle, Olaf Weber & Amr ElAlfy

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3.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) (IPCC Sixth Assessment Report) reinforced that human-induced climate change is causing rapid and irreversible changes to our planet (IPCC, 2021). Countries and supranational unions, such as the European Union, respond to this threat through market-based instruments such as carbon taxes (Stavins, 2022). By putting a price on and increasing the cost of carbon, governments aim to curtail greenhouse gas (GHG) emissions (Trinks et al., 2022).

This paper analyzes how carbon prices affect different economic sectors in a resource-based economy. With a specific focus on Canada but applicable to similar high carbon-dependent economies, we explored how the introduction of cost on carbon, such as carbon pricing, will impact carbon-intensive sectors that are significant contributors to the Gross Domestic Product (GDP) in such economies, and how this may expose the financial institutions that fund those sectors to increased costs and even bad debts. This is important as the full impact of regulatory climate transition risks, such as the introduction of carbon taxes on commercial credit risks, is not fully known, hence making it hard to predict how carbon control policies may play out in countries where essential sectors of the economy and substantial parts of the GDP come from

carbon-intensive sectors (Mukhtarov, 2022). For example, Canada's economy is strongly connected to carbon-intensive sectors such as mining and energy (Elder, 2021). These two sectors collectively contribute over 16% to the Canadian economy as of January 2023 (Statistics Canada, 2023). The contribution of carbon-intensive sectors to the economy increases substantially when other sectors with significant carbon emissions, e.g., manufacturing and transportation, are added to the mix.

Research has shown that there is a direct correlation between climate transition efforts like carbon pricing regulations and systemic risk (Li et al., 2022), which may negatively affect the financial industry's profitability and financial stability if not well managed (Weber & Oyegunle, 2019), though carbon pricing remains the most effective way to reduce carbon emissions (Baranzini et al., 2017). Considering this, our analysis of carbon price impact on commercial credit risk in a resource-based economy such as Canada will contribute to the academic knowledge in sustainable finance by addressing how such economies could react to carbon emissions pricing.

Our study differs from other studies conducted in this area because it addresses individual credit risks instead of analyzing the effect of climate exposure on lending and investment portfolios. For example, some studies investigated the impact of climate change exposure on the lending and investment portfolios of leading global banks and found that higher carbon exposure leads to higher financial risks (Battiston et al., 2021; Monasterolo et al., 2017). Other studies found that taking sustainability criteria, such as climate change, into account helps to identify and reduce commercial credit risks (Cui et al., 2018; Goss & Roberts, 2011; Mengze & Wei, 2015; Weber et al., 2010, 2015), while more recent studies found evidence that carbon price impacts the credit risk of companies (Bouchet & Guenedal, 2020; Capasso et al., 2020). However, these studies

used financial income and balance sheet indicators or Merton's distance to default model (Merton, 1974) to model credit risk.

We addressed a gap in the literature by analyzing the influence of different carbon pricing scenarios on different sectors in a resource-based economy such as Canada using Altman's Z-Score (Altman, 1968) and to understand if introducing carbon price without proper regulatory rail guards (e.g., carbon price ceiling mechanism) could contribute to insolvency risk in high emitting sectors. Empirical studies demonstrated that the model is valid for manufacturing and non-manufacturing companies and publicly traded companies (Altman, 2018). Consequently, our research asks two questions:

- (1) Do different carbon prices influence the credit risk score of Canadian companies, and
- (2) is the credit score of different sectors affected differently by carbon prices?

Theoretically, the study is based on credit risk scoring and Altman's Z-Score model (Altman, 1968; Altman & Saunders, 1998) for publicly listed firms since our sample is based on TSX 260 firms, constituting the Canadian stock index. We applied the Canadian Government Climate Plan carbon tax policy to determine the different carbon price scenarios between \$0 to \$170 per tonne by 2030 (Environment & Canada, 2020b).

We used ANOVA to analyze differences between carbon prices and between industries. To analyze the latter, we used ANOVA for a difference-in-differences approach (Conley & Taber, 2011) that compared the differences between carbon-intensive and less carbon-intensive sectors' results with and without a carbon price (WCP). Our results suggest that carbon price influence credit default risks. We found that the carbon price mainly affects the default risk of high-

emitting industries, such as energy and materials, that are important for the economy of resource-based countries such as Canada.

We contribute to the literature by showing the impact of different carbon pricing scenarios on Altman's Zscore, a widely used credit risk indicator that tests the likelihood of insolvency for publicly traded companies. Hence, we conclude that commercial lenders should assess carbon emission indicators and emission reduction strategies. Though carbon pricing probably does not lead to a significant credit risk increase overall, some industries could be affected more than others. Consequently, climate-exposed lending portfolios might be at risk.

The remainder of the paper includes a background section that discusses the theoretical approach and the methods followed by the study outcome. The paper concludes with a discussion of the results and conclusions.

3.2 Background

There is ample evidence that countries are struggling with meeting their Nationally Determined Contributions (NDCs) targets (Elzen et al., 2019) set as part of the 2015 Paris Agreement (UNFCCC, 2015). Based on the current emission trajectory, existing and new national climate pledges will lead to a 2.7°C temperature rise by the end of the 21st century instead of the targeted temperature increase of below 2°C (UNEP, 2021). This increase also extends beyond the United Nations's 1.5°C target increase above pre-industrial emission levels (Lawrence et al., 2018; Mahapatra & Ratha, 2017). To address this issue, there have been calls to halve annual GHG emissions by 2030 in line with the Paris Target to enhance the chances of fighting climate change (Furrer et al., 2012). Part of the response to this is exemplified by growing regulatory

efforts (e.g., carbon tax regimes) targeted at addressing climate risks to the economy, with some of the likely impacts being the crux of this paper.

The connection between climate change and the financial industry is twofold. On one side, financial institutions' finance activities support climate change mitigation and adaptation, such as green energy. On the other hand, institutions finance activities that worsen climate change, such as fossil fuel projects (Furrer et al., 2012). Unfortunately, the activities of the latter may lead to increased systemic risks for the financial industry, especially if it is exposed to significant sectorial or regional risks (Li et al., 2022). These risks could influence not only the financial risks of commercial borrowers, but also the stability of the financial sector (Ruiz & Weber, 2021).

Accomplishing these reduction goals needs a deliberate move towards a low-carbon economy at the regulatory level. This will directly impact the financial system and the economy (Monasterolo & De Angelis, 2020) since managing climate risk requires using various regulatory and other climate transition instruments such as macroprudential and monetary regulations targeted at enhancing the financial system's stability (Ferreiro et al., 2022). This transition effort comes in the form of policy change (as exemplified by governmental carbon pricing) and technological or market changes. Policymakers in many jurisdictions have also used carbon pricing to address climate challenges (Harvey et al., 2018). Though some researchers have argued that carbon pricing alone is insufficient to help curtail climate change (Rosenbloom et al., 2020), others have stated its effectiveness and ability to enhance innovation using a market-based approach (Baranzini et al., 2017). Regardless of whether placing a price on carbon is enough to fight climate change, it is still considered one of the most effective measures that regulators can employ to drive the transition to a low-carbon economy (Campiglio, 2016).

Carbon pricing is based on the assumption that climate change risks thrive because of markets' inability to adequately account for GHG emissions (Dafermos, 2021) and putting a cost on carbon is the most efficient way to reduce emissions (Ragan et al., 2015). However, pricing carbon primarily impacts high-emitting companies and sectors. This might lead to unintended consequences, such as unexpected asset revaluation, debt default, and uncontrolled carbon bubbles across evolving industries (Semieniuk et al., 2021). The effect of carbon pricing will not only influence high carbon-emitting sectors, which may accelerate green investment, but it could put current bank loans and financial commitments to high-emitting sectors at risk (Dafermos et al., 2018). These risks may lead to extensive economic impacts, particularly in countries with a high ratio of resource-based industries. Managing these risks becomes critical as the financial sector strives to achieve net-zero portfolios (Robins et al., 2021). This will have direct implications for the loan exposures of banks and consequently asks for pricing climate-related credit risks of borrowers (Ehlers et al., 2021). This paper seeks to identify how carbon pricing will impact specific industries and what this means for credit risk in resource-based economies. Though some studies analyzed the impact of carbon taxes (Campiglio, 2016; Li et al., 2022; Zhang et al., 2022), there is a gap in the literature that addresses how different carbon prices may play out for different sectors, especially in economies where carbon-intensive sectors are critical. Our paper also addresses the indirect impact of climate risks, such as carbon pricing, from a theoretical perspective. We consider the credit risk that borrowers and lenders might face due to increasing price points of carbon in the transition to a low-carbon economy (Benedetti et al., 2021).

3.3 Canadian Banks and Cost of Carbon

Canada manages its climate change through two separate approaches. The first is a Federal-led national carbon pricing policy that sets a minimum price on carbon emissions nationwide. The second involves respective provincial climate change carbon policies that supplement the federal rule using various approaches such as cap-and-trade and carbon intensity reduction systems. This paper is based on the Federal Climate Emission Reduction Plan (Government of Canada, 2022), which addresses the legislated carbon pricing cost until 2030. Through this legislation, the Canadian government has adopted a carbon price policy that will yearly increase the price of carbon emissions up to CAD \$170 per tonne of CO₂e by the Year 2030 (Environment & Canada, 2020b). This legislation represents a 467 per cent increase in cost for a tonne of CO₂e emissions for its duration, intending to add \$15 each year to the cost of carbon. This paper investigates the implication of this and other similar policies and how they could increase the risk of default for commercial loans to high carbon-emitting industries.

Understanding the impact of carbon pricing is even more critical considering that the cost of carbon is expected to rise until at least the year 2050 to help Canada meet its net zero target (Government of Canada, 2021). However, not much has changed in the financial sector's approach to lending to the most carbon-intensive sectors despite the enormous influence lenders and investors have on the carbon transition process (Dordi et al., 2022). Research has shown that increased carbon disclosure aids operational efficiency and helps reduce the cost of debt Wang et al., 2023). Also, financial institutions' climate disclosure has improved due to renewed commitments by banks, including the major Canadian chartered banks, to become net zero by 2050. Overall, it is unclear how banks intend to achieve their carbon emission reduction goal considering their current loan allocation, climate exposure to high emitting sectors and continued

exposure of Canadian financial institutions to fossil fuel investments and lending (Carter & Dordi, 2021).

Canadian banks are deeply involved in lending to carbon-intensive clients, with increased lending since 2016 (Rainforest Action Network, 2019) despite their public commitments to support global climate goals. Unfortunately, this is not too different from the global reality. For example, between 2015 when the Paris Agreement was signed and 2022, the world's top 60 largest banks have provided fossil fuel companies with over \$5.5 trillion in finance for investment in carbon-intensive fossil fuel projects, with Canadian banks providing \$862 billion of that amount (Rainforest Action Network, 2023). Canadian chartered banks also dominated new investments in Canada's oil sands crude oil projects, with multiple years of commitment in some cases (Rainforest Action Network, 2023; Rijk et al., 2021). In view of these new investments in carbon and increasing carbon cost, an important question is how these exposures would increase Canadian banks' (and other global creditors') credit risks considering the introduction of a carbon price regime by the government.

To put this in perspective, between 2014 and 2020, lending to the fossil fuel industry increased by over 50% among Canadian chartered banks, with one of them increasing its exposure by as high as 160 per cent (Rijk et al., 2021). The banks also increased their investment in oil shares and continued underwriting fossil fuel stocks and bond issuances (Gutstein, 2021). Since COP 21, Canadian chartered banks have been some of the most prominent financiers of the fossil fuel industry globally. Reports show that three of the top five banks in the country are among the top 10 fossil fuel financiers globally in 2022 (Network, 2023). As of 2021, Canadian chartered banks have collectively provided the coal and oil and gas industry with a combined value of over \$694 billion in loans and underwriting services (Kirsch et al., 2021; Rijk et al., 2021). The implication

of this increased carbon exposure could directly or indirectly affect the loan portfolio of banks as the cost of emitting carbon increases.

Also, Canadian banks continued exposure and investment in the fossil fuel industry contrast with the Bank of Canada's (BoC) classification of climate change as a critical risk to the economy and the stability of the Canadian financial system (Ens & Johnston, 2020). This poses a challenge as the Canadian economy is unique. The top six carbon-emitting sectors (oil and gas, transportation, buildings, utilities/electricity, heavy industry and agriculture) contribute over 55 per cent of the economy's total emissions and more than 30 per cent of Canada's GDP (*see Figure 3-1*). A review of the five Canadian chartered banks' loans and acceptances for the 2022 full year reveals that their respective exposure to high carbon-intensive sectors ranges from 14% to over 44%. This makes them highly vulnerable to regulatory imposed carbon prices on these sectors, considering that a carbon price increase may significantly affect the performance of these loans, which could increase climate transition risk for the banks.

This paper assesses how carbon pricing affects the credit risk of commercial loans in different industries using the Canadian government carbon price regime, as adopted by the BoC (Ens & Johnston, 2020; Environment & Canada, 2020b). We explore how the price increase will impact commercial credit. We posit that introducing a carbon price may have consequences for banks, since it may lead to increased default rates and reduced liquidity for carbon-intensive firms (Dafermos et al., 2018). Our analysis is also applicable to banks in similar resource-based countries, which may face stiffer impacts in this regard, especially if the composition of their loan books is skewed to carbon-intensive sectors.

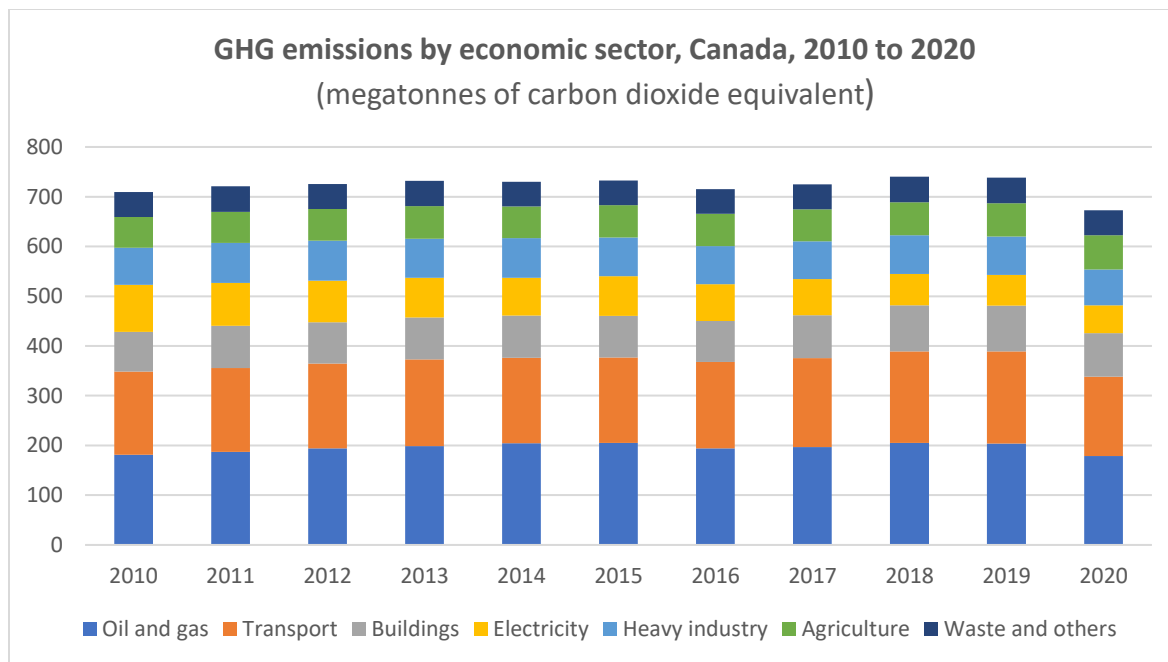


Figure 3-1: Canada's emission by sector adapted from environment Canada, 2023

3.4 Carbon Price Challenge for Resource-Based Economies

There is a growing body of work on the relationship between the economy and energy production in carbon-dependent countries and how climate mitigation efforts impact carbon-intensive sectors like oil and gas (Ike et al., 2020). This is important as studies have shown that climate transition efforts like the introduction of a carbon tax by major oil-producing countries like Norway and Canada have had little effect on oil production, but contributed to increased costs for consumers (Kopytin et al., 2020). Studies have also shown that a carbon tax has material implications for the share price of publicly quoted companies (Bimha & Nhamo, 2017). The combination of these two factors and the fact that there is a direct relationship between economic growth and activities in the carbon-intensive natural resource sector (Bekun et al., 2019) places banks exposed to these sectors at risk due to their importance to resource-based economies.

Also, market-based carbon pricing and the Emission Trading Systems (ETS) may be unsuccessful in transition economies and resource-dependent countries (Mukhtarov, 2022). Unlike what is obtainable in some parts of Europe where such measures are more established (Warwick & Ng, 2012), transition economies may struggle with adopting carbon prices due to issues of infrastructure, economic maturity and inadequate disclosure framework (Zheng et al., 2021; Z. Zhou et al., 2018). There is also a genuine concern over how carbon pricing will affect global competitiveness, especially for developing countries, and the price impact of the move on trade and the economy at large (Mukhtarov, 2022; Pradhan et al., 2017) all of which could have an indirect impact on lending cost thereby increasing credit risk (Bouchet & Guenedal, 2020) for the financial institutions operating in those sectors.

3.4.1 The Intersection of Climate Risk and Credit Risk

Several studies have been conducted to analyze the connection between environmental risks, such as climate change, and credit risk. Studies on environment-related credit risk suggest that integrating sustainability criteria, like carbon price decrease the default risk of commercial loans (Goss & Roberts, 2011; Weber et al., 2010). This is important considering that these risks should increase credit interest for high-emitting borrowers (Goss & Roberts, 2011), as well as reduce interest for low-emitters (Zeidan et al., 2015). Hence, there is an increasing credit spread between low and high environmentally conscious borrowers (Bae et al., 2018).

Concerning climate-related credit risk, Kabir et al. (2021) found that high-emitting companies have higher credit risks using Merton's difference-to-default approach (Merton, 1974). This study, however, did not consider carbon prices. In the European context, a study found that green portfolios have lower credit risks because of carbon-neutral obligors' low cash flow volatility (Umar et al., 2021) and because financial markets integrate carbon risks into their credit risk

assessment (Caragnano et al., 2020). This study used the costs of carbon emissions but did not use a credit risk model. A US study found similar results and emphasized the effect of carbon-intensive borrowers on credit risk (Safiullah et al., 2021). A study in India suggests similar findings (Kumar & Firoz, 2018). However, Jung et al. (2018) found that carbon awareness plays a significant role in helping to mitigate carbon-related risk and credit pricing. In line with Palea & Drogo (2020), they state that even high emitters aware of their emissions have to pay lower interest rates than others who are not transparent about their emissions.

We summarize that higher carbon emissions are associated with higher credit risk. However, since this is a fast-evolving field, no known studies use a carbon price and apply it to a credit risk assessment model, especially to consider sectoral peculiarity. Consequently, this study addresses this gap in literature.

Hence, the main objective of this research is to understand the impact of carbon pricing on commercial credit risk. To address this objective, we ask two questions:

- (1) Do different carbon prices influence the credit risk score of Canadian companies, and
- (2) is the credit score of different sectors affected differently by climate pricing.

3.4.2 Theoretical Framework and Methods

We used Altman's Z-Score model as our theoretical framework. Altman's Z-Score indicates credit default risk (Altman, 1968; Altman & Saunders, 1998) and its relation to credit risk management (Caouette et al., 1998). Companies with values below 1.8 are considered to be in distress. The area between 1.8 and 3.0 are considered grey, and Z-Scores above 3.0 are considered safe. We used the standard version of the Z-Score because all companies in the sample are publicly traded. The Z-Score for non-industrial companies (z'') only applied if these

companies are private. Furthermore, analyses demonstrated a high accuracy of the z score for mining companies (Altman, 2018). These mining companies are overrepresented in our Canadian sample. Moreover, studies suggest that mixing manufacturing and non-manufacturing firms in one sample does not change the results significantly (Altman et al., 1977). However, we calculated the correlation between the z and z'' for non-industrial companies to understand whether using z'' might make a difference. The correlation between both scores is $r = .98$ ($p < .0001$). The result demonstrates that there is no difference in using z'' instead of z (see Figure 3-2).

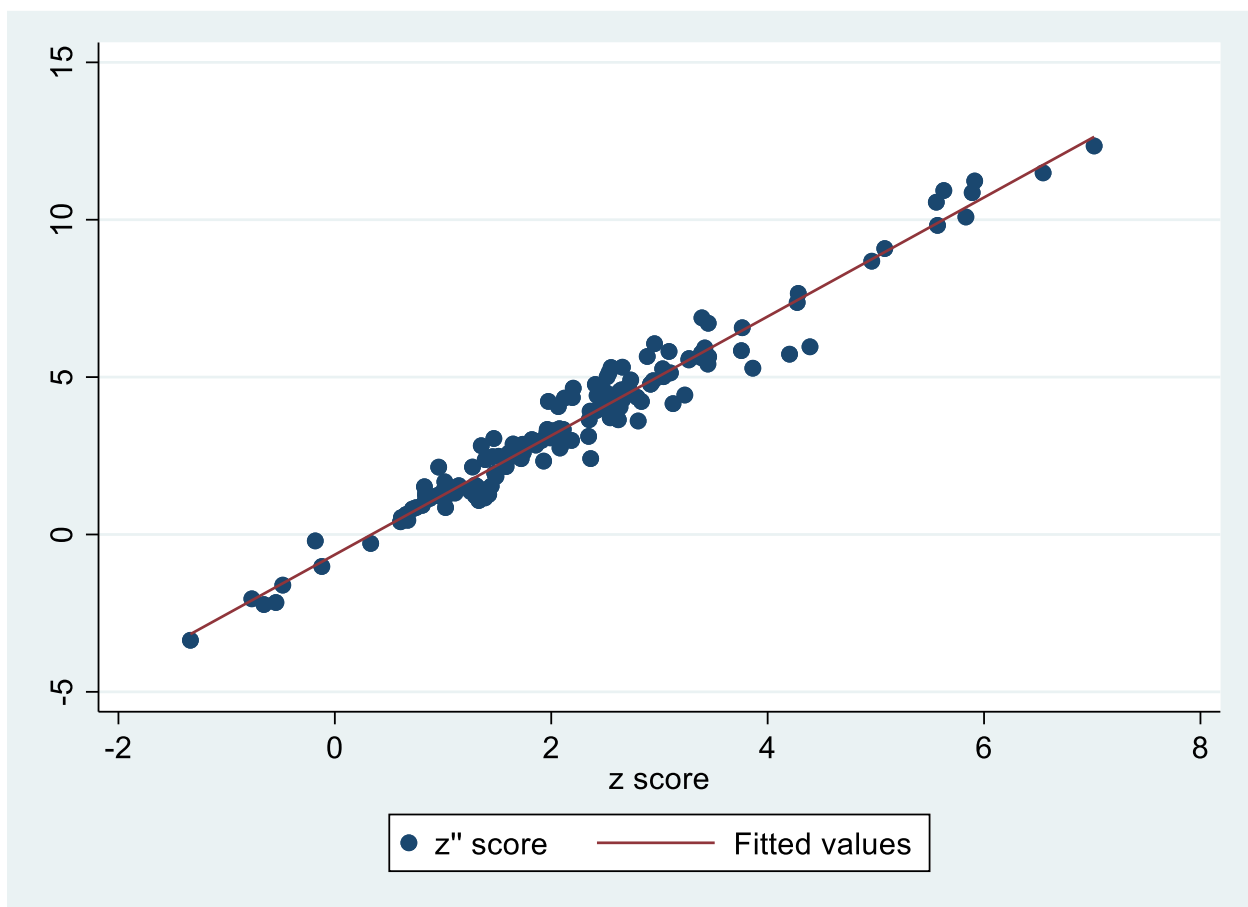


Figure 3-2: Correlation between z score and z'' score

We used Altman's Z-Score model with the financial indicators and weights presented in Equation

1:

Equation 1. Altman's Z-Score

$$Z = 1.2A + 1.4B + 3.3C + 0.6D + 1.0E$$

Where:

- Z represents Altman's Z-Score.
- A represents the Working Capital/Total Assets ratio.
- B represents Retained Earnings/Total Assets ratio.
- C represents EBIT/Total Assets ratio.
- D represents the Market Value of the Equity/Total Liabilities ratio.
- E represents the Total Sales/Total Assets ratio.

Values above 3.0 are considered safe, the area between 1.8 and 3.0 is considered grey, and borrowers with values below 1.8 are considered in distress.

To assess the influence of carbon prices on the Z-Score, we employed different carbon prices that align with the 2°C consistent carbon price projection used by the Bank of Canada scenarios (Ens & Johnston, 2020). As described above, the different scenarios are based on the carbon price, \$30, \$50, \$100, \$150, and \$170 per metric tonne of CO₂e.

We gathered the financial data for companies listed on the Canadian Toronto Stock Exchange (TSX) from Wharton Research Data Services (WRDS). The data for the total carbon emissions were also gathered from Refinitiv ESG hosted by WRDS. Using the historical emission data from publicly quoted companies, we calculated how the increase in carbon price impacts commercial borrowers and, consequently, a sector's credit default probability.

We calculated the Z-Score with and without carbon pricing based on the functions presented in Equation 1 and the financial indicators. The carbon costs were calculated by multiplying the carbon price per tonne of CO₂e with the total carbon emissions. Then we subtracted the value from the Earnings Before Interest and Tax (EBIT) and the Retained Earnings. This change leads to a decrease in the Z-Score and, consequently, to an increase in default risk.

We only used data for firms with Z-Score and emissions data for the same year between 2010 and 2020. Furthermore, we removed the financial sector because they use different financial indicators that do not fit the Z-Score model. The sample consists of 19 companies in 2020 and 2021, 20 companies per year between 2010 and 2014 and in 2019, 21 between 2015 and 2017, 22 in 2018, and eight companies for 2022.

To analyze the consequences of different emissions-cost scenarios, we used analyses of variance (ANOVA) with sectors and the year as factors and t-tests for the differences in the Z-Scores overall between industries and the difference in differences (the difference between a no-cost scenario and a carbon cost scenario between different sectors). Furthermore, we applied ANOVA for the difference in differences analysis. Using Global Industry Classification Standard (GICS), we could categorize the respective companies into individual sectors. Sectors' distributions are presented in Table 3-1. Hence, the sector distribution is typical for a resource and heavy energy industry, such as Canada and other countries that rely on high carbon-emitting industries.

Table 3-1: Canadian Sector Distribution for Years 2010 - 2022

GIC Sector	N	Total assets (\$mn)	Total debt (\$mn)	Manufacturing
Energy	49	2190778	570131	0
Materials	48	271595	48991	0
Industrials	12	295119	77332	0
Consumer discretionary	17	145707	15703	23
Information technologies	14	77264	18070	10
Communication services	10	480961	172704	0
Utilities	5	128098	52709	0

3.5 Results

The distribution of the Z-Score categorized by sector is presented in Figure 3-3. Overall, 25.5 per cent of the sample is in the distress zone below 1.8. However, ANOVA with the year and the sector as factors and the Z-Score as the dependent variable resulted in a significant difference between the industries regarding their Z-Score (ANOVA: $df = 71$, $F = 3.40$, $p < .0001$). The year did not have a significant effect, and there is no significant interaction between the year and the sectors. Consumer discretionary has a significantly higher Z-Score than the other sectors, according to a post hoc Scheffe test.

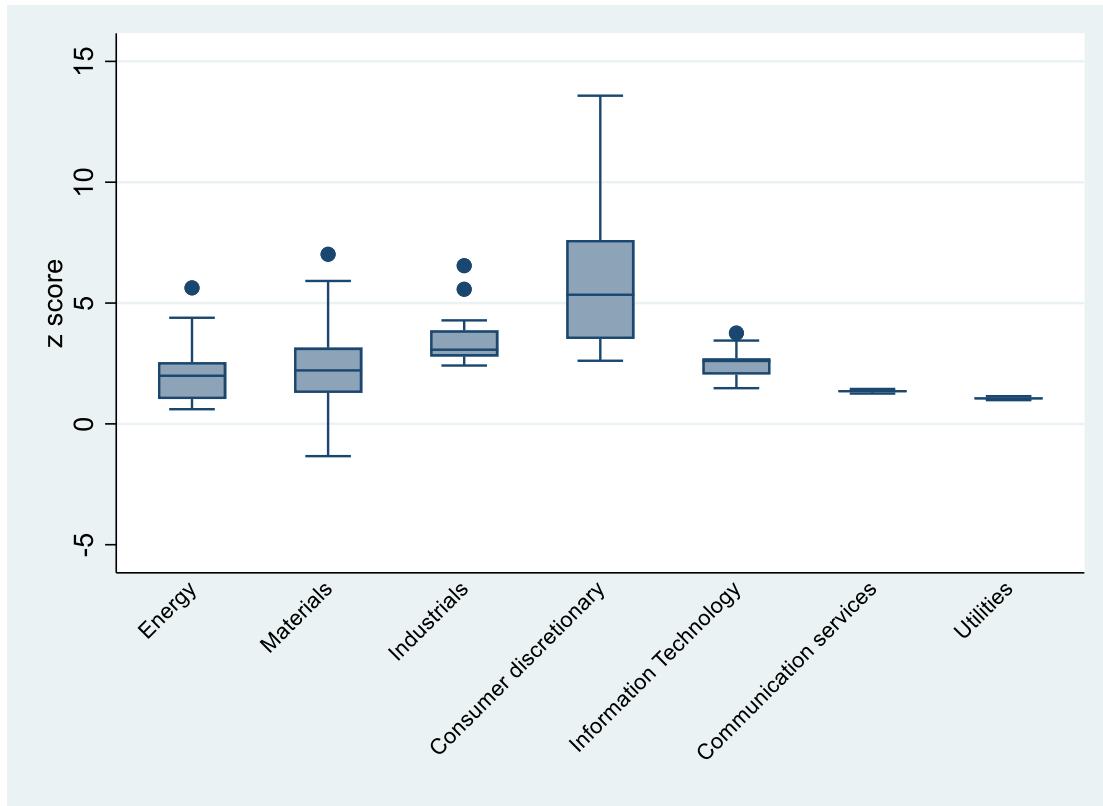


Figure 3-3: Box plots for the Z-Score without carbon price per sector

The average emission costs of \$ million for the different pricing scenarios are distributed as presented in Table 3-2. Energy, Industrials, and Materials sectors have the highest carbon emissions and must bear the highest costs if GHG emissions are priced.

Table 3-2: Average carbon costs under the different cost scenarios per sector in \$million

Sector	\$30	\$50	\$100	\$150	\$170
Energy	318.00	530.00	1060.00	1590.00	1800.00
Materials	38.10	63.50	127.00	190.00	216.00
Industrials	121.00	202.00	404.00	607.00	687.00
Consumer discretionary	24.30	40.40	80.90	121.00	137.00
Information technology	3.64	6.07	12.10	18.20	20.70
Communication services	9.20	15.30	30.70	46.00	52.20
Utilities	10.00	16.70	33.40	50.10	56.80
Total	121.00	201.00	402.00	603.00	683.00

Next, the influence of carbon costs on the Z-Score was calculated. Figure 3-4 presents the difference between the Z-Score, including the carbon costs, and the Z-Score without carbon costs for the different sectors. The highest differences can be found in energy and materials, which already have relatively low Z-Scores compared to lower-emitting industries. The difference in the z score between all pricing scenarios, including a carbon price of \$0, is significant (Hotelling test: $T = 112.54$, $p < .0001$).

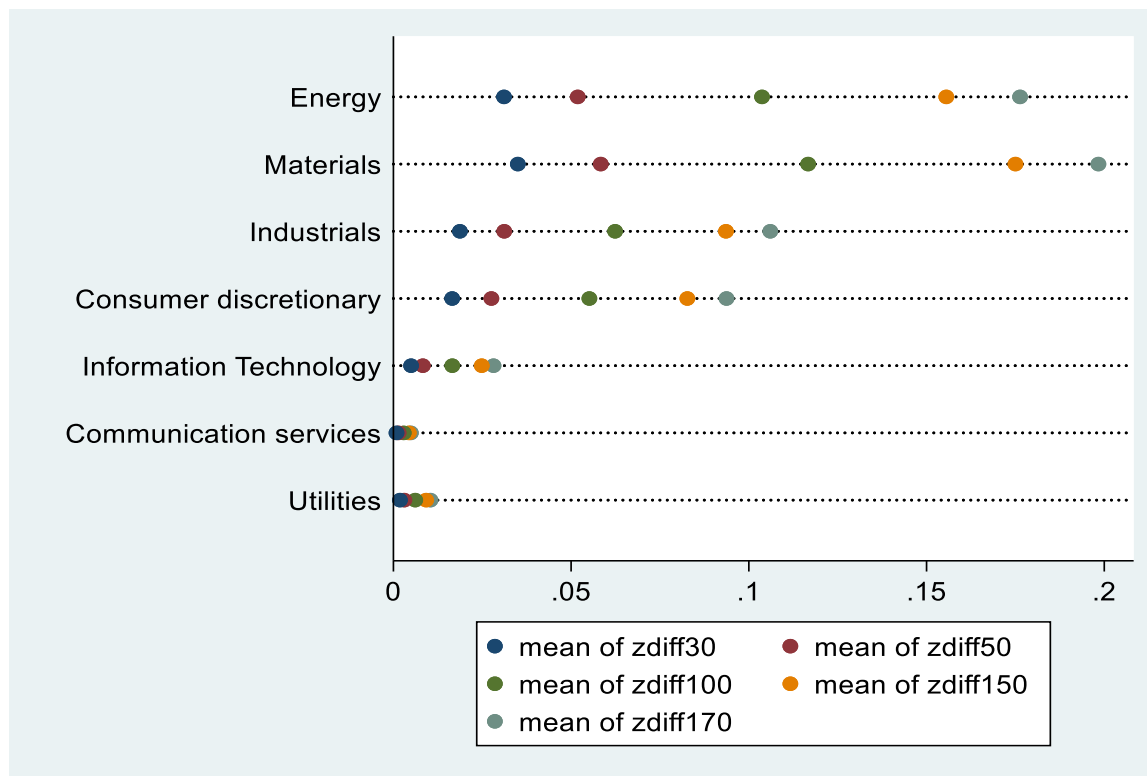


Figure 3-4: Difference in Z-Scores under different carbon price scenarios

On average, the Z-Score decreases by .024 for the \$30 scenario and by .14 under a \$170 scenario. Furthermore, the biggest change is for Materials with 0.20 and Energy with 0.18 for the \$170 scenario. Hence, the difference in the highest emitting industry (Materials) is 0.06 or 42 per cent higher than the average change induced by carbon pricing. The Z-Scores for materials and energy are already some of the lowest without carbon costs (see Table 3), so a carbon price can put high-emitting sectors in distress.

Table 3-3 demonstrates that the carbon price adjusted z score of firms from the Energy sector decreases to below 2.0, which is near the distress threshold. The low z score for utilities that are already in the distress zone decreases even more.

Table 3-3: Z-Scores by sector for different pricing scenarios (No pricing, \$30, \$50, \$100, \$150, \$170)

Sector	z score	z score \$30	z score \$50	z score \$100	z score \$150	z score \$170
Energy	2.027	1.996	1.975	1.924	1.872	1.851
Materials	2.278	2.243	2.220	2.162	2.103	2.080
Industrials	3.567	3.548	3.536	3.504	3.473	3.461
Consumer discretionary	6.199	6.181	6.170	6.141	6.112	6.100
Information technology	2.521	2.515	2.512	2.503	2.494	2.491
Communication services	1.354	1.353	1.352	1.351	1.350	1.349
Utilities	1.068	1.066	1.065	1.062	1.059	1.057
Total	2.636	2.612	2.595	2.555	2.514	2.497

Consequently, we conducted a difference-in-differences analysis using ANOVA with the sector and the year as independent factors and the z score difference between the z score without carbon costs and the z score with a carbon cost of \$30 per tonne CO₂e. The result of the model is significant ($p < .030$, $df = 17$, $F = 1.81$, $r^2 = .16$). On the factors, the sector is significant ($p < .0001$, $df = 6$, $F = 4.89$). The year is also not significant ($p < .9999$, $df = 11$, $F = .10$). The results show that the differences in z scores between sectors are different to those presented in Figure 3-4.

3.6 Discussion

We analyzed the impact of different carbon pricing scenarios on the Z-Score of various industries in an economy that is highly exposed to carbon-emitting sectors. Our results showed a significant decrease in the Z-Score value of Canadian companies if a carbon price is introduced.

Furthermore, the reduction is higher in high-emitting industries like materials and energy. This means that the default risk of banks' lending portfolios with considerable exposure to high-emitting industries increases under different carbon pricing scenarios. This is concerning, given that high-emitting industries already have lower Z-Scores than the average score of other sectors. It also underscores that carbon pricing would have different impacts on different industries, like studies on the environmental effects on various industries' financial performance (Semenova & Hassel, 2016). Consequently, there is a risk that specific sectors will find themselves in Altman's distress zone below 1.8, indicating a high risk of default. Thus, banks will need higher allowances for potential credit default.

In general, this study suggests that portfolios of banks in countries with high emitting industry exposure are exposed to higher financial risks than banks in economies based on lower emitting industries if carbon pricing is implemented since they are often more exposed to the high-emitting industries. This is prevalent in economies where such sectors are critically linked to other carbon-dependent sectors. Safiullah et al. (2021) and Kumar and Firoz (2018) found similar results for the United States and India respectively in both instances, they concluded that there are higher risks for high-emitting sectors.

Regarding our research questions, the results suggest that carbon pricing influences Canadian companies' credit scores. Also, the analysis shows that carbon pricing affects different sectors.

Hence, our study aligns with other studies that show the impact of environmental and sustainability criteria on credit risk.

Several studies have been conducted to analyze the connection between societal, environmental, and sustainability risks, such as climate change and credit risk. However, in contrast to studies by Goss and Roberts (2011) and Weber et al. (2010), we used different carbon prices and carbon emissions as our independent variables. Consequently, we could demonstrate the impact of carbon emissions based on financial indicators and not on the financial market or analysts' valuations.

Hence, carbon emissions and carbon price scenarios should be part of the credit risk assessment procedure because this study and others found an increase in credit risk for sustainability laggards (Bae et al., 2017; Zeidan et al., 2015). Our study, however, added the effect of carbon pricing to the analysis in contrast to studies that did not consider a carbon price but only GHG emissions (Kabir et al., 2021). High emissions that are not priced might not have a financial impact and might not influence credit risk. This might be the reason why many studies in Europe that have implemented carbon pricing find a connection between high carbon emissions and credit risk (Caragnano et al., 2020; Umar et al., 2021).

Furthermore, our study addresses a theoretical approach to credit risk using Altman's Z-Score (Altman, 1968). Hence, it is independent of real credit pricing, which might be biased. We conclude that whether lenders and financial markets consider GHG emissions and a climate price or not, there is a financial risk for high emitters due to increasing legislation on carbon prices.

3.7 Conclusion

This paper addresses an important gap in carbon cost and credit risk research. By analyzing the impact of carbon cost on credit, this study provides insights into how carbon pricing policies affect credit risk. Of particular interest is the role of evolving climate regulations on carbon transition efforts and the need to develop necessary policy strategy for regulators and an approach for lenders that will help drive a seamless transition to a low-carbon economy with minimal disruption to credit. Based on our results, we propose that lenders should start or continue to consider a real and a shadow carbon price that reflects pricing scenarios in their credit risk assessments. Perhaps, implementing an internal carbon price on credit will be a good starting point for financial institutions' climate mitigation efforts against transition climate risk like the government-imposed carbon tax impact that this study addresses. This will enable financial institutions to analyze carbon-related credit risks appropriately and set the appropriate interest rate. A consequence might be that high-emitting borrowers would have to pay higher interest.

Central Banks and other financial sector supervisors should also start introducing indicators that measure the financial sector's exposure to climate-related credit risks. Since introducing carbon price is very likely in many countries, these risks might affect the financial industry.

Consequently, supervisors and regulators should use carbon pricing scenarios proposed by the Task Force on Climate-related Financial Disclosures (2017) to analyze portfolio climate risks (Nguyen et al., 2020). Finally, there is a need to improve GHG emissions reporting and disclosure as this will help the quality of data. A weakness of this study is missing data, as some firms do not even disclose their Scope 1 emissions (direct emissions from a company's operations). This issue is exacerbated when data for Scope 2 (indirect emissions from purchased

energy) and Scope 3 emissions (indirect emissions across the value chain) are considered. Though Downie & Stubbs (2013) discussed this problem in 2013, this challenge persists a decade later as the data for Scope 2 and 3 emissions are still largely unavailable and unreliable.

3.8 Additional Comments

The paper contributes to the ongoing conversation on climate transition risk impact as it highlights the relationship between climate risk, regulatory action targeted at addressing it and the overall impact on financial stability especially in carbon-intensive economies. The study's findings provide a crucial lens through which policymakers, financial institutions, and corporate stakeholders can better understand the complicated impact of carbon pricing as a carbon regulatory instrument on credit risk. In an era of accelerating climate change and tightening regulatory frameworks, the paper exploration of how carbon costs impact the creditworthiness of firms within a resource-dependent economy such as Canada is both timely and pertinent especially considering the current geo-political climate in North America. The insights derived from the application of Altman's Z-Score model to evaluate the potential insolvency risks posed by various carbon pricing scenarios contribute to the growing body of literature on sustainable finance, bridging a critical gap in empirical knowledge on sectoral financial exposure to climate policies (Altman, 1968; Bouchet & Guenedal, 2020; Colmer et al., 2024).

This research is particularly relevant given the contemporary climate risk environment, which is characterized by the mounting pressure on governments to align economic activities with the Paris Agreement targets (UNFCCC, 2015). The study's findings highlight the challenges that carbon-intensive industries face under escalating carbon pricing policies, while providing insight into the broader economic implications for economies that are heavily reliant on carbon-intensive sectors (Stavins, 2022). This is even more important considering the current elections and geo-

political and economic climate and conversations where carbon price have been at the centerstage of political parties' campaigns and conversations in Canada (Global News, 2025), where industries such as energy and mining are integral to GDP contributions and employment (Environment & Canada, 2020a). This necessitates a comprehensive approach that integrates climate risk considerations into financial decision-making processes, ensuring that credit risk assessments account for evolving regulatory landscapes and transition risks (TCFD, 2017).

Looking forward, the findings of this research provide an invaluable foundation for future inquiries into the resilience of financial institutions and economies in the face of climate transition risks. As regulatory pressures intensify and market-based mechanisms such as carbon pricing become more widespread, understanding sector-specific vulnerabilities is critical to devising risk mitigation strategies (Bouchet & Le Guenedal, 2020). The study serves as a call to action for lenders to incorporate climate transition risk into their credit evaluation frameworks proactively and for policymakers to design transition strategies that minimize economic dislocation while fostering low-carbon innovation (Stavins, 2022). This is important considering that carbon pricing impacts extend beyond financial risk to social and economic stability. Overall, this chapter reinforces the pressing need for an integrated approach to financial stability and environmental sustainability, aligning economic growth with climate resilience and emissions reduction goals (Environment & Canada, 2020a).

Chapter 4

Carbon Pricing Impact on Credit Risk

Adeboye Oyegunle, Olaf Weber, Sara Aghakazemjourabbaf & Amr ElAlfy

This paper was submitted to the Journal of Sustainability and Finance, where it received a verdict of “Revise and Resubmit”. This chapter represents the final revised version of the manuscript, incorporating the feedback provided by the reviewers.

4.1 Introduction

Climate-related risks have increased regulatory interest in climate change mitigation, adaptation, and managing economic consequences such as financial stability. One market-based regulation targeted at reducing Greenhouse Gas (GHG) emissions (X. Li et al., 2017) is carbon pricing (Skovgaard et al., 2019). In its simplest form, carbon pricing puts a cost on GHG emissions, which can take the form of carbon taxes or an emission trading systems (ETS), commonly referred to as cap-and-trade systems. The goal is to make the emitters responsible for their emissions, with the expectation that pricing will incentivize the introduction of technologies to reduce emissions or enhance the purchase of emission credits in the case of the cap-and-trade system. In combination with a carbon cap, carbon pricing should reduce the total GHG emissions without regulating them directly. Various studies have recognized carbon pricing as the most economically efficient market-based mechanism for mitigating GHG emissions (Baranzini et al., 2017; Trinks et al., 2022). Intending to reduce carbon emissions and meet their Nationally Determined Contributions (NDCs) agreements (Leggett, 2020; UNFCCC, 2020), regulators and state actors have been adopting varied approaches to carbon pricing.

Though studies show that not addressing climate risks bears the highest risk for economies and the financial system (Battiston et al., 2021), carbon pricing is not without risks. Researchers have argued that carbon pricing poses a unique set of systemic risks to businesses with significant consequences for the financial sector (Khalfaoui et al., 2022). Implementing carbon pricing may also have local economic implications due to the direct impact on prices at the domestic market level, whereas the benefit of carbon reduction is global (Linsenmeier et al., 2023). The localization of the cost effect of carbon on a country, sector, or regional level raises the question of carbon cost context (HBDP, 2021), which addresses the contextual nature of carbon and, in this instance, investigates its impact on costs for sectors, regions, and markets. However, only very few studies address the effect of carbon pricing on commercial credit risk (Aiello & Angelico, 2023; Capasso et al., 2020; Mathiesen, 2018; Oyegunle et al., 2023), while studies on the comparability of outcomes at the regional levels are almost non-existent. Thus, there is a need for more research on the effect of carbon pricing on credit risk in different countries and regions, including emerging and developing countries.

This study analyzes the potential credit exposure associated with adopting carbon pricing at the sectoral and regional levels based on two International Energy Agency (IEA) scenarios. The IEA scenarios were chosen over alternatives such as the Network for Greening the Financial System (NGFS) scenarios because they align more closely with our research objectives, which is providing insights into the impact of carbon pricing on crucial sectors. Also, the IEA offers detailed carbon pricing data, enhancing the accuracy of our results, whereas the NGFS is focused on assessing the broad macroeconomic impacts, and data is mainly aggregated to the sector rather than firm-level responses (Gourdel et al., 2024; NGFS, 2020). Using Altman's Z-Score as our theoretical framework, we tested if introducing carbon pricing contributes to credit risk.

Understanding this connection is critical, considering that the financial sector is exposed to climate transition risk through transmission channels such as policies promoting a carbon-neutral economy, like carbon taxes, and its potential to increase the volatility of headline inflation, particularly through energy prices (Bolton et al., 2021).

Furthermore, we analyzed differences between regions and markets and how the policies could impact credit across different regions and sectors. We adopted the IEA carbon price scenario (IEA, 2023), the IEA's latest and most detailed carbon pricing model, for our analysis. This is critical to our assessment as it has a detailed breakdown of carbon pricing costs at the global level.

We modified Altman's Z-Score by adding carbon cost to the respective borrowers' operational costs and profitability. Similar approaches have been used in earlier studies that analyzed the impact of carbon costs on credit risk (Capasso et al., 2020; Jung et al., 2018; Kabir et al., 2021). We then analyzed regional, sectoral, and scenario-based outcomes to determine whether carbon pricing influences credit risk and whether there are differences between regions, sectors, and scenarios.

Our research found fundamental differences in how carbon prices influence credit risks across different sectors and regions. Our findings suggest discrepancies in the effects of carbon pricing across different sectors, where companies in carbon-intensive sectors tend to be more at risk than those with lower emissions.

This paper contributes to academic research by addressing contextual concerns in implementing climate policies and considering the regional and sectoral implications of carbon pricing on credit risk. Our study underscores the crucial importance of contextual considerations for transition climate risk implementation. It also emphasizes the need to address climate risk

impacts on credit risk at a more granular level that identifies regional, sectoral, and systemic implications of carbon pricing on credit risk. Theoretically, this paper contributes to climate discussion on financial stability by assessing the role of carbon pricing policy and its impact on climate transition efforts.

Our study establishes a theoretical link between financial stability theory and climate risk.

Specifically, our analysis focuses on regulation as a component of climate transition risk by emphasizing how changes in government climate transition efforts, such as introducing a carbon price policy, may impact credit risk and influence the stability of the economy and financial institutions that manage it. By going beyond traditional financial metrics and incorporating carbon pricing into the credit risk mix, the outcomes from this paper will enable financial institutions and policymakers to anticipate changes to credit risk outcomes because of climate risk impact under applicable different economic scenarios. Overall, this study will help advance the understanding of the complex interactions between climate risk and credit risk, providing valuable insights for academic scholars and practitioners in finance.

The remainder of the paper is structured as follows: We will start with a literature review of carbon pricing and credit risk. Then, we will discuss the research objective and questions, followed by the Methods section. After describing the model framework and development, we present the results of the study. The paper concludes with a discussion of the results and the limitations of the study.

4.2 Carbon Pricing and Credit Risk

Carbon pricing is based on the premise that climate change results from market failures (Andrew, 2008) and can be rectified by placing a price on carbon to cover the social, economic, and environmental costs of GHG emissions (Nordhaus, 2013). As research on carbon pricing and

climate risk advances, there is a growing interest in understanding the connection between carbon pricing and its impact on climate transition efforts. Recent studies have evaluated the influence of carbon pricing on credit risk at the national (Aiello & Angelico, 2023), regional levels (Umar et al., 2021), and for specific economic sectors such as oil and gas (Antón, 2020). These studies highlighted different findings regarding the impact of carbon pricing, thus reflecting varied perspectives in the literature. Despite differing opinions on the extent of carbon pricing's impact and how it manifests at the economic, geographical, and sector-specific levels, researchers generally agree that there is a connection between carbon pricing and credit risk (Ivanov et al., 2023).

This connection to credit risk increases the likelihood of credit portfolios being impacted, amplifies lenders' vulnerability, and decreases the financial industry's stability (F. Zhou et al., 2023). Credit risk contributes to the spillover effect of climate risk within the banking sector (Wu et al., 2023), mainly affecting banks with substantial exposure to carbon-intensive sectors (Semieniuk et al., 2021). Carbon pricing thus emerges as a focal point in the credit risk discourse, given that banks with high exposure to carbon-related assets may face an increased likelihood of credit default among specific borrowers (Ivanov et al., 2023). This may pose a unique challenge considering banks' crucial intermediary function vital for channeling financial resources in the economy (Aracil et al., 2021).

According to The World Bank, 73 carbon pricing initiatives exist worldwide at both national and supranational levels (The World Bank, 2024). These initiatives are designed to tax carbon by ensuring that emitters bear their fair share of GHG emissions in line with respective national and international obligations for carbon emission reduction, as outlined by the Intergovernmental Panel on Climate (IPCC, 2018). There is a growing body of research on carbon pricing (Bouchet

& Guenedal, 2020) which acknowledges the increasing divide (Cramton et al., 2017) and lack of uniformity in carbon pricing approaches and their adoption (Bergh et al., 2020).

Globally, countries, regions, and regulatory bodies actively pursue different carbon reduction strategies to address their respective greenhouse gas emissions challenges and use carbon pricing as a fundamental strategy to fulfill these objectives (Pradhan et al., 2017). For example, though it has been argued that climate change risk management should be the responsibility of elected officials and not central banks, numerous developing and emerging economies that rely on natural resources often engage in emission-intensive production and consumption practices (Ari & Sari, 2017). Consequently, these economies tend to be more lenient in adopting carbon pricing, given its critical implications for the carbon-intensive sector to their local economic survival (Dorband et al., 2019). This concern is not unfounded as a recent study exploring the macroeconomic effects of uncertainty surrounding environmental policies shows that firms reaction to uncertain climate regulations, such as carbon taxes and emission caps, will lead to reduced investment, lower employment, decreased consumption, and heightened inflation, which will require central banks to adopt aggressive monetary policies to stabilize GDP and inflation (B. Huang & Punzi, 2024).

At the corporate level, carbon pricing initiatives and other transition policies have proven to have varying impacts on credit risk and corporate behaviour across sectors. For example, Lin & Pan, (2023) investigated the financing decisions of heavily polluting enterprises under green credit policies. Also, Zhang et al. (2022) assessed operational strategies in low-carbon supply chains, considering the influence of carbon credits, while Gourdel et al. (2024) argue that organizational climate policy expectations influence their investment in high or low-carbon business since companies that have positive climate sentiments backed by credible climate policies, tend to

invest in low-carbon goods sooner, thus facilitating economic decarbonization and reducing carbon-stranded asset risks. These studies underscore the intricate relationship between climate policies, such as carbon pricing policies, their impact on corporate financial decisions, and the broader economic implications accompanying such interplay. Understanding these dynamics is crucial for policymakers and stakeholders seeking to design effective carbon pricing mechanisms that promote the climate transition process while mitigating financial risks.

Studies on credit risks have shown that financial institutions are critically exposed to climate change (Battiston et al., 2017), even as credit exposure to specific industries is crucial to local economies (BoC & OSFI, 2022). There is also the argument on the implication of different carbon pricing models, as some studies have argued on the inadequacy of the current carbon pricing system (X. Liu et al., 2023), while others have suggested a need for uniformly pricing global carbon emission at a discounted value of all future damage of today's emission (Olijslagers et al., 2023). Some studies also question the relevance of the market approach to GHG emissions, highlighting the shortcomings of carbon prices regarding achieving contextual policies and political priorities (Rosenbloom et al., 2020).

Studies have also explored the complex relationship between climate risk, investor sentiment, and corporate behaviour, providing valuable insights into carbon pricing's impact on financial stability. For example, Li et al. (2023) investigated market reactions to climate risk disclosures. Their research shows that investors' attention and sentiments are essential in shaping market responses. Also, Phan et al. (2022) examined the impact of carbon risk (also known as carbon transition risk such as the adverse effects of unexpected changes in carbon prices on businesses and investment portfolios) on corporate investment across countries; they discovered that carbon risk affects corporate investment patterns across different countries differently, suggesting that

high carbon risk can deter firms from making substantial long-term investments, which could indirectly affect credit risk. Meanwhile, Arfaoui et al. (2024) assessed whether green investment funds could hedge climate risk, providing a perspective on how investment strategies might adapt to increasing carbon risks. The different outcomes across these studies suggest a nuanced relationship between carbon risk, market behaviour, and corporate investment, illustrating the broader implications of carbon pricing on credit risk.

Conversely, it has been argued that carbon pricing has an insignificant effect on the overall economic activity and greenhouse gas emissions in developing countries with low emissions and economic activities (Mengistu et al., 2019). Not considering that there is an increased push for carbon pricing implementation globally (Khan & Johansson, 2022), and some developed economies have seen an increase in adoption (Narassimhan et al., 2018) despite heightened political pushback fueled by a growing anti-ESG movement (Garrett & Ivanov, 2022). However, more recent research on the EU Emissions Trading System (ETS) shows that the policy helped to reduce CO₂ emissions by 14-16% in regulated manufacturing firms without negatively impacting economic performance, primarily through investments in cleaner technologies that lowered emissions intensity (Colmer et al., 2024). Despite this evidence, some studies have argued for the absence of statistically significant impacts on competitive dimensions from carbon pricing adoption (Venmans et al., 2020). Other papers have also expressed concerns about economies with high carbon-intensive exposure facing heightened challenges (Cust & Zeufack, 2023) since carbon pricing may elevate risks for businesses in carbon-intensive industries that are ill-prepared for the transition, which may potentially impact their creditworthiness (Bouchet & Le Guenedal, 2020) while increasing credit risk for the banks that fund them (Weber & Oyegunle, 2019). Other studies have demonstrated a causal relationship between climate exposure and

increased borrower risk (Bernstein et al., 2019), suggesting that climate-related risk can influence creditworthiness and lending decisions (Bolton et al., 2020).

Considering the diverse arguments against and in favour of the viability of carbon pricing, there is a need for empirical analysis of its impact on credit risks, considering the highlighted social and political influences (Shang, 2023). This paper addresses this need by taking a forward-looking approach to assessing the plausible regional and sectorial impact of carbon pricing on credit risks over the next two and a half decades in line with global carbon transition targets (Dubash, 2023). This helps address the impact beyond the impact of existing policies such as the EU ETS (Colmer et al., 2024), but further provides critical stakeholders, including investors, banks, and regulators, insights to further comprehend how climate-related transition risks, such as introducing carbon pricing (Emeka-Okoli et al., 2024) will affect their portfolios and interests.

4.3 Research Objective and Questions

This research analyzes the impact of different carbon pricing scenarios on commercial credit risks compared to a no-price scenario. Consequently, our research questions are:

- What are the effects of different carbon pricing scenarios on commercial credit risk?
- How do different carbon pricing scenarios affect commercial credit risk for different sectors and regions?

We hypothesize that higher carbon prices decrease the Z-Score. We further hypothesize that the credit scores of high-emitting sectors are more affected than those of low-emitting sectors. The rationale behind these hypotheses is that carbon costs, like other costs, impact credit risk. This connection has been found in the literature in other studies (Aiello & Angelico, 2023; Bouchet & Guenedal, 2020; Oyegunle et al., 2023; Safiullah et al., 2021). Another group of studies suggests that particularly high-emitting industries' credit risks are influenced by carbon prices (Benjamin,

2013; Mésonnier, 2022; Pineau & Zuñiga, 2024). However, in contrast to these studies, we focus on emerging countries.

4.4 Methods

Using the IEA Scenarios (IEA, 2022) and Year 2019 as our baseline, this paper modeled and calculated credit risk for different sectors under various scenarios. Countries' income levels are classified using the World Bank and IMF classification (See Table 4-1) of their respective economies into developing, emerging, and developed economies (See Table 4-2).

Table 4-1: Country breakdown based on World Bank, Market and IEA Classifications

World Bank Classification	Market Classification	IEA Scenario Classification adopted for this research	
		Announced Pledge Scenario (APS)	Net Zero Emissions (NZE)
High-income	Advanced Economies	Advanced economies with net zero emissions pledges	Advanced Economies with net zero pledges
Upper middle	Emerging Economies	Emerging Market and developing economies with net zero emissions pledges	Emerging Market and developing economies (without net zero pledges)
Lower middle		Other Emerging Markets & Developing economies	Selected emerging Market and developing economies with net zero pledges
Low Income	Developing Economies		Other Emerging Markets & Developing economies

Note: Table developed by authors based on World Bank Classification (The World Bank, 2024)

This study analyses the impact of the respective climate price policies across different regions and how increasing carbon price impacts the credit risk in various economic sectors, countries,

and regions until 2050. We also explored how APS and NZE Scenarios (IEA, 2022) influence credit risk in different regions.

Table 4-2: Country breakdown based on income level

Countries, Economic Classifications and Sector			
Advanced Economies	Major Emerging Economies	Other Emerging Markets & Developing	Sectors
The EU and European Economic Area (EEA)	Mainly BRICS Economies –	Argentina	Utilities
Countries: (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Norway, Poland, Portugal, Luxembourg, Netherlands, Spain, Sweden, Switzerland),	Brazil	Colombia	Energy
Australia, Hong Kong, Canada, Chile, Israel, Japan, Korea, New Zealand, Qatar, Saudi Arabia, Singapore, Taiwan United Arab Emirates, United Kingdom, United States	China	Egypt	Healthcare
	India	Indonesia	Consumer
	Russia	Malaysia	Discretionary
	South Africa	Mexico	Industrials
		Nigeria	Consumer Staples
		Philippines	Information
		Thailand	Technology
		Turkey	Materials

Note: Table developed by authors based on IEA (2023)

For the scenarios, we simulated the influence of corresponding carbon prices on two indicators of the Z-Score – Earnings Before Interest and Taxes (EBIT), which measures a company's net income before deducting income tax and interest expenses (indicative of its operating profit and

earnings generation efficiency), and Retained Earnings, representing the cumulative net income of the evaluated companies after accounting for dividends. This approach assists in assessing the cost of carbon on a company's operations and profits by subtracting the cost from the original values of the two indicators and comparing the resulting impact on the Z-Score (Oyegunle et al., 2023). The Refinitiv ESG hosted by Wharton Research Data Services was used to collate publicly available data on companies' financial results across different regions. In contrast, the emissions data was sourced from Sustainalytics. Both data were matched and reviewed for completeness for the period analyzed. 1243 publicly quoted companies were analyzed across eight sectors and six global regions (see Table 4-3).

Table 4-3: Regional classification of the sample.

Regional Classification (k)	No of Companies	(N=1243)
Latin America & Caribbean	23	1.85%
East Asia & Pacific	65	5.229%
Europe and Central Asia	77	6.195%
North America	1059	85%
Middle East and North Africa	12	0.963%
Sub-Saharan Africa	7	0.563%

4.5 Model Framework and Development

To calculate the cost of carbon, an individual company and its sector are denoted as i and j , respectively, while the carbon price is denoted at each time by $P(t)$ in which $t \in [2030, 2040, 2050]$. In this study, the price of carbon at each region, k , depends on two scenarios, denoted by s , as follows:

Announced Pledge Scenario (APS)

Net-Zero Emission Scenario (NZE)

We calculate the cost of carbon, cc , for each company operating in a sector within its region across each scenario as follows:

$$cc_{i,j}^{s,k}(t) = P^{s,k}(t) \times e_{i,j}^k(t) \quad (1)$$

Where: e denotes the company's CO₂e emissions.

To calculate the average cost of carbon at each sector for each scenario, $CC_j^{s,k}$, we take the average of all companies' emissions in each sector within a region. Thus, we have:

$$CC_j^{s,k}(t) = P^{s,k}(t) \times E_j^k(t) \quad (2)$$

Where: $CC_j(t) = \frac{\sum_{i=1}^N cc_{i,j}^k(t)}{N_j^k}$, $E_j(t) = \frac{\sum_{i=1}^N e_{i,j}^k(t)}{N_j^k}$, and N_j^k denotes the number of companies in sector j and region k

All notations and variables are summarized in *Table 4-4*

Table 4-4: Table of Variables

Variable Name	Notation
Company	i
Sector	j
Region	k
Scenario	s
Time	$t \in [2030, 2040, 2050]$
Carbon Price per region and scenario	$P^{s,k}$
Company emissions in a sector region at each time	$e_{i,j}^k(t)$
Average sectoral and regional-based emissions across each scenario	E_j^k
A company's sectoral and regional-based cost of carbon across each scenario	$cc_{i,j}^{s,k}$
Average sectoral and regional-based cost of carbon across each scenario	$CC_j^{s,k}$
Number of companies in a sector and region	N_j^k
Retained Earnings in a sector region at each time	$RE_{i,j}^k(t)$

To calculate the Z-Score, we used the Altman Z-Score model (Altman, 1968). This model forecasts the possibility of a publicly quoted company being distressed. The model uses a combination of weighted financial ratios (see Table 4-5) to model the likelihood of a credit default (see Equation 1).

Table 4-5: Altman Z-Score Variables

Altman's Z-Score variables	
$U_{i,j}^k(t)$	Working capital / total assets in a sector region at each time
$V_{i,j}^k(t)$	Retained earnings / total assets in a sector region at each time
$W_{i,j}^k(t)$	Earnings before interest and task payment /total assets in a sector region at each time
$X_{i,j}^k(t)$	The equity's market value / total liabilities in a sector region at each time
$Y_{i,j}^k(t)$	Total sales / total assets in a sector region at each time

Equation 1: Altman's Z-Score (represented by notation “z”)

$$z_{i,j}^k(t) = 1.2U_{i,j}^k(t) + 1.4V_{i,j}^k(t) + 3.3W_{i,j}^k(t) + 0.6X_{i,j}^k(t) + 1.0Y_{i,j}^k(t)$$

$$\text{Where } U_{i,j}^k(t) = \frac{\text{Working Capital}}{\text{Total Assets}}, V_{i,j}^k(t) = \frac{\text{Retained Earnings}}{\text{Total Assets}}, W_{i,j}^k(t) = \frac{\text{Earnings Before Interest and Tax}}{\text{Total Assets}}, X_{i,j}^k(t) = \frac{\text{Market Value of Equity}}{\text{Total Liabilities}}, Y_{i,j}^k(t) = \frac{\text{Total Sales}}{\text{Total Assets}}.$$

To calculate the impact of carbon costs on a company's Z-Score (z), we define $z_{i,j}^{s,k}$ as (See Equation 2):

Equation 2: Including carbon costs into the Z-Score model (to simplify the notation, the time variable (t) has been omitted):

$$z_{i,j}^{s,k} = 1.2U_{i,j}^k + 1.4V_{i,j}^{s,k} + 3.3W_{i,j}^{s,k} + 0.6X_{i,j}^k + 1.0Y_{i,j}^k$$

Where:

$$V_{i,j}^{s,k} = \frac{RE_{i,j}^k - cc_{i,t}^{s,r}}{Total\ Assets} \quad \text{and} \quad W_{i,j}^{s,k} = \frac{EBIT_{i,j}^k - cc_{i,j}^{s,k}}{Total\ Assets}$$

We dropped the time notation for ease of notation. To calculate the average Z-Score at each sector for each scenario, $z_j^{s,k}$, we used the average of all companies' Z-Scores in each sector within a region.

Each sector is represented as "j" and time with "t" for the analysis. Where "t" is 2019, 2030, 2040 and 2050. For simplicity, it is assumed that emissions will stay constant at the baseline level of 2019 throughout the entire assessment period. This assumption is made due to the lack of data on historical emission data that is typically required to calculate historical growth rates. We assume that cost and price stay the same throughout the scenario, allowing for a comparative assessment of the outcome. We then calculated the average scope one and scope two emissions per sector at each point of time, denoted by j_t . Scope 3 was not considered due to poor data quality and sparseness of data across the firms considered. Emissions are in terms of tonnes of carbon dioxide equivalent (tCO₂e).

4.6 IEA Scenarios

The IEA Scenarios are some of the world's leading and most authoritative energy scenarios sources (Paltsev, 2017). They are a part of IEA's annual energy projection through its World Energy Outlook (WEO) (IEA, 2021, 2022). The projection offers up-to-date scenarios and trends from analyzing energy demand and supply dynamics, highlighting their ramifications on global economic development and energy security. The carbon prices used in this research are the latest

released by IEA in its 2023 WEO report (IEA, 2023), which was also replicated in the 2024 IEA Report (IEA, 2024). The two scenarios applied to this paper are the Announced Pledges Scenario (APS) and Net Zero Emissions (NZE) by 2050 Scenario. In addition, we used a no-carbon price scenario.

APS, introduced in 2021, is designed to evaluate nations' advancement in fulfilling their commitments to reduce emissions, ultimately striving to attain net zero emissions by 2050. This framework considers the latest national declarations, encompassing interim objectives for 2030 and long-term pledges toward achieving net zero emissions. APS evaluates these commitments irrespective of their legal enforcement or incorporation into updated Nationally Determined Contributions (NDCs) (UNFCCC, 2015). It operates under the assumption that countries will adhere to their targets for 2030 and 2050, with the prospects of fossil fuel exporters and producers of low-emissions fuels, such as hydrogen, being influenced by the global demand from the NDCs. Moreover, APS assumes that all nations will universally achieve their access to electricity and clean cooking targets within the specified timeframe.

NZE, an ambitious blueprint developed by the International Energy Agency (IEA), outlines a trajectory for the global energy sector to achieve net zero greenhouse gas (GHG) emissions by 2050 (IEA, 2022). This framework suggests that advanced economies will achieve net zero emissions faster than developing and emerging markets. Aligned with the Sustainable Development Goals (SDGs) set by the United Nations in 2015, NZE focuses on achieving universal energy access by 2030 and improving air quality. It also aligns with limiting global temperature rise to 1.5°C, as outlined in the Intergovernmental Panel on Climate Change's sixth assessment report (IPCC, 2022). NZE recognizes multiple pathways to net zero and

acknowledges technological uncertainties. Unlike other scenarios, NZE is normative rather than aspirational, aiming to keep temperature increases below 1.5°C by 2100.

4.7 Carbon Pricing Assumptions

Based on the latest IEA Report published in October 2023 (IEA, 2023), we defined two carbon scenarios, APS and NZE (see Table 4-6).

Table 4-6: Carbon Cost in nominal USD per tCO₂.

Scenario	Scenario Classification/Region	2030	2040	2050
APS	Advanced economies with net zero emissions pledges	135	175	200
APS	Emerging Market and developing economies with net zero emissions pledges	40	110	160
APS	Other emerging markets and developing economies	-	17	47
NZE	Advanced economies with net zero emissions pledges	140	205	250
NZE	Emerging markets and developing economies (with net zero emissions pledges)	90	160	200
NZE	Selected emerging markets and developing economies without net zero emissions pledges	25	85	180
NZE	Other emerging markets and developing economies	15	35	55

Note: Prices are based on the IEA WEO Report 2023 carbon cost (IEA, 2023).

4.8 Country Classifications

For our analysis, we classified the companies based on their country of operation using the World Bank economic classifications. The World Bank utilizes national income to classify countries into four major income groups: "low," "lower-middle," "upper-middle," and "high-income" countries (The World Bank, 2024). For our research, we considered companies with complete financial and carbon data between 2012 and 2019 provided by Sustainalytics. We

categorized each company according to its sector and country. For our analysis, we aligned the World Bank's classification with the IEA Carbon Pricing classification of respective countries based on their income levels of advanced, emerging (further broken down into major emerging markets and other emerging markets), and developing economies (IEA, 2021) (see Table 4-7)

4.9 Results

To test the accuracy of the scenario outcomes, we further analyzed the impact of carbon pricing on Altman's Z-Score across two climate scenarios and a baseline scenario using multivariate linear regressions. Table 4-7 presents the descriptive statistics.

Table 4-7: Descriptive statistics (N = 1243)

Scenario		Present	2030	2040	2050
APS	Mean	2.40	2.28	2.25	2.23
	SD	1.52	1.56	1.58	1.60
NZE	Mean	2.40	2.28	2.22	2.18
	SD	1.52	1.56	1.60	1.63
Total	Mean	2.40	2.28	2.23	2.20
	SD	1.52	1.56	1.59	1.61

First, we examined the effects of carbon pricing based on different scenarios over time. Figure 4-1 shows that the Z-Score decreases over time with a higher carbon price in all pricing scenarios. The differences between APS and NZE are minor because there is no high difference between the carbon prices between the scenarios; however, there are differences between introducing carbon pricing in both scenarios and not increasing carbon prices over time.

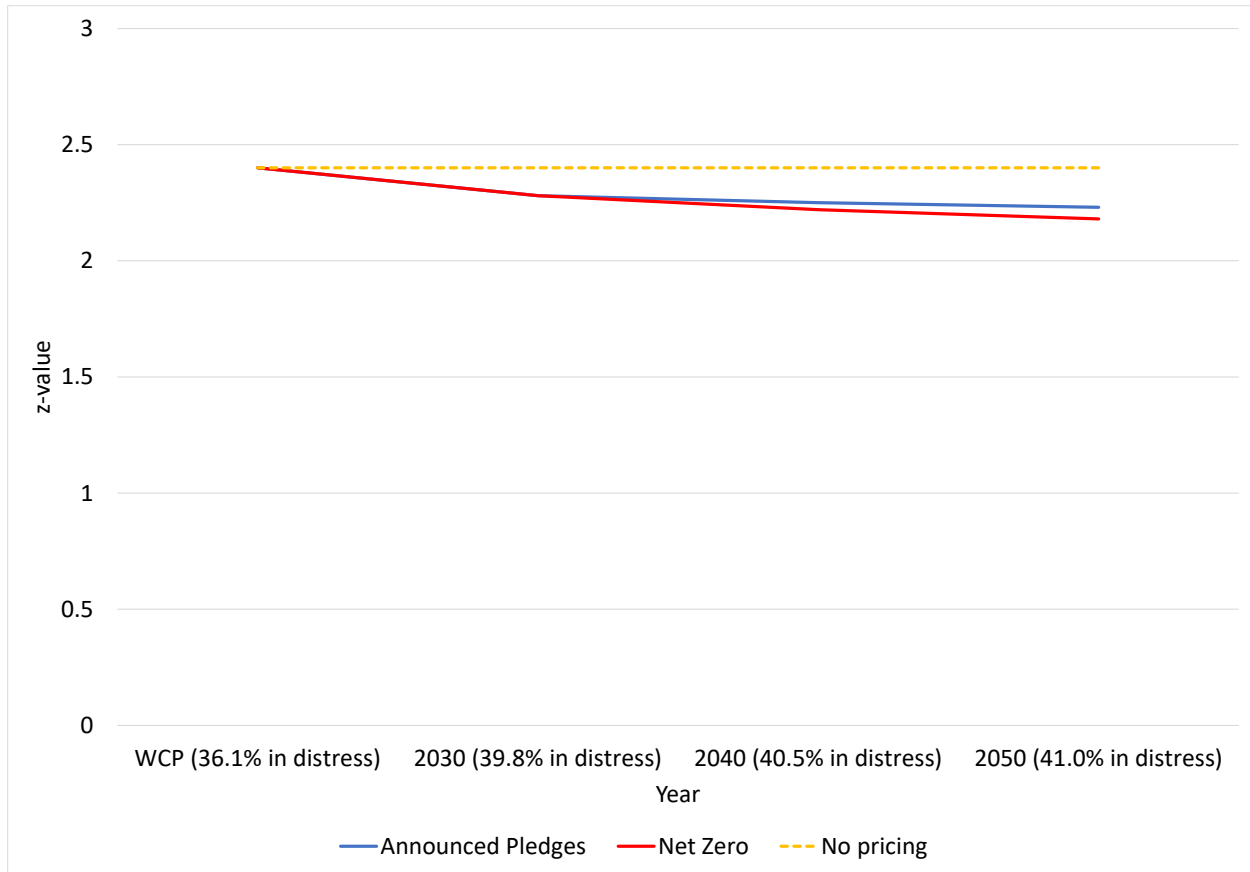


Figure 4-1: Impact of the scenarios on the Z-Score

4.9.1 Statistical Tests

To analyze the difference between the Z-Score between 2019 and 2050, we use a multivariate test of means (Hotelling test). The differences are significant ($T = 686.5$, $F = 343.1$, $p < .00001$). However, the results of the t-tests with the Z-Score as dependent variables and the scenarios as factors demonstrate that the differences between the scenarios are not significant (See Table 4-8).

Table 4-8: *T-tests for the two scenarios*

Year (t)	df	T	p
2019	2	.0	.99
2030	2	.08	.94
2040	2	.43	0.67
2050	2	.70	0.49

An analysis of the differences between the scenarios for the different years did not result in significant results. Hence, the pricing scenarios do not significantly influence the differences between $t \in [2030, 2040, 2050]$.

Finally, we analyzed the impact of the carbon price scenarios on the Z-Score, including control variables such as region (k) and sector (j). The multivariate linear regression analysis used the no-pricing scenario as our baseline scenario, serving as the reference point against which other climate scenarios (APS, NZE) are compared, providing a benchmark for assessing the impact of climate-related variables on credit risk. Within the linear regression framework, categories with the highest 2019 Z-Score were utilized as the base categories. These base categories acted as the reference points for comparison with other categories within each variable, allowing for a systematic evaluation of the relative impact of different climate scenarios and other factors on credit risk. By employing a baseline scenario and establishing base categories within each variable, the regression analysis enables a comprehensive assessment of the complex interplay between climate scenarios and credit risk across k and j .

The results of the linear regression are presented in Table 4-9. They show that the model can estimate the relationships between the outcomes and the predictors. Furthermore, carbon pricing significantly decreases the Z-Scores in 2030, 2040, and 2050. NZE decreases the Z-Score more

than APS. Significant regional effects appear for Latin America and the Caribbean, with a significantly lower Z-Score than other regions. Furthermore, advanced and emerging markets have significantly lower Z-Scores than developing markets. Finally, the Z-Score of energy, materials, and utilities sectors decrease the most when compared to consumer staples.

Table 4-9: Multivariate linear regression with the Z-Score for 2030, 2040, and 2050 as dependent variables and scenarios, sectors, regions, and markets as independent variables

Dependent Variables	R²	F	P-Value
Zscore2030	0.1303	46.43	<.00001
Zscore2040	0.1379	49.58	<.00001
Zscore2050	0.1432	51.79	<.00001

Independent Variable	Coefficient	P-Value
<i>Zscore2030</i>		
Scenario		
APS	-0.1188	0.017
NZE	-0.1237	0.013
Region (k)		
East Asia & Pacific	-0.0247	0.915
Europe and Central Asia	-0.1738	0.451
Latin America & Caribbean	-0.6788	0.014
North America	-0.0932	0.669
Sub-Saharan Africa	-0.4439	0.22
Market		
Advanced	-0.9199	<.00001
Emerging	-0.5562	0.018

Sector (<i>j</i>)		
Consumer Discretionary	-0.4468	<.00001
Energy	-1.4051	<.00001
Healthcare	-0.1669	0.403
Industrials	-0.4801	<.00001
Information Technology	-0.6456	<.00001
Materials	-1.0221	<.00001
Utilities	-2.2667	<.00001
Constant	4.1317	<.00001
<i>Zscore2040</i>		
Scenario		
(APS)	-0.1549	0.002
(NZE)	-0.1821	<.00001
Region (<i>k</i>)		
East Asia & Pacific	-0.0295	0.899
Europe and Central Asia	-0.1958	0.398
Latin America & Caribbean	-0.6824	0.014
North America	-0.1177	0.591
Sub-Saharan Africa	-0.4713	0.195
Market		
Advanced	-0.9323	<.00001
Emerging	-0.5558	0.019
Sector (<i>j</i>)		
Consumer Discretionary	-0.4430	<.00001

Energy	-1.4265	<.00001
Healthcare	-0.1707	0.394
Industrials	-0.4897	<.00001
Information Technology	-0.6365	<.00001
Materials	-1.0739	<.00001
Utilities	-2.3384	<.00001
Constant	4.1783	<.00001
<i>Zscore2050</i>		
Scenario		
(APS)	-0.1778	<.00001
(NZE)	-0.2229	<.00001
Region (<i>k</i>)		
East Asia & Pacific	-0.0333	0.887
Europe and Central Asia	-0.2115	0.363
Latin America & Caribbean	-0.6843	0.014
North America	-0.1347	0.54
Sub-Saharan Africa	-0.4930	0.177
Market		
Advanced	-0.9385	<.00001
Emerging	-0.5586	0.019
Sector (<i>j</i>)		
Consumer Discretionary	-0.4407	<.00001
Energy	-1.4411	<.00001
Healthcare	-0.1723	0.392

Industrials	-0.4963	<.00001
Information Technology	-0.6308	<.00001
Materials	-1.1094	<.00001
Utilities	-2.3873	<.00001
Constant	4.2086	<.00001

In addition to the influence of a carbon price on the Z-Score, we calculated the impact on the EBIT. We analyzed the number of firms with negative EBITs based on different carbon pricing scenarios. The results are presented in Table 4-10.

Table 4-10: Frequency of firms with positive and negative EBIT

Year (<i>t</i>)	NZE Negative EBIT	NZE Positive EBIT	APS Negative EBIT	APS Positive EBIT
Baseline	929	8957	467	9442
2030	2090	7796	2062	7847
2040	2439	7447	2285	7624
2040	2652	7234	2416	7493

For both scenarios, the number of firms with negative EBIT increases with an increase in the carbon price (p). For both scenarios, we find a significant difference in the EBIT across the carbon price ($p < .0001$, $\chi^2_{NZ}=1098.2$, $\chi^2_{AP}=1664.6$, $df = 3$). The sample comprises 9 percent of companies with a negative EBIT without a carbon price (WCP). However, in the NZE scenario, firms with a negative EBIT increase to 27%. Under the APS scenario, the percentage of firms with a negative EBIT increased to 24%. By this result we can confirm that the introduction of

carbon price has significant impact on the EBIT and, consequently, on credit risk when compared to the outcomes observed prior to the implementation of the carbon price

4.10 Discussion

Our results demonstrate that carbon pricing significantly impacts credit risk, particularly for high-emitting sectors. This impact will become stronger if these sectors cannot reduce their emissions. Furthermore, the impact on the Z-Score in the NZE Scenario is higher than in the APS. Further, the results demonstrate significantly different carbon price impacts in regions, markets, and sectors.

A carbon price influences the credit score of high emitters more than that of low emitters. This finding is consistent with previous studies that have examined the influence of carbon pricing on credit risk (Oyegunle et al., 2023). It also adds to the general literature on the effect of corporate environmental and sustainability performance on credit risk (Bauer & Hann, 2010; Höck et al., 2020; Mengze & Wei, 2015). Furthermore, as other studies demonstrated, it specifies why green lending might be lower due to concerns about its impact on credit risk (Cui et al., 2018).

Our finding suggests that the respective sector's exposure, though increasing through 2050, is minimal under the two scenarios assessed. This aligns with similar recent research that concludes that carbon policies targeting carbon neutrality by 2050 lead to smaller financial losses in the short term when an orderly transition is pursued, as opposed to a disorderly one (Prosperi & Zanin, 2024). The study also shows that the materials and utilities sectors would be the most affected by carbon prices, similar to Bouchet and Le Guenedal (2020). However, our study broadens the literature using a global sample, including emerging and developing countries. Other studies mainly used North American and European samples and did not distinguish between different carbon pricing scenarios. With our methodological approach, we could

demonstrate that the application of Altman's Z-Score model (Altman, 2018) creates similar results to other models, such as Merton's Distance-to-Default model (Capasso et al., 2020; Merton, 1974). Hence, using different credit risk models can help identify emission cost-related credit risks.

Another important finding of the study is that the effect of carbon pricing on credit risks is global, though specific pricing scenarios count. Since all IEA scenarios use significant carbon prices (IEA, 2023), they will affect commercial lenders through higher emissions costs.

However, NZE has a more substantial effect than APS. Countries should integrate this difference into their stress-testing approaches.

The presented research results shed light on the intricate relationship between carbon pricing and credit risk across markets, regions, and sectors. The negative coefficients observed in our analysis underscore the urgency for financial stakeholders to incorporate climate risk considerations into credit risk assessments. The findings provide valuable insights for risk managers, policymakers, and investors, highlighting the need for nuanced, context-specific strategies to address the evolving landscape of climate-related credit risk.

This research found no evidence that introducing carbon pricing regulations will significantly impact the financial sector or cause major macroeconomic shifts. These findings align with recent studies, suggesting minimal impact of carbon regulation on individual economies (Chu et al., 2024). Nevertheless, carbon pricing without adequate mitigation could still be a source of disruptions and imbalances to the financial sectors exposed to specific industries. This observation aligns with other studies stressing the importance of harmonizing carbon pricing policies between developed and less developed countries to mitigate trade disruptions and promote global climate (Bolton & Kacperczyk, 2023; Boute, 2024).

Finally, while market-based regulations like carbon pricing can help enhance the carbon performance of firms (Siddique et al., 2024), it could potentially lead to unintended consequences that may necessitate a disorderly climate transition if not well-managed (Gualandri et al., 2024). This research highlights that introducing key transition regulations carries risks and may require a more gradual, deliberate approach to manage regulatory impacts and mitigate exposure in critical sectors effectively. It provides insight for regulators and credit providers like banks on necessary considerations for climate policy actions. One way to address this is through regular climate stress testing, which is crucial for assessing the level of portfolio risk related to carbon exposure (Reinders et al., 2023; Weber, 2024) when carbon pricing is factored. This research contributes to the ongoing discourse on climate finance by providing insights into the impact of carbon pricing on credit risk, emphasizing that failure to address these risks could have far-reaching consequences for both key sectors of the economy.

4.11 Conclusion

We conclude that carbon pricing significantly influences credit risk, particularly within high-emitting sectors such as energy, materials, and utilities. The findings underscore the importance of integrating climate transition policies into financial risk assessment frameworks, highlighting that higher carbon pricing affects high-emitting industries. This research bridges a critical gap in understanding the interplay between carbon pricing and credit risk across global sectors and regions, emphasizing the necessity for proactive strategies to manage credit exposures under evolving climate policies. While demonstrating the methodological robustness of applying carbon pricing to credit risk models, our results also identify limitations in regional and sector-specific adaptations, calling for deeper investigations into the interrelations of carbon cost pass-through, corporate behavior, and financial stability. Ultimately, this study advances the discourse

on climate finance by offering evidence-based insights for regulators, policymakers, and financial institutions to navigate the complex interactions of climate risk and credit systems.

4.12 Limitations

Some limitations of this paper include the inability to determine how carbon pricing impacts various borrowing costs and whether commercial borrowers can transfer these costs to consumers. Identifying how this may impact key emitting sectors such as energy and heavy industry and the implications for carbon-dependent economies will be important. Also, it will be interesting to understand the interaction between corporate carbon performance, carbon pricing, and credit risks and whether they have significant economic implications for carbon-intensive sectors as they navigate decarbonization efforts and financial challenges under carbon pricing regulation. Therefore, additional research is needed to address these gaps and analyze the effect of a carbon price on different types of borrowing costs and whether commercial borrowers can pass the costs to consumers. Secondly, further research is required to investigate the interaction between corporate carbon performance, carbon pricing, and credit risks.

Chapter 5

Are climate risk regulations evidence-based? Leveraging Artificial Intelligence to Bridge the Gap between Regulatory Practice and Academic Research

This paper was submitted to The Journal of Impact & ESG Investing, where it received a verdict of “Revise and Resubmit”. This chapter represents the final revised version of the manuscript, incorporating the feedback provided by the reviewers.

5.1 Introduction

The 2015 ratification of the Paris Agreement (COP 2015) marked a significant milestone in global climate governance, setting legally binding commitments for nations to limit global warming, leading to the adoption of Nationally Determined Contributions (NDCs), which outline each country’s specific strategies for reducing greenhouse gas emissions and adapting to climate change (Weber et al., 2020) and the establishment of the Task Force on Climate-Related Financial Disclosures (TCFD) in 2017, which provides a framework to enhance transparency in climate-related financial risks. In response to these three events – COP 2015, NDC, and TCFD – financial regulators worldwide have intensified efforts to integrate climate risk into financial oversight and regulatory frameworks to ensure that financial institutions assess, disclose, and manage climate-related risks effectively, thereby strengthening the resilience of financial systems against climate risk.

Due to their significant role in the economy, the emergence of climate risks has increased regulatory scrutiny on the climate exposure of financial institutions, particularly banks. Mainly developed as guidelines to mitigate the increasing exposure of banks and other financial

institutions to climate risk, climate-related financial regulations attempt to address the growing vulnerability and exposure of banks' investments and lending activities (Mésonnier, 2022).

Consequently, many regulatory bodies mandated climate risk disclosures from financial institutions (Kölbel et al., 2024) to mitigate climate risk to global financial systems and stability.

As interest in climate risk regulation grows, the academic focus on the intersection of climate regulation and financial risk has also intensified (Alogoskoufis et al., 2021; Long et al., 2022; Weber, 2024) even as researchers continue to explore the impact of climate-related risks on the financial sector (Z. Liu et al., 2024; Schult et al., 2024). For example, multiple studies have extensively probed and continue to address financial institutions' exposure to climate risk (Nieto, 2019), its potential hindrance to economic growth (Battiston et al., 2020; Giglio et al., 2021), its adverse effects on the economy (Dafermos et al., 2018), financial stability (Monasterolo et al., 2017), and its impact on banks' ability to meet financial and credit commitment (Aiello & Angelico, 2023). Simultaneously, regulators are advocating for standardized models to assess financial institutions' vulnerabilities to climate risk (Sanfilippo, 2023), developing approaches to applying prudential regulatory tools (Hidalgo-Oñate et al., 2023), and addressing the impacts of climate change on financial stability (Z. Liu et al., 2024). Unfortunately, today's regulatory approach remains largely uncoordinated and could best be described as polycentric (Marshall, 2015), and the different viewpoints on research and policy have created divergent perspectives. This divergence underscores the need to identify if there are existing gaps in the approach between academic literature expectations and regulations requirements, as well as identify if alignment exists. This raises the question of what evidentiary basis the different regulations are based on and if the issues addressed by academic research and those addressed by regulations are related or dissimilar.

Aligning academic research and regulations is crucial for developing an informed, science-based climate risk policy. Consequently, this study extends beyond previous studies that analyze emerging regulatory frameworks to mitigate climate risks (Feridun & Güngör, 2020) or characterize climate risk regulations (Carè, 2023) by not just highlighting the evolving nature of climate risk policies but taking additional steps to critically review the contents of the policies and compare the same with academic literature results to highlight areas for future research improvements. It also provides an analytical lens into the content of the evolving policies and literature, which surpasses the systematic peer review of current and emerging academic literature in this field (Hidalgo-Oñate et al., 2023). The research includes an in-depth analysis of peer-reviewed journal publications and existing climate risk regulations, examining their composition and alignment with climate literature outcomes and recommendations.

Specifically, we try to understand if the regulations as developed are based on evidence or aligned with established climate risk research. Evidence-based policy helps assert decisions with rigorous, objective evidence, using research to inform policy development and implementation (Strassheim & Kettunen, 2014). This approach fosters more effective governance by reducing reliance on assumptions and enhancing outcomes through scientifically validated knowledge (Sanderson, 2002). In the context of this paper, aligning policy with academic research strengthens frameworks by incorporating real-world impacts and contextual dynamics into scientifically validated researched outcomes, which helps bridge the gap between theory and practice (Head, 2016). In financial regulation and climate risk management, applying evidence-based approaches is critical to ensure that policies effectively address emerging risks. This approach is relevant to this research since evidence-based approaches, like those used in policy development, focus on integrating research into practice by continuously evaluating outcomes

and adjusting strategies (Lum & Koper, 2024). It also provides a basis for critically assessing these regulations' contextual focus and helps identify gaps for future improvement. This is particularly relevant for emerging climate risk regulations, where continuous collaboration between academics and policymakers can help enhance the effectiveness of financial regulations. By leveraging empirical research and data-driven insights, such as the ones proposed in this research, regulatory bodies can improve climate risk management strategies, ensuring policies are robust, responsive, and adaptable to new challenges (Carè, 2023; Hidalgo-Oñate et al., 2023).

This paper applied artificial intelligence (AI) and natural language processing (NLP) techniques to analyze the alignment of regulatory policies with peer-reviewed academic publications on climate risk regulations. For its analysis, it reviewed sixteen published climate risk regulations and standards developed by different financial sector regulators and governing bodies. These regulations were then categorized into three distinct inter-categories: Central Banks, standard-setting bodies and other regulatory institutions. The regulations from these bodies were collectively and individually compared to eighty-three peer-reviewed research papers processed from Scopus. The articles assessed were published between 2017 and 2024. The starting point of 2017 was chosen due to the publication of the TCFD, which significantly influenced corporate efforts and awareness regarding climate financial risks and aligned with the observed development of the regulations.

The result of the AI and NLP analysis revealed that while there is a moderately high similarity between climate risk regulations and academic expectations, considerable differences in approach and implementation remain. The assessment shows that different regulation categories have various levels of alignment and that different respective regulatory segments show individual differences in focus and interest. To address this, we propose a polycentric

governance approach (Carlisle & Gruby, 2019; Tobin et al., 2024) that is rooted in collaboration and helps ensure a seamless climate risk adaptation (Bousema et al., 2024; Hatfield-Dodds et al., 2007; Marshall, 2015) across relevant regulatory bodies. This research contributes theoretically to adaptive governance by examining how well institutional regulatory practices align with the dynamic demands of climate adaptation, while addressing regulators' capacity to integrate emerging trends and academic insights. The study proposes strategies to bridge these divides and enhance regulatory effectiveness by identifying gaps between current regulatory practices and academic expectations. Our findings reveal a disconnect between research and practice, highlighting areas for future research and where practical improvements are required to support relevant academic contributions to emerging climate risk policies.

5.2 Climate-Related Risk Policy and Research

This paper assesses evolving climate-related risk guidelines and regulations. We aim to understand the backdrop upon which these emerging regulatory policies were developed and how they align with academic research outcomes. Identifying and understanding these alignments and gaps are crucial, given the diverse regulations and standards within the climate risk impact space, their broad applications, and divergent expectations (Roncoroni et al., 2021). Unfortunately, as an emerging field of study, there is no standardized approach to climate risk integration or disclosure methodology. This research is the first effort to address this gap, as it offers insight into an approach that can help enhance regulatory efforts toward mitigating climate financial stability risk and enhancing monetary regulations (Blondeel et al., 2024). No existing academic research has analyzed the contextual composition of emerging climate risk regulations despite the increasing lack of standardized climate risk regulatory expectations (Hidalgo-Oñate et al., 2024). This lack of standardization necessitates a comprehensive understanding of

evolving materiality issues within the climate-related risk space while creating an evidence-based approach for future policy development.

This research addresses three key questions:

1. Is there evidence that emerging climate-related risk regulations align with academic research?
2. Does the polycentric nature of the climate regulatory approach impact the policy framework and output?
3. What gaps exist between academic research outcomes and climate risk regulation within the financial sector, and how can these differences be addressed?

The rest of this paper includes a deep dive into climate risk literature, methods, research analysis, findings, and conclusions.

5.3 Climate-Related Risk, Banks and Regulations

Central Banks and financial regulators have historically overlooked climate as a critical risk to the banking sector (BCBS, 2021), leading to insufficient data on banks' exposure to these risks (Mariano, 2023). This indifferent approach is fast evolving as banks begin acknowledging the increasing risk of climate change to their business (Feridun & Güngör, 2020; Yang et al., 2024). This growing awareness has driven increased regulatory scrutiny, disclosure requirements, and new guidelines (Carè, 2023; Ozdemir, 2023). However, these guidelines often emerge from different regulators (Weber, 2024) with differing approaches to climate risk management (Hidalgo-Oñate et al., 2024). Despite this, many regulations share some common objectives but differ regarding expectations, methodologies, and approaches (Smoleńska & Klooster, 2022).

Despite this, they all emphasize the crucial intersection of climate risk and financial regulation for maintaining financial stability (Lagarde, 2021).

As climate-related regulations evolve, so do supervisory practices integrating climate risks into governance frameworks, risk management, and capital assessment (Hu et al., 2024; Semieniuk et al., 2021). These efforts are reflected through scenario analysis and stress testing (Battiston et al., 2020; Schult et al., 2024). Also, collaboration among central banks through initiatives like the Network for Greening the Financial System (NGFS) highlights the emerging collective effort to manage climate risks and foster a sustainable economy (NGFS, 2019). However, this has not been experienced across other prudential standards and other regulatory bodies even though policymakers at various levels, such as The Sustainability Accounting Standards Board (SASB) (IFRS & SASB, 2023) and Basel Committee on Banking Supervision (BCBS), have also released guidelines for addressing climate-related financial risk (BCBS, 2021), which is critical since banks have historically struggled to manage climate risks effectively (Ramakrishna, 2023). As a result, there is a disjointed approach to climate risk regulation disclosure (Zournatzidou et al., 2025), where respective bodies release climate policies that are not dissimilar but are unaligned, creating multiple compliance requirements for financial institutions burdened with the responsibility of complying with often repetitive disclosure requirements.

Despite this lack of cohesion, the involvement of regulators, rating agencies, and standard-setting bodies has driven changes within the banking sector, even as they push for integrating climate considerations into credit (Redondo & Aracil, 2024) and other areas of risk management (Vestrelli et al., 2024). However, it should be noted that limited research has been published on the approach of these regulations, and there is even less clarity on how these regulations are

aligned or the impact of these regulations, considering the diversity of interests among the various governance bodies (Z. Liu et al., 2024).

Addressing this issue is more complex, considering that implementing climate risk considerations within the banking sector could be challenging (Chalabi-Jabado & Ziane, 2024). This has necessitated an evidence-based assessment to help determine the alignment or otherwise of emerging climate risk regulations in the financial sector. Some of the suggestions studies have made to address this include but are not limited to the need for consistency in methodologies among regulators, which is required to quantify and address the macroprudential implication for climate-related financial risk (Chabot & Bertrand, 2023) and the application of market-driven solutions, such as climate disclosure, stress testing, and scenario instruments (Baer, 2024; DeMenno, 2023). Beyond these approaches, climate regulation development also requires careful consideration to ensure effectiveness (Bruno & Lagasio, 2021; Bryant et al., 2020). This is particularly important to help address gaps in policy methodology and fragmentation (Roncoroni et al., 2021).

Academic research has extensively explored the potential risks climate change poses to financial institutions, highlighting the necessity for robust regulatory measures (Sodokin et al., 2023). Considering the various areas explored in research and how this could benefit regulations, it is interesting that there have been no clear-cut approaches or efforts to align the two. This lack of clarity has resulted in a significant disconnect between the theoretical approaches derived from research outcomes and regulatory practices. Also, regulatory practices have historically lagged academic research in adopting measures to mitigate climate financial risk despite efforts by researchers to develop sophisticated models to predict and manage the financial impacts of climate change (Gourdel et al., 2024; Roncoroni et al., 2021).

Consequently, it is important to identify gaps and pinpoint disconnected areas. This study is, therefore, crucial to advancing climate regulation and disclosure research by addressing alignment issues and highlighting discrepancies between current climate risk regulations and academic research. Bridging these gaps is critical, given the rapid adoption of climate risk regulations and the potential for unforeseen outcomes arising from unknown variables. Achieving this requires a careful, nonpartisan approach considering market impacts (Demekas & Grippa, 2022; Gruenewald et al., 2024).

5.4 Methods

This paper examines emerging climate risk regulations in the banking sector and assesses whether there is evidence of regulatory alignment with academic research expectations. We employed AI and NLP techniques to develop text summaries, perform keyword extraction, and conduct comparative analyses of various climate risk standards and academic literature. NLP involves systems that enable computers to understand and manipulate human language, efficiently and accurately analyzing text or speech (Ali & Shandilya, 2021). Text summarization, a common NLP technique, reduces documents to their main ideas by creating concise summaries that include essential sentences and relevant information (Widyassari et al., 2022). Summarizers are categorized as extractive, selecting critical sentences from the text, or abstractive, which helps generate summaries with original human-like phrases (Awasthi et al., 2021).

This paper applies extractive and abstractive methods for our analysis, focusing on reducing redundancy and enhancing summary concentration. The aim was to extract and compare content from various sources, including academic research papers and regulatory documents, using two critical models for the best results and in line with best text summarization analysis standards (Lenka et al., 2022; Mehta, 2016; S. Wang et al., 2017; Widyassari et al., 2022). For the

extractive summary and analysis, this paper applied Facebook's Bidirectional and Auto-Regressive Transformers (BART), a transformer-based sequence-to-sequence (seq2seq) model developed by Facebook AI, which integrates techniques from Google's Bidirectional Encoder Representations from Transformers (BERT) and Open AI's Generative Pre-trained Transformer (GPT), making it highly versatile for a range of natural language processing tasks, particularly those focused on text generation, summarization, and machine translation. For the abstractive text analysis, we employed Google's Pre-training with Extracted gap sentences for Abstractive Summarization Sequence-to-sequence (PEGASUS), a transformer-based model by Google Research, optimized for abstractive summarization, which creates concise summaries by generating new sentences rather than extracting existing ones (Lenka et al., 2022). Both models capture explicit and implicit themes in the literature and regulatory standards, using comparative evaluations based on large language models (Faheem, 2024). As a result, this paper incorporates semantic analysis to help assess the underlying meanings and relationships within the regulatory texts and academic literature. By conducting a semantic comparative analysis, we aim to capture the deeper contextual connections between climate risk regulations and academic expectations, thereby ensuring a more comprehensive evaluation of the reviewed documents.

5.4.1 Data Collection

We compiled climate-related risk regulatory guidelines and standards from Central Banks and the banking sector for our data collation by reviewing NGFS members and leading banks' latest climate reports. To ensure diligence, we reviewed the Climate Change Laws of the World database, which includes over 5,000 global climate regulations, laws, and rules compiled by the Grantham Research Institute at the London School of Economics and Political Science (LSE) and the Sabin Center at Columbia Law School (Grantham Research Institute, 2024). This review

exclusively focused on climate risk regulations relevant to the banking sector, especially those covering commercial banks (e.g., United States SEC). The assessed regulations do not include general sustainability, Environmental, Social, and Governance (ESG) policies or regulated disclosures like the Corporate Sustainability Reporting Directive (CSRD) or TCFD. It also excludes different laws and acts of parliament on climate change. Regulations are categorized into Central Banks and National Prudential Authorities, Other Regulators, and Standard-setting bodies (See Table 5-1).

Table 5-1: List of Regulators of Reviewed Guidelines, Standards and Regulations

Policy Number	Country	Region	Policy Name	Regulation Classification
Policy 1	EU	Europe	European Commission: Guidelines on Reporting Climate-Related Information	Other Regulators (securities and policy bodies)
Policy 2	International	International	Basel Committee: Principles for Climate-Related Financial Risk Management	Standard setting bodies
Policy 3	Brazil	South America	Central Bank of Brazil: Climate Risk and Social Responsibility Regulation	Central Banks and National Prudential Authorities
Policy 4	Australia	APAC	Australian Prudential Regulation Authority: CPG 229 Climate Change Financial Risks	Central Banks and National Prudential Authorities
Policy 5	Mauritius	Africa	Bank of Mauritius: Environmental Financial Risk Guidelines	Central Banks and National Prudential Authorities
Policy 6	Hong Kong	APAC	Hong Kong Monetary Authority: SPM Module GS-1 on Climate Risk Management	Central Banks and National Prudential Authorities
Policy 7	International	International	IFRS and ISSB: IFRS S2 Climate-Related Disclosures	Standard setting bodies
Policy 8	Kenya	Africa	Central Bank of Kenya: Climate Risk Guidance for Commercial Banks	Central Banks and National Prudential Authorities
Policy 9	Singapore	APAC	Monetary Authority of Singapore: Environmental Risk Management Guidelines	Central Banks and National Prudential Authorities
Policy 10	New Zealand	APAC	New Zealand Government: NZ CS 1 Climate-Related Disclosures	Other Regulators (securities and policy bodies)

Policy 11	USA	North America	Office of the Comptroller of the Currency: Climate Risk Management Principles	Other Regulators (securities and policy bodies)
Policy 12	Canada	North America	Bank of Canada and OSFI: B-15 Climate Risk Management	Central Banks and National Prudential Authorities
Policy 13	Malaysia	APAC	Bank Negara Malaysia: Climate Risk and Scenario Analysis	Central Banks and National Prudential Authorities
Policy 14	EU	Europe	European Central Bank: Climate and Environmental Risk Supervisory Guide	Central Banks and National Prudential Authorities
Policy 15	United Kingdom	Europe	Prudential Regulation Authority: Managing Financial Risks from Climate Change	Central Banks and National Prudential Authorities
Policy 16	USA	North America	Securities and Exchange Commission: Climate Disclosures for Investors	Other Regulators (securities and policy bodies)

5.4.2 Academic Papers Selection

Academic papers were sourced from Scopus using the keywords “Climate Risk,” “Climate Risk Regulations,” and “Climate Regulations, “Bank” and “Banks.” We reduced the initial 3,709 documents to 131 banking-specific studies. Further filtering (2017–2024, peer-reviewed journal articles) yielded 94 papers. After a manual relevance check, 83 papers were selected. Papers unrelated to banking (e.g., forestry, water banks) were excluded.

5.4.3 Regulatory and Academic Document Processing

Each of the 16 regulations and standards was manually reviewed. Our analysis focused exclusively on the relevant regulatory sections, excluding non-relevant contents (e.g., executive summaries). The extracted sections were compiled into a single corpus for respective climate risk standards and policy documents.

The corpus was divided into sentence chunks within model token constraints (BART & PEGASUS: 1024 tokens) to handle large text volumes and model token limits. As the next step,

we used abstractive methods to condense the documents while preserving core regulatory concepts. The outcome was further summarized using extractive process to refine key insights and merged to generate a final, comprehensive summary. This approach is commonly used in long-text summarization within language processing research (Mehta, 2016; S. Wang et al., 2017).

The same extractive and abstractive summarization process used for the regulations was applied to academic papers to ensure methodological consistency. Each of the extractive and abstractive summarizations was also manually reviewed by the authors for consistency and reliability. To validate the result and synthesize insight from the extractive and abstractive summaries, ChatGPT was employed to perform a semantic analysis of the policy and literature results, focusing on both abstractive and subtractive dimensions. The semantic analysis output was manually analyzed and reviewed for consistency and validity.

5.4.4 Vector Embedding and Cosine Similarity Analysis

For our analysis, we calculated the cosine similarity applied to measure the similarity between peer-reviewed papers and regulations (Xia et al., 2015). This metric helps compare texts of varying lengths, scoring their similarity between 0 and 1 (See Figure 1). Each text is represented as a vector in a multi-dimensional space, where dimensions correspond to unique features learned by the model. These vectors capture the contextual and semantic relationships within the documents, a process known as vector embedding (Singh et al., 2023). Cosine similarities between 0.00 – 0.39 are considered low, between 0.40 and 0.69 are considered moderate. Cosine similarities between 0.70 and 0.85 are moderately high, and those above 0.86 and below 1 are considered very high (Christopher et al., 2008; Xia et al., 2015).

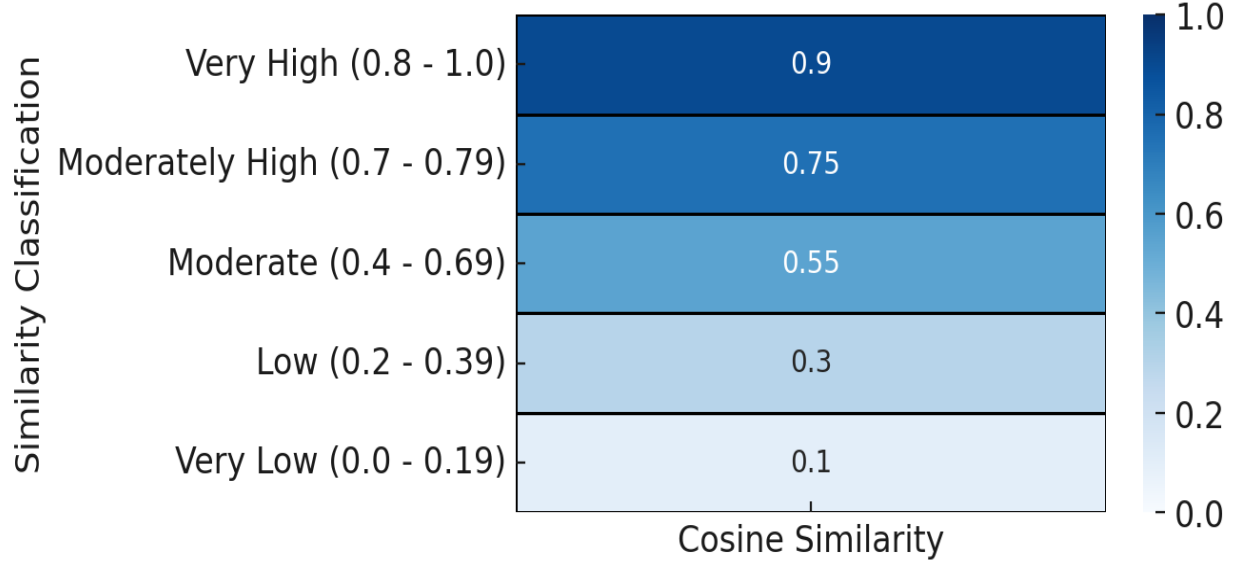


Figure 5-2. Cosine Similarity Heat Map Representation – Source Authors

We used Alibaba-NLP gte-large-en-v1.5, a 1024-dimensional embedding model optimized for text similarity (Muennighoff et al., 2023). Each document was embedded into the vector space:

$$v(d) = M(d), v(d) \in R^{1024}$$

Where:

$$V_L = \{V(d_{L1}), V(d_{L2}), \dots, V(d_{Ln})\}$$

$$V_P = \{V(d_{P1}), V(d_{P2}), \dots, V(d_{Pn})\}$$

5.4.4.1 Vector embedding Creation:

For step 1, vector embedding, the embedding model, M converts each d (literature and policy) into a vector $v(d)$ in a 1024-dimensional space:

$$v(d) = M(d), v(d) \in R^{1024}$$

Where:

- D_L = Set of academic literature documents where each document is represented as d_{Li}
- D_P = Set of regulatory documents where each document is represented as dp_j .
- V_L and V_P are the vector embeddings of the respective documents.

5.4.4.2 Application of Cosine Similarity:

In step 2, cosine similarity was applied to quantify textual alignment:

$$(d_{Li}, dp_j) = \frac{v(d_{Li}) \cdot v(dp_j)}{\|v(d_{Li})\| \|v(dp_j)\|}$$

5.4.4.3 Semantic Analysis and Correlation Assessment

For step 3, a combined semantic correlation score (C_{sem}) was computed to assess the alignment of the regulations with the academic papers, integrating:

1. Cosine similarity – $S(d_{Li}, dp_j)$ = Semantic similarity score based on cosine similarity between $v(d_{Li})$ and $v(dp_j)$ (i.e., contextual alignment).
2. Reference density – $R(dp_j)$ = Set of references (direct or implied) in regulation dp_j that align with academic outcomes. (i.e., the proportion of explicit/implicit academic references.)
3. Thematic alignment – $T(d_{Li}, dp_j)$ = Thematic alignment score that captures implied relationships and topic-level connections of the texts (topic-level connections via ChatGPT).

The overall semantic correlation score between an academic document d_{Li} and regulatory document dp_j is given by:

$$C_{sem}(d_{Li}, dp_j) = \alpha S(d_{Li}, dp_j) + \beta \frac{|R(dp_j)|}{|dp_j|} + \gamma T(d_{Li}, dp_j)$$

Where:

- α, β, γ are weighting factors (such that $\alpha+\beta+\gamma=1$) that represent the relative importance of semantic similarity, reference density, and thematic alignment.
- $|R(dp_j)| / |dp_j|$ captures regulatory references to academic research.

This equation formalizes the combination of explicit similarity metrics, reference identification, and thematic analysis, providing a comprehensive score for evaluating semantic correlations between academic research and regulatory texts. To verify our result, a manual review of the output was conducted to ensure consistency and accuracy. This approach enables a structured evaluation of regulatory-academic alignment, identifying both direct references and broader thematic connections of our results.

5.5 Results

The following paragraphs describe the results of the similarity assessments. We start with the descriptive statistics, followed by the results of the policy and academic literature similarity assessment and the semantic analysis.

5.5.1 Descriptive statistics

The study uses 83 academic publications and 16 climate-related regulations. The cosine similarity between the academic publications and the regulations is 0.742, with a standard deviation of 0.05. The cosine similarity between the different regulatory bodies and the academic papers is presented in Table 5-2. The highest similarity is for Central Banks and national prudential authorities.

Table 5-2: Cosine similarities between regulatory bodies and the academic literature

Bodies	Literature Cosine Similarity
Standard setting bodies	0.731
Central Banks and National Prudential Authorities	0.772
Other Regulators (securities and policy bodies)	0.653

The keywords extracted from the documents including the academic papers and the regulatory bodies are presented in Table 3.

Table 5-3: Extracted keywords

Origin	Keywords
Literature	ESG banking, banking regulation, banking regulator, banking regulators, financial regulation, sustainable banking, financial regulator, banking supervision, climate bank, finance regulation, banking supervisory, financial regulators, decarbonize banking, regulation banking, governance banking, climate finance, sustainable finance, banking finance, financial regulations, banking prudential
Standard setting body	risks entity, disclose entity, scope accounting, assessment climate, entity targets, entity disclose, transition risk, reporting standard, information entity, related risk, scope greenhouse, disclose information, related risks, relevant bank, entity assessment, entity overall, risk-relevant, affect entity, purpose financial, risk opportunity
Central Banks and National Prudential Authorities	risk institution, institution risks, risk climate, risk business, risk committee, climate risks, risk bank, climate risk, social risk environmental, incorporate climate, risk understood, bank risk, risk comprises, risk firm, include risk, risk risk, reporting board, financial risks, reporting council, risk management
Other Regulators	disclosure climate, disclosure requirement, rule registrant, risk disclosure, risks rule, requiring disclosure, registrant climate, risk rule, rule disclose, disclosure registrant, required rule, requirement rule, requirement disclose, disclose registrant, disclosure discussion, emission disclosure, required disclose, risk institution, required comply, rule require

5.5.2 Policy and Academic Literature Similarity Assessment

Second, we compared extractive summaries of individual regulations and peer-reviewed papers, using cosine similarity analysis to assess how aligned climate-related regulations are to peer-reviewed academic literature. The combined extractive and abstractive text analysis of

regulations and literature assessed resulted in a cosine similarity score of 0.742 (74.2%), indicating that the two vectors are fairly but not perfectly aligned (Bernstein & Cheng, 2023; Goldberg, 2016). The results indicate that, despite a moderately high correlation, a 26% gap difference remains between published regulatory policies and academic literature output. This output suggests that while many regulatory bodies integrate scientific insights, there is still significant room for improved alignment and strengthening of regulations. Additionally, Figure 2 shows that literature and policies align closely in specific areas, particularly in clusters related to climate transition regulations, as demonstrated by the proximity of two key academic papers (Nieto et al., 2024; Sanfilippo, 2023) within the graph.

Additionally, the analysis of the output from the extracted keywords highlights distinct yet overlapping areas of focus in climate regulation categories and academic literature. For example, academic literature primarily emphasizes governance, supervision, and sustainable finance, closely linking ESG considerations with banking prudential frameworks. However, standard-setting bodies prioritize disclosure and risk assessment at the entity level, focusing on transition risks and financial reporting standards. Central banks and prudential authorities concentrate on climate-related financial risks, incorporating them into institutional risk management. Other regulators, in contrast, stress disclosure mandates and compliance requirements, underscoring emissions and registrant obligations. Overall, while there are intersections in climate and risk-related terminology, variations in their areas of interest suggest differing priorities and scopes of regulatory responsibility.

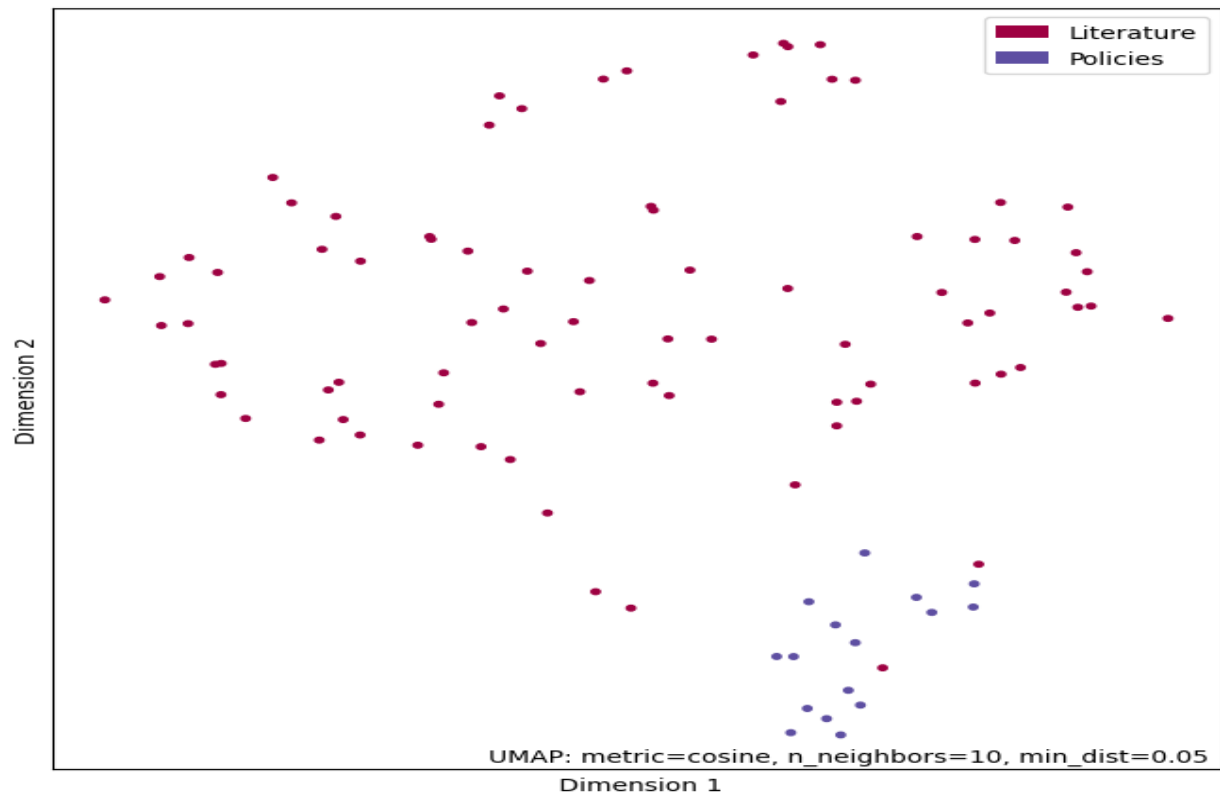


Figure 5-2: Data distribution visualization of policies and the academic literature, Source: Authors

A breakdown of all the policies and literature indicates that all policies have a degree of similarity, even at an individual level, with the lowest being 0.399. Our analysis also shows a pattern: academic papers most closely aligned with regulatory policies primarily focus on transition risk. In contrast, academic papers that take a broader approach to ESG and climate risk literature must be more closely aligned. This discrepancy may be due to the difference in the scope of the papers, with some approaching the topic from a narrower perspective while others took a broader perspective. Overall, the average similarity per paper was calculated to be 0.583. This similarity score indicates that when respective policies are individually compared to academic literature, there is moderate similarity between policies and academic papers, which is less than when the similarity assessments are collectively done.

5.5.3 *Semantic Analysis*

To assess if there is a semantic relationship between academic literature and policy documents, we initially calculated the cosine similarity to determine the extent of their semantic correlation and comparability. Our results indicate an overall cosine similarity score of 0.953, suggesting a high semantic relationship between the two. This strong correlation stems from shared focus areas, such as climate governance, risk management, and compliance with international standards like TCFD and IFRS S2. Both sources emphasize the necessity of embedding climate risks into governance frameworks and stress-testing methodologies, highlighting a growing consensus on the importance of resilience in financial systems. Hence, the comparative assessment was justified as there was a clear semantic basis for the analysis.

However, gaps remain in the operationalization of these concepts and how regulators and academics approach the application of the concepts, which is the major focus of this research. For example, to quantify the proportion of sentences in the regulatory document that contain direct or implied references to academic research findings, we classified the policies into three categories based on the categorization highlighted above. Our evaluation shows that there are gaps in the contextual assessment across the various categories analyzed. Our analysis shows that when the Central Banks and National Prudential Authorities, Other Regulators (securities and policy bodies) and standard-setting bodies, are individually analyzed, there is a moderately high similarity level. The reason for this gap could be connected to the respective policies' focus areas. For example, our analysis shows that academic literature often delves into theoretical concepts, advanced multi-period financial models, and adaptive scenario analyses that are not comprehensively addressed in regulatory policies. Additionally, while policies are robust in

disclosure and governance requirements, they often lack the forward-looking instruments and sector-specific guidance necessary for dynamic climate risk assessment.

Finally, we analyzed the identified thematic areas across academic literature and regulatory policies, showing the observed key concept areas in literature and policies and the identified gaps between them. Table 4 below addresses key thematic areas that need to be addressed, and the gaps identified within each thematic area.

Table 5-4: Thematic mapping and gap

Thematic Area	Key Concepts in Literature	Key Concepts in Policies	Identified Gaps
Governance and Disclosure	Board oversight, risk management integration, strategic alignment	TCFD-aligned disclosures, scenario analyses, board-level reporting	The academic discussion emphasizes deeper research-oriented insights, while policies highlight compliance aspects.
Prudential Supervision	Macroprudential frameworks, climate stress testing, green taxonomies	Risk-weighted assets, reporting frameworks, capital buffers	The academic paper discusses advanced multi-period financial models not fully addressed in policies.
Reporting and Metrics	Scope 1, 2, 3 GHG emissions, scenario-based projections	Annual disclosures, emission reduction goals, resilience metrics	The literature includes long-term research-based scenario methods, while policies focus on immediate compliance.
Climate Risk Mitigation	Transition risk, liability risks, operational efficiency	Guidelines for market risks, transition pathways, financial disclosures	Lack of specific financial instruments to address transition risk in the regulatory frameworks.
International Standards	EU's Macroprudential rulebook, policy harmonization	IFRS S2, Basel Committee climate-related risk management principles	Limited discussion in policies about harmonized global adoption challenges seen in the literature.

5.6 Discussion

This study reveals a moderately high alignment between climate risk regulations and academic research outcomes, as indicated by a cosine similarity score of 74.2%. A semantic assessment of

academic literature and policy comparability shows a very high level of contextual alignment, supporting the validity of the comparability analysis conducted. However, despite substantial overlap in areas of interest, the moderately high similarity score suggests that while many regulatory bodies incorporate scientific insights to some extent, significant gaps in integrating academic outcomes into practice remain. These gaps, as evidenced by differences in disclosure standards and risk management practices, reflect an ongoing divergence between regulatory frameworks and academic insights on climate risks, indicating that while some alignment exists, notable gaps remain.. For example, central banks and national prudential authorities exhibit a higher alignment with academic literature (0.772 similarity score) compared to standards and other regulators (0.653). This closer alignment stems from central bank and prudential authorities' primary focus on risk management and financial stability. In contrast, other regulators tend to focus on broader economic and social impact issues. Despite this similarity, there is a need for more evidence in the composition of the regulation to help determine if it follows a given approach, research, or methodology. Our in-depth assessment shows that the overall regulatory approach needs coherence and standardization across respective regulations when individually assessed or reviewed in line with their geographical regions or sectors, as the cosine scores were inconsistent and not in line with any observed pattern.

The lack of a coherent approach, even among regulatory bodies with similar mandates, raises a question on the need for more consistency and aligns with recent studies on the lack of comparability of prudential regulations on climate risk (D'Orazio et al., 2024) and the inconsistencies in banks' climate risk regulations (Martini et al., 2024). Given that effective regulations help ensure efficient capital allocation, reduce default rates, and increase overall credit by redirecting lending from high-carbon firms to less risky, low-carbon firms (Grill et al.,

2024), regulators can benefit from further aligning their approaches and guidelines, which can start by adopting results from academic research. This raises a fundamental question about the need for coordination among regulators. While the NGFS plays a role in coordinating central bank policies on climate risk, there is limited publicly available evidence assessing the depth and effectiveness of collaboration among its members. Future research could examine whether initiatives such as the NGFS-led could lead to consistent regulatory outcomes among central banks.

Consequently, this paper suggests a more engaged polycentric governance approach (Carlisle & Gruby, 2019; Marshall, 2015) to help enhance the management of climate risk regulations and the effectiveness of such an approach to driving climate governance long-term while being able to manage the complexities of climate risk management as well as adapting to emerging concerns from research (Bousema et al., 2024; Tobin et al., 2024). A polycentric governance approach, which fosters coordination across multiple regulatory bodies, could help address inconsistencies in climate risk regulations.. A more structured engagement between regulators and researchers could help further close this gap and enhance climate risk management strategies. Since some regulations do not fully incorporate advanced academic methodologies, increased collaboration between regulators and researchers could help integrate emerging scientific insights into future regulatory frameworks.

5.7 Conclusion

This study examines emerging climate risk regulations in the banking sector, comparing them to peer-reviewed academic literature using AI and NLP text analysis. It examined patterns of alignment between research papers and climate-related policy documents, focusing on the extent

to which research-policy alignment is associated with greater coherence across national policy frameworks. While the analysis does not demonstrate a causal relationship, it highlights patterns that may inform future efforts to better integrate evidence into policy processes. More importantly, it provides interesting links that might be worth studying further as it helps to lay the groundwork for future causal research on the relationship and the extent of influence of research on emerging climate risk regulations. Thus, this research should be seen as exploratory, rather than prescriptive. Further research is needed to understand when and how alignment contributes effectively to timely and equitable climate governance.

In addition, analysis in the research revealed a positive alignment between climate research and the level coherence observed in emerging climate policies. However, these findings should be interpreted with caution. It should be noted that while the observed association and moderately high alignment are notable, they do not establish causality. It is particularly important to make this distinction for the outcomes of this research since correlational analyses can suggest important patterns, but without longitudinal data or experimental controls, we cannot determine the direction or mechanism of influence (Kelloway & Francis, 2012; Rutter, 2007).

Consequently, this research is majorly exploratory and should not be read as a call for uniform alignment or a normative claim that more research integration will always be beneficial. This call for caution is important considering the fact that in policy domains like climate change, where urgent action is often required, the appeal to wait for more evidence or to pursue perfect alignment can inadvertently lead to inaction or delay (McConnell & 't Hart, 2019). This risk is particularly acute in regulatory or crisis-driven settings, where the demand for actionable knowledge must often be balanced against the uncertainties inherent in evolving research fields (Jagannathan et al., 2023).

Moreover, alignment is by itself context dependent (B. Y. Lin et al., 2023; Millière, 2023). While alignment may enhance coherence and facilitate more integrated responses, it can also obscure conflict, marginalize dissenting views, or reduce institutional flexibility (Weible, 2023). A very good example of this is currently playing out in the United States in real time with the fragmentation and culture wars on ESG and other concepts (Crews, 2023; Padfield, 2022). Coherence might also be hard to achieve in countries where the political or economic systems are fragmented or highly decentralized. Alos, policy coherence may not only be difficult to achieve but potentially undesirable if it suppresses locally adaptive responses or plural policy experimentation (Jordan & Huitema, 2014).

As next step, the association between research-policy alignment and policy coherence is a promising area for further research, even as caution is needed in deriving policy prescriptions directly from these results. Rather than suggesting that alignment should be universally pursued, this research propose that future work investigate under what conditions deeper alignment is beneficial. This will require deeper engagement with case-specific institutional, cultural, and temporal dynamics and needs that shape both policymaking and research work. This research's contribution lies in identifying patterns of alignment that may inform national strategies aiming to improve the integration of science and policy, particularly in complex domains like climate governance. However, the translation of these patterns into actionable recommendations must be tempered by an understanding of the political and institutional context constraints that may have direct impact on aligning certain aspects in specific contexts and jurisdictions. As such, our findings are best viewed as indicative of ideal scenario rather than a blanket prescriptive approach. This research also call for a more nuanced, context-sensitive approach to the role of research in shaping public policy.

This study introduces a novel approach by leveraging AI text analysis capabilities to assess and review academic literature and regulatory processes. This methodology enhances the depth and accuracy of textual analysis, providing insights that can help improve future policy development. One area of research gap that future research could investigate is the enhancement of polycentric governance among the different categories of regulations. Progress is being made on this front as evidenced by NGFS's facilitated collaboration among central banks on climate risk regulation, suggesting that structured cooperation might be feasible within specific regulatory categories.

Theoretically, this research advances the role and need for adaptive governance in climate risk by emphasizing the need for collaboration between different regulatory frameworks and the role of research in achieving this (D. Armitage, 2008). Such collaboration bridges the gap between research and practice, ensuring that policies evolve in response to the latest evidence. The paper emphasizes the need for policymakers to continuously refine climate risk regulations based on emerging academic insights and in line with adaptive governance's principle of learning through experience (Kato & Ahern, 2008). This iterative process fosters institutional resilience by enabling adaptation to evolving climate risks. Overall, the study serves as an essential call for the continuous improvement and future development of regulatory frameworks in the rapidly growing climate risk policy and regulations field.

Chapter 6

6.1 Conclusion

Climate risk has emerged as one of the most pressing issues facing the financial sector in the 21st century. This risk is particularly pronounced for banks due to their pivotal role in the economy and the threat climate change poses to their portfolios (Roncoroni et al., 2021). The combined impact of these two factors has necessitated increased scrutiny from regulators to ensure financial stability, leading to additional regulatory pressure in the form of climate policy and risk disclosure. These policies directly impact banks' operations, with significant implications for their credit exposure.

Research shows that climate risk exponentially increases the likelihood of business bankruptcies (Feng et al., 2024). This risk is especially pronounced for carbon-intensive sectors, where climate policies designed to mitigate these risks can create shocks that adversely affect the creditworthiness of borrowers. These factors significantly heighten the risk of loan defaults (Oyegunle et al., 2023), increasing regulatory pressure and scrutiny.

This dissertation examines the impact of climate transition risks, particularly regulatory actions, on banks' credit exposure. A comprehensive analysis delves into the implications for banks, focusing on credit risk, carbon pricing, and climate risk regulation. The study explores how regulatory actions shape banks' roles in the climate transition process and influence their credit exposure. It assesses the importance of regulations in driving banks' climate strategies and analyzes their impact on credit exposure across different regions. Considering the evolving nature of climate regulations, this dissertation also provides an insight into closing gaps between research expectations and regulatory frameworks.

This research deepens our understanding of how climate risks affect the banking sector. It achieves this in multiple ways. First, it provides valuable insights into the intersection of climate risks, regulatory frameworks, and financial stability. It also addresses critical challenges in implementing transition risk policies, including regulatory and market risks. Specifically, the research highlights the sector- and market-specific implications of integrating transition climate risk considerations, such as carbon pricing regulations, into credit risk assessment methodologies. It also underscores the importance of scenario analysis as a tool for addressing these challenges and evaluates the likely outcomes of different climate scenarios and commitments, offering a more detailed perspective on the potential impact of these transition climate risks areas.

Ultimately, this research provides additional insight into our understanding of the challenges of aligning regulatory mandates with climate risk disclosure expectations, ensuring that these frameworks are adaptable for financial institutions' operational needs. In doing so, it strengthens adaptive governance theory by demonstrating how regulatory coherence and evidence-based policies directly enhance financial stability and adaptive capacity. This provides a practical framework for incorporating climate considerations into financial governance that will be important even as the climate risk regulation space matures, while emphasizing the importance of a unified approach to tackling these challenges (Ens & Johnston, 2020).

This dissertation adopts an unconventional approach by examining how regulatory actions to address climate risk can complicate credit risk management for banks. It underscores the complex position banks often find themselves in balancing economic and environmental priorities. By addressing regulatory gaps and aligning academic research with practical application, this work contributes to the emerging field of climate risk regulation, offering

insights into bridging theory and practice. Ultimately, this thesis offers a foundation for developing regulatory strategies grounded in both business realities and academic insight, supporting the transition to a low-carbon economy.

6.2 Contribution to Knowledge

This paper makes several unique contributions to academic literature and research. First, it offers insights into how evolving climate policies, such as the introduction of carbon pricing, affect financial institutions' loan portfolios, especially in resource-dependent economies. Focusing on Canada, the research examines how carbon pricing influences commercial credit risk in an economy that is heavily reliant on the carbon industry. It identifies specific impacts of climate risk management on banks' credit exposure in such economies, thus addressing a gap in previous studies that either looked at broader portfolio effects or relied on traditional financial indicators and models (Bouchet & Guenedal, 2020; Ivanov et al., 2023).

This dissertation also provides a regional and economic analysis of how climate policy instruments, like carbon pricing, present challenges and limitations across different regions. It explores the broader implications of climate risk on financial stability, emphasizing the need for comprehensive data and scenario analysis to accurately predict climate impacts on financial assets. By using established scenarios such as the IEA and Altman's Z-Score model, this study expanded on previous work on the impact of carbon pricing on credit risk (Aiello & Angelico, 2023; Capasso et al., 2020; Dumrose & Höck, 2023), highlights the importance of integrating transition risk considerations into traditional financial risk models to enhance banks' resilience to climate-related shocks (Oyegunle, 2020).

This thesis also contributed to the operationalization of adaptive governance, by demonstrating how its principles can be applied in the banking sector to mitigate climate risks. This addresses an important gap in translating adaptive governance frameworks from theory to practice (Hurlbert & Gupta, 2016). While adaptive governance has been extensively discussed in academic literature, often emphasizing high-level principles like flexibility, collaboration, and resilience (Hatfield-Dodds et al., 2007), few studies provide actionable approaches for specific sectors (Kivimaa et al., 2024; Van Assche et al., 2022). This thesis fills that void by embedding adaptive governance principles into the financial sector's response to climate risks, particularly through tools like collaboration, regulatory coherence, and scenario analysis, thus demonstrating its practical utility (Sharma-Wallace et al., 2018).

In using Altman's Z-Score model to determine the impact of carbon pricing on credit, this thesis makes a distinctive contribution to climate risk assessment by employing a traditional credit assessment approach to assess climate sector-specific risks (Oyegunle et al., 2023). This involves the combination of an established financial model such as Altman's Z-Score, which is traditionally applied to evaluate a company's financial health using factors like profitability, leverage, and liquidity (Altman et al., 2019; Caouette et al., 1998), with a climate policy tool that assigns a monetary cost to carbon emissions, into this financial model. This combination allows the model to account for climate-related financial risks in a way that conventional approaches does not. By capturing these dynamics, the model provides a realistic assessment of risk exposure. Thus, offering a practical methodology for enhancing credit risk evaluations and supporting sustainable financial governance.

Lastly, using AI, this research assesses the alignment between academic research and regulatory frameworks. In assessing this, the research highlights gaps in data availability, methodological

inconsistencies, and implementation challenges for climate regulation and practice. This dissertation underscores the importance of regulatory mandates for standardized climate risk disclosures, since the absence of reliable data hampers informed decision-making by researchers and regulators (NGFS, 2019). Through this analysis and gaps identification, this thesis aims to bridge the divide between academic and regulatory perspectives (Campiglio et al., 2018). To bridge this gap, this dissertation advocates for evidence-based policymaking to align research with regulatory needs. By grounding regulations in empirical evidence, this approach enhances their effectiveness and adaptability. This thesis contributes to this alignment by demonstrating how climate-related risks influence financial systems and offering pathways for crafting practical, data-driven policies. No known research has applied this approach to climate risk before. By systematically comparing these regulations with peer-reviewed academic literature, the paper highlights the gaps and discrepancies between theoretical research and practical implementation. This gap analysis is crucial for identifying areas where regulatory practices can be improved and better aligned with academic insights, ensuring that climate risk management strategies are scientifically sound and practical.

6.3 Contributions to Theory

This thesis makes several significant contributions to theoretical frameworks, which are discussed in detail below:

6.3.1 Credit Risk Theory:

One of this dissertation's most important theoretical contributions is its contribution to Credit Risk Theory. This theory assesses the likelihood of financial loss due to borrowers' inability to meet contractual loan obligations (Altman, 1968; Merton, 1974). Central to this theory is the ability to assess the probability that a borrower might default, which influences the potential

financial loss and the corresponding impact on lenders. Credit Risk Theory encompasses various concepts such as credit scoring, creditworthiness, and risk assessment models, all designed to evaluate borrower risk and appropriately price loans (Jarrow & Turnbull, 1995; Trueck & Rachev, 2009).

This research advances Credit Risk Theory by addressing an emerging and impactful area – the link between climate risk and credit risk, particularly the effect of transition risks on borrowing costs and the increased likelihood of default. Understanding this connection is critical as the world strives to meet net zero targets, which necessitate regulatory changes and shifts in consumer behaviour. These shifts pose significant risks for banks exposed to carbon-intensive sectors, impacting corporate credit risk if not adequately priced into loan considerations (Ugolini et al., 2024).

Our research further confirms the connection between regulatory transition risks related to carbon and their impact on credit risk, emphasizing the need to mitigate these risks to prevent increased default rates, loss of revenue, or heightened borrowing costs. By applying Altman's theoretical model (Altman, 1968, 2018; Altman et al., 2019; Altman & Saunders, 1998), this study improves upon established methods for evaluating borrower risk by helping lenders to incorporate carbon considerations into loan pricing and managing their portfolios more effectively. This approach and findings align with recent literature on integrating carbon risk into credit risk assessments and further highlight the need for credit risk theory to continue adapting (Duffie & Singleton, 2012) by integrating advanced approaches, methods, economic theories and evolving risks such as carbon to predict better and mitigate potential losses.

6.3.2 *Financial Stability Theory:*

By connecting Financial Stability Theory to climate risk, this research highlights how climate transition efforts, such as carbon pricing, can influence credit risk and the stability of financial institutions. This integration is crucial for understanding the systemic nature of climate risks and the need for macroprudential responses to address these challenges.

This study contributes to Financial Stability Theory by expanding its application to emerging systemic risks like climate change (Crockett, 1996; Goodhart & Tsomocos, 2007). A critical theoretical gap in financial stability theory lies in managing risk, which is traditionally addressed through macroprudential decisions based on models and stress testing. While adequate for market risks, these approaches are inadequate for the dynamic and unpredictable nature of climate risk, particularly climate transition risks, such as regulatory and market risks (Baer, 2024; Battiston & Martinez-Jaramillo, 2018; Chabot & Bertrand, 2023; Z. Liu et al., 2024; Trinh, 2024).

The reason for this is because traditional approaches, such as those used for assessing market risks, rely heavily on historical data, statistical models, and relatively predictable patterns of market behavior (Baer, 2024; Board of Governors of the Federal Reserve System, 2024b; D’Orazio et al., 2024). These methods are effective for identifying and quantifying risks tied to financial markets, such as price volatility, currency fluctuations, or interest rate changes but are ineffective in assessing climate risks, especially transition risks, which evolve rapidly and unpredictably due to the complex interplay of environmental, political, technological, and societal factors (Grill et al., 2024; Martini et al., 2024; Ugolini et al., 2024). Also, unlike market risks, there is no established historical precedent or stable patterns for many climate-related events (Capasso et al., 2020; Hong et al., 2019). So, while traditional approaches are effective for

relatively stable and quantifiable market risks, they fall short in addressing the systemic, uncertain, and rapidly evolving nature of climate transition risks (BoC & OSFI, 2022; Ferreiro et al., 2022; Monasterolo et al., 2018; Nguyen et al., 2020; Roncoroni et al., 2021). This highlights the need for more sophisticated, adaptive risk assessment methodologies tailored to the unique challenges posed by climate transition risk. This study bridges this gap by assessing climate risk's financial, credit, and economic sector impacts on financial stability using climate risk scenarios to evaluate plausible future states and their implications for banks' credit risk assessments. Scenario analysis was applied in this research instead of alternatives like stress as it provides significant advantages by offering forward-looking insights that evaluate plausible futures and support proactive decision-making (TCFD, 2017). It is also highly customizable which allows for the integration of diverse factors such as economic, policy, and technological variables, enabling a more comprehensive assessment of risks (Baer, 2024).

6.3.3 Adaptive Governance Theory

This study contributes to adaptive governance theory (Hatfield-Dodds et al., 2007; Hurlbert & Gupta, 2016) by examining the diversity and alignment of emerging climate risk regulations with academic research expectations in this field. In analyzing the gaps between climate regulations and academic research, this research addresses the need for policies to incorporate multiple perspectives and align policy objectives with scientific findings. As a result, this research provides a framework for developing climate risk policies in the banking sector, emphasizing the importance of regulatory coherence across governing bodies and alignment with emerging scientific evidence. Such coherence and alignment can strengthen financial institutions' resilience to climate risks, a fundamental tenet of adaptive governance (Djalante, 2012; Steelman, 2016).

In the context of this paper’s findings, regulatory coherence is critical for enhancing resilience and advancing adaptive governance within the banking and financial sectors as they face climate-related risks. By harmonizing policy frameworks, regulatory coherence addresses inconsistencies across jurisdictions that undermine resilience, providing clear expectations and minimizing uncertainty for financial institutions (Ens & Johnston, 2020; NGFS, 2019). Specifically, having a unified framework allows banks and stakeholders to anticipate and adapt to climate-related risks effectively while integrating these considerations into credit risk assessments and operational strategies. This reduces vulnerabilities in critical sectors, especially those reliant on carbon-intensive industries.

This research further advances adaptive governance theory by illustrating how policy coherence directly influences financial stability within banks, echoing findings in climate risk research that highlight the vulnerabilities created by regulatory uncertainty. By analyzing regulatory consistency and linking outcomes to climate risk research outcomes, this study offers a nuanced understanding of how incoherent policies can limit the adaptive capacity of financial institutions, a foundational concept in adaptive governance (Hurlbert & Gupta, 2016). This research also identifies specific gaps and potential areas for cooperation, supporting the development of cohesive and effective global strategies to manage climate-related financial risks within polycentric governance systems (Bousema et al., 2024; Tobin et al., 2024).

Finally, this study underscores the importance of collaboration across regulatory frameworks, particularly between regulatory bodies and academia (Armitage, 2008; Armitage et al., 2009). By showing how such collaboration can foster alignment among stakeholders, the research supports the development of policies grounded in the latest scientific evidence (T. Dietz et al., 2003; Folke

et al., 2005), while highlighting the need for iterative policy adjustments that integrate new academic insights, foster resilience, and enable institutions to adapt to evolving climate risks.

6.4 Future Directions for Research

While this study covers essential areas on the impact of climate risk on credit, there are still opportunities for future research to enhance this evolving field for academia and practice. One of the primary recommendations is the urgent need for alignment in climate modelling and assessment. A major challenge in assessing climate risk is the difficulty in aligning climate risk projections with future financial risk impacts. This challenge, as highlighted in this study, is particularly acute in the banking sector due in part to the short-term nature of banks' credit exposure, and the proliferation of models and approaches needs to be clarified. A lack of reliable data and a need for more scenario analysis models compound this problem. Despite efforts by regulatory bodies such as NGFS (Board of Governors of the Federal Reserve System, 2024b; NGFS, 2019, 2020), the challenge persists. This situation presents an opportunity for future research to improve climate risk modelling techniques and develop a generally accepted, standardized approach that can provide more accurate assessments of climate impacts on financial assets. This includes enhancing data collection methods and refining scenario analysis models to address the short to medium nature of bank's credit exposure.

Another area that requires further study is the harmonization of global climate regulations. Exploring the effectiveness of different regulatory approaches across regions can contribute to designing policies that more effectively mitigate the financial risks associated with climate change. Additional research is also required to assess the alignment of further regulatory approaches at regional and sectoral levels. While this research has addressed gaps between regulatory approaches and academic literature, conducting a detailed study on how academic

perspectives on climate regulations differ across various areas of climate focus would be beneficial. For example, there is an opportunity to align regulations more closely with research outcomes through collaborations which could start with the provision of accessible and consistent data-sharing opportunities that provide both researchers and regulators with robust, real-time data on climate and financial exposures. Collaborative initiatives, such as joint working groups and pilot programs, can also ensure that academic innovations in scenario analysis and adaptive governance frameworks are integrated into policy frameworks in ways that meet both regulatory compliance and practical application needs. This synergy would ultimately enhance evidence-based policymaking and adaptive resilience in the financial sector.

Further research is needed to understand the sector-specific impacts of carbon pricing and other climate policies. This is particularly important for sectors not typically classified as fossil fuel industries such as manufacturing, real estate (residential and commercial), and transportation, but that are heavily carbon-dependent and contribute significantly to climate impact through direct and indirect fossil fuel use and electricity consumption. A deeper understanding of these sectors and their collective impact will enable banks and policymakers to tailor their strategies to address the unique risks and opportunities within different industries.

6.5 Practical Application of this Research

The studies that comprise this dissertation offer practical insights relevant to policymakers and financial institutions. First, the research supports enhancing regulatory standards for integrating climate risks into credit and financial stability assessments. To achieve this, regulators should focus on aligning climate risk approaches through collaboration and addressing the systemic nature of climate risks observed in the studies. A critical aspect of this alignment is developing and standardizing climate stress testing and scenario analysis models, essential for strengthening

the financial sector's resilience. A few regulatory led scenario development have either been triaged or is currently ongoing at different regulatory and other stakeholders levels and more are still expected in the future (Bank of England (BoE), 2022; Board of Governors of the Federal Reserve System, 2024a, 2024b; BoC & OSFI, 2022; NGFS, 2020), however there needs to be a concerted effort to align the findings of these works and seek a means of using it to driving a unified front towards the singular objective.

Furthermore, banks must urgently align their credit criteria with climate risk. Many banks still treat climate risk primarily as a reputational rather than a financial and systemic one.

Incorporating carbon pricing into credit risk assessments and adjusting lending practices and pricing to reflect the actual cost of carbon and the transition to a low-carbon economy (Ugolini et al., 2024) will ensure that the cost of borrowing more accurately reflects the embedded climate risk in loans.

Data is one of the biggest challenges in addressing climate risk issues, particularly in developing models, scenarios and critical elements for precise and accurate credit risk assessment (Bruneau et al., 2023). Enhancing the availability, quality, and transparency of climate-related data is crucial. Doing so will not only expedite research and progress in the field of climate-related risk but also address significant gaps highlighted in this research. The implications of improved data access include developing more accurate projections and assessments, enhancing climate disclosures, and enabling better decision-making by financial institutions.

6.6 Research Limitations

This dissertation explores the impact of climate transition risk on banks through two lenses. First, it applies the Altman Z-score model to assess the effect of carbon pricing on firm-level credit

risk, comparing outcomes across a carbon-dependent economy and other jurisdictions under different scenarios. Second, it reviews how emerging climate risk regulations in the banking sector and aligns with evolving academic research outcomes. While the methodologies employed in both instances offer valuable insights, considering that climate risk is an emerging field of study, and the methodological frameworks in this area of study is still not fully matured, it is important to acknowledge, highlight and discuss the limitations of this study, since this may limit the interpretation and generalization of the findings in different contexts.

First, the use of the Altman Z-score model to assess the impact of carbon pricing on credit risk, though valuable, presents significant constraints. The key issues are the linearity of the Z-score as it is based on the combination of backward-looking financial ratios (Altman et al., 2017, 2019) and does not reflect forward-looking dynamics critical to understanding transition risk (Bender et al., 2024; Hubert & Hilke, 2024). For example, in situations where carbon pricing has yet to impact firm earnings fully, the model may understate the insolvency risk. Additionally, it fails to account for sectoral heterogeneity in price transmission (e.g., businesses' ability to adjust their prices to reflect changes in their input costs), firm-level adaptation strategies, and government policy intervention i.e. subsidies (Fitó-Bertran et al., 2018; Mattio, 2024). The model also does not capture innovation, decarbonization pathways, or strategic repositioning, all of which are increasingly relevant to a firm's long-term viability under climate policy regimes. Consequently, the Z-score may misclassify firms either by overstating distress in policy-supported industries or understating risk in carbon-intensive sectors with limited flexibility.

Alternatively, it could be argued that models such as the Merton Distance-to-Default model could offer a more market-sensitive approach by incorporating equity volatility and asset value to estimate the probability of default, this has been applied by certain studies to assess real-time

investor sentiment and potential market adjustments in response to carbon exposure (Capasso et al., 2020; Nguyen et al., 2023; Park et al., 2023). Also, some emerging literature in this field also adopted different variants of Value-at-Risk (VaR) and Climate Value-at-Risk (Climate VaR) frameworks which enables a probabilistic assessment of potential losses under various carbon pricing scenarios, accommodating both tail risks and transition pathways (Azar-Ibrahim et al., 2024; Bianchini & Gianfrate, 2018; S. Dietz et al., 2016), are also some of the methodologies that could also be explored. Specifically, unlike the static nature of Altman's Zscore, the use of one or a combination of these models may help provide additional insight into regulatory uncertainty, sector-specific vulnerabilities, and opportunities for decarbonization that may underestimate or overestimate the credit risk which the Z-score is prone to.

On the regulatory side, while the use of AI and NLP is novel, the study could do more by addressing the question of correlation and directionality as Chapter 5 only assessed the alignment and did not provide a deep analysis into causality and correlation. Future research needs to go beyond just assessing similarity to investigate the relationship between regulatory activity and academic output, which in this study is inherently correlational. This is important since this dissertation only offered descriptive assessment, which creates a gap as it did not establish causality. One area of limitation of this research that also needs to be explored here is the concept of directionality of influence (Apfelthaler, 2019; Bergek et al., 2023; Parks, 2022), which in this research will help to determine whether regulation stimulates research, vice versa, or both, one future research is to investigate this as it remains unresolved. It may also be important to review academic papers, published before the regulations are released due to the anticipatory nature of many climate policies, where academic discourse may precede regulatory release and see if prior research outcomes have an influence on emerging regulations. One other area of limitation that

may be explored is to critically analyze factors influencing regulatory differences beyond the text, especially at the jurisdictional level as those differences may reflect other structural factors such as language, availability of funding, geopolitical sentiments or local priorities, rather than true differences in regulatory effectiveness.

Lastly, it should be noted that this study does not evaluate the quality or success of regulatory regimes. Variations in academic output across regions should not be construed as indicators of policy ambition or impact. Without robust causal identification methods (e.g. difference-in-differences, natural experiments or instrumental variable techniques), conclusions about policy effectiveness or research influence may be considered speculative. Future research should consider financial climate models, textual analysis, and stakeholder mapping to better capture feedback loops between regulation and research.

Ultimately, these limitations underscore the importance of contextualizing findings within broader institutional, strategic, and socio-political dynamics when assessing climate-related financial risks and regulatory influence.

6.7 Final Words

This dissertation has underscored the critical intersection of climate transition risks, climate regulations, and credit risk, offering valuable insights into the regulatory impacts, credit risk implications, and the need for robust risk management policies. By addressing these challenges, the banking sector can play a pivotal role in supporting the global transition to a sustainable and resilient economy. The study concludes by summarizing the key insights and implications of the research.

First, there is a pressing need for a coordinated global response to climate risk in the banking sector, starting with robust regulatory measures to ensure financial stability in the face of climate transition to a carbon free economy. Today, banks remain significantly exposed to climate-vulnerable sectors, leading to indirect impacts as climate transition shocks ripple through an interconnected financial system (Bruneau et al., 2023). Regulatory efforts to address climate impacts, heightened awareness of climate-related risks and expectations of stricter rules often prompt banks to shift away from climate-sensitive sectors (Reghezza et al., 2022). However, it is crucial to understand that this shift, often driven by regulatory pressure, directly affects credit and financial stability, all influenced by climate regulation.

There are also critical research gaps that can be addressed based on the findings of this dissertation. Firstly, more work is needed to develop methodologies for analyzing and addressing climate risk, particularly concerning commercial credit. Although this dissertation has partially addressed this issue, significant work remains. Additionally, there is a need to focus on non-carbon-dependent sectors since achieving the desired orderly transition (NGFS, 2020) requires a coordinated effort that will help align and improve climate models and the proliferation of climate-related risk policies. Part of the required efforts will involve improving climate risk assessment models and methodologies, harmonizing regulations across jurisdictions, and incorporating comprehensive data for more accurate climate modelling.

This research has explored emerging areas of carbon pricing impact on commercial credit and the effects of evolving regulatory policies on banks' credit exposure. It also addresses regulatory gaps in climate risk research by providing insights and recommendations to bridge the divide between industry practices and academic literature. Additionally, the research examines regional approaches to climate risk assessment, highlighting how differences in banking and economic

strategies can be aligned to advance climate solutions. A key finding emphasizes the importance of understanding and identifying the distinct characteristics of various regions to account for each country's unique circumstances as they work towards net-zero climate targets. This research's timely contributions will support the development of a sustainable banking future. The issues addressed in this study will help ensure a more orderly transition, safeguarding banks' credit exposure while enabling a coordinated and realistic shift that better aligns with each country's economic realities.

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[:text=The%20Climate%20Biennial%20Exploratory%20Scenario%20\(CBES\)%20includes%20three%20scenarios%20exploring,Action'%20\(LA\)%20scenario.](https://www.bankofengland.co.uk/stress-testing/2022/results-of-the-2021-climate-biennial-exploratory-scenario#:text=The%20Climate%20Biennial%20Exploratory%20Scenario%20(CBES)%20includes%20three%20scenarios%20exploring,Action'%20(LA)%20scenario.)
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