An Analysis of Physical Climate Change Events on Commercial Bank Stock Prices

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Events resulting from climate change can cause a wide range of serious implications for investors and insurance companies. However, there is currently a lack of understanding of how banks can be affected. Exploring a range of disaster experiences is essential to build a systematic understanding of the effects of the physical impacts of climate change on banking. Climate related effects can potentially increase the risk exposure of banks both directly and indirectly, through production interruptions, destroyed collateral and affected loans. This increased risk exposure is often reflected through declines in share prices for the banks at risk. This research aims to explore physical risks in the context of commercial banking by using event study tools to analyze changes in returns after a physical event period in both North America and the Caribbean, comparing the effects of physical climate change in each region, in order to gain an understanding of how physical risks are perceived by banks. This highlights how physical climate change may affect their business, as well as any differences in the effects of physical risks in developed versus developing countries. The results indicate a need for promoting appropriate risk responses in both developed and especially developing countries for climate-related physical risks. It also highlights the importance of climate-related financial disclosures. The results from this research can be used in the development of climate risk matrices and are especially relevant to banks conducting business in developing countries.

Keywords: physical risk, event study, banking, finance, TCFD

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Chapter 1

Introduction

The physical effects of climate change have already started to cause a wide range of serious implications for investors and businesses (Ceres, 2012). In fact, science shows that while extreme weather events and variability has always existed, these events are now becoming more frequent and intense (Ceres, 2012, Munich RE, 2018). However, while the physical risks of climate change have received attention within the insurance sector, they have not been widely assessed in credit and lending portfolios held by banks, who place greater emphasis on transition-related risks and opportunities resulting from a shift to a low-carbon economy (UNEPFI, 2018). This thesis aims to assess the effect of physical climate change related events on the banking sector by measuring deviations in share-prices of major banks after significant physical weather events, to better understand the effects of an increased frequency of climate catastrophes on banking.

A lack of understanding on how banks can be affected by physical weather events provided the impetus for this research. Typical financial arguments would state that these weather-related events would be idiosyncratic, and therefore can be diversified away (Ouazad and Kahn, 2019), however the mispricing of disaster risk and the correlation of such risk across loans in a credit pool can together be a substantial source of systemic risk for lenders (Ouazad and Kahn, 2019). Realizing this lack of understanding, the UNEPFI began to assess physical climate risks in banks loan portfolios for climate sensitive sectors, using climate change scenarios and methodologies which evaluate impacts on key credit risk measures, and estimating how these changes could affect the Probability of Default (PD) and

Loan-to-Value (LTV) ratios at a borrower and portfolio level (UNEPFI, 2018) as a first step in gaining an understanding of how physical climate change can affect the business of banks.

1.1 Problem Background

Recent evidence suggests an increasing risk of natural disasters of increasing magnitudes (Ouazad and Kahn, 2019). In fact, some studies have found that households who have purchased a house in coastal areas are at an increasing risk of defaulting on mortgages, which can affect the performance of commercial banks (Ouazad and Kahn, 2019). Studies have found that there is a substantial increase in sales of mortgages with flood risk to the two main agency securitizers in the USA after natural disasters that cause more than a billion dollars in damages, especially in areas where disasters of such magnitude don't usually occur (Ouazad and Kahn, 2019). These sudden sales of mortgages after natural disasters indicate the need for developing a framework for assessing the financial impacts of physical climate change.

1.2 Purpose of the study

Now more than ever, central banks are beginning to recognize climate change as a major vulnerability facing the world's economies. In fact, in May of 2019, the Bank of Canada released its 2019 Financial System Review listing climate change as a major vulnerability for the first time ever (Kilpatrick, 2019). Now that physical and transitional climate risks are being mentioned in the same conversation as household debt and the housing market, it is important for us to understand what these risks mean and how they can affect the business of

commercial banks. The rising awareness of central banks to the dangers of climate change can move markets as central banks tend to have data-driven reports and an inherently cautious nature, therefore it's harder for market participants to dismiss their advice.

With central banks now taking environmental risks into account, including risks from climate change which can have a material impact on short and long-term development of the financial sector and macroeconomy (Dikau and Volz, 2018), the importance of environmental factors and how they affect conventional goals must also now be considered in retail and commercial banking. There is already a heavy focus on the risks and opportunities available from the transitional climate change perspective, however risks and opportunities from physical climate change are equally as important. Increasing the understanding of how physical climate change has affected banking in the past reflected through fluctuations in share prices can help build an understanding of how they may also be affected in the future if physical risks increase as climate change progresses, and can help banks align their goals with the interests of all stakeholders, especially if current operations prove detrimental to shareholder value through indirect costs from physical climate change.

1.3 Questions and Hypothesis

This research challenges whether or not there is a business case for sustainability for banks to address external pressures from physical climate change. With this in mind, two research questions have been developed, firstly;

1. Are the share prices of commercial banks affected by climate-related physical events?

Understanding the answer to this question can help banks increase their resilience through integrating core sustainability strategies to help mitigate the effects of climate change on their profitability. There is also a significance in where the banks included in this study are located, as different regions will experience different levels of vulnerability and sensitivity to physical climate change risks, as suggested by the results of studies done by Briguglio (1995) and Benson and Clay (2004) which suggest that certain economies, especially small islands are more sensitive to economic shocks including those introduced by natural hazards. For this reason, a second research question was developed;

2. Is there a difference between the effects of climate-related physical events in developed vs developing countries?

Highlighting any differences in the effects of physical climate events in emerging vs developed markets can help banks that operate in vulnerable countries maximize profitability and build an understanding of how they can keep the stakeholders' interest as a core value.

For each question, a null hypothesis has been developed in that there is no significant effect on share prices from climate-related physical events, and thus there is no difference

between the effects of climate-related physical events in developed vs developing countries. Statistical tests will be used to either reject or fail to reject the null hypotheses based on the secondary data collected.

1.4 Significance of the study

The findings from this study can highlight the extent to which climate-related risks can affect the profitability of banks. Many commercial banks are beginning to claim that they are transitioning to pursue a sustainable agenda, however evidence suggests that these claims may be varying forms of greenwashing. With many central banks now considering environmental risks, structural uniformity among organizations may become a necessity, as there is the possibility of external regulation forcing a shift in behavior of commercial banks. This research can highlight the opportunity for profit maximization through integrating sustainability strategies in order to minimize physical risks. If it is found that climate change can bring losses for banks, the profitability of sustainable activity can be realized, and banks can create more value for stakeholders thereby creating a business case for sustainability.

This study will also aid in learning about the shift in regulatory practices by groups that advocate for climate change risk management within the financial sector such as the Financial Stability Board's Task force on Climate-Related Financial Disclosures. The findings will help understand how these groups can effectively integrate climate risks and opportunities with a special focus on banks but may also be applied more broadly to other financial institutions.

Further, studies suggest that there are significant information gaps with regards to the physical effects of climate change for business (Mahalingam et al., 2018, Latchman et al., 2019, Oxfam America, 2012, Wingward, 2015). These academic studies regarding physical risk conclude that disclosure practices can aid in reducing the potential effects of physical climate change, however there has been no formal assessment of the financial effects of physical climate change on specifically the banking sector to date. This study aims to explore ways of providing the actionable information required by banks in order to mitigate the effects of physical climate change.

1.5 Definitions

A few key terms used consistently throughout this study require clear definitions as the understanding of their meaning can vary based on context. Thus, a list of definitions of these terms as used in the study has been compiled;

Disaster: An unanticipated natural catastrophe that results in large financial losses, significant damage, and can also cause casualties.

Vulnerability: The degree of exposure to risks and likelihood of those risks to present harm.

Risk: The chance or uncertainty of gains or losses.

Causality: The relationship between an effect and its causes.

Chapter 2: Climate Related Risks

It is essential to understand the relationships between banking and risk management, as their correlation presents the rationale for this experimentation. According to several studies, banks can observe losses from destructive natural catastrophes due to the increased exposures in the areas at risk (Mahalingham et al, 2018, Ackerman et al., 2008, Bailey et al, 2006). Places with rising wealth and increased population concentrations in hazardous areas such as coastal regions increase the bank's risk exposure, especially depending on the banks' lending portfolio composition. Efficiency in insurance markets can also affect the losses observed by banks. Risk transfer is visualized in a top-down hierarchy where losses cascade from the insured policyholders, to the re-insurers who are the ultimate bearers of risk.

Figure 1. Showing Nat Cat Risk transfer (Source: von Dahlen and Peter, 2012, Cambridge center for risk studies)

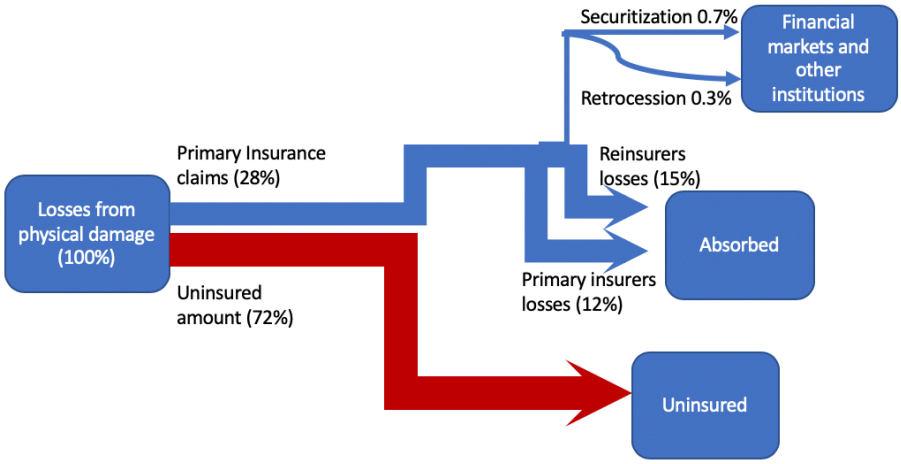


Figure 1 (von Dahlen and Peter, 2012), presents an illustration of the extent to which banks can observe risk from natural catastrophes. Only a fraction of losses is passed to broader financial markets through securitization, and an even smaller fraction of this goes towards commercial banks. Other deposit-taking institutions also absorb some of these losses, which suggests a minimal effect on the share price of banks after a natural catastrophe. This literature appears to support the null hypothesis of this study suggesting that physical risks should have very minimal effects on banks.

2.1 Risk assessment in banking

Risk management in banking is theoretically defined as "the logical development and execution of a plan to deal with potential losses" (Turgot, 2018). This process requires risk managers in the banking industry to know the answers to various questions, they must know what kind of events can damage their business, and how much damage can each of these events cause. Risk managers should also know what actions should be taken by institutions in order to manage these risks. Banks must investigate their activities that are creating risks or losses, and also assess the potential damage that those risks could cause (Turgot, 2018). Banks are invariably faced with different types of risks in the course of their operations, that may have a potentially adverse effect on their business.

All banks are obliged to have established a comprehensive and reliable risk management system, which is integrated in all business activities and tailored to the banks'

risk profile. It is important, however, for risk managers to consistently monitor these risk management systems, as it is imperative that the institution's exposure to certain existing risks and the development of new threats to their business be known at all times in order to mitigate potential losses.

This highlights the importance of understanding non-traditional risks such as those caused by climate change. Climate change risk management is still in its infancy in many banks around the world, especially those in developing countries, however climate risks can potentially affect all aspects of traditional risk management, as transitional and physical risks as a result of climate change have potential implications on liquidity risks, default rates, market risks, country risks as well as compliance risks to some extent as more central banks focus on greening their respective financial systems.

According to Weber. and Feltmate (2016), a risk-adjusted return approach can be used in a broadened context that takes non-financial risks into account, supplementing conventional criteria. This helps banks conduct responsible financial business by taking sustainability risks into account in their investing and lending processes (Weber and Feltmate, 2016). Implementing a strategy for measuring and adjusting for non-traditional risk may be essential for banks, as some banks have indirect GHG emissions through financed clients more than 900 times higher than direct emissions caused by energy use, business travel and others (Weber and Feltmate, 2016) This presents a significant amount of indirect climate risk exposure.

2.2 Climate change risk

In the banking industry, risk is often inseparable from profit. It is important, however, to manage the different types of risks that banks are exposed to. Successful risk mitigation begins with accurately identifying the risks to which the bank is exposed, understanding why they arise and the damage that they can cause. This risk management process is the same for risks in the context of climate change. In this section, different climate change risks are identified and described, and the mechanisms by which they present material financial losses are defined.

2.2.1 Physical Risks

Climate change exposes individual assets, industries and entire regional economies to new risks. Physical events such as droughts, hurricanes, high tide flooding and other extreme weather events have become more severe and costlier. Just as tools are needed for assessing the implications of traditional risks, physical risk management also requires tools and data in order to understand and respond to these risks. In modern times “Climate risks” has entered mainstream investment and banking lexicon as there is now a focus of the financial implications that it may bring. While most of the financial industry has focused on the implications of transitioning to a lower-carbon economy, physical risks remain hard to quantify (Rhodium group, 2019). Further, actionable information that investors and financial

actors need to effectively incorporate into portfolio construction and management has been hard to come by.

There has been one major collaboration in the financial industry in order to begin accounting physical climate risk between BlackRock and Rhodium Group, in order to identify how physical risks can impact financial performance. This methodology aims to provide a granular assessment of physical climate risks at the asset, portfolio and industry level, including damage to fixed assets such as buildings and property, losses from labor force disruptions, falling crop yields, rising energy demands and other physical impact categories (Rhodium group, 2019). This approach uses a scenario-based analysis and draws on climate models to map the bounds of future risks ensuring that their goals are aligned with the recommendations from the TCFD.

2.2.2 Transition Risks

Climate risks could result from the transition to a low-carbon economy (Batten et al. 2016, ESRB, 2016). Risks arising from these contexts are commonly known by market participants as transitional risks. The shift of capital away from GHG intensive sectors towards low-carbon sectors is one source of transitional risk. It is becoming more apparent that a transition to sustainable finance is critical in scaling up the low-carbon investments that may be needed to achieve climate targets such as the Paris agreement (Monasterolo and Angelis, 2019). According to Battiston et al. (2017), climate policy shocks can pose relevance for values at risk in investment funds, as well as banks with high holdings in

climate-policy relevant sectors. This highlights the need to accurately assess exposure to climate risks. One method to begin adjusting prices to reflect transitional risks includes better disclosure of climate-related financial information (Monasterolo et al., 2017). One study has found that the two most critical dimensions of measuring climate transition risk are vulnerability in terms of portfolio exposure to transition risk and relevance in terms of market share (Monasterolo et al., 2017). Using these variables, a greenhouse gas holding index was developed which weighs the market share of a portfolio in each index by the contribution of that sector to GHG emissions. This is important, as the other main source of transitional risk is the implementation of regulatory measures that price carbon, which can devalue the GHG exposed parts of a portfolio.

2.2.3 Reputational Risks

Reputation is one of the most valuable and fragile assets that a bank can have (Weber and Feltmate, 2016. Eccles, Newquist and Schatz, 2007). Management of reputational risk is an extremely important process for financial institutions, as it is key to building public and consumer trust. Negative reputation can drive away potential clients. For banks, reputational risk is the risk of loss of reputation, which can be a consequence of corporate irresponsibility. Due to its intangible nature, reputational risk is hard to measure.

Climate change has been identified as a source of reputational risk as it can change customer perception of an organization's contribution or detraction from the transition to a low-carbon economy (Weber and Feltmate, 2016, TCFD, 2017). Community perceptions are

affected by whether or not banks are taking initiative in assessing the uncertainty surrounding the potential effects climate change can have on their business. The reputation of a bank can also be harmed significantly if it lends to a borrower who has a negative reputation for sustainability issues (Weber and Feltmate, 2016).

2.2.4 Legal Risks

Legal risks can be succinctly defined as the loss to an institution which is primarily caused by legal or regulatory sanctions. The failure to comply with laws, regulations and rules may result in material financial losses for banks or reputational losses (BIS, 2010). Policy actions that are made to constrain the contribution to the adverse effects of climate change are considered to be legal risks by the TCFD (TCFD, 2017). These may have the material financial impacts of write-offs and increased operating costs resulting from higher compliance costs and increased insurance premiums. Policies such as emission pricing and emissions-reporting obligations all have the potential to increase legal risks for banks, in addition to mandates on existing products and services (TCFD, 2017). Increased exposure to lawsuits due to failure to comply with GHG emission regulations results in increased liability risks.

This highlights the need to understand how the share price of banks can be affected by these risks, as it can serve as an indicator of the banks' strategic planning and management of non-conventional risks.

2.3 Climate risk assessment

Climate risk estimations in banking depends heavily on disclosure of climate-relevant financial information (TCFD, 2017, Battiston et al., 2016). Battiston and Monasterolo (2016), examined climate risk penetration of the financial system by conducting a climate stress test (Battiston et al., 2016). This research found that not only is disclosure of climate-relevant financial information key, the timing and credibility of the implementation of climate policies also matters in climate risk assessments. A late implementation of climate policies can have adverse systemic consequences for the financial system, additionally, traditional cost-benefit analyses are often not adequate to identify individual climate risks and their propagation through the financial system. A similar notion is echoed through the TCFD recommendations, which serves as guidelines for players in the financial sector to properly disclose climate-relevant financial information to mitigate risks (TCFD, 2017). The TCFD literature is critical to this research and is further discussed in chapter 3.

Chapter 3: Research and Theory

This chapter examines the existing academic background of climate related risks in the context of banking. The potential consequences of climate-related risks amount to a new form of systemic risk with implications for economic stability (da Silva, 2020. Mahalingam et al, 2018). There is a quickly growing body of research including studies by academics, central banks, institutions, and dedicated research teams such as the Task Force on climate-related financial disclosures (TCFD). The increasing availability of studies suggest mounting evidence of climate-related risks as a clear and present danger to financial stability, however there are still gaps in understanding that must be researched in order to increase the awareness of all agents in the economy.

3.1 Linking physical climate change and financial performance

Natural disasters have caused at least $113 billion dollars of damage per year during the first decade of the twenty-first century (MunichRE, 2020). While the financial shock of a natural disaster may be understood in the context of property insurance and household finance, the link between physical climate change and commercial banks must still be investigated. Studies suggest that physical climate change events can result in spikes in credit card borrowing and overall delinquency rates (Gallagher and Hartley, 2017). Though these spikes are often modest in size and short-lived, it is not clearly understood whether or not an increased frequency of physical climate events will make periods of delinquency last longer,

result in higher debt levels, mortgage defaults, and affect the overall performance of financial institutions.

Research suggests that despite the sizable aggregate cost and long history of natural disasters in developed countries, little is known about how affected residents are able to cope with the financial shock of a disaster (Gallagher and Hartley, 2017). The aggregate cost of each event suggests large negative wealth shocks for those within disaster areas, however potential losses are also mitigated by the presence of insurance markets effective disaster risk reduction within developed countries (Gallagher and Hartley, 2017). In fact, some studies have found that after flooding in developed countries, total debt balances are reduced due to a sharp and immediate drop in total debt for the most flooded residents, driven almost exclusively by lower home debt. This is due to the timing and magnitude of flood insurance payouts being used to pay off mortgages rather than being used for the intended purpose of rebuilding homes (Gallagher and Hartley, 2017). In addition, there is only modest evidence that flooding increases credit card debt in order to pay for unexpected costs after the event. One study has found that in the case of hurricane Katrina, credit card debt only increased by about 15 percent for those affected versus the unaffected residents, which was not economically significant (Gallagher and Hartley, 2017).

Physical climate change also presents credit risks as banks can experience losses through contaminated or damaged sites used as collateral (Weber and Feltmate, 2016). Increased frequency of natural catastrophes can result in higher risks for banks as damage to the physical instrument used as collateral can result in a loss of value, in addition to credit

defaults from the borrower, this can be a significant indirect source of risk after physical events.

Aside from inflicting serious damage on tangible assets used as collateral, physical risks can also affect human capital, and deteriorate production capacity of the bank (Ono, 2015). Though the academic evidence on the economic impact of natural disasters is mixed, one underlying mechanism though which they may affect a firm's productivity is explored by Skidmore and Toya (2007) and Crespo-Cuaresma et al. (2008). These studies used aggregate data and found that natural disasters can lower productivity due to extended periods of downtime, however they may also increase productivity through the creative destruction hypothesis, which is attributed to a mechanism known as firm selection, where natural disasters expel inefficient firms, leaving a higher market share for those which operate more efficiently (Skidmore and Toya, 2007. Crespo-Cuaresma et al. (2008).

3.1.1 Country-Specific financial impacts of physical climate change

Exploring a range of disaster experiences in economies of varying size and complexity in different regions of the world is essential to build a systematic understanding of the effect of physical climate change on public finance (Benson and Clay, 2004). Studies suggest that the effects of physical climate change on finance has only been explored in the narrow context for a single major disaster in one specific area (Benson and Clay, 2004). With this issue in mind, some researchers compared the effects of physical climate change events

using case studies from three different countries, all with very different economies and of different sizes, however using complementary methodological and policy issues. Dominica, Bangladesh and Malawi were all found to be severely affected by climate change hazards, though the nature of each event was different, the focus of this study was on the sensitivity of the country's economy to natural hazards overall. This study found that Dominica, as well as many small, open-island economies face disadvantages associated with their size, insularity and remoteness (Briguglio, 1995), making them highly sensitive to economic shocks in any form including natural hazards. These countries were found to be the most vulnerable to financial losses from natural hazards (Benson and Clay, 2004).

In the case of Bangladesh and Malawi, the decline in GDP around times of natural disasters could be attributed to the percentage composition of the GDP made up by agriculture (Benson and Clay, 2004). Still, the sharp shifts in GDP during natural hazards indicate that these countries are also very sensitive to physical climate change, however their vulnerability and sensitivity varies based on other factors such as structural composition of the economy, availability of governmental assistance and relief programs and protection measures implemented by central banks through tools such as microfinancing for the urban and rural poor to aid in their ability to cope with the costs of natural hazards (Benson and Clay, 2004).

In contrast to first world countries, developed countries are typically more equipped to deal with the impact of natural disasters. One study presents an analysis of returns in the Australian equity market and the impact of natural events due to physical climate change. This study found that including variables for natural disasters did not account for any

variation observed in daily market returns for the ASE all ordinaries index (Worthington, 2008). This finding could be due to the impact of the disaster being diversified away at the market level. Instead of being a systematically priced market factor, the events included in this study only impacted particular companies or regional areas as non-systematic risk (Worthington, 2008). Moreover, the anticipated costs or benefits of these disasters are considered to be uncertain for relatively long periods of time therefore no immediate impact is felt in the market until further information comes to hand. This is also a product of market efficiency in developed countries, which refers to the degree to which market prices reflect all available and relevant information.

Restoring livelihoods and rebuilding economic and social infrastructure after a natural catastrophe requires significant financial resources. According to a comprehensive review done by the OECD, some components of a comprehensive strategy in emerging countries includes various forms of public-private cooperation to support the coverage of disaster risks, this involves varying levels of government intervention to support the disaster insurance market, as well as implementing risk-mitigation measures for high-impact events by the private sector (OECD, 2015). While in many countries, insurance or reinsurance is provided directly by governments to support catastrophe risks, there are many developing countries with limited insurance penetration, or an overall lack of insurance culture (OECD, 2015). These countries are often given financial assistance in the form of low interest loans to individuals affected by large-scale catastrophes (OECD, 2015). While this may be necessary to support economic recovery, banks that provide these low interest loans are invariably

exposed to much higher levels of risk, which can result in a fall in share price through increased credit-default ratios and significantly lowered returns on assets.

This research highlighted a particular problem with the analysis of the effects of natural disasters in developed countries, in that the assessment of the effects of natural disasters are often made in isolation from other potential impacts including the effects of calendar and macroeconomic announcements (Worthington, 2008). Additionally, the financial impact of these events varies according to their economic impact, a focus is needed on a smaller number of major disasters in order to indicate more significant financial influences across sectors, industries or even companies (Worthington, 2008).

3.2 Natural disasters in emerging markets

Latin America and the Caribbean (LAC) is the second most disaster-prone region in the world, with 152 million people being affected by over 1000 disasters between 2000 and 2019 alone (OCHA, 2019). The effects of climate change are made obvious in this region, with floods becoming among the most common disasters in the region. In fact, Brazil ranks among the top 15 countries in the world with the greatest population exposed to flood risk (OCHA, 2019), and many Caribbean islands are particularly prone to flooding due to their elevation and proximity to major water bodies. The increasing effects of climate change are also seen through a progressive increase in major storms in the region. On average, the LAC region saw 17 hurricanes per year, 23 of which were recorded as category 5 hurricanes between

2000 and 2019 (OCHA, 2019). Evidence of the increasing frequency and magnitude of hurricanes is provided by the 2017 hurricane season being the third worst on record in terms of number of disasters and countries affected as well as magnitude of damage (OCHA, 2019), with the strongest Atlantic hurricane on record directly impacting a landmass in 2019 (OCHA, 2019).

More frequent and intense storms in the region results in less time for recovery between events. Such a phenomenon has been demonstrated in the case of Dominica, where the country was still recovering from the impact of tropical storm Erika in 2015 when it was completely devastated in 2017 by hurricane Maria (OCHA, 2019). Since 2000, the countries most impacted by climate-related weather events in the region have been Cuba, Mexico and Haiti with approximately US$39 billion in total damages (OCHA, 2019). It is, however, important to note that most of the deaths from these events were recorded in Haiti, the poorest and most vulnerable country in the Caribbean, which underscores the importance of country-specific contexts for disasters in the region. In addition, weak storms can be equally as destructive as more powerful storms especially in vulnerable countries, a tropical storm Erika in Dominica did not have a very high intensity, however the torrential downpours from the storm triggered flash flooding and landslides, with total damages accounting for 90 percent of the country's GDP (OCHA, 2019).

3.2.1 Recurring climate shocks

The LAC region is particularly vulnerable to the adverse effects of climate change, as the region is repeatedly affected by drought, intense rains, cyclones and the el Niño phenomenon. El Niño is a global climate phenomenon caused by cyclical shifts in the water temperature of the Pacific Ocean. Each event lasts approximately 9 to 12 months and occurs on average every two to seven years (OCHA, 2019). The 2015/16 el Niño event was one of the strongest within the past century, leading to weather pattern disruptions that resulted in both floods and droughts during different phases (OCHA, 2019). Climate-related events of this scale can have a significant impact on food security, agricultural production, health, water, sanitation, education and affects other sectors within the region.

3.3 Task Force on Climate-Related Financial Disclosures

In order to effectively manage climate risks and protect banks from its potential impact, banks should treat climate risks as a financial risk, not only a reputational one. The FSB's TCFD provides guidance on the implementation of climate considerations into financial risk management. Formed by the Financial Stability Board, the Task force on Climate-related Financial Disclosure, hereafter referred to as TCFD, was formed to develop voluntary, consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers and other stakeholders (TCFD, 2017). The recommendations made by the TCFD are intended to address a key gap, which has been identified around the climate-related aspects of an organization's business and their financial

implications (Bloomberg, 2017). They are also intended to address inconsistencies in disclosure practices and non-comparable reporting methods that are quoted as major obstacles in incorporating climate-related risks and opportunities as considerations in investment, lending and insurance underwriting decisions in the medium and long-term (TCFD, 2017). The TCFD has recognized that inadequate information about risks can lead to a mispricing of assets and a misallocation of capital, and gives rise to potential concerns about financial stability, since markets are generally vulnerable to abrupt corrections (TCFD, 2017).

In an attempt to promote a standardized climate-related financial disclosure framework, the TCFD first defined climate related risks and opportunities across G20 jurisdictions. The climate related risks are divided into two major categories, first the risks related to the transition to a lower-carbon economy, and second, the risks related to the physical impacts of climate change (TCFD, 2017). The TCFD then highlighted categories of risks under each major division that are most relevant and pose varying levels of financial and reputational risks to organizations. The transitional risks included policy and legal, technology, market and reputation risk while the physical risks were simply categorized as acute (event-driven risks such as extreme weather events), or chronic (sustained higher global temperatures) (TCFD, 2017). In addition, climate-related opportunities were identified in several areas by the TCFD through resource efficiency and cost savings from efforts to mitigate and adapt to climate change, including innovation of products and services, resilience, resource efficiency, energy source and new markets (TCFD, 2017). The TCFD clearly identified these climate-related risks and opportunities to facilitate better disclosure of

their financial impacts, it helps organizations understand their exposure to these risks and opportunities, and how they might affect their future financial position (TCFD, 2017).

Understanding that some companies may not have the immediate capacity or knowledge to identify material issues and reflect them in financial filings, the TCFD also presents a table of climate-related risks and their potential financial impacts, for example, the increased pricing of GHG emissions can increase operating costs for some organizations through higher compliance costs or increased insurance premiums (TCFD, 2017). These issues may present varying levels of risk depending on the sector in which the organization exists, for this reason, the TCFD encourages in their initial report that organizations incorporate scenario analysis into strategic planning or risk-management practices (TCFD, 2017). In addition to this initial recommendation, a technical supplement was provided by the task force indicating how scenario analysis should be used in the disclosure of climate-related risks and opportunities. This technical supplement indicated the characteristics that should be included in different two degree or greater scenarios; they should be plausible, distinctive, consistent, relevant and challenging. The range of scenarios used should illuminate future exposure to both transitional and physical climate-related risks (TCFD, 2017).

With these risks and opportunities in mind, the TCFD structured recommendations around four thematic areas that represent core elements of how organizations operate; governance, strategy, risk-management and metrics and targets (TCFD, 2017) i.e., for all sectors the TCFD recommends that organizations disclose the governance around climate-related risks and opportunities, the actual and potential impacts of climate-related risks and opportunities on business strategy where such information is material, how the organization

identifies, assesses and manages climate-related risks and the metrics and targets used to assess and manage relevant climate-related risks and opportunities where such information is material (TCFD, 2017). These recommendations are then supported by key climate-related financial disclosures for each category, referred to throughout the report as recommended disclosures. The TCFD supplemented this with guidance for the financial sector, including banks, insurance companies, asset owners and asset managers as well as non-financial groups. Scenario analysis is quoted throughout the report as an important and useful tool for understanding the strategic implications of climate-related risks and opportunities. TCFD acknowledged that for many organizations, this type of analysis would be largely qualitative, however organizations with more significant exposure to transition risks or physical risks should undertake more rigorous qualitative, and quantitative analysis with respect to key drivers and trends that may affect their operations (TCFD, 2017). The task force suggests that all organizations exposed to climate-related risks should consider using a scenario analysis to help inform strategic and financial planning processes and disclosing how resilient their strategies are to a range of plausible scenarios (TCFD, 2017).

Implementation of the TCFD recommendations was accompanied by a list of indicators that should be considered for all sectors, to assist organizations in understanding the financial impacts that are most relevant to them. This included a high-level overview of four major areas of financial impact for climate-related issues; revenues, expenditure, assets and liabilities and capital and financing. Each of these areas can be affected by the aforementioned transition and physical risks and may be affected differently depending on the organization's exposure to and anticipated effects of climate-related risks and

opportunities. For the financial industry, banks, insurers, asset owners and asset manager were all subject to impact on revenues and assets and liabilities, with insurers having an additional impact of climate-related issues on expenditures. The energy sector, transportation, materials and building and agriculture sectors were all grouped and the categories for each group that may be used as indicators for financial impact of climate-related issues were also indicated.

Subsequent to the release of the TCFD recommendations report in June 2017, the task force focused on promoting and monitoring the adoption of the recommendations. Their findings were presented in a status report published fifteen months later in September of 2018. Generally, the task force found that disclosing information in alignment with its recommendations was possible for preparers and helpful to users, they were also able to identify that further work was needed for disclosures to contain more decision-useful climate-related information (TCFD, 2018). This status report revealed that the majority of organizations disclosed some form of climate-related information, that aligned with at least one recommended disclosure, often present in the organizations' sustainability reports (TCFD, 2018). It was also observed that the financial implications of the climate-related information were often not disclosed. The TCFD also found that the disclosures vary significantly across industries and regions, identifying a trend that more non-financial companies reported information on climate-related metrics and targets compared to financial companies, whereas more financial companies disclosed their risk management processes including climate-related risks (TCFD, 2018). European countries also disclosed information

that aligned with the TCFD recommendations more than companies in any other region (TCFD, 2018).

3.4 Banking risks

In order to integrate climate considerations into traditional financial risk management, the traditional approaches to risk management must first be understood. Risk management is an essential tool in the realm of finance. Though risk is necessary and inseparable from performance, it is essential for firms to use a variety of tactics to ascertain risk (Pyle, 1997). Copeland et al. 2005 argue that one of the most important developments in finance theory in the last decades is the ability to talk about risk in a quantifiable fashion. The adequate valuation of risky assets depends on the proper knowledge, identification and analysis of uncertainty in financial risk (Mullins, 1982). This in turn leads to better allocation of resources in the economy. Investors can do a better job of allocating their savings to various types of securities tailored to risk tolerance, and managers can better allocate funds provided by shareholders and creditors among capital resources based on their capacity to assume volatility.

The theory of risk management is closely connected to two concepts, with the foundation of this theory being laid by the work of Markowitz (1952 and 1959) in portfolio selection under conditions of uncertainty. One of the most important elements of the risk management theory is the capital asset pricing model (CAPM). This modern financial theory rests on two assumptions, the first being that markets are dominated by rational, risk-averse investors, and

secondly, securities markets are very competitive and efficient (Mullins, 1982). The formal development of CAPM also includes more limiting assumptions, including frictionless markets, and the agreement on likely performance and risk of securities based on a common time horizon (Mullins, 1982). Though CAPM was developed with unrealistic assumptions, this extreme simplification of its underpinnings was necessary to develop a useful model (Mullins, 1982).

In the freely competitive markets described by the CAPM, unsystematic risk can be greatly reduced through diversification, and will not affect a security's expected return (Mullins, 1982). Changes in systematic risk, however, should be reflected though a change in security pricing such that expected returns lie along the security market line, which can devalue more risky securities (Mullins, 1982).

Another pillar of modern finance is credited to the insights of Modigliani and Miller, who assert the irrelevance of corporate financial decisions for the value of the firm through the development of the MM-framework. Modigliani and Miller (1958) state that under restrictive neoclassic assumptions, corporate financial decisions such as capital structure choice or dividend policies do not influence the value of the firm, defined as the sum of all expected cash flows discounted at the cost of capital. Instead, the MM-framework suggests that these decisions redistribute the income stream among different investors (Pyle, 1997). The MM-framework suggests that corporate risk management is purely a financial transaction (Froot et al, 1994), where any changes to the firm's hedging policy is made irrelevant because investors can alter their holdings of risky assets and undo changes in the firm's hedging policy by themselves (Pyle, 1997). A critical assumption of this framework, however is that

investors can act in the capital markets at the same conditions as the firm itself. In this case, the only way to impact the value of the firm is by influencing the expected level of cash flows towards the firm (Froot et al., 1994).

The theory of corporate risk management is applicable to this study as it can be used to explain why the share price of banks may decline once the firm is exposed to higher levels of physical risk. According to the CAPM and MM-framework, which form the pillars of corporate risk theory, if physical risk presents a significant systematic market threat, this threat should be reflected through a change in security pricing. Similarly, according to the MM-model, any hedging of increased risks or changes in cash flows due to physical events should also be reflected though share price changes in the capital markets.

3.5 Literature gap

Many previous studies have found that physical climate change has the potential for adverse effects on the economic infrastructure in both developed and emerging markets. Despite this, there has been no explicit link made between a bank share price decline and increase in physical risk exposure, although many of the academic papers suggest that physical climate change can be harmful for banks, this study aims to explore the financial materiality of physical risks, providing an indicator of how efficiently banks are handling their increased exposure to non-traditional risks if at all. The literature confirms that

according to the bank risk theory, if increases in physical risks have occurred in the past, there should be a change reflected through security pricing.

Chapter 4: Methodology

In contrast to the economic analysis of natural disasters, financial analysis is concerned solely with the financial impact on those individuals and enterprises directly affected (Sprecher and Pertl, 1983.). Market prices can be used to value all costs and benefits, other impacts outside of these entities are ignored. For the most part, the limited context of most financial analysis of natural disasters has focused almost primarily on the property-liability insurance industry (Worthington, 2008). The analysis used in this research applies a similar event analysis methodology but aims instead on identifying an effect of natural disasters on banking as reflected through declines or increases in the stock prices of each bank.

The focus is on the effect of the event on the bank stock ticker in capital markets in the particular country, as the local exchanges are more likely to reflect specific changes related to "black box" events that may have occurred in that country (Benson and Clay, 2004). We want to see the magnitude of the effect of particular events on the performance, not necessarily focusing on whether the different types of events had different effects. A comparison of the effects for differences in each region based on income class may also be a significant result, hence the analysis will be split into different regions for ease of comparison. Data were collected for each event, defined as meteorological, climatological or hydrological weather-related loss events between the period 1985 - 2018 on the day before the event and for 30 days following the event, as research indicates that natural disasters typically have longer-lasting effects, especially in low-income countries than other common

intervention analysis variables. In order to create a middle ground for comparison between low-income and high-income countries, 30 days following the event is used as a global average, although some countries may take a little as a few days up to years in order to recover depending on the magnitude of the event and the resources available to the disaster recovery facilities within that country.

4.1 Model design

A quantitative strategy is used to effectively address the research questions in this study. This section will examine the blueprint for collection, measurement and analysis of the relevant data needed in order to measure the impact of climate-related risks on banking. The exploratory nature of the research questions included in this study lends itself to the utilization of research models that are familiar to a large majority of professionals within the industry, yet still remain valid enough to provide proof of concept through conclusive results.

4.1.1 Data

The method for this study was partially adopted from a similar methodology used by Tavor and Teitler-Regev, 2019 in the Journal of Disaster Risk studies. In this research, data were collected for three types of climate-related weather events (meteorological, hydrological and climatological) in North America and the Caribbean within the period 1985 – 2018. Data were collected from several websites that cover international disasters and included a description of the event, the number of casualties and fatalities, the location of the

event, estimated financial damage and other data regarding the country in which the event occurred. Preliminary assessment involved the costliest event in terms of insured and uninsured losses within the specified period. These events were hurricane Katrina in the North America region and hurricane Irma for the Caribbean region.

Data regarding each country's major financial indices were collected from yahoo finance, investing.com and Bloomberg.com, as well as local stock exchange websites for the companies that were not listed on these major databases. The closing prices for the top 5 banks by assets in each region were collected for 30 days before and after the event date. In addition, the closing prices for indexes containing these companies were collected for the same period in order to develop a capital asset pricing model to determine the abnormal returns of the banks under investigation vs the market.

4.1.2 Defining the events

The methodology employed in this research requires distinct definition of the events under examination. In this case, the events being analyzed are exclusively meteorological, hydrological and climatological in nature. That is, though the causes of these events cannot be completely attributed to climate change, their intensity and frequency may be increased as climate change progresses. Other costly events that may have indirectly affected the performance of banks such as earthquakes, volcanic eruptions and acts of terrorism were not considered in this study as the cause of these events cannot be attributed to anthropogenic climate change. In addition, a threshold for the magnitude of the events was implemented for

use in this study, as banks are indirectly affected by their costs, events with low overall costs were not considered as it is unlikely that banks would have any residual losses after the initial costs are absorbed by insurance markets. Using this reasoning, the events averaging the highest overall losses both insured and uninsured were chosen for this study, as these events are more likely to show an effect on the stock price. The events were chosen by collecting data from MunichRE NatCat Service, eliminating the events that were not of hydrological, climatological or meteorological nature, then sorting the remaining events by highest overall losses. The NatCat Service limits this methodology to 5 events. Therefore, the events were first chosen on a worldwide scale in areas of relevance (I.e. North America and the Caribbean), then these regions were selected, and the program was reset, producing a total of 6 relevant events.

Table 1: Table showing major physical events and their dates

Date	Event	Affected Area
25 – 30 Aug, 2005	Hurricane Katrina	United States (LA, New Orleans, Slidell, MS, Biloxi, Pascagoula, Waveland, Gulfport, Bay St., St. Louis, Hattiesburg, McComb, AL, FL

6 – 14 Sep, 2017	Hurricane Irma, storm surge, flood	Virgin Islands, U.S. Virgin Islands, Cuba, Saint Martin, Sint Maarten, Saint Barthelemy, Anguilla, Puerto Rico, Turks and Caicos Islands, Antigua and Barbuda, Bahamas, Bonaire, Dominican Republic, Haiti, Saint Kitts and Nevis
25 Aug – 1 Sep, 2017	Hurricane Harvey, storm surge, flood	United States: TX, Harris County, Houston, Rockport, Refugio, Corpus Christi, Galveston, LA, Lake Charles, AL, MS, NC, TN, Nashville, Davidson County
23 – 27 Aug, 1992	Hurricane Andrew	United States, Bahamas
23 – 31 Oct, 2012	Hurricane Sandy, storm surge	United States, Cuba, Haiti, Bahamas, Canada, Jamaica, Dominican Republic, Puerto Rico

19 – 22 Sep, 2002	Hurricane Maria, flood	Puerto Rico, Virgin Islands, USA, Dominica, Guadeloupe, Dominican Republic, Martinique, Haiti

4.2 The event study method

The event study method is a powerful tool that is commonly used in financial research in order to help the investigator assess the impact of events through determining whether or not there is an abnormal stock price effect associated with an unanticipated event (McWilliams and Siegel, 2017). This method has been used extensively in accounting and finance, most commonly to assess the impact of corporate control changes (McWilliams and Siegel, 2017). This framework has also been used to judge the effects of endogenous corporate events such as divestitures, corporate refocusing, CEO turnover, corporate illegalities, layoffs, plant closures, product recalls and the effects of exogenous events such as major legislation and the death of CEOs.

This method has gained popularity because it obviates the need to analyze accounting-based measures of profit, which face constant criticism as they are often not very good indicators of the true performance of firms, as managers can manipulate profits by selecting different accounting procedures (Benston, 1982). Stock prices, however, are not subject to manipulation by insiders. Stock prices can reflect the true value of the firms, as they are assumed to reflect the discounted value of all future cash flows and incorporate all

relevant information. Event studies based on stock price changes measure the financial impact of an event more effectively than a methodology based on accounting returns.

In addition, this methodology was chosen for its simplicity. This research already examines a very complex relationship, therefore using a simple methodology can assist in its widespread adoption for assessing physical risks. The only data necessary for this method are the names of publicly traded firms, stock prices and the event dates. The banks chosen for use in this methodology involved selecting the top 5 largest banks by assets in each area researched. These banks were chosen as information is readily available, and their stock prices are consistently tracked therefore simplifying the process of correlating increased physical risks with changes in stock prices.

Table 2: Table showing banks used for event study method

Bank Name	Location	Assets
Bank of America	Charlotte, USA (HQ)	US$ 2.33 trillion
Bank of Nova Scotia Caribbean	St. Kitts, Bahamas, Trinidad and Tobago, Jamaica, Dominica, Barbados, Haiti, Antigua, Anguilla, St. Lucia	US$ 20 billion
Citigroup	New York, USA (HQ)	US$1.91 trillion
First Caribbean	Trinidad and Tobago, Barbados, Jamaica	US$ 12.4 billion

First Citizens	Port of Spain, Trinidad and Tobago (HQ), Barbados, Saint Lucia	US$ 5.43 billion
Goldman Sachs	New York, USA (HQ)	US$ 1.29 trillion
JP Morgan Chase	New York, USA (HQ)	US$ 2.69 trillion
National Caribbean	Trinidad and Tobago, Barbados (HQ)	US$ 12.4 billion
Republic Financial	Port of Spain, Trinidad and Tobago (HQ) Anguilla, Saint Kitts, Dominica, Saint Lucia, St. Vincent, Sint Maarten	US$ 13.09 billion
Wells Fargo	California, USA (HQ)	US$ 1.89 trillion

4.3 Research design

The standard approach for the event study methodology is based on estimating a market model for each firm and then calculating abnormal returns. The abnormal returns are assumed to reflect the stock market's reaction to new information. This means that there are critical assumptions to ensure the validity of this research.

The methodology employed in this research is as follows;

$Rit=\alpha i+\beta iRmt+\varepsilon it$,

Where Rit = the rate of return on the share price of firm i on day t,

Rmt = the rate of return on a market portfolio of stocks (TTSE all T&T and NYA)

α = the intercept

β = the systematic risk of stock i

εit= the error term

From this estimation, daily abnormal returns can be derived from each form using the following equation;

$ARit$=Rit−(ai+$biRmt$)

Where ai and bi are ordinary least squares parameter estimates obtained from the regression of Rit on Rmt over an estimation period.

For events that last more than one day, which is the case for most hurricanes, the standardized abnormal returns (the abnormal returns standardized by its standard deviation) can be cumulated over a number of days, represented by k or the event window.

$CARi$=(1/k0.5) −t=1$kSARit$

After obtaining the average cumulative abnormal return, test statistics are used to determine its significant difference from zero or its expected value in order to determine if the event caused a significant increase or decrease in returns for that stock.

4.4 Validity

The validity of this research requires critical assumptions underlying the identification of abnormal returns. Primarily, this method assumes that markets are efficient. The efficient market hypothesis as summarized by Bromiley, Govekar and Marcus (1988), states that this attention is warranted as it provides the bases for use of the event study method. Market efficiency implies that stock prices incorporate all relevant information that is available to market traders. If this holds true, newly revealed information should be reflected through changes in stock prices, allowing the researcher to identify significant events by their impact on the stock price of firms.

The second assumption coincides with the first, in that the event must be unanticipated. If the market previously did not have information on the event, and traders gain information from a news announcement, it can be assumed that the abnormal returns viewed are as a result of the market's reaction to the presence of new information. This is difficult for physical climate change, however, as it is difficult to determine when traders become aware of new information. Storms and other natural disasters are closely monitored on a daily basis; therefore, markets have some degree of anticipation before the effects of the

event are actually felt, and its associated costs are known. The cost of a climate event may not be calculated until much longer after the event has already occurred or can be assumed to be minimal based on the monitoring of weather patterns in the area. This makes it difficult to incorporate in an event study method, as there may be no abnormal returns while the storm is in progress, but significant abnormal returns when the associated costs are calculated and released to the public.

Finally, the validity of this method is based on the isolation of the event under investigation from other events, preventing confounding effects. Confounding events can include the declaration of dividends, announcement of an impending merger, filing of a large damage suit or announcement of unexpected earnings, among other events. Any of these events may have an impact on the share price during the event window. In order to mitigate this, the event windows used in the research must be kept at a minimum, as the longer the event window is, the more difficult it becomes to control for confounding events. In this study, longer event windows from physical events will control for confounding effects by eliminating abnormal returns on days where climate events and major announcements occur simultaneously.

Chapter 5: Results

5.1 Hypothesis 1

The first hypothesis is: The share prices of commercial banks are not affected by climate-related physical events.

This theory postulates that climate-related physical events have a negative effect on the share price of commercial banks. The null hypothesis states that banks are unaffected by physical weather events therefore their share prices are unaffected during event periods. The alternate hypothesis states that the physical climate events negatively affect the share prices of banks. In order to test this, events in each region were selected and analyzed.

The first test examines the effect of the costliest climate-related weather events in each region and its effects on the top 5 largest banks by assets in each region. This is because the insurance industry absorbs most of the effects of these events, therefore changes in share prices for smaller banks may go unnoticed as they have fewer overall assets that are affected.

The parameters used in the event study calculations for determining abnormal returns on stock prices involved the use of the market model as the benchmark model with simple returns. The market model considers the firm individual CAPM risk by multiplying the market return with the firm individual beta factor. The market model is widely accepted as the standard for event studies however it can conflict with the presumption that market

returns vary over time. Cumulative abnormal returns can then be plotted for each firm against the benchmark index.

Only two of the 6 examined weather events are included, as there was no apparent effect on abnormal returns or stock prices for any other event. The results for Hurricane Katrina and Hurricane Irma are ultimately shown in this study and are also historically the most expensive events to make landfall in North America and the Caribbean respectively, which may be a significant factor when drawing interpretations from these results.

Figure 2. Abnormal returns during event period for north American banks

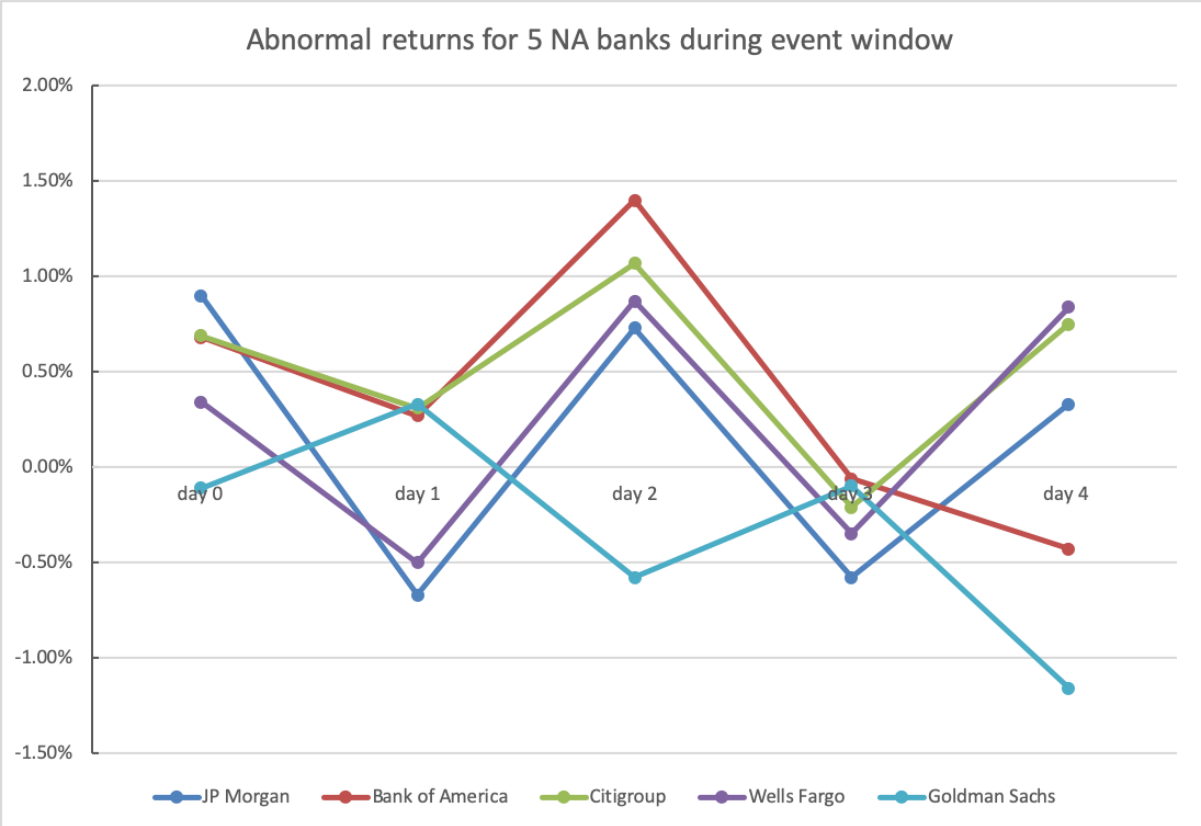


Figure 2 shows the abnormal returns for the 5 largest banks in north America during the event period examined. The highest point of abnormal returns can be seen on day 2 for most banks, except Goldman Sachs. Many of the banks, however, remain below 1 percentage point changed for the entire duration of the event.

Figure 3. Abnormal returns during event period for Caribbean banks

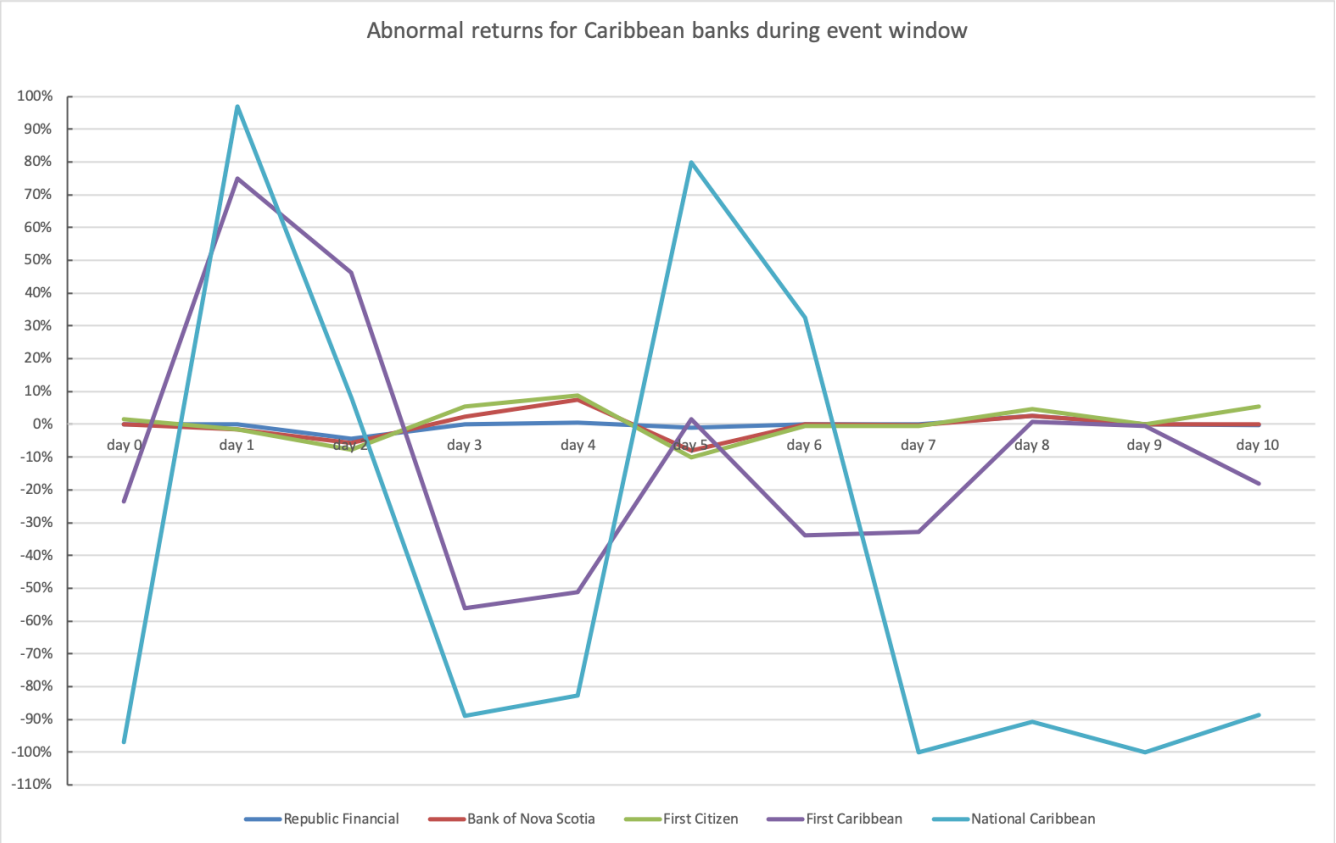


Figure 3 shows abnormal returns during a longer event period for the top 5 Caribbean banks. There are very large fluctuations in abnormal returns, however it returns to 0 for some

banks at the end of the event period, other banks such as National Caribbean, however, continue to observe significantly lower returns.

Figure 4. Abnormal returns during event period for Caribbean banks vs North American bank averages

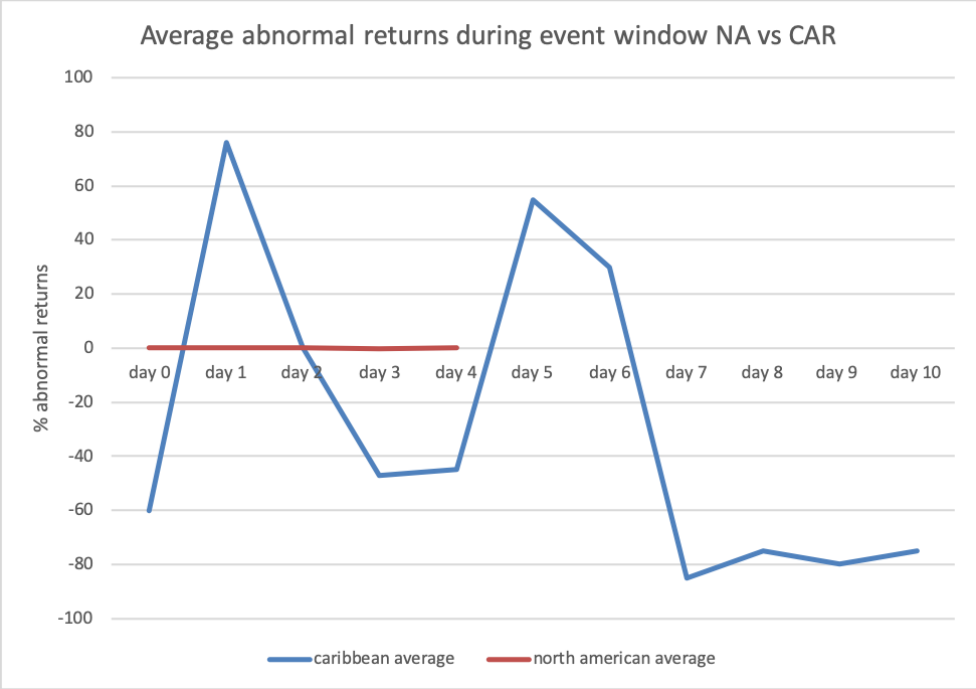


Figure 4 provides a comparison between the North American and Caribbean average abnormal returns. Though there were fluctuations in the North American data, it appears flat in contrast to the Caribbean data.

Testing for significance involved a comparison of the cumulative abnormal returns before the event period, with the cumulative abnormal returns after the event period. This parameter was used to correct for any pre-existing trends in the data. A paired (dependent) t-test was then used to determine the appropriate t-statistic, using the formula;

$T = mean1 - mean2 / (\mathrm{s(diff)} / \mathrm{sqrt}(\mathrm{n}))$

Where s(diff) = the standard deviation of the differences of the paired data values

n = the sample size

n – 1 = the degrees of freedom

The abnormal return values are the dependent variables while the independent variable is the start date of the defined event.

For the north American data, residual standard deviation varies between .003 and .009, while the Caribbean data shows a standard deviation range of .001 to .012. The t test provided a t-statistic of 0.9531 for the North American data set, and a t-statistic of 1.702 for the Caribbean data set. In order to determine the significance of the t-statistics, the p values were calculated at a 90% confidence interval.

Beginning with the North American data, a t-stat of 0.9531 and 29 degrees of freedom (n = 30) at a .10 significance level, resulted in a p-value of .174208. This result is not significant at $p < .10$, therefore we fail to reject the null hypothesis, there is no difference between the means before and after climate events for the North American data.

For the Caribbean data, a t-statistic of 1.702 and p-value calculated at a 90% confidence interval with 29 degrees of freedom (n=30). The resulting p-value is .049727 This result is significant at p <..05, therefore we reject the null hypothesis, and conclude that there is a difference between the mean abnormal returns before and after climate events for Caribbean data.

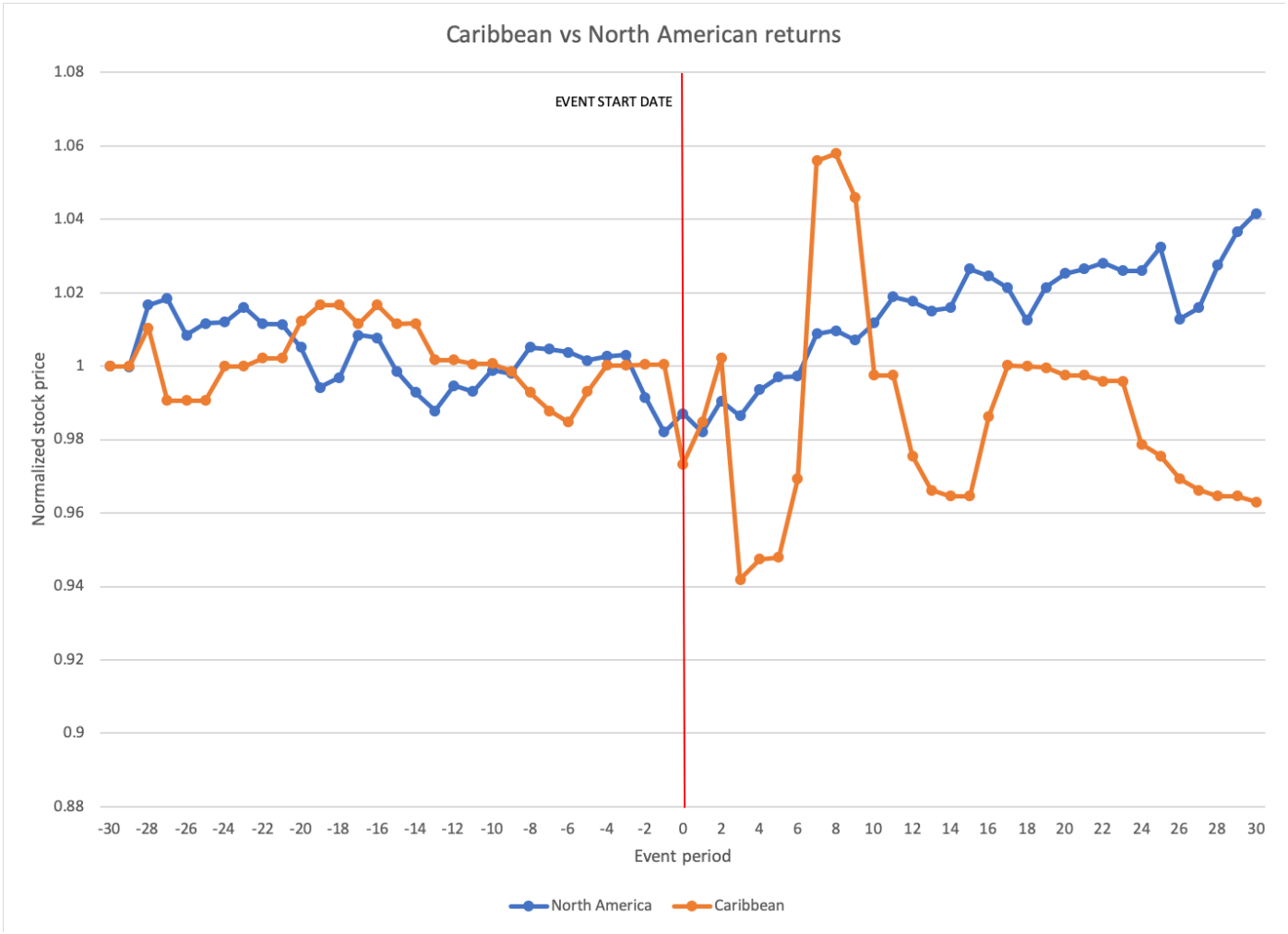
5.2 Hypothesis 2

The second hypothesis is: There is no difference between the effects of climate-related physical events in developed vs developing countries.

Though hypothesis one aims to investigate the magnitude of effects of physical weather events on banks, there is still a question of whether the effects are different in developing vs developed countries. In order to test this hypothesis, the Caribbean data is compared to the north American data instead of each being compared to individual indexes in the region.

In order to test this hypothesis, the mean returns for North America are compared against the mean returns for the Caribbean rather than comparing each of their abnormal returns in isolation. The dependent variable is therefore the normalized stock price while the independent variable is the event's start date.

Figure 5. Graph showing fluctuations in returns during event period for north American vs Caribbean banks



In order to test for differences between these effects for both samples, an independent t-test is used in order to compare the difference between the means. Each dataset contains 61 observations and the data has been normalized in order to control for differences in price not due to effects of the physical event under examination.

Succeeding price normalization, test statistics were carried out on each sample set in order to test the difference between the North America and the Caribbean.

Table 3. Test statistics for comparison between North American and Caribbean data

	N	**Mean**	**Median**	**St. Dev**	**Variance**	**SE mean**
NA	61	1.008530042	1.00839487	0.013818808	0.00019096	0.00176932
Caribbean	61	0.993344902	0.99749436	0.022506354	0.00050654	0.00288164

These statistics were used to determine if there is a significant difference between the mean returns in North America vs the Caribbean, testing the following hypothesis;

H_0: μ1 = μ2

H_a: μ1 =/= μ2

An independent t-test was then carried out using the formula;

$$Tvalue = \frac{mean1 - mean2}{\sqrt{\frac{S_1^2}{n1} + \frac{S_2^2}{n2}}}$$

This test resulted in a t-value of 4.491. The critical value was then calculated in order to test the null hypothesis. The critical value was calculated at a 95% confidence interval, or .05 significance level (P = .05) and 120 degrees of freedom ((n1 + n2) – 2). This resulted in a critical value of 1.658. Since the calculated T value is greater than the critical value, we reject the null hypothesis (T 4.491 > 1.658).

The P value was calculated at 120 degrees of freedom and T = 4.491. This resulted in a p-value of .000016 at the .05 significance level.

In order to determine the magnitude of the effects, a Cohen's d test was used.

Cohen suggests that a d of 0.2 or less reflects a small effect size, while 0.8 reflects a large effect size, regardless of statistical significance. It is calculated using;

Cohen's $d = (M_2 - M_1) / SD_{\text{pooled}}$

This results in a Cohen's d = 0.816009, suggesting that there is a considerable effect on the data that is resulting in a difference between the means. It can be seen that the event start date represents a significant change between the means, implying that one group is significantly more affected by the independent variable than the other. The lower mean and higher standard deviation of normalized data implies that the Caribbean is more affected.

We can conclude that there is a statistically significant difference between the means of the two sample sets, and that there is a difference in effects of climate-related physical events between North America and The Caribbean.

Chapter 6: Discussion

6.1 Interpretation of results

The results section indicates that physical climate change poses a risk to the business of banks and has already affected their business in some developing countries as reflected through shifts in their stock prices due to increased risk exposure. Commercial banks in developed countries are not significantly affected by past physical events, however it is still uncertain whether or not an increase in frequency of these events will eventually pose greater risk to commercial banks in developed countries, and if these risks will be reflected in their stock returns. Further, only two events out of the total observed were used for calculations as there were little to no changes observed in any other events, suggesting that there may be a price threshold before banks begin to notice an impact.

These results are consistent with most of the literature on physical risks, as other researchers also suggest that developing regions such as the Caribbean are more susceptible to market shocks and economic downturns from climate change than developed regions (Mahalingham et al., 2018). To date, few natural catastrophes have registered any large impact on the shape of the global market. In fact, one of the catastrophes analyzed in this research paper, Hurricane Katrina, is the costliest climate-related natural catastrophe in history but only moved the New York stock exchange by less than a single percentage point, with approximately $150 billion in direct damages (Mahalingham et al., 2018, MunichRE,

2020) which remained uniform with the results observed in this study, as most of the data collected from North American banks were based on the NYSE, and the results observed abnormal returns of less than 1.5%. By contrast, physical events of lesser magnitude and cost have moved markets in the Caribbean and resulted in major declines in GDP and stock returns, given that Hurricane Irma was a less expensive physical event overall, but had more dramatic effects on banks in the Caribbean vs North America. The Caribbean banks, however, seem to be greatly affected with large fluctuations in their returns, although some returns are positive which can possibly be attributed to insurance payouts from different companies being used to resolve business with the banks, or government intervention. Further, there is a significant difference in the effects of physical climate change in developing vs developed countries. Developed countries may be more prepared and have more measures in place to adapt to these events, and therefore the returns are unaffected when they take place, banks in developing countries appear to be more affected by physical climate change with larger fluctuations in returns during event periods, and a longer time period required for recovery.

6.2 Connection to the literature

Subsequent to physical events in the Caribbean, dramatic shifts in returns are observed in both directions, with a gradual decent in returns for a period after the final event date. This can be credited to multiple factors that have been indicated in previous literature.

Firstly, Charverait, 2000 and Gaytan, 2019 indicate the Caribbean region's particular vulnerability to climate change. With many islands' major assets and most populated regions being in close proximity to coastal areas, torrential rain and flooding can result in major losses for banks. Further, it is particularly difficult for insurance companies in the Caribbean to reduce their risk exposure while still maintaining a profitable business case, resulting in large losses to insurance companies after natural disasters and other "black box" events. The spikes in returns for Caribbean banks can be due to insurance payouts entering the banking sector, as was the case of hurricane Katrina investigated by Gallagher and Hartley, 2017, where many households particularly from lower-income demographics used insurance money after a natural catastrophe to pay off interest on mortgages. Notwithstanding positive pulses in returns, a gradual decline is observed for a long period after the event window, indicating a very long recovery period for banks in the Caribbean after a natural disaster. By contrast, North American banks are negligibly affected by climate-related natural catastrophes and continue to observe ascending returns immediately after event windows.

Differences in insurance penetration can account for the disparities between the effects of physical risks in North America vs the Caribbean. Caribbean banks may be exposed to more physical risks due to relatively lower insurance penetration compared to North American markets. This results in a higher exposure of Caribbean banks to property markets, resulting in a greater likelihood of those banks observing mortgage defaults after a physical event as the insurance payouts needed to mitigate losses aren't present. Regulatory variations can also be an influential factor for this study and can account for some of the results observed. The markets compared in this study may be at different stages of development, resulting in the

presence of regulations in one market that may not be present in the other. This presents itself as a possible explanatory factor for the differences observed in the results.

Disclosure practices may also play a pivotal role in the way banks' business are affected by physical climate change. Busch and Hoffman, 2011, TCFD, 2017 and Weber, 2012 all describe how the performance of financial institutions can be affected by their carbon disclosure. Though these relationships were not investigated in this research, the connection can still be used as an assumption to explain why banks with better disclosure practices may be less affected by physical events.

It is also important to account for differences in assets in each region, resulting in storms of lesser magnitude being more expensive in the north American region and vice versa. This can be seen in the case of Dominica described by OCHA, 2019 and Charverait, 2000. Where a hurricane followed closely by a subsequent tropical storm cost 90% of their GDP. Additionally, the differences in lending portfolios and real assets of banks in each region may also play a role in determining the losses observed after a physical event. Retaining a large mortgage portfolio in risk-exposed areas may result in a larger shift in returns after physical events affect that area, as household finance for the borrower can be greatly affected. Additionally, the bank's profitability can also be affected by consumer behavior after natural catastrophes. Gallagher and Hartley, 2017, observed that consumers often use credit cards to cover unforeseen costs after catastrophe. This behavior can increase the profitability of banks as interest is paid on a higher credit card debt value. This can also be used to explain positive pulses in returns after a natural disaster.

6.3 Limitations

The limitations of this research originate from critical assumptions that must be held in order to ensure the validity of the methods chosen. Firstly, the efficient market theory is an assumption of the event study methodology, which posits that markets interpret information as it becomes available, and the availability of this new information is immediately reflected in stock prices. The Caribbean market efficiency may not be comparable to well established exchanges such as the NYSE or TSE. One example of this provides the explanation for omitting the use of the Barbados Stock Exchange from data collection steps. This exchange is Barbados' sole market has a total of 15 listed companies, and 5 government bonds. Of the 15 listed companies, 2 are deposit-taking institutions, and one of those institutions has no historical data at all listed on the exchange website, with the other having a fairly recent history of prices dating back to 2018. The data for these banks is listed more thoroughly on the TTSE, therefore this was used instead, however it would have been interesting to observe any differences in a country-specific context.

The limited understanding of the relationship between cause and effect for climate change and financial risks presents itself as another limitation of the study. An explanatory perspective must be taken in order to completely understand the mechanisms by which climate change causes financial losses for banks.

6.4 Next steps

The impetus for this research was driven by the release of the TCFD recommendations and the realization of a need to understand the effects physical risks can have on banking. Now that the effects of physical risks are understood in the context of profitability, the next steps taken should be the same as those in a standard risk management process. The appropriate climate-related physical risk-response must be identified and selected. This will allow for banking professionals to control for and monitor these risks and provide simple integration of non-traditional risks into already established risk-management processes. After monitoring climate-related risks, banks must continue to set objectives, and implement methods to detect and identify new events that may pose a threat to their business.

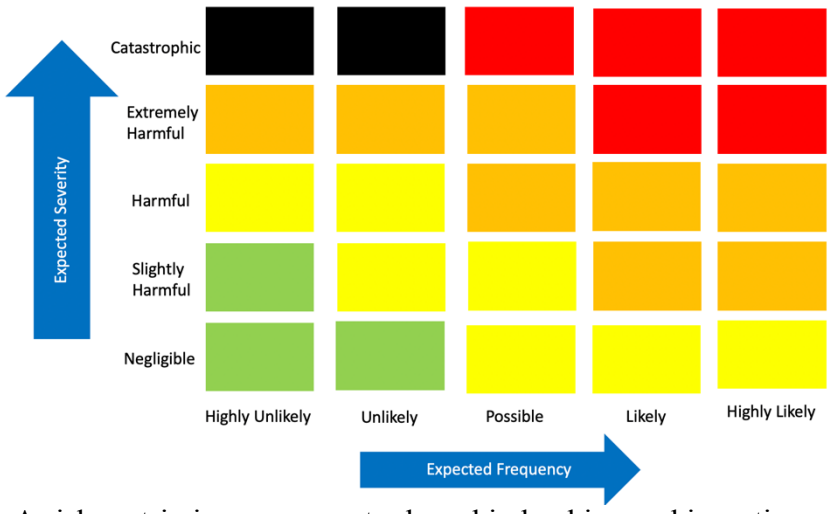
Furthermore, the findings from this research can aid in the development of physical asset maps in order to determine risk exposure for banks. Physical asset maps are input from borrower information held by banks, and include assets such as financed commercial buildings, power plants and more, and are overlaid with climate maps that include extreme weather event forecasts in order to produce a risk exposure map of physical assets. This can provide banks with credit rating models based on borrower location on the asset map and help mitigate losses from physical climate change.

6.5 Further research areas

An important area for further research includes the development of a risk matrix for physical climate change, similar to those developed by authorities in financial analysis such

as the CFA institute risk matrix as shown in Figure 6 (CFA, 2019). A risk matrix is helpful in understanding the costs associated with climate change, as the frequency and intensity of climate-related events increases. In order to develop a valid risk matrix, the severity of risks must first be understood, which was achieved through this research. The next step would be to understand how the frequency of these events might occur in each region. A physical risk matrix can assist banks in prioritizing their risk mitigation procedures and can be adapted from traditional risk matrices similar to those developed by the CFA institute (CFA, 2019).

Figure 6. Risk matrix with black box events (Source: CFA 2019)



A risk matrix is a common tool used in banking and investing and can be a powerful tool for helping investors understand their portfolio risk exposure. Developing a risk matrix for climate-related risks can help sustainable investors adjust their portfolios based on their risk appetite and can help banks be more sustainable by reducing their exposure to catastrophic and frequent risks. Building one for climate-related risks can bolster confidence in risk manager's abilities to mitigate losses due to climate change.

Chapter 7 Conclusions

7.1 Significance of findings

This research was an investigation into the effects of physical risks on banking and challenged the business case for sustainability for banks facing external pressures from climate change. The findings support the notion that the global south and developing countries may be disproportionately exposed to and affected by climate-related risks, whereas developed countries are less affected. There is therefore a business case for banks in developing countries to operate with more prioritization of resiliency as their business is affected more by the effects of climate change. These banks, however, play a small role as the banks with the largest carbon footprints in their lending portfolios are often headquartered in developed countries.

In summary, it was found using test statistics that North American banks are not greatly affected by physical climate change events in comparison to Caribbean banks. The Caribbean banks appear to be facing greater levels of risk reflected through larger fluctuations in share prices during catastrophic events. Additionally, there are dramatic shifts in returns in both directions after a catastrophic event for Caribbean banks, whereas the north American banks remain relatively consistent with increasing returns. A few limitations were also discussed in this study, which can possibly be addressed in future research. Relying on stock price changes to reflect an increased or decreased risk exposure assumes that the markets used in the study are efficient, however this may not always be the case. In future studies, markets of comparable efficiency with similar events can also be compared. Additionally, this study focused exclusively on the event period, which ignores the potential effects of announcements of physical events and weather predictions. Further research should be done taking these variables into account in order to assess whether there is a higher perceived risk with the initial knowledge that a catastrophic event may occur rather than the price changes due to risk associated with the event in progress.

7.2 Interpretation and conclusion

The first hypothesis showed that there seems to be no significant effect of physical weather events on commercial banks in north America, this can be attributed to several factors that were seen in several previous research papers as well as in the discussion. The

effects on Caribbean banks, however, are moderately significant. This shows the need for climate risk mitigation measures in developing countries. Further, the second hypothesis supports this assertation as there is a significant difference in the effects of physical events between North America and the Caribbean.

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