The impact of climate change on investment risk and credit risk

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DECLARATION

I, Francesca Bell, declare that this dissertation is my own unaided work, submitted in fulfilment of the requirements for the degree of Master of Commerce (MCom) in Finance at the University of the Witwatersrand, Johannesburg.

It has not been submitted before for any degree or examination at this or any other university.

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Francesca Bell
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DEDICATION

To my family

For their unwavering belief in me

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To my family and supervisor – thank you for the support, guidance and encouragement you have provided me throughout my educational career.

To my employer – RiskWorx – I am grateful for the space you created which aided me to further explore my interests, enabled them to be listened to as well as the continued supportive environment for the topic of climate risk to be explored.

ABSTRACT

ESG (Environmental, Social, and Governance) factors have evolved from being a minor consideration in the 2000s to a major factor for many companies in 2023. Many companies are now assigned ESG grades, which are closely examined by investors. While it would be ideal for responsible firms to be rewarded and culprits to be penalised, this is not always the case in a profit-driven world. Investors are likely to always prioritise profitability, so some compromise is necessary. Recent efforts to balance corporate responsibility with portfolio performance are promising. Using Lagrangian calculus, portfolio optimisation techniques have been developed that show returns and risk profiles comparable to those of unconstrained portfolios (i.e., ones which did not consider ESG scores). As expected, low ESG scores influence portfolio performance negatively (as measured by the Sharpe ratio), but very high ESG scores have the same effect. Optimal ESG scores are those which represent the turning points of these relationships, i.e., those ESG scores which result in maximal Sharpe ratios. These optimisation techniques are applied to emerging market corporates for the first time. Over time, ESG scores have improved globally, at varying rates, and have resulted in a statistically significant decrease in risk and increase in returns. As volatility increases, optimal ESG grades rise slowly, and associated Sharpe ratios decrease, and it is postulated that this could be due to the option-like relationship between underlying volatility and inherent value. With a better understanding of trends, asset managers who consider ESG metrics can confidently assert that ESG compliant portfolios do generate healthy risk-adjusted returns (Sharpe ratios) and that these values are improving over time. ESG compliant portfolios are now viable investments that align with responsible investment principles.

Firms must estimate expected credit losses (EL) to comply with accounting standards and unexpected credit losses (UL) to determine regulatory credit risk capital. Both rely on estimates of obligor probabilities of default (PD). Changes in climate, however gradual, increase firm default rates and climate shocks such as floods or droughts exacerbate these impacts. Investors pay close attention to credit ratings which are derived from *inter alia* default rates, but studies investigating the impact of climate change on PDs are currently limited and data are still relatively scarce. Africa will be most severely impacted by climate change: default rates will deteriorate leading to increased PDs, losses given default (LGDs), provision requirements (through increased ELs) and

regulatory credit risk capital (through increased ULs). To investigate these effects theoretically, corporate equity prices are simulated using Geometric Brownian Motion (GBM) and shocks brought about by climate events of differing frequency and severity are applied to these simulated prices. Post shock prices and return volatilities are differentially affected depending on the nature of the applied shock. These are used as inputs into a well-known Merton (1974) model of corporate default from which market-implied PDs may be extracted. A possible calibration approach is developed for climate event-based impacts on corporate default rates. A scaling factor matrix (an amount by which the unaffected default rate increases after a specified climate event type occurs) can help market participants forecast default rate changes. Climate related impacts have been quantified, calibrated, and used to assess credit quality degradation.

DEFINITION OF TERMS

AFME	Association for financial markets in europe	GBM	Geometric Brownian Motion
BCBS	Basel committee on banking supervision	GDP	Gross domestic product
BIS	Bank for international settlements	IFRS9	International financial risk standards 9
CFA	Chartered financial analyst	IPCC	Intergovernmental panel on climate change
DD	Distance to default	KMV	Kolmogorov Merton Vasicek
EAD	Exposure at default	LGD	Loss given default
EBA	European banking authority	PD	Probability of default
ECL	Expected credit loss	SR	Sharpe ratio
EDF	Expected default frequency	SRI	Socially responsible investing
EL	Expected loss	UL	Unexpected loss
ESG	Environmental, social, governance	UNCTAD	United Nations conference on trade and development
ESG-SR	ESG Sharpe ratio	UNEP	United Nations environment programme
ETF	Exchange traded fund	VaR	Value at risk

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1. INTRODUCTION

1.1 BACKGROUND AND OVERVIEW

1.1.1 ESG efficient frontier

Climate change and social justice concerns are increasingly dominating headlines, so these factors are no longer considered trivial issues confined to a company’s corporate social responsibility department (Iazzolino, Bruni, Veltri, Morea & Baldissarro, 2023; Luo, Wei & He, 2023 and Suttipun, 2023). ESG, an abbreviation of Environmental, Social, and Governance (a relatively new acronym used to describe the important factors applied by investors to analyse material risks and growth opportunities while simultaneously acknowledging and attempting to mitigate detrimental influences). ESG now warrants substantial scrutiny from investors, regulators, rating agencies and affected corporates and as a result, determining and monitoring a company's ESG score has been established as central to corporate financial reputations and performance (Lee & Suh, 2022).

Environment-friendly investing (the E in ESG) has become increasingly popular and is the most likely investing approach used by millennials. Morgan Stanley Bank (Morgan Stanley, 2019) found that nearly 90% of millennial investors were interested in pursuing investments that more closely reflect the values they hold. In 2018, about US$12tn worth of assets were invested in socially responsible investment strategies, increasing to US$18tn in 2021 and forecasted to be US$34tn by 2026. With a projected compound annual growth rate of 12.9%, ESG assets would constitute 21.5% of total global assets under management by 2028 (Stanton, 2022). As millennials and environmentally conscious generations will constitute larger and larger proportions of the total pool of investors as time passes, ESG investment ideals are expected to expand in tandem.

Financial services have responded to the growing demand for ESG investments in various ways, one of which is by offering ESG-focused exchange-traded funds (ETFs). Two of the largest ETF providers – BlackRock and Vanguard – currently (2023) offer clients a choice of ESG-focused funds with BlackRock adding six new ESG funds in 2020, and its equity investment team now including a Head of Sustainable Investing (Blackrock, 2023 and Vanguard, 2023). It is common for brokerage firms to offer stock analysis employing ESG investment strategies, and robo-advisors such as Wealthfront in the US can be set to seek only socially responsible investments (Wealthfront, 2023).

1.1.2 Environmental shock impact on expected credit losses

Although ESG metrics are not currently a required part of financial reports for publicly traded companies, a growing number of companies have begun to include them in their reported statements or in separately issued documents (Luo, Wei & He, 2023).

While current research (e.g., Aydoğmuş, Gülay, & Ergun, 2022 and Singhania & Saini, 2023) employs various methods to study these risks, more attention has been given to the effects of climate change on macroeconomic systems than on specific companies. By 2050, the losses in regions of Central and Western Africa will be 50% and 85% higher respectively in high warming scenarios proposed by the United Nations Environment Programme (UNEP). However, if the goals of the Intergovernmental Panel on Climate Change (IPCC) are met, limiting global warming to below 2°C, the most severe economic consequences for African countries can be avoided (Feyen, Utz, Huertas, Bodgan & Moon, 2020).

Climate-related disasters are expected to retard growth of GDP per person in Africa, pressurising government finances, increasing government spending, decreasing tax revenues and ultimately increasing government debt. A framework to establish the link between climate related impacts on corporate credit quality (including default probability) based on multiple research studies, including work by the Basel Committee on Banking Supervision (BCBS) is needed. This framework could also potentially be applied to loss given default and exposure at default.

1.2 KNOWLEDGE GAP

1.2.1 ESG efficient frontier

The devastating global economic impact of the COVID-19 pandemic, worrying accounts of corporate negligence and relentlessly accumulating evidence for climate change and its possible impact, have all contributed to a growing awareness of individual and collective responsibility. Modern investors are increasingly calling corporations to account, punishing miscreants by reducing holdings in their stock or shunning them completely (Singhania & Saini, 2023).

To make informed decisions about these tactics, investors – the bulk of whom cannot possibly investigate and assess each potentially investable stock – rely on environmental, social and governance (ESG) scores provided by dozens of ratings providers, five of whom (MSCI, Refinitiv, Sustainalytics, RepRisk, and Institutional Shareholder Services (ISS)) currently (Dec-23) dominate the market (Sikochi & Serafeim, 2021). Using self-disclosed corporate information (such as board diversity (social score), carbon emissions (environmental score) and safety policies (governance score)) and firms' own, often concealed, analysis and algorithms, these providers formulate, synthesise, and consolidate results into single ESG scores.

Sustainable investment increasingly relies on these ESG scores, but the investment strategies typically assemble investment portfolios using a ranked list of 'good' (high ESG score) stocks while ignoring portfolio completeness. Although the field has begun to flourish, literature which investigates sustainable investment asset allocation remains limited and no consolidated best practice approach has been proposed. Developing economies are particularly impacted by climate change and (often) poor governance. The literature is replete with research which has repeatedly demonstrated that developing countries are suffering, and will suffer, considerably more than their developed country neighbours from the effects of climate change (Kompas, Ha Pham & Nhu Che, 2018 and Huang & Tian, 2021) and the ongoing toxic effects of poor governance (Kłosowicz, 2019 and Yahyaoui & Bouchoucha, 2021). At the November 2021 COP26 summit in Glasgow, for example, South Africa (the world's 15th-largest emitter of carbon dioxide) announced that it had secured commitments for US$8.5bn in financing from 2022 – 2026 from France, the UK, Germany, the US and the European Union to help install more clean energy and accelerate the country's transition away from coal power.[1] The funds will also be used to mitigate the impact on workers affected by this transition. This news was welcomed by investors, among others, wishing to capitalise on improved ESG scores and thus a wider universe of appropriate securities from responsible corporations.

Recent work designed to measure and optimise portfolio performance while observing corporate conscientiousness is promising: return/risk profiles comparable to those attained by unconstrained portfolios appear possible. Identifying and implementing an optimal investment solution in a mean-variance framework while observing additional constraints (i.e., over and above 'traditional' constraints of simultaneously maximising excess returns and minimising associated risk) imposed

[1] South Africa relies overwhelmingly on coal, which supplies 87% of the nation's electricity (Kwaka, 2022).

by the new milieu such as selecting 'optimal' ESG scores for investable securities, remains a complex issue faced by investors.

1.2.2 Environmental shock impact on ECL

International Financial Reporting Standards (IFRS) require corporates to estimate their relevant expected credit losses (ECLs) by developing forecasts and to use significant judgement. Detailed rules for these calculations have been established by the International Accounting Standards Board (IASB). Institutions required to calculate their ECL have only begun to understand how ESG may impact ECL components such as probabilities of default, losses given default, exposures at default and discount rates. How (or whether) these components will change 'traditional' lender ECLs has not yet been fully investigated – at least not in developing economies.

ECL approaches require lenders to use forward-looking macroeconomic assumptions (such as GDP growth, unemployment rates and housing price changes) as model inputs (Renneboog, Horst, & Zhang, 2008). These assumptions are quite general because they may relate to macroeconomic factors which are often outside lend-ers' control (Luo, Wei & He, 2023). In contrast, entity-specific assumptions relate to a lender's actions (e.g., the decision to lend to a vulnerable sector or borrower) and characteristics (e.g., its customer base). When two similar lenders use similar general assumptions (e.g., about the path of economic recovery) and arrive at different ECL balances relative to their gross loan books (i.e., their coverage ratios), users want additional information to be able to assess differences in these coverage ratios. For each lender, users desire information that helps them understand the extent to which each ECL balance is driven by general assumptions or by entity-specific assumptions that may reflect differences in customer characteristics (e.g., retail versus commercial), loan products, collateral, or other loan terms. Without this information, investors find it challenging to make meaningful comparisons.

How environmental shocks affect lenders' ECLs is currently the subject of intense investigation (Marlin, 2022; Luo, Wei & He, 2023 and Singhania & Saini, 2023) but the impact of their inclusion has not yet yielded a wide or deep research base.

The effects of climate risk drivers on financial risks are complex and inter-related. Although current research practices have embraced a wide spectrum of methodologies for how these risks may be examined, much focus has been on the impact of climate change on macroeconomic systems than on corporates. Borrowing from bank-focused research by the Basel Committee on Banking Supervision (BCBS, 2021a) on the ways in which climate risk drivers foment financial risks, this article synthesises contemporary literature to create a single, connected methodology based on multiple research strands. This framework demonstrates how climate-related changes may be incorporated into corporate financial risks, such as PDs (and potentially both LGDs and EADs as well).

ESG issues are an important contemporary part of corporate evaluations (Ahmad, Mobarek & Roni, 2021). Climate risk drivers – the E in ESG – are classified as physical risk and transition risk (Figure 1).

Physical risk is the risk which arises from the physical effects of climate change on corporate operations such as the workforce, infrastructure, raw materials, markets, and assets. Acute physical risks are classified as severe weather-driven events (such as floods and fires) and chronic physical risks refer to longer term climatic shifts which may result in precipitation/temperature changes and elevated sea levels. Physical risks translate into credit risk, such as the PD, the loss given default (LGD), expected losses (ELs) and unexpected credit losses (ULs).

Transition risk drivers represent societal changes (such as progress toward affordability of existing technologies, alterations in public sector policies and investor/consumer sentiment towards a responsible, sustainable environment) which arise from the transition to a low-carbon economy. Although closely monitored by affected parties, these risk drivers could impact financial risks substantially because of their scale and synchronous deployment. Transition risks contribute to portfolio impacts such as value at risk (VaR) and tail – or extreme value – risk.

Transmission channels are the causal conduits through which climate risk drivers influence institutions (such as banks, corporates, and sovereigns) directly and indirectly through their assets, counterparties, and the local economy. The frequency and severity of climate risk driver impacts is influenced by several other variables including the geographic location of the corporate and correlations between transmission channels and climate risk drivers. The impact of climate risk drivers on corporates is manifest through traditional risk categories of credit, market, liquidity, and operational risk. Although the BCBS provides information regarding how climate risk drivers influence bank-specific financial risks, the framework is easily extended to all corporates (and other institutions) so the Basel Framework is included in Figure 1.1.

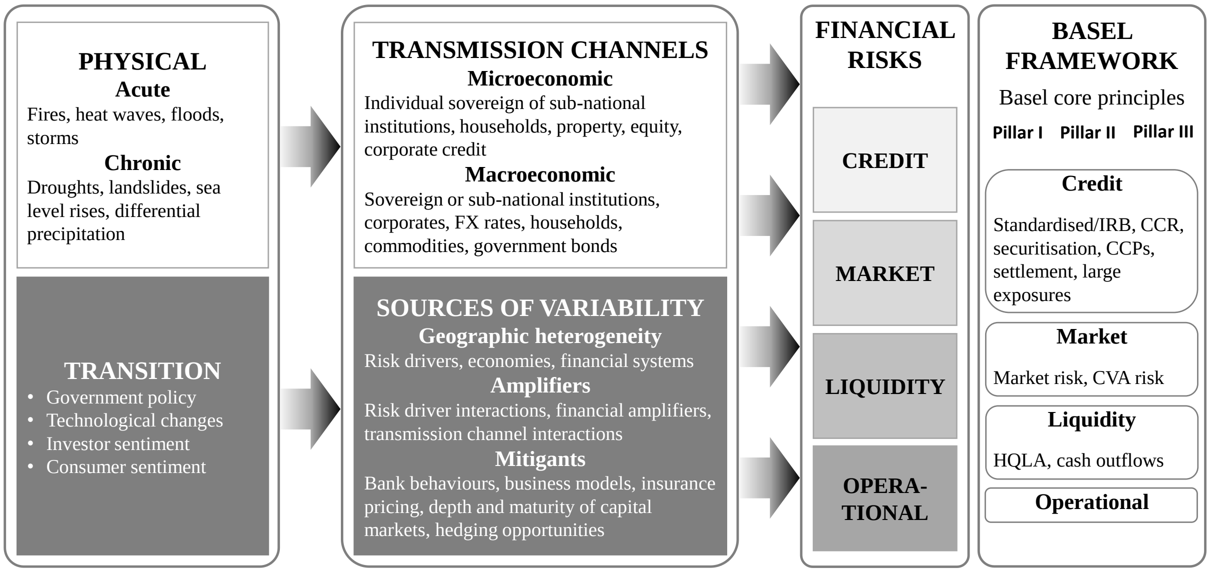


Figure 1.1: Financial risks from climate risk drivers.

Source: Adapted from BCBS (2021a).

A joint report commissioned by the United Nations Environment Programme (UNEP) recently explored economic growth and development risks for African countries. Regions which will experience disproportionally higher risks from climate change (involving deteriorating health, reduced human and food security, altered water supply, and diminished economic growth) are developing island states and Least Developed Countries (UNCTAD, 2022) – of which 70% (32 out of 46) are African (IPCC, 2018) as shown in Figure 1.2. African countries will therefore be among the worst affected by rising temperatures impelled by climate change (indeed, any level of warming), with severe macroeconomic consequences impeding economic development.

Two climate change scenarios were considered: a low or optimistic scenario consistent with the goals established by the Paris Agreement (United Nations, 2015) in which global temperature rises are well below +2˚C (at least until 2050) and a high-warming, pessimistic scenario which posits a global temperature increase of +2˚C by 2050, and more than +4˚C by 2100 (Baarsch & Schaeffer, 2019). Baarsch & Schaeffer (2019) argue that mitigating these impacts will require

African Governments to integrate climate change risks into development and macroeconomic planning. At the microeconomic scale, assessing the impact of climate change on individual corporations' credit risk and thus economic value, would contribute considerably to this integration.

Figure 1.2: African countries that will be severely affected by rising temperatures due to climate change (shaded red). The remainder will also, inevitably, be impacted, but perhaps not as severely. **Source**: Mapchart (2022) and author inputs.

Schlenker & Roberts (2009) developed and implemented a model for estimating the impacts of climate change on crop yields in the US. Bezabih, Di Falco & Mekonnen (2014) replicated and updated this approach to determine the effects of climate variability on Ethiopian crop production. Using these models, Baarsch & Schaeffer (2019) found that several African countries are already

(2022) experiencing lower growth rates and diminished development due to climate change because of low adaptive capacities and limited resilience. GDP per capita growth is already lower in the poorest African countries, on average, by between 10% and 13% and projected macroeconomic consequences from climate change over the next three decades are severely detrimental. In a high-warming scenario, the GDP growth per capita of Eastern and Western African countries is forecast to fall below a baseline scenario (in which climate change does not affect macroeconomic development) by 15% by 2050. Northern and Southern Africa would also be considerably affected, with a 10% decrease in GDP growth by 2050. Central Africa would be less severely affected, with a decrease of 5% in a high-warming scenario (Baarsch & Schaeffer, 2019 and Feyen, et al, 2020).

By 2030 differences in macroeconomic costs between low and high-warming scenarios become apparent. By 2050, losses in high-warming scenarios are 50% higher for Central Africa and 85% higher for Western African regions. In optimistic (low-warming, low-emission, global) scenarios, however, i.e., those in line with the Paris Agreement's aim of limiting global warming to below +2°C, simulations show that the most serious macroeconomic consequences for African countries can be circumvented (Feyen, et al, 2020).

Climate-related disasters are expected to decelerate per capita African GDP growth, heaping pressure on sovereign budgets and fiscal balances, increasing government expenditure, reducing tax volumes, and ultimately swelling government debt. Figure 1.3 shows the GDP per capital deviation from a baseline over the next three decades for southern African countries resulting from simulations assuming two climate change scenarios.

1.3 PROBLEM STATEMENT

The way in which climate change (as measured using ESG scores) affects portfolio performance and the impact of climate change on both the likelihood and severity of credit losses have not been widely investigated.

1.4 RESEARCH OBJECTIVES

The research aims to

- explore and interrogate ESG efficient portfolios:
  - ✓ do they outperform traditional (equity/bond) efficient portfolios?

- ✓ investigate whether ESG portfolios are more efficient than traditional portfolios?
- ✓ investigate whether ESG portfolios are less risky than traditional portfolios?
- ✓ explore the extent of these differences between ESG and traditional portfolios and
- ✓ is optimisation of ESG portfolios (e.g., maximisation of portfolio returns relative to a risk free rate per unit of risk undertaken to generate these returns) possible using ESG metrics?

- explore and interrogate ESG ECLs:
  - ✓ how do environmental shocks impact ECL components such as PD and LGD?
  - ✓ using simulated data and known impact severity from historical climate-related shocks, how are different credit grades affected by environmental shocks?
  - ✓ how quickly or slowly do environmental based shocks dissipate to the extent that ECL components may be considered to have returned to "normal"?

1.5 Hypotheses

1.5.1 ESG efficient frontier analysis

H_0: Portfolios which do invest substantially in ESG companies perform better than portfolios which do not invest substantially in ESG companies.

H_a: Portfolios which do not invest substantially in ESG companies perform worse than portfolios which do invest substantially in ESG companies.

1.5.2 Environmental shock impact on ECL

H_0: The impact of environmental shocks on default probability is statistically different from zero.

H_a: The impact of environmental shocks on default probability is statistically zero.

1.6 POTENTIAL STUDY BENEFITS

Establishing the superiority (or not) of ESG portfolios in developing economic environments is a critical result which would have global implications. ESG remains relatively new and unexplored so being able to provide (or at least contribute to providing) information to assist investors in the decision to invest in ESG portfolios or not is of considerable importance.

Demonstrating that ESG portfolios exhibit market efficiency, for example, could help encourage otherwise reluctant investors to further explore the investment possibilities that ESG portfolios offer. The benefits to the planet and society, even if secondary considerations after profitability, risk reduction and market efficiency, would be enormous.

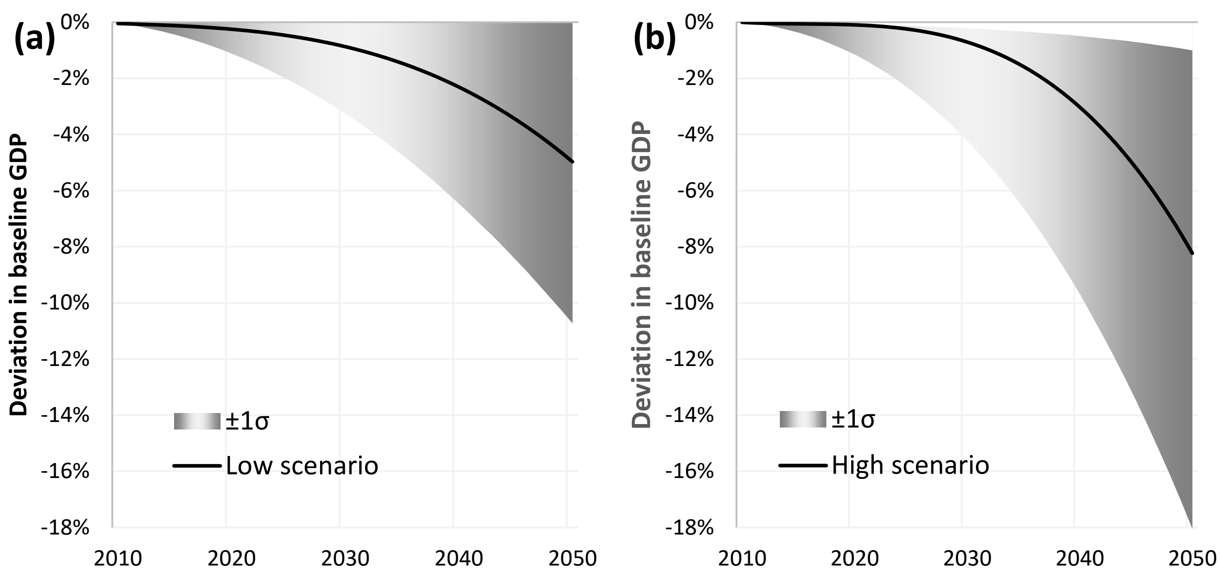


Figure 1.3: GDP per capita deviation from a GDP per capita baseline scenario (in which climate change does not affect macroeconomic development) resulting from continued global warming for southern African countries until 2050. (a) scenario in which global warming is below +2°C and (b) scenario in which global warming exceeds +2°C by 2050 and exceeds +4°C by 2100. Shaded regions represent a 68% statistical confidence interval (i.e., one standard deviation).

Source: authors' calculations and Baarsch & Schaeffer (2019).

Showing ways to measure ESG portfolio ECLs and establishing that these ECLs are comparable (or superior) to non-ESG portfolios would also contribute to investor knowledge about the potential benefits of ESG portfolios. Again, even if the benefits that accrue to the planet and society are secondary investor considerations, they will nevertheless accrue and – hopefully – eventually become mainstream.

1.7 SUMMARY OF FINDINGS

1.7.1 ESG efficient frontier analysis

ESG scores of companies in emerging markets were found to have been steadily improving since they were first introduced in 2007. At this current rate, emerging markets are expected to have similar ESG scores as developed nations by the late 2030s, although other factors may affect this timeline. The best risk-adjusted returns for portfolios were found to not necessarily arise from portfolios with the highest ESG scores: very high and very low ESG scores resulted in diminished portfolio performance as measured by the Sharpe ratio. There is a limit to the amount of returns that can be achieved with a specific ESG score, but both higher and lower ESG scores result in lower portfolio performance. The study suggests that the reason for this may be that companies with very high ESG scores may invest more in employee conditions and environmental projects, rather than increasing profits, which can lead to lower returns. However, as ESG scores continue to improve, the difference between portfolios that ignore ESG scores and those that prioritise them is reducing.

1.7.2 Environmental shock impact on ECL

Quantified and calibrated climate-related impacts may be used to assess credit quality degradation in companies. The inputs for this assessment are subjective and must be determined by the user, as different companies have unique share price movements and volatilities, and the effects of different climate-related events can vary in terms of type, severity, and frequency. As more data on climate-related events becomes available, it may be possible to link specific events to specific credit quality degradation, resulting in less subjective assessments. This approach can be useful for assessing credit quality and pricing loans, but it does have limitations such as requiring subjective input and the assumption that asset returns are normally distributed. As more data on the link between climate events and credit quality are collected, it may be possible to map specific events to credit quality degradation, but this may take some time to be widely adopted (Faccini, Rastin & Skiadopoulos, 2022).

The next chapter explores the prevailing literature regarding possible ways to optimise portfolios in a mean-variance framework while also taking into account ESG scores and the impact of climate change on credit risk.

2. LITERATURE REVIEW

This chapter provides a critical review of the existing studies in the research area.

The concept of socially responsible investing has a long history. Religious texts dating back centuries, including the Jewish Torah, the Islamic Quran, and the Biblical book of Leviticus, provide investment principles that regulate moral property ownership, fair taxation practices, and appropriate interest charges for lenders. In the 18th century, US Quakers were prohibited from profiting from the slave trade, and in the 19th century, US Methodists adopted the practice of only investing in businesses that did not harm others (Marable, 1974).

In the mid-20th century, trade unions started investing in socially relevant enterprises such as medical facilities and housing developments. In the 70s, opponents of the Vietnam War boycotted companies involved in manufacturing or distributing weapons (Rudd, 1979). During the 80s, economic sanctions were imposed on apartheid South Africa, and in the 90s, activists urged divestment and active avoidance of companies involved with gambling, alcohol, tobacco, weapons, the 'adult industry,' and nuclear energy (Dimson, Marsh & Staunton, 2020). The United Nations Environmental Programme (UNEP) was the first organisation to require brokerage houses to disclose and classify their holdings into three categories: environmental, social, and governance (ESG).

While these categories are somewhat broadly defined, some pertinent examples are provided in Table 2.1 below (UNEP FI, 2005).

Table 2.1: Examples of environmental, social and governance issues – often called ESG Pillars.

Environmental Issues	Social Issues	Governance Issues
Climate change and carbon emissions	Customer satisfaction	Board composition
Air and water pollution	Data protection and privacy	Audit committee structure
Biodiversity	Gender and diversity	Bribery and corruption
Deforestation	Employee engagement	Executive compensation
Energy efficiency	Community relations	Lobbying
Waste management	Human rights	Whistleblower schemes

The remarkable growth of ESG assets can be attributed to the belief that ESG factors have a significant impact on corporate performance and market value. From a value of US$22.8tn in 2016, ESG assets grew by 34% to US$30.6tn in 2018, and then by another 14% to US$35.0tn in 2020. This constitutes about one-third of the total global assets under management (Bloomberg Intelligence, 2021). If ESG assets continue to grow at an annual rate of 15% (which is approximately half of the average growth rate of the past five years), they are expected to exceed US$50tn in assets under management by 2025, with US$1tn in ESG ETFs and US$11tn in ESG debt (Global Sustainable Investment Association, 2020).

The field of sustainable investing has advanced beyond early ethics-based methods like negative screening (Utz, Wimmer, Hirschberger & Steuer, 2014). These new strategies still prioritise ethical considerations but also aim to maximise risk-adjusted returns (Bernow, Klempner & Magnin, 2017). It would be misguided to assume that investors will readily adopt ESG portfolios filled with sustainable assets if doing so requires sacrificing significant returns in the name of responsible, philanthropic environmentalism (Barracchini, 2012). While traditional analytical methods have been used to measure ESG portfolio performance and data are becoming more abundant and trustworthy, the literature is still divided on whether high ESG-score portfolios outperform those with lower ESG scores.[2]

2.1 LOWER ESG SCORES AND HIGHER RETURNS

In a study conducted by Hong & Kacperczyk (2009), it was discovered that "sin" stocks generate higher average returns due to their rejection by ethical investors and instead being embraced by mutual and hedge funds (i.e. considerably larger investors). On the other hand, investors are willing to accept lower returns from socially responsible investments, which is a direct reflection of their investment motives involving social signaling and preferences, rather than superior performance, as noted by Riedl & Smeets (2017). Furthermore, Barber, Morse & Yasuda (2021) discovered that high ESG score venture capital funds generate returns which are 4.7% lower than funds with comparable geography and vintage, with investors once again willing to accept lower returns

[2] An ESG score is a metric which reflects a company's performance based on several environmental, social and governance indicators. Generating an ESG score involves evaluating a company's adherence to and observance of these indicators using simple numerical scales and then aggregating these individual scores into a single appraisal. These are then mapped to an ESG rating much like a credit rating is assigned by credit rating agencies. Like credit ratings and the agencies that provide them, ESG ratings and ESG raters employ different approaches, thresholds, and scales and thus different outputs for the same company.

as compensation for social impact. Bolton & Kacperczyk (2020) also found that companies which produce high CO_2 generate higher-than-average returns, possibly because a carbon risk premium is included that compensates investors for the risks associated with future carbon pricing regulations.

2.2 HIGHER ESG SCORES AND HIGHER RETURNS

According to Gompers, Ishii & Metrick (2003), portfolios that invest in stocks with high governance scores (such as those that have strong shareholder rights) and those with low governance scores (such as those with poor employee satisfaction ratings) have outperformed the market by 8.5% annually. Core, Guay & Rusticus (2003) conducted a follow-up study to Gompers et al.'s (2003) work and found that companies with weak governance have worse operating performance, while companies with strong governance have better operating performance, which may explain the high market outperformance reported by Gompers et al. (2003).

Dimson, Karakas & Li (2015) conducted a study on US public companies over the period of a decade (1999 – 2009) using a proprietary database of corporate social responsibility engagements. The study found that engagements which addressed ESG concerns resulted in positive abnormal returns. Engaged firms that were concerned about reputational issues and had the ability to implement changes were more likely to participate in the engagements. The work also found that accounting performance improved in the relevant companies after engagement, and better governance led to increased institutional ownership.

A study conducted by Brav, Jiang, Partnoy & Thomas (2008) found that following investment announcements made by activist funds, stock prices increased, resulting in abnormal returns of up to +7%. Similarly, Alok, Kumar & Wermers (2020) discovered that money managers investing in climate-change-affected areas held fewer stocks than other managers. This could be attributed to the psychological tendency of overestimating the likelihood of severe events in proportion to their proximity and emotional significance.

In a comprehensive review of primary research on the relationship between ESG criteria and corporate financial performance, Friede, Busch & Bassen (2015) discovered that 90% of studies showed a positive correlation between ESG and corporate finance performance. Most studies also reported positive findings, indicating that the positive impact of ESG on corporate finance performance remains stable over time.

Choi, Gao & Jiang (2020) found that investors tend to reduce their holdings in high emission companies following periods of above-average seasonal temperatures. Moreover, after abnormally hot periods, stocks with high carbon intensity underperform those with low carbon emissions. The interest in ESG investing in emerging markets is also on the rise, as highlighted by Cole, Melecky, Mölders & Reed (2020). However, caution is often recommended due to inadequate non-financial disclosure and limited fundamental research in these regions, as noted by Bilbao-Terol, Arenas-Parra & Cañal (2012), Chauhan & Kumar (2018), Mobius & Ali (2021).

There is limited research on ESG investment in South Africa. Johnson, Mans-Kemp & Erasmus (2019) studied the relationship between ESG scores and corporate financial performance measures, McCallum & Viviers (2020) examined key obstacles (and potential opportunities) for impact investment in an emerging market, and Johnson (2020) linked ESG disclosure to the capital costs of South African firms. Although these studies fill a gap in emerging market ESG literature, they did not evaluate the empirical performance of ESG in South Africa, and ESG portfolio optimisation in an emerging market context was not within the scope of their research.

2.3 THE ESG EFFICIENT FRONTIER

Although the evidence for ESG stock investments generating superior returns is often inconclusive, the popularity of ESG investing among institutional and private investors persists and shows no signs of diminishing. Nonetheless, ESG investing as a developing field, has no universally accepted methodology for effectively integrating profit-maximising metrics with ESG criteria.

Méndez-Rodríguez, Bernabeu, Hilario & Pérez-Gladish (2013) suggested a flexible method to calculate social responsibility scores of mutual funds that considers various dimensions and strategies of socially responsible investing (SRI). They plotted efficient frontiers for different SRI strategies and dimensions and found that incorporating SRI constraints into the optimisation framework shifts the efficient frontier to the southeast in the mean-variance space. Consequently, for the same return as portfolios on the traditional efficient frontier, the risk tends to be higher on the ESG constrained efficient frontier as the level of social responsibility increases (Gompers, Ishii & Metrick, 2009 and Pérez-Gladish, Méndez-Rodríguez, M'Zali & Lang, 2013).

Beiting, Ioannou & Serafeim (2014) discovered that companies with superior corporate social responsibility performance faced significantly less capital constraints. However, their study did not focus on minimising capital or maximising risk-adjusted returns. Meanwhile, Chen and Mussalli (2020) developed an ESG investment framework that optimises the dual objectives of sustainability performance and alpha (excess market returns). Although Beiting, Ioannou & Serafeim's (2014) work is crucial, the aim is to examine the optimal ESG risk-adjusted returns, not just to maximise alpha.

Qi & Li (2020) expanded the conventional portfolio-selection model by enforcing ESG constraints to compute the efficient frontier. They discovered that all of the ESG-constrained frontier's portfolio weights lie on a ray (half line). The authors demonstrated that portfolios on the ESG constrained frontier and those that constitute the traditional efficient frontier have significantly different portfolio weights. Since portfolio weights are the foundation of asset selection and portfolio composition, this finding is critical for sustainable investments. Using component stocks of the Dow Jones Industrial Average Index from 2004 to 2013, Qi & Li (2020) observed that the ESG-constrained and traditional efficient frontiers were comparable (i.e., both occupied similar loci in mean-variance space), demonstrating that investors can still achieve the risk-return profile of traditional efficient portfolios or one similar to them after imposing strict ESG requirements, despite the substantial differences in portfolio weights (Lee, Humphrey, Benson & Ahn, 2020).

Pedersen, Fitzgibbons & Pomorski (2020) aimed to tackle this issue by creating an equilibrium asset pricing model that includes ESG preferences. They derived an ESG efficient frontier that investors can use to invest in stocks based on risk-adjusted performance and ESG scores. The authors discovered that optimal portfolios could be generated by combining the minimum variance portfolio, the risk-free asset, the maximum Sharpe Ratio (optimal risk-adjusted) portfolio, and a new 'ESG-tangency' portfolio, which is similar to the maximum Sharpe ratio portfolio on the traditional efficient frontier. According to Pedersen, et al (2020), ESG portfolios are advantageous to investors because they are used to update expectations of returns and risk, which in turn raises the efficient frontier. However, the pursuit of ESG preferences incurs a cost as investors deviate from the traditional efficient frontier and do not achieve the optimal Sharpe ratio portfolio returns or risk (Barnett & Salomon, 2006; Ballestero, Bravo, Pérez-Gladish, Arenas-Parra & Pla-Santamaria, D. 2012 and Gupta, Mehlawat & Saxena, 2013).

2.4 CLIMATE CHANGE ON CREDIT RISK

There is a limited amount of empirical literature that explores the impact of climate-related natural disasters, such as floods and droughts, on economic and social variables. To fill this research gap, Shimada (2022) conducted a regression analysis using a panel dataset of 50 years of African data spanning from 1961 to 2011. The study found that natural disasters related to climate change, particularly droughts, had a significantly negative impact on agriculture, economic growth, and poverty in Africa. These natural disasters adversely affected crops like maize and coffee and increased the frequency and intensity of armed conflicts in the region (Shimada, 2022).

The BCBS (2021b) conducted an investigation into methodologies for measuring climate-related financial risks that concern banks and regulatory supervisors. The key findings distilled from this work include the unique features of financial risks, which require forward-looking and granular measurement methodologies, involving forecasts based on sensible simulations. Banks and supervisors tend to concentrate on near-term transition risk drivers, with less progress made on bank exposures to physical risks. To translate climate-related exposures into financial risk categories, banks have focused on credit risk, with less attention given to market risk and even less to operational and liquidity risk. The modelling of the impact of climate change on traditional credit risk parameters such as probabilities of default (PD) and losses given default (LGD) is still in the early stages and has yet to be standardised. Trial analyses have thus far preferred a combination of approaches, including forward-looking methodologies and multiple scenario analysis, both of which involve forecasting of relevant variables, usually through simulations (BCBS, 2021b).

Polbennikov, Desclée, Dynkin & Maitra (2016) conducted a study on the correlation between historical environmental, social, and governance (ESG) ratings and the spread and performance of corporate bonds in the US. They discovered that corporate bonds with high composite ESG ratings had lower spreads and outperformed bonds with low composite ESG ratings. In another study on Korean corporate bond data from 2010 to 2015, Jang, Kang, Lee & Bae (2020) concluded that ESG scores provided valuable information about the downside risk of firms, particularly for small corporations with high information asymmetry. Of the three ESG criteria, only environmental scores significantly impacted bond returns. ESG scores were also found to complement credit ratings in assessing corporate credit quality. A similar study on stocks found that those with high ESG composite ratings generated higher realised returns and provided better tail-risk protection than those with low ESG composite ratings (Xiong, 2021). High ESG composite-rated stocks provided considerable tail-risk protection benefits during the COVID-19 crisis.

Thi Thu Truong & Kim (2019) investigated the impact of ESG activities on implied credit risk using credit derivative prices. The authors employed Fama-MacBeth regressions (Bai & Zhou, 2015) and found that firms with higher ESG scores had lower credit risk, as indicated by associated credit default swaps. The study suggests that ESG activities have a greater impact on reducing credit risk in the long term than in the short term.

Bauer and Hann (2010) demonstrated the correlation between poor environmental performance and the combination of low-grade credit ratings and higher spreads for corporate bonds. Oikonomou, Brooks & Pavelin (2014) investigated the relationship between sustainability performance dimensions and corporate debt pricing, concluding that adding corporate social responsibility factors significantly lowered risk premia and reduced corporate debt costs. Hoepner & Nilsson (2017) found that companies without any environmental, social, or governance issues outperform market benchmarks significantly, especially during market turmoil, implying that investors price bonds based on their perceptions of riskiness.

Capasso, Gianfrate & Spinelli (2020) investigated the correlation between climate change and corporate credit risk by analyzing data from 458 US-based companies that had issued fixed-rate investment grade corporate bonds between December 2007 and December 2017. The researchers used a market-based measure called the distance-to-default approach to estimate default probabilities, which served as a proxy for credit risk. This approach is based on the work of Black and Scholes (1973) and Merton (1974) on option pricing, and it was applied in this study to price corporate debt. The results of Capasso, Gianfrate & Spinelli's study provided evidence of a strong link between exposure to climate risks and the creditworthiness of bonds and loans issued by corporations.

In January 2022, the European Banking Authority (EBA) released the final version of Pillar III disclosures for implementing technical standards on ESG risks (EBA, 2022). These disclosures are intended, like other Pillar III disclosures, to encourage market discipline and enable stakeholders to evaluate banks' ESG-related risks and sustainable finance strategies. Banks are now required to reveal how climate change amplifies their other balance sheet risks and how they are being mitigated. Additionally, banks must disclose their Green Asset Ratio, which is the proportion of the bank's loans and securities meeting the EU environmental taxonomy to on-balance sheet banking book assets. All Basel-compliant banks are required to make these disclosures from January 1, 2024.

Licari, Zemcik, Lafakis & Lee (2021) devised a potential set of solutions that can enable institutions to evaluate the risks posed by climate change in anticipation of the new requirements. One component of this approach involves modeling the continuous accumulation of carbon dioxide emissions and the corresponding changes in global temperature. These outcomes are then incorporated into other modeling elements to determine the physical and transition impacts of climate change on the relevant economy. The scenarios are adaptable and can be adjusted to include user inputs, but Licari, et al (2021) examine scenarios that align with those established by the Network of Central Banks and Supervisors for Greening the Financial System, such as Orderly, Disorderly, and Hot House World scenarios. To establish validity, the modeling framework is applied to two regions, namely the US and the UK.

Edwards, Cui & Mukherjee (2021) extended the macroeconomic forecasting work of Licari, et al (2021) and adapted the approach to be used for evaluating corporate credit. The methodology utilises Moody's Analytics Climate Adjusted Expected Default Frequency (EDF) framework, which is explained in greater detail in Chapter 3. Although the augmented Moody's EDF approach for climate risk comprises several interconnected components, the physical risk-adjusted EDF and the transition risk-adjusted EDF modules are of particular interest.

Then next chapter sets out the data required for the generation of the ESG frontier and for the exploration of climate change on credit risk. The methodologies employed by each investigation are also described in this chapter.

3. DATA AND RESEARCH METHODOLOGY

This chapter describes the data used in the studies as well as the research methodology applied in each case.

3.1 THE ESG FRONTIER

3.1.1 Data

The dataset used in this study comprised of 3 143 global emerging economy stocks categorised into seven business sectors (financials, industrials, basic materials, energy, consumer cyclicals, technology, and academic and educational services). These data were obtained from Reuters Refinitiv database (Refinitiv, 2021), which was selected because it offers one of the most comprehensive ESG databases in the industry, covering over 80% of global market capitalisation and providing details on more than 450 different ESG metrics over two decades since 2002. The purpose of this sample was to obtain general insights into emerging economy ESG trends and patterns. In addition, a smaller sample of 140 South African stocks from three economic sectors, namely financials (banks, insurance, and reinsurance agencies, and asset managers), consumer cyclicals (retailers), and technology (software and IT services, internet providers, and mobile telecommunications), were utilised to focus on the ESG evolution of a single emerging economy. Since South African corporate ESG data only date from 2007, the time frame for the study spanned from 2007 to 2020, with an annual sampling frequency similar to that of credit rating agency grades. Many institutions have been advocating for a more frequent assessment and reporting of ESG data for years (CFA institute, 2019), and ESG information is now a regular feature of quarterly earnings reports (AFME, 2021) as a direct result of this advocacy.

The ESG information includes various metrics provided on a numeric scale ranging from 0 to 100, such as an ESG score, an ESG controversies overlay, and a combined ESG score, which are also mapped to grades on an A to D scale, with additional notching identifiers. The ESG scores are an assessment of a company's ESG performance based on publicly available information related to ESG pillars (Table 2.1), and include an overlay of ESG controversies based on 23 topics captured from global media reports. The ESG controversy overlay is designed to discount ESG performance scores based on negative media reporting and impacts of material controversies on a company's ESG score. The overall ESG score is calculated as a weighted average of the two component scores per fiscal period, with recent controversies reflected in the latest complete period. In this study, only the overall ESG score was used, and the individual components were not independently investigated due to the limited dataset. Other ESG data providers may use different scales, ranges, and methodologies.

After selecting corporates with ESG scores, weekly share prices were collected over the relevant period, going as far back as 2007 in some cases. The share prices were used to compute share returns, volatility, portfolio variance-covariance matrices (where applicable), and Sharpe ratios. Refinitiv (2021) provided these weekly data. Additionally, weekly risk-free rates were obtained from the St Louis Federal Reserve database (2021), which are 90-day rates of South African treasury securities.

3.1.2 Research methodology

3.1.2.1 Efficient frontier

This section presents the mathematics required to plot the efficient frontier and to determine the portfolios analysed in this work. The equations are valid for the following conditions:

- short sales are allowed, and
- portfolios are fully invested i.e., the portfolio weights sum to unity.

The notation used is from Roll (1992) and Jorion (2003) with minor adaptations. The equations presented are primarily in matrix notation and thus some definitions are provided before proceeding.

Portfolios on the efficient frontier have an expected return of $(\mu^U_{frontier})$ and variance $\left(\sigma^U_{frontier}\right)^2$ calculated respectively using:

$$\mu^U_{frontier} = \boldsymbol{w^{U}}'\boldsymbol{E} \tag{3.1}$$

$$\left(\sigma^U_{frontier}\right)^2 = \boldsymbol{w^{U}}'\boldsymbol{\Sigma}\boldsymbol{w^{U}} \tag{3.2}$$

where $\boldsymbol{w^U}$ is the row vector of weights for a portfolio of n assets:

$$\boldsymbol{w^U} = \begin{bmatrix} w_1^U \\ w_2^U \\ \vdots \\ w_n^U \end{bmatrix}$$

U symbolises a universal efficient frontier, i.e., unconstrained (component assets may be selected from the universe of available assets), $\boldsymbol{E}$ is the vector of expected asset returns and $\boldsymbol{\Sigma}$ is the variance-covariance matrix of asset returns. The subscript varies to indicate the relevant portfolio and the prime symbol ($'$) indicates the vector transpose such that the un-transformed vector is a row vector, and the transposed vector is a column vector.

Following Merton (1972), the following constants are defined:

$$a = \boldsymbol{E}'^{\boldsymbol{\Sigma}^{-1}}\boldsymbol{E}$$

$$b = \boldsymbol{E}'^{\boldsymbol{\Sigma}^{-1}}\boldsymbol{1}$$

$$c = \boldsymbol{1}'^{\boldsymbol{\Sigma}^{-1}}\boldsymbol{1}$$

$$d = a - \frac{b^2}{c}$$

where $\boldsymbol{1}$ is an n-dimensional row vector of 1s.

To plot the efficient frontier, the portfolio variance is minimised over the weights subject to a target expected return (G) i.e.,

minimise $\boldsymbol{w^U}'\boldsymbol{\Sigma w^U}$

subject to $\boldsymbol{w^U}'\boldsymbol{1} = 1$ and

$\boldsymbol{w^U}'\boldsymbol{E} = G$.

Jorion (2003) showed that the solution is given by:

$$\boldsymbol{w^U}'\boldsymbol{1} = \left(\frac{a - bG}{d}\right)\boldsymbol{w^U_{MV}} + \left(\frac{bG - \frac{b^2}{c}}{d}\right)\boldsymbol{w^U_{TG}} \qquad (3.3)$$

where $\boldsymbol{w_{MV}^{U}} = \boldsymbol{\Sigma^{-1}} \frac{\boldsymbol{1}}{c}$ is the vector of portfolio weights for the global efficient minimum variance portfolio, $\boldsymbol{w_{TG}^{U}} = \boldsymbol{\Sigma^{-1}} \frac{\boldsymbol{E}}{b}$ is the vector of portfolio weights for the tangent portfolio (the optimal portfolio in the absence of a risk-free asset), and the expected return and variance of these portfolios are: $\mu_{TG}^{U} = \frac{a}{b}$; $(\sigma_{TG}^{U})^2 = \frac{a}{b^2}$; $\mu_{MV}^{U} = \frac{b}{c}$; $(\sigma_{MV}^{U})^2 = \frac{1}{c}$.

Substituting (3.3) into (3.2) and setting G equal to μ_P, the equation for the efficient frontier is obtained:

$$\sigma_{frontier}^2 = \frac{1}{d}\left(\mu_{frontier} - \mu_{MV}^{U}\right)^2 + (\sigma_{MV}^{U})^2$$

From

$$\boldsymbol{w_{TG}^{U}} = \boldsymbol{\Sigma^{-1}} \frac{\boldsymbol{E'}}{b} = \boldsymbol{\Sigma^{-1}} \frac{\boldsymbol{E}}{\boldsymbol{E'\Sigma^{-1}1}}$$

the vector of portfolio weights for the tangent portfolio when $r_f \neq 0$ is obtained using the expected returns in excess of the risk-free rate, r_f:

$$\underset{r_f \neq 0}{\boldsymbol{w_{TG}^{U}}} = \boldsymbol{\Sigma^{-1}} \frac{(\boldsymbol{E} - r_f)}{(\boldsymbol{E} - r_f)\boldsymbol{\Sigma^{-1}1}} \tag{3.4}$$

The return and risk for this portfolio are obtained by substituting (3.4) into (3.1) and (3.2): $\underset{r_f \neq 0}{\mu_{TG}^{U}} = \underset{r_f \neq 0}{\boldsymbol{w_{TG}^{U'}}}\boldsymbol{E}$ and $(\underset{r_f \neq 0}{\sigma_{TG}^{U}})^2 = \underset{r_f \neq 0}{\boldsymbol{w_{TG}^{U'}}}\boldsymbol{\Sigma}\underset{r_f \neq 0}{\boldsymbol{w_{TG}^{U}}}$.

3.1.2.2 ESG frontier

The investor's problem is that of assembling a portfolio from n possible ESG assets and a risk-free security (whose return is r_f) such that its risk-adjusted returns are maximised on the ESG frontier.

The investor commences with wealth W and chooses a portfolio of risky assets with weights given by the vector w:

$$\boldsymbol{w^{ESG}} = \begin{bmatrix} w_1^{ESG} \\ w_2^{ESG} \\ \vdots \\ w_n^{ESG} \end{bmatrix}$$

where w_i^{ESG} is the fraction of capital invested in security i so the investor purchases $w_i^{ESG} W$ worth of security i. The returns of the risky assets are given by the vector of returns, r:

$$r = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{bmatrix}$$

and the ESG scores of the component assets are given by the vector s:

$$s = \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_n \end{bmatrix}$$

The assets' average expected returns are given by

$$E^{ESG} = \begin{bmatrix} E_1^{ESG} \\ E_2^{ESG} \\ \vdots \\ E_n^{ESG} \end{bmatrix}$$

where $E_i^{ESG} = E(r_i | s_i)$.

The investor's utility depends on future wealth ($\widehat{W}$) and the portfolio's ESG characteristics, given by

$$\widehat{W} = W\left(1 + r_f + \boldsymbol{w}^{\boldsymbol{ESG}'}\boldsymbol{r}\right).$$

Where W is current wealth. To maximise utility U over final wealth $\widehat{W}$ and average ESG score $\overline{s}$ (given by $\overline{s} = \frac{\boldsymbol{w}^{\boldsymbol{ESG}'}\boldsymbol{s}}{\boldsymbol{w}^{\boldsymbol{ESG}'}\boldsymbol{1}}$);

$$U = E\left(\widehat{W} \middle| s\right) - \frac{\overline{\gamma}}{2} Var\left(\widehat{W} \middle| s\right) + Wf(\overline{s})$$

where γ is the absolute risk-aversion parameter and $f: R \to R \cup \{-\infty\}$ is the ESG preference function. The ESG preference function depends on the average ESG score among the risky asset positions (i.e., $\overline{s}$ is the weighted sum of ESG scores, scaled by the total position in risky assets, $\boldsymbol{w}^{\boldsymbol{ESG}'}\boldsymbol{1}$), meaning that the investor enjoys no ESG utility from investing in the risk-free asset. The overall utility may then be written

$$U = W\left(1 + r_f + \boldsymbol{w^{ESG'}}\boldsymbol{E^{ESG}}\right) - \frac{\overline{\gamma}}{2}W^2\boldsymbol{w^{ESG'}}\boldsymbol{E^{ESG}} + Wf\left(\frac{\boldsymbol{w^{ESG'}}\boldsymbol{s}}{\boldsymbol{w^{ESG'}}\boldsymbol{1}}\right)$$

$$= W\left(1 + r_f + \boldsymbol{w^{ESG'}}\boldsymbol{E^{ESG}} - \frac{\gamma}{2}\boldsymbol{w^{ESG'}}\boldsymbol{\Sigma}\boldsymbol{w}^{\mathrm{ESG}} + f\left(\frac{\boldsymbol{w^{ESG'}}\boldsymbol{s}}{\boldsymbol{w^{ESG'}}\boldsymbol{1}}\right)\right).$$

where $\gamma = \overline{\gamma}W$ is the relative risk aversion. Omitting constant terms gives the utility maximisation problem:

$$\max_{w^{ESG}\in\Omega}\left(\boldsymbol{w^{ESG'}}\boldsymbol{E^{ESG}} - \frac{\gamma}{2}\boldsymbol{w^{ESG'}}\boldsymbol{\Sigma}\boldsymbol{w^{ESG}} + f\left(\frac{\boldsymbol{w^{ESG'}}\boldsymbol{s}}{\boldsymbol{w^{ESG'}}\boldsymbol{1}}\right)\right) \tag{3.5}$$

where the set of feasible portfolios is given by $\Omega = \{\boldsymbol{w^{ESG}} \in R^n | \boldsymbol{w^{ESG'}}\boldsymbol{1} > 0\}$, or all long-biased portfolios. Portfolios that invest at least as much long as short were considered because defining the overall ESG characteristic for a portfolio that is short overall is difficult, but, in principle, the framework can be defined more generally.

The ESG-motivated investor's portfolio problem may now be solved. The objective function depends on the ESG scores, s, so the optimal portfolio depends on these scores. In a standard mean-variance analysis, the investor optimally combines the tangency portfolio with the risk-free security. The tangency portfolio is the portfolio that maximises the Sharpe ratio, namely, the quotient of the expected excess returns and the standard deviation of excess returns. To generalise this idea, the maximum Sharpe ratio (SR) for each level of ESG score was considered. The maximum SR that can be achieved with an ESG score of $\overline{s}$ is denoted by the ESG-SR frontier, $SR(\overline{s})$:

$$SR(\overline{s}) = \max_{\substack{\boldsymbol{w^{ESG}}\in\Omega \\ s.t.\ \overline{s} = \frac{\boldsymbol{w^{ESG'}}\boldsymbol{s}}{\boldsymbol{w^{ESG'}}\boldsymbol{1}}}}\left(\frac{\boldsymbol{w^{ESG'}}\boldsymbol{E^{ESG}}}{\sqrt{\boldsymbol{w^{ESG'}}\boldsymbol{\Sigma}\boldsymbol{w^{ESG}}}}\right) = \max_{\substack{w \\ s.t.\ \boldsymbol{w^{ESG'}}\boldsymbol{1} = 1 \\ \text{and } \boldsymbol{w^{ESG'}}\boldsymbol{s} = \overline{s}}}\left(\frac{\boldsymbol{w^{ESG'}}\boldsymbol{E^{ESG}}}{\sqrt{\boldsymbol{w^{ESG'}}\boldsymbol{\Sigma}\boldsymbol{w^{ESG}}}}\right) \tag{3.6}$$

To use this definition of the maximal SR for each ESG level, the utility maximisation problem (3.5) must be rewritten

$$\max_{\bar{s}}\left[\max_{\sigma}\left\{\max_{\substack{\boldsymbol{w}^{ESG}\in\Omega \\ s.t.\ \bar{s}=\frac{\boldsymbol{w}^{ESG'}\boldsymbol{s}}{\boldsymbol{w}^{ESG'}\boldsymbol{1}} \\ \sigma^2=\boldsymbol{w}^{ESG'}\boldsymbol{\Sigma}\boldsymbol{w}^{ESG}}}\left(\boldsymbol{w}^{ESG'}\boldsymbol{E}^{ESG}-\frac{\gamma}{2}\sigma^2+f(\bar{s})\right)\right\}\right] \tag{3.7}$$

(3.2) may be thought of as first choosing the best portfolio given a level of risk σ and an ESG score $\bar{s}$ and then maximising over σ and $\bar{s}$. The former problem is solved by choosing the portfolio with the highest SR for the given ESG score which gives

$$\max_{\bar{s}}\left[\max_{\sigma}\left\{SR(\bar{s})\sigma-\frac{\gamma}{2}\sigma^2+f(\bar{s})\right\}\right] \tag{3.8}$$

The optimal level of risk is given by

$$\sigma=\frac{SR(\bar{s})}{\gamma}$$

Inserting this risk level and simplifying (3.8) gives the proposition which asserts how investors optimally trade off ESG and SRs, i.e., investors should choose the average ESG score $\bar{s}$ to maximise the function in (8) of the squared SR and the ESG preference function:

$$f:\max_{\bar{s}}\left[\left(SR(\bar{s})\right)^2+2\gamma f(\bar{s})\right] \tag{3.9}$$

ESG affects optimal portfolio choice given that ESG is included in the utility function, but the interesting result here is that this trade-off may be analysed using a part that depends only on securities (the ESG-SR frontier, $SR(\bar{s})$) and another part that depends only on preferences: $2\gamma f(\bar{s})$. Standard Markowitz (1952) theory is powerful because the mean-variance frontier can be computed independent of preference parameters and then decisions about what portfolio to pick are based on risk aversion. In a similar way, the ESG-SR frontier can be computed independent of preferences and then the investor can decide in the end where to be placed on the frontier. Put differently, the ESG-SR frontier summarises all security-relevant information. The investor's problem is to first decide on a position on the the ESG-SR frontier and then to decide on the amount of risk.

Understanding the ESG-SR frontier shows how differences in risk aversion and differences in ESG preferences can be distinguished. If a group of investors have no direct preferences for ESG ($f \equiv 0$) but differ in their risk aversion γ, then all these investors should invest in the same portfolio of risky assets (i.e., with the same Sharpe ratio and average ESG score), but the more risk tolerant should put a larger fraction of their wealth in this portfolio (i.e., own less cash instruments). If a group of investors have the same risk aversion but differ in their ESG preferences, then investors with stronger ESG preferences should buy a portfolio with lower SR, but higher average ESG score. Interaction effects also exist.

If a group of investors care equally about ESG but differ in their risk aversion, then an investor with higher risk aversion not only increases investment in the risk-free asset, but also tilts the portfolio toward higher ESG and lower SR. Mathematically, this behavior arises because the second term in (3.4) is $\gamma f(\overline{s})$, and, economically, this interaction arises because SR matters less when an investor is more risk averse, so, relatively speaking, ESG increases in importance. More generally, observing an investor's portfolio of risky assets and its placement on the ESG-SR frontier is revelatory about $\gamma f(\overline{s})$; observing the investor's cash position (or leverage), about the risk aversion γ.

Using the notation $c_{ab} = a'\Sigma^{-1}b \in R$ for any row vectors $a, b \in R^n$, the maximum Sharpe ratio, $SR(\overline{s})$, that can be achieved with an ESG score of $\overline{s}$ is

$$SR(\overline{s}) = \sqrt{c_{\mu\mu} - \frac{\left(c_{s\mu} - \overline{s}c_{1\mu}\right)^2}{c_{ss} - 2\overline{s}c_{1s} + \overline{s}^2 c_{11}}} \tag{3.10}$$

3.2 CLIMATE CHANGE IMPACT ON CREDIT RISK

3.2.1 Data

In contrast to Capasso, Gianfrate & Spinelli (2020), who analysed real corporate data over a specific historical period (selecting companies that had issued investment grade debt during this period), this analysis used simulated data. While studies like Castro, Gutierrez-Lopez, Tascon & Castano's (2021) investigation of the impact of severe environmental changes on stock prices are becoming more common, there is still a lack of data connecting climate-related impacts to share prices. Therefore, the results are simulated for a range of potential impacts. Companies affected by such impacts may determine their nature (physical or transition) and magnitude using their own judgment, and a theoretical (and practical) method for calibrating such impacts is offered.

In order to analyse changes in the values of corporate assets and liabilities over time, a Geometric Brownian Motion (GBM) approach was employed. This involved utilising weekly share prices over a ten-year period, with various annual volatility and drift values selected based on different styles. Additionally, shocks of varying intensity (expressed as a percentage) were introduced at different points in time. It should be noted that the specific frequency and severity of such shocks can be determined by the individual firms affected, and subsequently incorporated into the approach.

Similar to Baarsch & Schaeffer (2019), the Kolmogorov Merton Vasicek (KMV) (Crosbie & Bohn, 2005) model for which the outputs of the GBM analysis serve as inputs was used. Simulated, yet realistic, parameters for equity volatility, liabilities, market value of assets, risk-free rates, and others were used. Firms may opt to use their own values for these parameters or obtain them from publicly available balance sheets and other corporate data.

3.2.2 Research methodology

The primary aim is to assess the impact of climate transition and physical risk on obligor creditworthiness. This evaluation could be translated into a measure of default probability, which may then be used for IFRS-9 accounting reporting, regulatory credit risk measurements, forecasting and other relevant and important information of affected firms.

The approach involves simulating asset values over time (using GBM) and then stress testing these asset values by introducing a climate event. If the event is 'physical', the shock is immediate, unexpected, and the ramifications can be of varying severity and duration. An important distinction between physical and transition climate shocks is that physical shocks cause the underlying asset volatility to *increase* after the event while for transition shocks asset volatilities *do not increase* because the event (such as a policy change or a new sustainable tax) was anticipated.

3.2.2.1 Geometric Brownian Motion

Assuming stock price returns are lognormally distributed (i.e., that asset values, S, evolve according to a lognormal distribution) over time (Agustini, Restu, Endah & Putri, 2018), then

$$\ln\left(\frac{S_t}{S_0}\right) \sim \phi\left[\left(\mu - \frac{\sigma^2}{2}\right)dt, \sigma\sqrt{dt}\right]$$

implies that

$$dS = S_t \exp\left[\left(\mu - \frac{\sigma^2}{2}\right)dt + \sigma\varepsilon\sqrt{dt}\right]$$

where S_t represents the stock price at time t, dt is the time over which the return is measured, μ is the average return, σ^2 is the return variance, the term in round brackets represents the stock price drift over time, and ε is distributed $\sim N(0,1)$. In discrete terms (i.e., where the continuous time variable dt is replaced by the discrete time step Δt)

$$S_{dt+\Delta t} = S_t \exp\left[\left(\mu - \frac{\sigma^2}{2}\right)\Delta t + \sigma\varepsilon\sqrt{\Delta t}\right]$$

The time step is commonly taken to be $t = 1$ day for most stock price simulations, although t can be any sensible time unit, and which may be adjusted to fit the specific forecast problem. In this work, because *annual* default rates are the product, daily simulations were deemed too granular while monthly and annual simulation steps led to considerably reduced scenario numbers and diminished forecast accuracy. As a result, weekly timesteps were used to provide some output granularity without sacrificing model accuracy.

Ten years of weekly simulations were generated. This provided enough forecast scenarios to make reasoned observations on ESG event impact severity and duration. By arranging the event to occur – say – in one year's time and allowing the event's impact to affect the asset value in accordance with the KMV model predictions, the propagation of the impact could be monitored and assessed over the next nine years. While longer obligation periods exist, this period is sufficient to identify patterns and features in default rates (and other outputs such as post-event volatility) and isolate the effects of event severity and duration. The impact of multiple climate-related impacts, of different severities, to assess the effect of such events was also explored.

Some 10 000 stock price simulations were generated, all with the arbitrarily selected start value of 100 but only a few paths are reproduced in Figure 3.1 for clarity. Share price (y) axes scales are the same for both types of events for comparison.

3.2.2.2 KMV PD estimation

Crosbie & Bohn (2005) set out the mathematics governing the estimation of default probabilities from equity prices. Assume

$$dV_A = \mu V_A\, dt + \sigma_A V_A dz \tag{3.11}$$

where V_A and dV_A are the firm's asset value and change in asset value, μ and σ_A are the firm's asset value drift rate and volatility, and dz is a Wiener process.

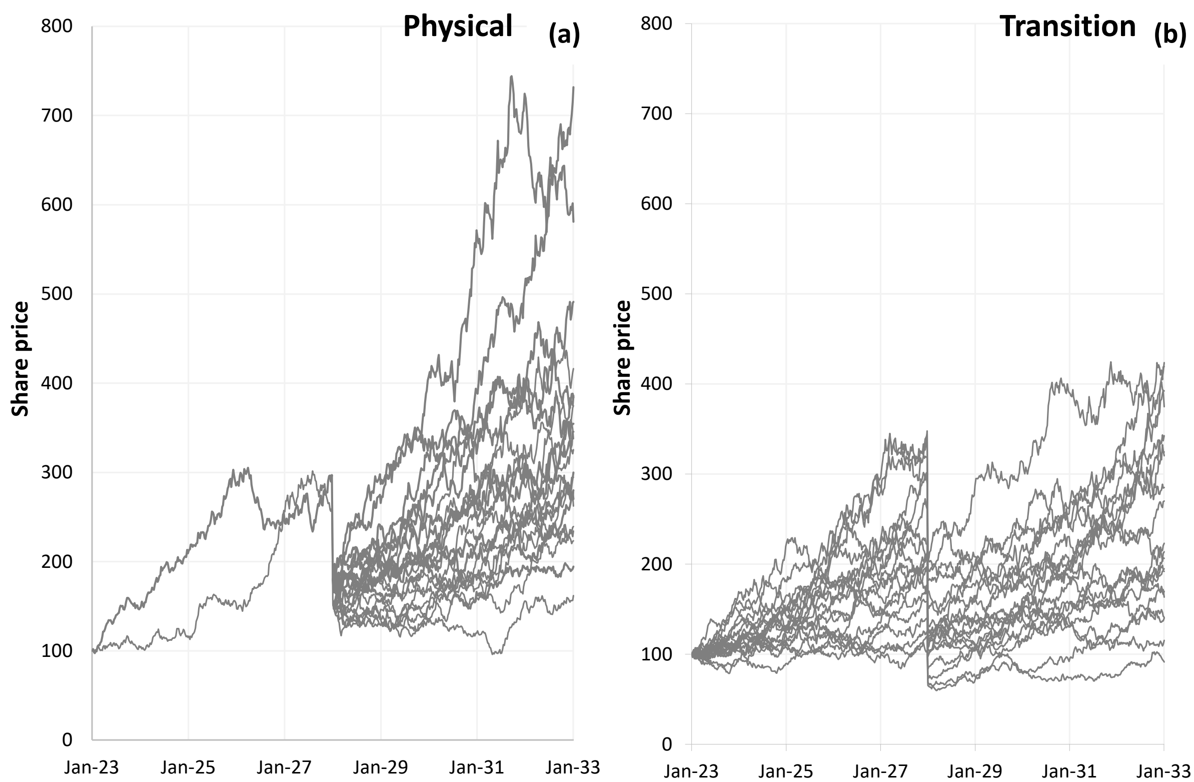


Figure 3.1: Simulated share prices for a 60% share price shock occurring halfway through a ten-year simulation cycle, due to (a) a physical climate risk event in which volatilities post the even do increase by 10% and (b) a transition climate risk event in which equity volatilities do not increase after the event. Note the same vertical scale for comparison.

Source: Author's calculations.

The KMV model allows only two types of liabilities, a single class of debt (X) and a single class of equity. If X is the book value of the debt due at time T then the market value of equity and the market value of assets, respectively, are related using:

$$V_E = V_A N(d_1) - \exp(rT)\, X N(d_2) \tag{3.12}$$

where V_E is the market value of the firm’s equity, r is the risk-free interest rate and

$$d_1 = \frac{\ln\left(\frac{V_A}{X}\right) + \left(r + \frac{\sigma_A^2}{2}\right)T}{\sigma_A\sqrt{T}}$$

$$d_2 = d_1 - \sigma_A\sqrt{T} \ ,$$

A firm's equity volatility is then related to its asset volatility using

$$\sigma_E = \frac{V_A}{V_E}\Delta\sigma_A \tag{3.13}$$

Asset values and volatilities implied by equity values, volatilities and liabilities are determined by solving the call price (3.12) and volatility (3.13) equations, simultaneously.

The probability of such a firm defaulting is the probability that the firm's asset market value will be less than the firm’s liabilities book value when the debt matures. This may be written

$$p_t = \Pr[V_A^t \leq X_t | V_A^0 = V_A] \ = \Pr[\ln V_A^t \leq \ln X_t | V_A^0 = V_A] \tag{3.14}$$

where p_t is the probability of default by time t, V_A^t is the market value of the firm’s assets at time t, and X_t is the book value of the firm’s liabilities due at time t. The change in the value of the firm’s assets is described by (3.12) and thus the value at time t, V_A^t, given that the value at time 0 is V_A, is:

$$\ln\left(\frac{V_A^t}{V_A^0}\right) = \left(\mu - \frac{\sigma_A^2}{2}\right)t + \sigma_A\varepsilon\sqrt{t} \tag{3.15}$$

where μ is the expected return on the firm’s asset, and ε is the random component of the firm’s return. This is the evolution of the asset value. Combining (3.14) and (3.15) gives the probability of default below:

$$p_t = \Pr\left[\ln V_A + \left(\mu - \frac{\sigma_A^2}{2}\right)t + \sigma_A\varepsilon\sqrt{t} \leq X_t\right]$$

which may be rearranged to give

$$p_t = \Pr - \frac{\ln\left(\frac{V_A}{X_t}\right) + \left(\mu - \frac{\sigma_A^2}{2}\right)t}{\sigma_A\sqrt{t}} \leq \varepsilon$$

Recall that the Black and Scholes model assumes that the random component of the firm's asset returns is normally distributed, $\boldsymbol{\varepsilon} \sim \boldsymbol{N}(\mathbf{0}, \mathbf{1})$ as a result the default probability may be defined in terms of the cumulative Normal distribution:

$$p_t = N\left[-\frac{\ln\left(\frac{V_A}{X_t}\right) + \left(\mu - \frac{\sigma_A^2}{2}\right)t}{\sigma_A\sqrt{t}}\right]$$

The distance-to-default is the number of standard deviations that the firm is away from default and thus in the Black and Scholes formulation is:

$$DD = \frac{\ln\left(\frac{V_A}{X_t}\right) + \left(\mu - \frac{\sigma_A^2}{2}\right)t}{\sigma_A\sqrt{t}} \tag{3.16}$$

The approach, then, is:

1. simulate share prices using realistic parameter inputs, such as drift and equity return volatility
2. introduce realistic climate-induced shocks of different frequencies and severities
3. record resulting average firm market values (via share prices) and equity volatilities at selected time intervals after the introduction of the shock(s)
4. input these asset values and equity volatilities into the KMV model to estimate the DD (3.16) and hence the change from *unshocked* DDs
5. set up a calibration scale for different climate shocks (physical or transition), shock severities and impact on underlying credit quality.

Steps (1 – 5) provide a way to calibrate the impact of shock size on corporate default rates.

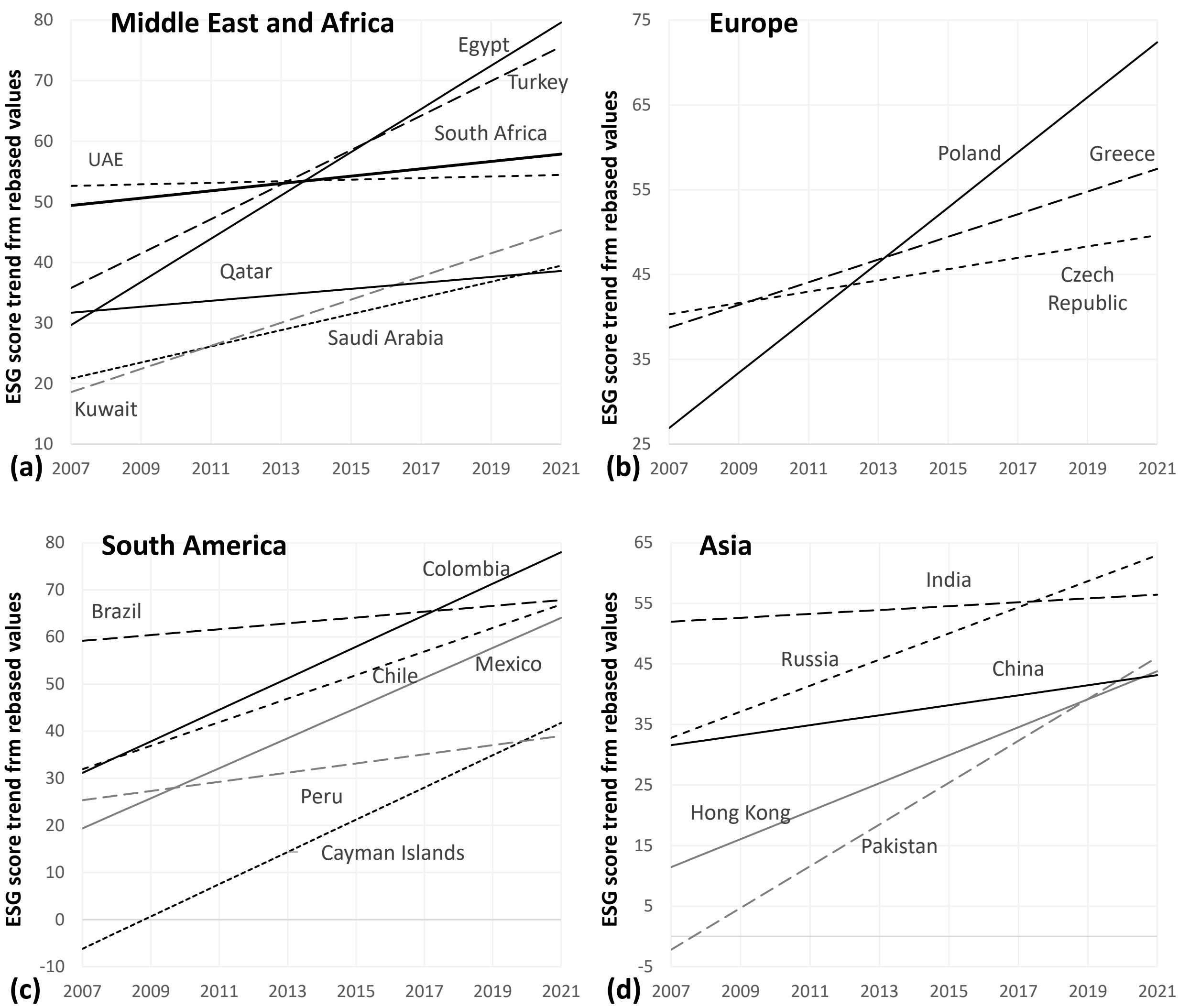
The next chapter presents the results obtained from the respective invesitgations, discusses and contextualises these results and sets out some possible conclusions that may be drawn from them.

4. RESULTS AND DISCUSSION

This chapter outlines the findings from the methodology explained in the preceding section. Firstly, the section presents the descriptive statistics for the variables used in the study, followed by the results from the specific hypotheses developed for the study.

4.1 ESG FRONTIER

The investigation commences by analysing the evolution of average ESG scores over time of several emerging economy countries, grouped into various regions, and shown in Figure 4.1(a) through (e). Figure 4.1(f) represents the overall emerging economy equally-weighted average over all 3 143 stocks.



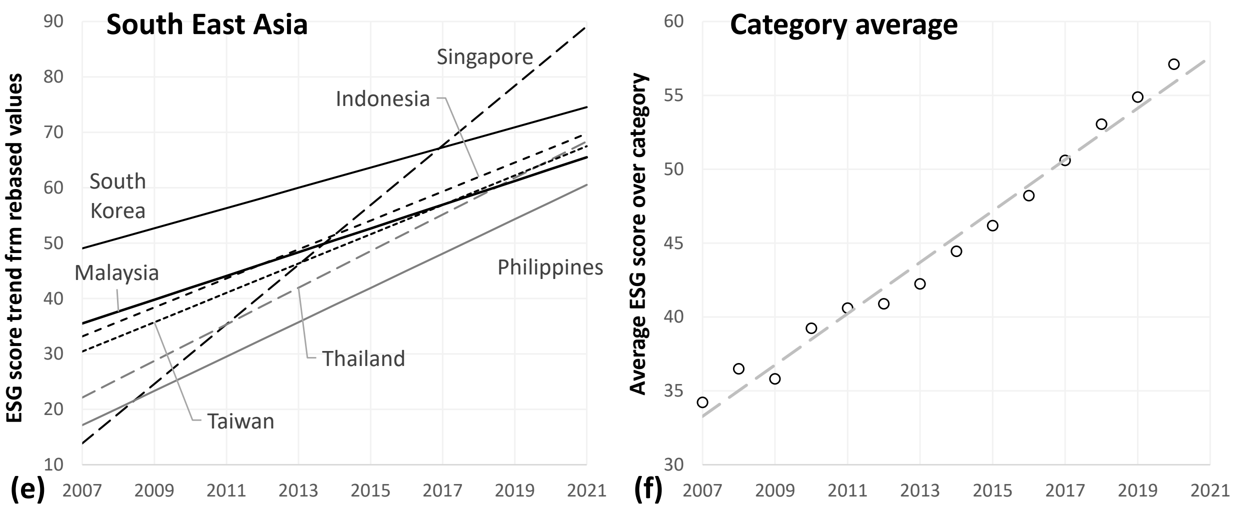


Figure 4.1: ESG score trends for various global developing market regions: (a) Middle East and Africa, (b) Europe, (c) South America, (d) Asia, (e) Southeast Asia and (f) the emerging economy average ESG score over time. Vertical scales are different.

Source: Reuters Refinitiv and author calculations.

For all countries analysed, ESG scores increase over time, albeit at different rates. The average ESG score for emerging economies using the entire sample shows a pronounced linear trend, increasing at a rate of 1.63/annum. At this rate, average emerging economy ESG scores will be comparable to current (2022) developed economy scores (∼ 85) by the end of the 2030s. The average trend could, of course, be considerably different if rates accelerate or decelerate due to the many contributing factors. So far, however, the slow but relentless improvement in ESG scores is encouraging.

Corporate ESG scores at individual country level using actual ESG scores rather than regional averages display substantial volatility and – in some cases – decreasing scores. This is not unexpected: companies making progress on environmental issues may have deteriorating working conditions or be governed by a weak board. A representative sample of South African stocks is shown in Figure 4.2.

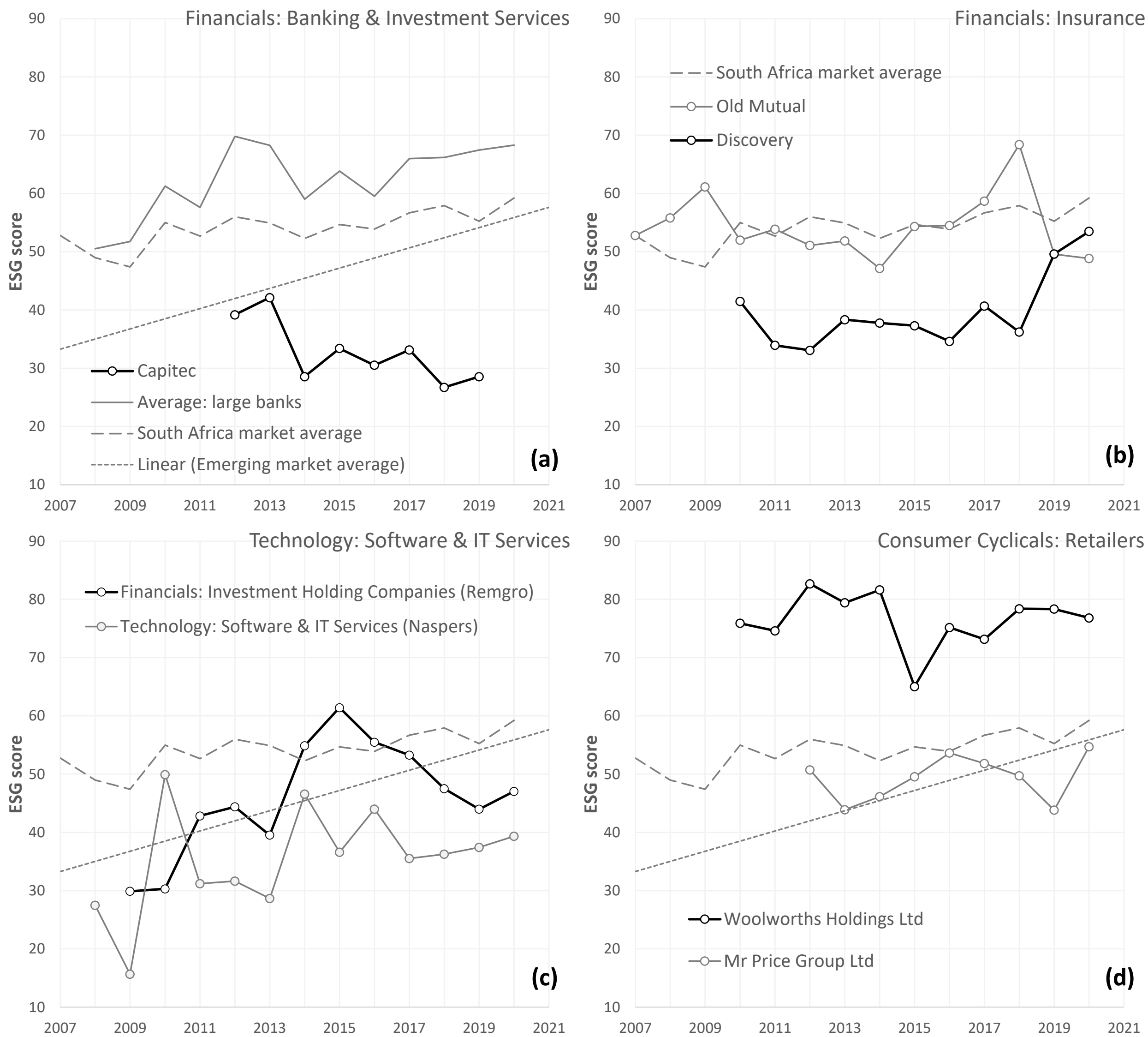


Figure 4.2: ESG scores for representative South African stocks selected from the (a) banking, (b) insurances, (c) technology and (d) consumer cyclicals sectors over 2007 – 2020. Vertical scales are identical for comparison.

Source: Reuters Refinitiv and author calculations.

A well-diversified, multi-sector portfolio comprising 30 South African stocks with (current – 2022) ESG scores ranging from 14 to 81 was analysed using (3.10). The results – shown in Figure 4.3 – display some important features.

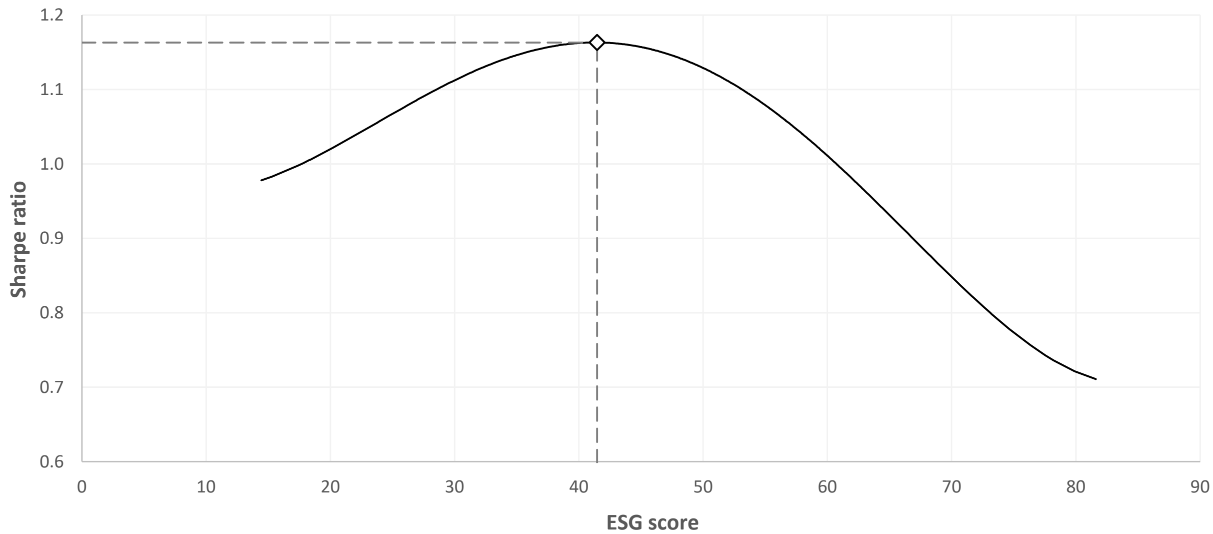


Figure 4.3: Sharpe ratio as a function of ESG score for a portfolio of 30 South African stocks. **Source**: Author calculations.

The optimal Sharpe ratio for such a stylised portfolio occurs at an ESG score *which is not the maximum*. While construction of higher ($\sim 50 - 80$) ESG-scored portfolios is possible (heavier weighting in higher-rated ESG score stocks), investment in these would not generate an optimal risk-adjusted return. The same is true for lower ($\sim 10 - 40$) ESG-scored portfolios (higher weighting in lower-rated ESG score stocks): such portfolios would generate sub-optimal performance. Both higher and lower ESG-scored portfolios are thus penalised in terms of risk-adjusted return performance.

Non-optimal Sharpe ratios for low ESG-scored portfolios are explained by their generally higher volatility and lower returns (Sikochi & Serafeim, 2021). Investors have begun to shun companies with poor environmental records, poor management and toxic corporate cultures resulting in poor return performance, and scandals, even if arising in different companies, tend to amplify negative public perceptions of already poorly-rated firms, resulting in higher volatilities (Mobius & Ali, 2021).

Non-optimal Sharpe ratios for high ESG-scored portfolios require a more nuanced explanation. At this stage, however, a lack of relevant data and noisy samples prevents more than heuristic justification. It is possible that, broadly speaking, high ESG-scored companies are willing to accept lower profits in the interests of protecting the environment, improving working conditions and adhering to good governance. Note that this does not imply they are willing to forego *all* profits, rather that profits benefit the employees and community (rather than the company only) more so than lower ESG rated firms. Lower profits lead to lower returns which leads to lower Sharpe ratios. For the moment at least, then, ESG investors must decide between maximal ESG rating portfolios (and accept the associated sub-optimal portfolio performance) and maximal risk-adjusted returns (and accept the associated reduction in the portfolio's ESG score).

As average portfolio risk decreases, the Sharpe ratio versus ESG score graph flattens (less variation in attainable Sharpe ratios over the range of ESG scores). In addition, as portfolio risk decreases, the locus of the optimal Sharpe ratio versus ESG moves down (decreasing Sharpe ratio) and to the right (increasing ESG) as shown in Figure 4.4.

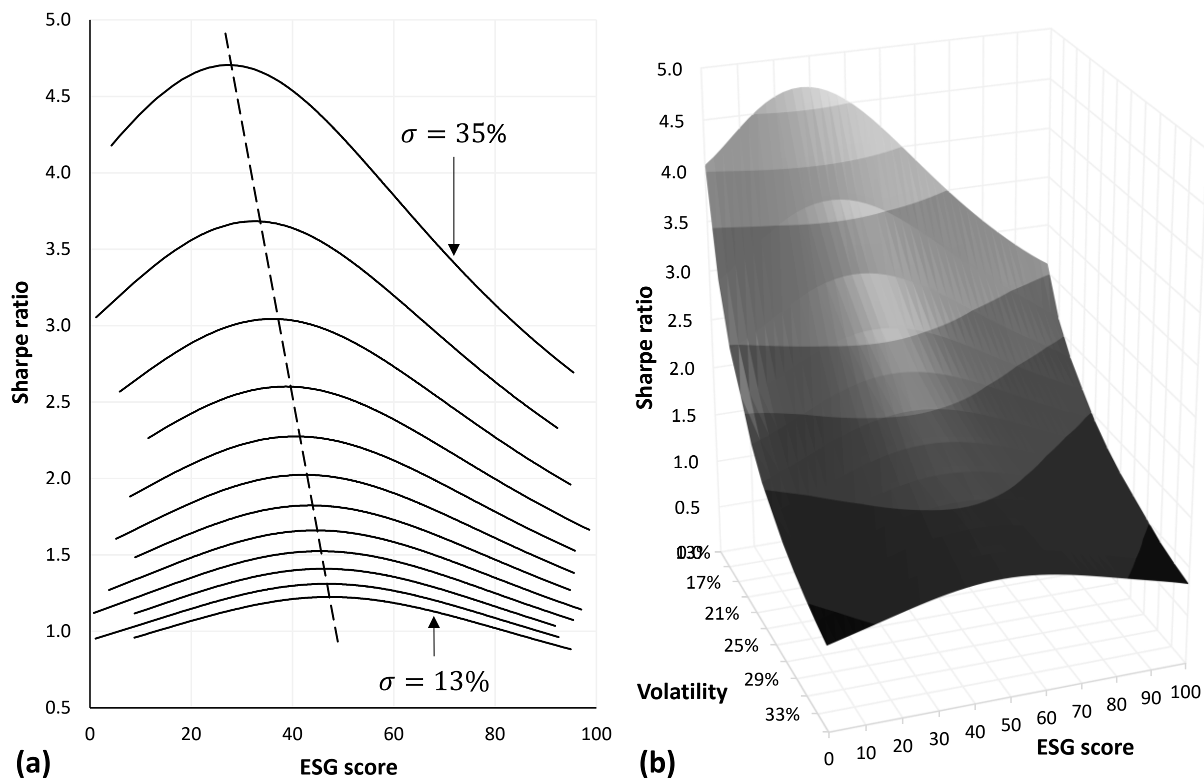


Figure 4.4: Sharpe ratio versus ESG score as a function of volatility (increasing from the upper-most to lowest curve) in (a) two and (b) three dimensions.

Source: Author calculations.

It is not obvious why the locus of the optimal Sharpe ratio/ESG score – as a function of portfolio volatility – should behave in this way. The results indicate that, unsurprisingly, portfolios with higher volatilities in general have lower ESG scores, but they also show that high volatility portfolios can also generate generally higher Sharpe ratios (all else being equal). It is possible this could be an artefact of the risk/return relationship like that observed in option pricing (increases in volatility precipitate higher option prices because the option has a higher likelihood of exercise): higher volatility ESG portfolios generate higher Sharpe ratios as they may generate higher returns. This possibility requires deeper interrogation when more data become available.

Using portfolio constituent weights from (3.16), the ESG efficient frontier may be determined. Similar in shape to the "global" efficient frontier, the ESG efficient frontier is generally characterised, nevertheless, by lower returns and higher risk, though variations are possible (Figure 4.5). The global efficient portfolio here is constructed using the Markowitz (1952) efficient asset allocation framework and the stocks which constitute the Johannesburg Stock Exchange's all share index (the ALSI40) using data which span the period 2016 and 2020 (i.e., pre COVID).

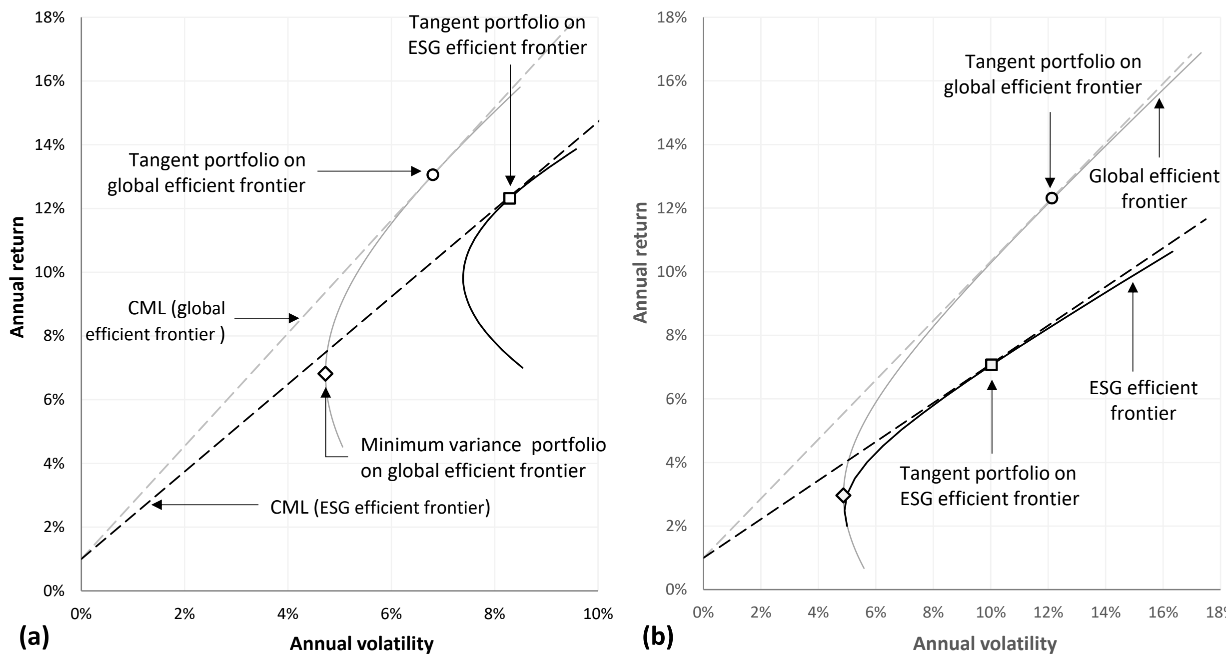


Figure 4.5: Global and ESG efficient frontiers with associated CMLs, minimum variance portfolios and tangent (optimal) portfolios. In (a) optimal portfolios have similar return levels but the ESG portfolio has higher volatility (lower Sharpe ratio) and in (b) optimal portfolios have similar risk levels, but the ESG portfolio has lower returns (again, a lower Sharpe ratio).

Source: Author calculations.

Empirical evidence shows that as portfolio ESG scores increase (all else equal) returns deteriorate and risk (volatility) increases. Examining country-specific portfolios comprising the ESG-rated companies in the sample, this was indeed found to be the case: the ESG efficient frontier moves southeast (down and to the right) away from the global efficient portfolio (in each case comprising most – or all – of the stocks which constitute the country's principal stock exchange index). These shifts are illustrated in Figure 4.6(a). In all cases, these were again constructed using the standard Markowitz (1952) efficient asset allocation framework. Statistical results of tests to compare mean returns and variances (of ESG portfolios versus standard maximal Sharpe Ratio (optimal) portfolios) are given in Table 4.1.

Figure 4.6(b) shows a summary of the results of these tests using the South African portfolios described earlier over a period spanning over a decade of ESG scoring. For clarity, only ESG efficient frontiers as at 2009, 2013, 2016 and 2020 are presented along with the global efficient frontier as it stood in 2020 using two prior years, in each case, of historical return data. The global efficient frontier has remained relatively static over these years – hence the decision to display only the latest (2020) frontier, again for the sake of clarity. Combining these observations with those displayed in Figures 4.1(a) and 4.2 (i.e., a monotonically increasing ESG score), it is evident that the ESG efficient frontier is approaching the global efficient frontier, and the locus of the optimal ESG portfolio is northwest – i.e., up and to the left, edging ever closer to the global optimal portfolio over time (the ESG score for this South African portfolio increased over 2009 – 2020 from 50 to 60). These observations show statistically significant increases in returns and statistically significant reductions in risk over time (Table 4.1). Similar results for all emerging economies in the sample were obtained.

Table 4.1: t statistics for comparison of variances and return means. p values of 1%, 5% and 10% are indicated by ***, ** and * respectively.

	Comparison of variances	**Comparison of means (returns)**
	F	t
Egypt	4.46***	2.99***
Kuwait	2.76**	2.99***
Qatar	5.11***	2.40**
Saudi Arabia	4.35***	2.81***

South Africa	3.41**	3.20***
UAE	4.37***	1.98*
Turkey	3.93***	4.01***
Czech Republic	1.89*	4.20***
Greece	4.67***	4.67***
Poland	3.78***	3.96***
Chile	4.97***	3.44***
Brazil	2.32*	4.33***
Colombia	4.07***	1.32*
Mexico	3.31**	2.42**
Peru	4.66***	2.35**
Cayman Islands	3.08**	2.68**
China	5.39***	2.46**
Hong Kong	4.95***	4.82***
India	3.27**	2.69**
Pakistan	3.43**	2.75***
Russia	4.92***	2.46**
Indonesia	4.33***	2.17**
Malaysia	4.93***	3.07***
Philippines	2.53**	1.00*
Singapore	3.74***	2.33**
South Korea	4.61***	3.33***
Taiwan	3.09**	4.00***
Thailand	4.35***	2.82***

4.2 CLIMATE CHANGE IMPACT ON CREDIT RISK

The GBM approach was used to simulate 10 000 potential equity price scenarios, weekly, over ten years. Figure 4.7 shows a 3D view of the results of these simulations. At each timestep, the mean and standard deviation of the distribution of possible share prices are used to plot the log normal distribution of outcomes. A shock (in this example a -40% share price shock) is then introduced at time t (in this example halfway through the 10-year simulation on 1-Jan-28). Prices after physical shocks have increased volatilities while those for transition shocks do not.

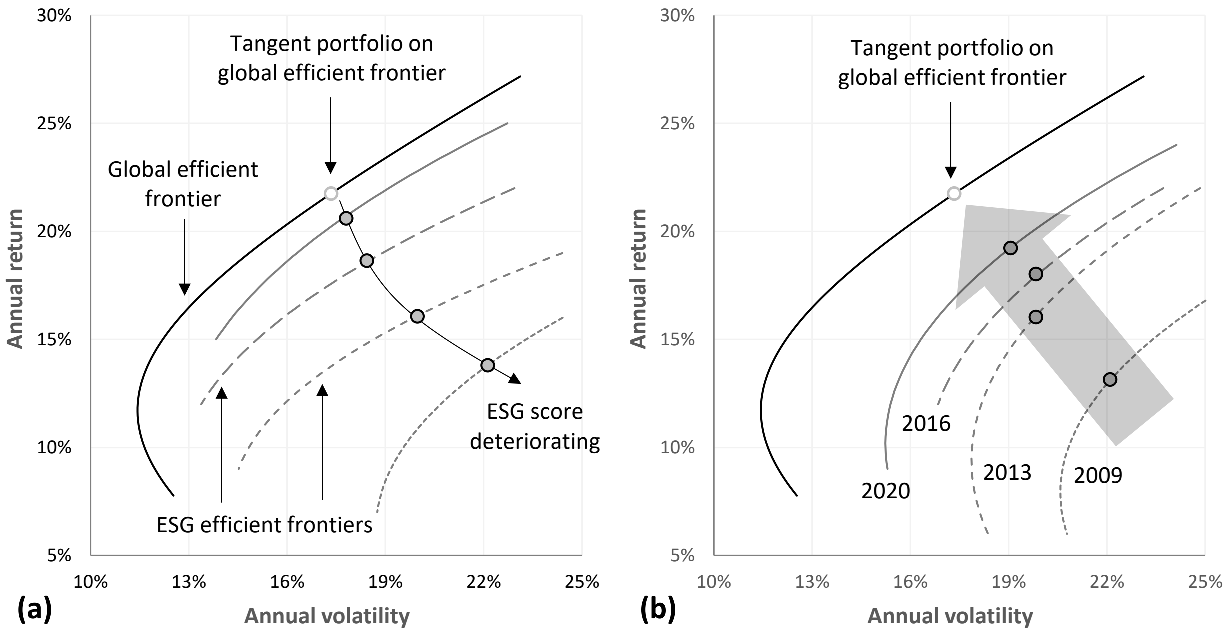


Figure 4.6: Return-risk loci for the global efficient frontier score and ESG-constrained frontiers as a function of ESG scores; (a) as the ESG score deteriorates the maximal tangent portfolio moves down and right (southeast) i.e., lower returns and higher risk and (b) time evolution of ESG-constrained efficient frontiers for South African portfolios. ESG monotonically increases over the period from 50 to 60. Grey arrow indicates the direction of improving ESG scores and their effect on the ESG efficient frontier's tangent portfolio.

Source: Author calculations.

Scenarios involving several shocks were also investigated. In Figure 4.8, these were introduced at two-year intervals since the start (1-Jan-23) of the simulations, but frequencies and severities can be altered to suit practitioner expectations.

Outputs (average share prices and equity volatilities) were then used to assess DDs using the KMV model and (3.16) for various shock severities, shock frequencies and applied to different credit grades. A 40% equity price shock, for example, is expected to have a considerably greater impact on a CCC-rated (high PD) credit than on a AAA-rated (low PD) credit. This turns out to be the case, with average uncertainty ranges being roughly equal as shown in Figure 4.9. For the results shown in Figure 4.9, PDs averaged over the period 1920 – 2020 from associated credit ratings were sourced from S&P Global Ratings (2021).

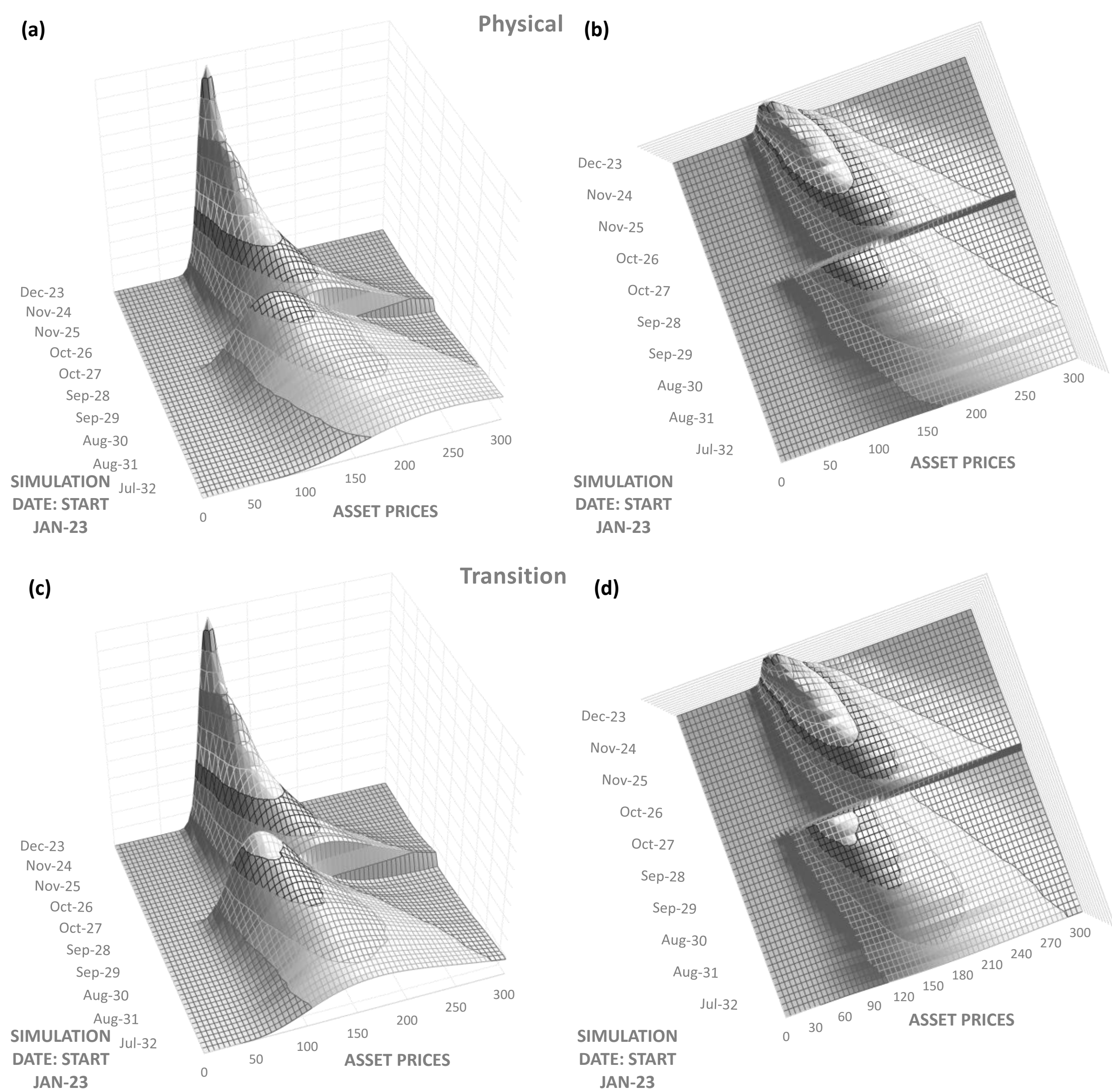


Figure 4.7: Simulated lognormal distributions (side and plan view) of share prices for a 40% share price shock occurring halfway through a ten-year simulation cycle, due to (a) a physical climate risk event and (b) a transition climate risk event.

Source: Author's calculations.

Increases in PDs for highly rated credit are negligible, but increase in severity up to ≈ 4 % for poorest rated credits. Climate change impacts on PDs are non-negligible and can be severe.

Figure 4.10 shows the time decay of a 60% climate change shock on the implied PD of an A- credit with average unshocked PD of ∼ 1% (derived from DDs). The shock introduces a steep fourfold increase in PD, and if there are *no subsequent shocks*, the PD recovers, *ceteris paribus*, roughly exponentially to former PD levels within five years. This is by design a stylistic example, subject to the user's inputs and opinions on volatilities, and both the frequency and the severity of the applied shocks, but it does give some indiciation of how PDs may change with climate-related events.

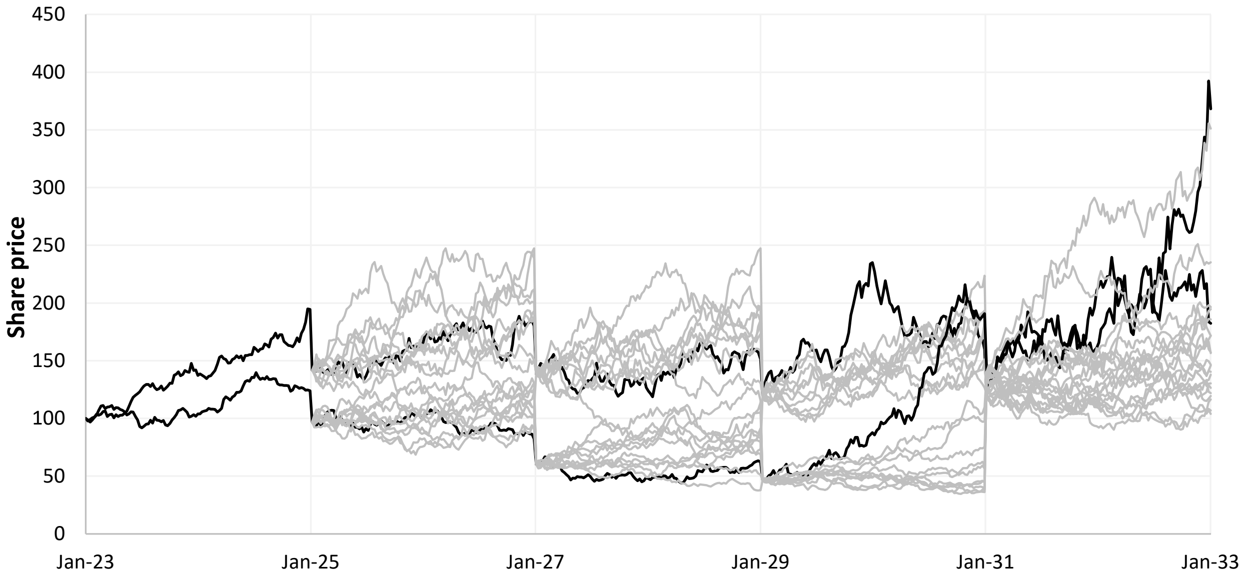


Figure 4.8: Simulated share prices for 40% share price shocks occurring at two-year intervals through a ten-year simulation cycle, due to physical climate risk events.

Source: Author's calculations.

If mutliple climate-event shocks – even of mild (20%) severity – are adminstered at a frequency of one year or less, the firm invariably defaults. The share price is unable to recover no matter the price drift or post-shock equity volatility and the firm defaults. This scenario speaks to consequences for a future in which climate related shocks arrive with increasing frequency, regardless of the shock's severity.

The outcome of the analysis is shown in Figure 4.11. The scaling factor, which should be applied to unshocked PDs (z-axis) has been plotted as a function of shock size and original PD to which the climate-related shock has been applied. As expected, the scaling factor increases as a function of both parameters (shock severity and original, unshocked PD) for both physical and transition climate events. Such a calibration can be applied to a firm's obligors to assess forward looking PDs, dependent on climate shocks.

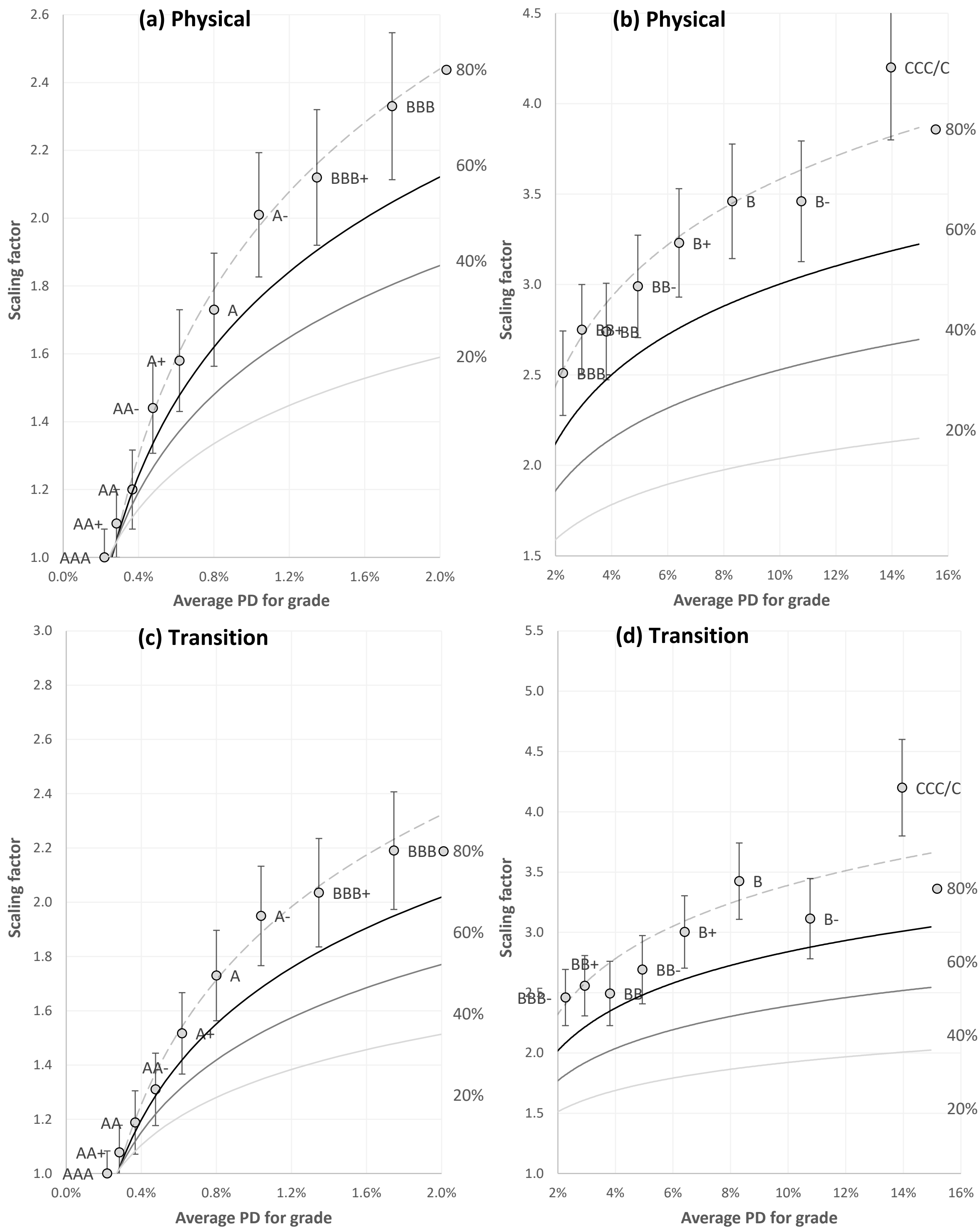


Figure 4.9: Scaling factor increase in PD for $\mathbf{-20}\%$, $\mathbf{-40}\%$, $\mathbf{-60}\%$ and $\mathbf{-80}\%$ equity price shocks for (a) a physical climate event for credit grades AAA through BBB, (b) a physical climate event for credit grades BBB- through CCC/C, (c) a transition climate event for credit grades AAA through BBB and (d) a transition climate event for credit grades BBB- through CCC/C.

Source: Authors' calculations.

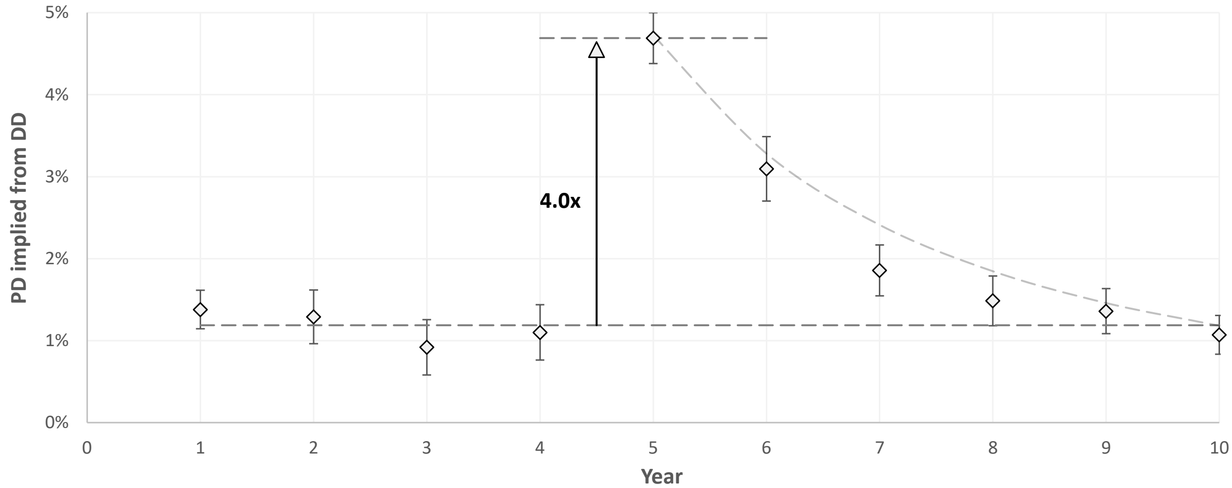


Figure 4.10: Time decay of a 60% climate change shock on the implied PD of an A- credit.

Source: Author's calculations.

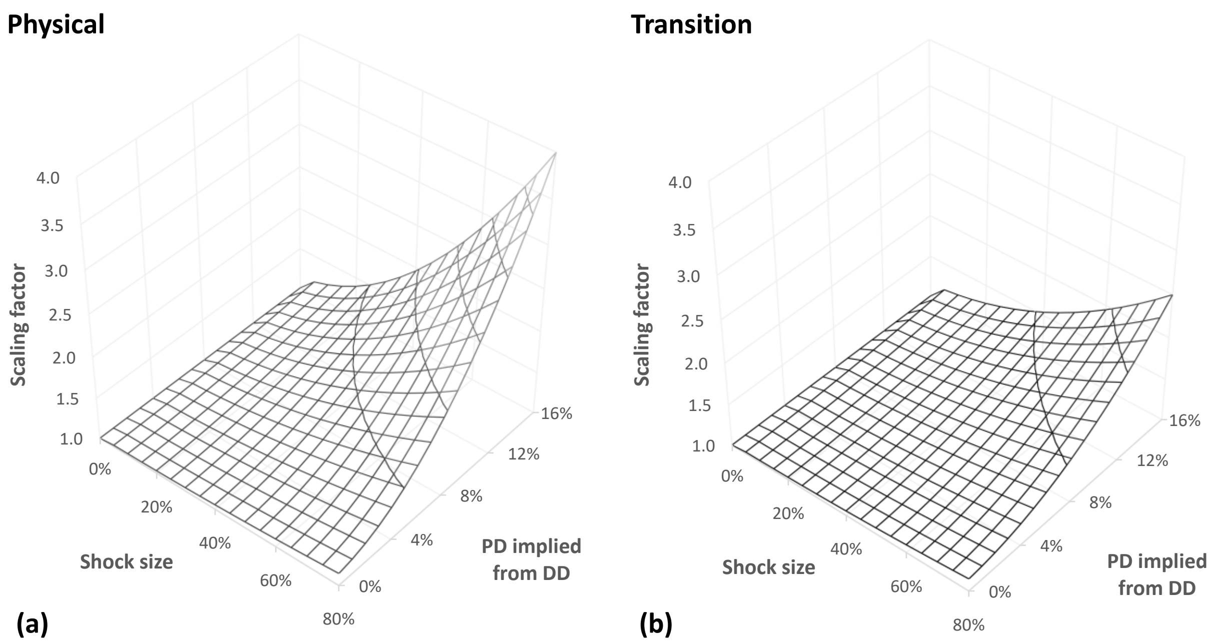


Figure 4.11: Scaling factor to be applied to unshocked obligor PDs for (a) physical and (b) transition related climate events as a function of shock size and unshocked PD. Again, note the same vertical scale for comparison.

Source: Author's calculations.

5. CONCLUSIONS, LIMITATIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 ESG FRONTIER

5.1.1 Conclusions

The importance of ESG criteria has increased significantly and cannot be overlooked anymore. What used to be associated with militant activists is now a mainstream concern. The widespread adoption of ESG quantification is a significant development because it is impossible to manage what is not measured. ESG factors are now analysed and reported in financial statements, and investors avoid companies that engage in irresponsible behavior. Asset managers must also adapt to these developments and adjust portfolio structures accordingly. However, the absence of a well-established and robust mathematical framework has made this challenging, if not impossible.

The adoption of new asset allocation techniques, which are inspired by the well-established Markowitz (1952) efficient portfolio framework, is a positive development given the increasing importance of ESG criteria. However, despite its potential benefits, these techniques have been slow to gain acceptance and implementation. As with any new approach to address evolving problems, it requires years of data to demonstrate its reliability and robustness. Although efforts to gather data are underway in developing markets, emerging markets face even greater challenges due to limited data availability and a later start. This work aims to bridge this gap by adapting innovative approaches and applying them to global emerging market data, which has not been done before.

Subsequent studies should examine additional ESG metrics and their continuing influence on portfolio effectiveness and risk-adjusted return optimality. Conducting a thorough comparison of the findings presented in this study and those obtained from developed markets would also be a valuable addition to the ongoing effort to generate profits while upholding responsibility to the environment, employees, and society at large.

The findings indicate that ESG scores in emerging markets have been gradually improving since their introduction in 2007, albeit at a slow pace. Based on this growth rate, it is projected that emerging markets will achieve similar ESG scores to developed nations by the late 2030s, although various factors could impact this progress. Currently (2023), portfolios with the highest ESG scores do not necessarily yield the optimal risk-adjusted returns. There is an optimal Sharpe ratio portfolio that corresponds to a specific ESG score, and ESG scores both on the high and low ends result in lower Sharpe ratio portfolios. The observation that lower ESG scores lead to lower Sharpe ratios seems intuitive, but the decreasing Sharpe ratios for increasing ESG scores are more complex and require further investigation. This trend could be due to the fact that firms with very high ESG scores invest their profits in corporate working conditions and environmental projects, rather than maximising their bottom lines. While this approach is beneficial for the planet and their employees, such firms have not yet been able to generate superior returns compared to their less responsible counterparts. However, this trend is gradually changing over time, and the distinction between global efficient portfolios (which ignore ESG scores) and ESG-efficient portfolios is constantly narrowing.

5.1.2 Limitations

ESG studies, which analyse environmental, social, and governance factors in investments, have become increasingly popular in recent years. However, like any analytical approach, ESG studies also have some limitations, including:

Lack of standardised metrics: There is currently no standardised set of metrics for measuring ESG factors, and different analysts and researchers may use different approaches. This can lead to inconsistent findings and make it difficult to compare companies or investments.

Limited historical data: ESG studies are a relatively new field, and there are limited historical data available to analyse. This can make it difficult to determine the long-term impact of ESG factors on investments.

Limited data availability: ESG data are not always readily available or transparent, particularly for smaller or privately held companies. This can make it difficult to accurately assess their ESG performance.

Subjectivity: ESG assessments are often based on subjective judgments and interpretations, which can lead to differences in opinion among analysts and researchers.

Incomplete coverage: ESG studies may not consider all relevant factors or may focus on only certain aspects of a company's ESG performance, which can lead to incomplete or biased conclusions.

Lack of correlation with financial performance: While many ESG proponents argue that ESG factors can have a positive impact on financial performance, the evidence of this correlation is mixed. Some studies have found a positive relationship, while others have not.

Overall, while ESG studies can provide valuable insights into a company's environmental, social, and governance performance, investors should be aware of these limitations and consider them when making investment decisions.

5.1.3 Future research

ESG-related investment research can help investors to make informed decisions about the environmental, social, and governance factors associated with their investments. Suggestions for conducting ESG-related investment research include:

Define investment goals and objectives: Before conducting ESG-related investment research, investors should define their investment goals and objectives. This will help to guide their research and ensure that they are focusing on the factors that are most important to them.

Identify relevant ESG factors: Investors should identify the ESG factors that are most relevant to their investment goals and objectives. This may include factors such as carbon emissions, employee turnover, executive compensation, and labor standards, among others.

Use multiple sources of data: Investors should use multiple sources of data to gather information about ESG factors. This may include company reports, third-party ESG ratings, industry reports, and news articles, among others. Using multiple sources can help to ensure that the information is accurate and reliable.

Consider the materiality of ESG factors: Not all ESG factors are equally material to every company or investment. Investors should consider the materiality of each ESG factor to the specific investment and industry. This will help to ensure that they are focusing on the factors that are most likely to impact investment performance.

Analyse ESG trends over time: Investors should analyse ESG trends over time to identify potential risks and opportunities. This may include analysing changes in ESG factors over time, as well as changes in regulations and market trends.

Engage with companies on ESG issues: Investors should engage with companies on ESG issues, including discussing the company's ESG policies and practices and encouraging the adoption of best practices. This can help to improve the company's ESG performance and reduce potential risks associated with ESG factors.

By following these suggestions, investors can conduct effective ESG-related investment research, helping to identify investment opportunities that align with their values and reduce potential risks associated with ESG factors.

5.2 CLIMATE CHANGE IMPACT ON CREDIT RISK

5.2.1 Conclusions

The assessment of credit quality degradation due to climate-related impacts, whether physical or transitional, relies on quantification and calibration of inputs, which are inherently subjective and must be determined by the user. Each obligor has unique share price drifts and volatilities, and shock scenarios vary in type, severity, and frequency. However, this subjectivity provides significant flexibility. As more climate-related events are added to the literature and global databases, specific events will eventually be linked to specific shock sizes. For instance, floods might result in a physical shock of 32%, while a policy announcement of a carbon tax increase might result in a transition shock of 18%. In this scenario, the approach outlined in this article would become less subjective, as only the event type needs to be identified.

The outcomes of this study would be advantageous to all market participants who adhere to IFRS-9 regulations for assessing future credit quality of obligors. In addition, loan pricing, which is based on obligor PDs, and regulatory capital calculations that necessitate knowledge of PDs at various maturities, would benefit from these results.

5.2.2 Limitations

The KMV model has some limitations, which are common to the model. It requires subjective estimation of some input parameters and assumes that asset returns follow a normal distribution. It also does not differentiate between bonds of different seniority, collateral, covenants, or convertibility. For private (unlisted) firms, their expected default frequencies can only be calculated by applying some comparability analysis based on accounting information. Additionally, until an objective database is established that isolates the relevant frequency and severity of different climate-related events, these inputs will remain subjective and based on the knowledge of subject matter experts or experienced economists. Therefore, some degree of caution should be applied, and error bars reflecting the inherent uncertainty associated with this analysis should be observed.

5.2.3 Future research

Climate change can have a variety of impacts on credit risk, including physical risks such as property damage and business interruption, as well as transition risks such as changes in regulations and market shifts. Suggestions to address these impacts are:

Develop climate risk management strategies: Financial institutions should develop climate risk management strategies that incorporate climate-related risks into their credit risk assessments. This may include developing climate risk scenarios and stress testing to evaluate the potential impact of different climate scenarios on credit risk.

Incorporate climate data into credit risk analysis: Financial institutions should incorporate climate data and other relevant ESG factors into their credit risk analysis. This may include data on the physical risks of climate change, such as the potential for flooding or wildfires, as well as data on the transition risks associated with the shift to a low-carbon economy.

Monitor and manage exposure to high-risk sectors: Financial institutions should monitor and manage their exposure to high-risk sectors that are particularly vulnerable to climate change, such as agriculture, real estate, and energy. This may involve adjusting credit terms, raising capital requirements, or reducing exposure to high-risk sectors altogether.

Engage with borrowers on climate risk: Financial institutions should engage with their borrowers on climate risk, including discussing the potential impact of climate change on their businesses and encouraging the adoption of climate risk mitigation strategies. This can help to reduce the potential impact of climate risk on credit risk.

Collaborate with other stakeholders: Financial institutions should collaborate with other stakeholders, such as regulators, policymakers, and other financial institutions, to share best practices and develop industry-wide standards for managing climate risk. This can help to ensure a consistent approach to climate risk management across the financial sector.

Linking particular climate events to credit quality deterioration as additional data become accessible. While it may take some time for comprehensive databases outlining these connections to emerge, become prevalent, and be widely adopted, by taking these steps, financial institutions can better understand and manage the impact of climate change on credit risk, helping to mitigate the potential financial impact of climate-related events.

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