SCHOOL OF ECONOMICS AND FINANCE
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Are climate risks priced by environmentally sustainable rated share portfolios?

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Abstract

The conversation on climate change has gained momentum in the last few years sparking investor interest in understanding the broad impact of climate change risk on the overall financial system. To further develop this theory, this research sort to determine if climate risks are priced by Environmentally Sustainable rated share portfolios. The results found that there is price impact as most variables where statistically significant across BRIC countries apart from South Africa. These results are not surprising as they align with other similar studies conducted for other asset classes like real estate. These results were generated by regressing environmentally sustainable rated share portfolio abnormal returns against Temperature, Climate Change Policy and Green Technological Adaptability Shifts as proxies for climate risks. Ordinary Least Squares methodology (OLS) and Time-Varying Parameter regressions (VPR) models are used over a 14-year period from 2006 to coincide with the launch of the United Nations Principle for Responsible Investing, in the same year. Intuitively these results are not surprising given that climate change is a hot topic and markets have since 2015, started to active shift capital into sustainable investments, to align with the climate action initiatives like the Paris Accord.

Declaration

I, Obey Chipetekure, declare that this research paper is my own work and that I have correctly acknowledged the work of others. It is submitted to fulfil the requirements for the degree of Master of Commerce in Finance at the University of the Witwatersrand, Johannesburg. I declare that this research paper has not been submitted for any other degree or examination in this or any other institution.

Obey Chipetekure

June 2022

Acknowledgements

There is a saying in Zulu that says “ongabongiyo uyaloya”, which can be loosely translated; “ingratitude is similar to witchcraft”, in this spirit of being grateful, I would like to thank my family, in particular, my parents for their unrelenting support on this journey towards mastery. I thank God for them. Further, this journey would have been a whole lot more difficult if I had not been supervised by my supportive and highly insightful Professor Yudhvir Seetharam. I have grown under his guidance both as my supervisor and as my course coordinator. Thank you, Professor may God bless, you and increase your territory.

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Definition of abbreviations, terms and symbols

APF	Adaptation Policy Framework developed by UNDP on behalf of the Global Environment Facility provides a structured approach to formulating and implementing adaptation strategies, policies and measures to ensure human development in the face of climate variability and change.
BRICS	Brazil, Russia, India, China, and South Africa
ESG	Economic, Social and Governance Considerations The Criteria used to identify the issues that companies must meet to show that they have integrated triple bottom line practices across their activities. The indicators are structured along the three broad categories of Environment, Society and Governance and related sustainability concerns (JSE Limited, 2014)
FTSE/JSE RSI	The FTSE/JSE Responsible Investment Index Series represents South African companies meeting ESG (Environmental, Social, and Governance) criteria as defined by the FTSE ESG Model.
JSE	Johannesburg Stock Exchange
OLS	Ordinary Least Squares
VPR	Time Varying Parameter regressions

CHAPTER 1
INTRODUCTION

1.1 Background

The reality of climate change has evolved into a real threat to people's lives globally. In many parts of the world this is reflected in the increased volatility of extreme weather events. Between 1999 and 2018, about 495 000 people died worldwide and losses of US$ 3.54 trillion were incurred as a direct result of more than 12 000 extreme weather events (Global Climate Risk Index 2020). In its "Fifth Assessment Report" published in 2014, the Intergovernmental Panel on Climate Change (IPCC) has already predicted that risks associated with extreme events will continue to increase as the global mean temperature rises. This eventuality fosters a need for a comprehensive research program to assess and quantify the risks from climate change and the appropriate responses, to inform decision-making in the private and public sectors. These responses may, by and of themselves, add to the riskiness of doing business. The United Nations Development Programme – Global Environment Facility (UNDP-GEF), developed the Adaptation Policy Framework (APF) that gives a clear roadmap on climate risks. In their Technical Research 4: Assessing Current Climate Risks, it describes the major components of risk as hazard, probability and vulnerability and the consequences of an adverse event. Through planned adaptation, public sector adaptation may rely largely on science and government policy, and private sector adaptation relies on market forces, business models and regulation. Climate variables and their impact can be analysed and measured by several methods such as ranking in order of importance, identifying critical control points within relationships, and quantifying interactions through sensitivity analysis. Given the on-going debates which emphasise sustainable investment around current social, political, and environmental, investors are more aware of firms' environmental performance, more than the firms' social and governance responsibility. Hence, in this research a quantitative approach was adopted to measure if climate risks are priced in environmentally sustainable rated share portfolios. By using a sample of environmentally rated shares across Brazil, Russia, India, China, and South Africa (referred to as the BRICS countries), the research used temperature, government policy and technological shifts as proxies for climate risks. The results of this study may assist to see how the BRICS countries will behave as climate risks escalate in the future as they are forecasted to be the leading emerging group of the world. These results were generated by regressing environmentally sustainable rated share portfolio abnormal returns against Temperature, Policy and Technological Adaptability shifts, using Ordinary Least Squares methodology (OLS) and Time-Varying Parameter regressions (VPR) over a 14-year period from 2006 to coincide with the launch of the United Nations Principle for Responsible Investing in the same year. In this study we focused on how climate risks across the five emerging countries impact stock prices, seeing that all these economies are characterised by fast paced economic growth driven largely by using cheaper fossil fuels. The results found that there is price impact as most variables where statistically significant across BRIC countries with the exception of South Africa. These results are not surprising as they align with other similar studies conducted for other asset classes like real estate. The need for measuring the economic cost of rising temperature is now more dire, as calls for sustainable investing principles grows. Albeit it presents significant empirical challenges, given the direct consequences of global warming are only starting to manifest and therefore are hard to identify from the past output or income.

1.2 Research gap and objectives

1.2.1 Motivation of the study

With the on-going debates which emphasise sustainable investment around current social, political, and environmental, investors are more aware of firms' environmental performance, more than the firms' social and governance responsibility. As such, enhanced corporate disclosures are needed to facilitate investors' assessment of firms' environmental risk, pollution costs and contingent environmental liabilities. Regulatory bodies are making strides to provide more guidelines for firms to disclose the level of environmental footprints concerning environmental risks at the micro level. The impact on firm value of environmental risk can be approached from two different angles, one related to future cash-flows uncertainty, and the other related to the uncertainty of information. Chapple, Clarkson, and Gold, (2009) highlight that the expenses required to adhere to regulation and legislation, costs of cleaning up and lawsuits related to accidental spill and other uncontrollable events, and contingent environmental liabilities are the direct cause of uncertainty of future cash flows. As such, this study seeks to ascertain if these climate risks factors are already priced into the share prices especially environmentally sustainable stocks and to further test if these shares are only affected by these three climate risk factors, overall, the results seek to see if environmental factor-based investing can help to shield the investor from climatic risk exposures. The losses of US$ 3.54 trillion incurred between 1999 and 2018 as a direct result of more than 12 000 extreme weather events is a significant amount that has a financial implication on most capital markets. As such it is important to ascertain the degree to which risks are "priced" into investor portfolios. The ripple effect also affects future cash flows which are also affected by potential technology shifts in supply and demand value chains as firms adapt to climate risks. Apart from mitigation and adaptation, a major scientific report issued by thirteen U.S. federal agencies in November 2018 predicted that the potential damage from the consequences of climate change would knock as much as 14% off the size of the U.S. economy by century's end. It is therefore a key motivation for this study to ascertain the degree to which this potential value loss will be priced and potentially encourage the escalation of sustainable investing to avert this imminent loss.

1.2.2 Knowledge gap

With the significant risks of global warming for firm profits, capital markets, and household wealth, the area of climate risks has not received enough coverage, although it is growing. Cases of wavering commitments to the Paris Climate Agreement goals have been areas of concern showing a lack of commitment that prompted efforts to mobilise initiatives such as the Climate Finance Leadership Initiative and the September 2019 Principles for Responsible Banking. Even though questions such as pricing and hedging of risks, the formation of expectations, and financial innovations are natural ones for financial economists to tackle, little research has been published to date in top finance journals. The award of 2018's Nobel Prize in Economics to William Nordhaus for his work on integrated assessment models for climate change going back to the mid-1970s (for example, Nordhaus, 1977) reminds us of the missed research opportunity for financial economists to assess the risks associated with climate change as a global externality (Nordhaus, 2019). Bansal, Kiku and Ochoa (2016) cover the US market where they assert that "if rising temperature has a long-run impact on the aggregate economy (such that it increases future volatility or tail risk, or lowers growth), it should be reflected in current equity prices and the risk-return trade-off." Their empirical analysis shows that this is indeed the case, the long-run temperature elasticity of equity valuations is significantly negative and long-run temperature fluctuations in equity markets have a positive risk premium. This finding seems to hold in Hong, Li and Xu (2019) as they observe thirty-one countries with publicly traded food companies, which are ranked each year based on their long-term trends toward droughts. They found that poor trend ranking for a country forecasts relatively poor profit growth for food companies in that country. It also forecasts relatively poor food stock returns in that country. This return predictability is consistent with food stock prices underreacting to climate change risks. As regulations change, so do the costs of compliance and adaptation to wade off new technology shifts. As such, this approach is in line with the Institutional Investors Group on Climate Change (IIGCC), a syndicate of asset managers with over €37 trillion in assets under management as of June 2021, in a recent policy research argue that "risk associated with climate change needs to be better reflected in the price of financial assets to encourage a shift in capital allocation. Recent studies by Giglio *et al.*, 2015; Bansal *et al*. 2016; Hong *et al*. 2019; Daniel *et al*. 2016, are the only known empirical research on the impact of climate risks on asset prices. This is limited. This research represents an effort to add to this dearth of research on climate finance.

1.2.3 Research objective and question

The main objective of this study is to analyse the extent to which climate risks are priced in environmentally sustainable rated share portfolios.

1.2.4 Potential benefits

In the context of the American capital market, Bansal, Kiku and Ochoa (2019) find that equities reflect the risks in long run temperature fluctuations, while Hong, Li, and Xu (2018) observe a correlation between drought exposure and the eventual stock return's decline in the countries they study. Chen and Gao (2019) investigate the impact on asset prices in capital market by corporate climate risk. They observed traded U.S. electric companies, which had carbon dioxide emission rates reporting and found that climate risk is positively associated with cost of capital measures, more specifically priced into the implied cost of equity and the cost of debt. Wang, Yu, and Shen (2021) investigated the effect of online environmental news on green industry stocks. They found a significant negative relationship between media environmental attention and the stock returns of green industry companies. Environmental news had a significant impact on investor sentiment, which in turn played a mediating role in the process of affecting green industry stocks. Given that sustainable investing is growing, this research seeks to determine the impact of climate risks on portfolios that speak directly to that portfolio strategy, while observing this across the BRICS countries. Emerging market investors need to know if their ethical values will be compensated for by investing in environmentally sustainable rated share portfolios. This research seeks to use environmentally sustainable rated shares that encompass most of the green companies across the five emerging countries to add to the dearth in this area outside of the USA. This study will use climate risks proxies (temperature, environmental policy, and environmental technological shifts) to regress them against five emerging market environmentally (E) sustainable rated share portfolios over a 14-year period from 2006 to 2020. Tracking the responsiveness of environmental shares to varying changes in temperature, policy, and technology will give us an indication as to how these influence the company over time. This will assist investors to deploy capital accordingly to hedge against climate change risks, if there is a notable effect on stock prices that shows climate risks are being priced in by E rated portfolios.

1.2.5 Hypotheses testing

Primary Hypothesis

H_0: there is no climate risk effect on share price performance of environmentally sustainable rated shares portfolios

H_1: there is a climate risk effect on share price performance of environmentally sustainable rated shares portfolios.

1.3 Structure of the study

This research is structured in five chapters and will proceed as follows: **Chapter 2** reviews the literature on climate change and their risk, **Chapter 3** describes the data, variables, hypotheses and methodology of climate risk. **Chapter 4** shows the empirical results of climate risk. **Chapter 5** concludes.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The literature explores the pricing dynamics in relation to the broad topic of climate change as applicable to emerging economies. This chapter will discuss the evolution of climate change, followed by climate risks and measurement thereof. Relationships between climate risk and asset prices will also be explored.

2.2 Evolution of Climate Change

The post-World War II era saw significant economic industrialisation and standardisation such that by the 1950s a change in the state of the climate emerged. The rise of China is cited as the major contributor to this growth, which went from being the seventh-largest economy in 1997[1] to the second-largest economy in 2021. To put this into context, China now produces as much steel in a year as the entire world did in 1980[2], thereby making a significant impact on the environment. To measure this impact, scientists used statistical tests to observe changes in the mean, which was observed to be persistent for an extended period, typically decades or longer. Scientists posited that this change may have been due to heterogeneous processes or exogenous doing, or to recurring anthropogenic actions (mainly of environmental pollution and pollutants) originating in human activity in land use. The attendant results led to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and resulted in unprecedented extreme weather and climate events like draughts. (IPCC, 2007a). The Special Report on Managing the Risks of Extreme Events (SREX) illustration in Figure 1 below, gives an overview of the scientific literature on issues that range from the relationship between climate change and extreme weather and climate events (‘climate extremes’) to the implications of these events for society and sustainable development.

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[1] 1997 is the year Hong Kong was returned to China by the United Kingdom. Chinese growth expanded rapidly post 2001, when it joined the World Trade Organisation.

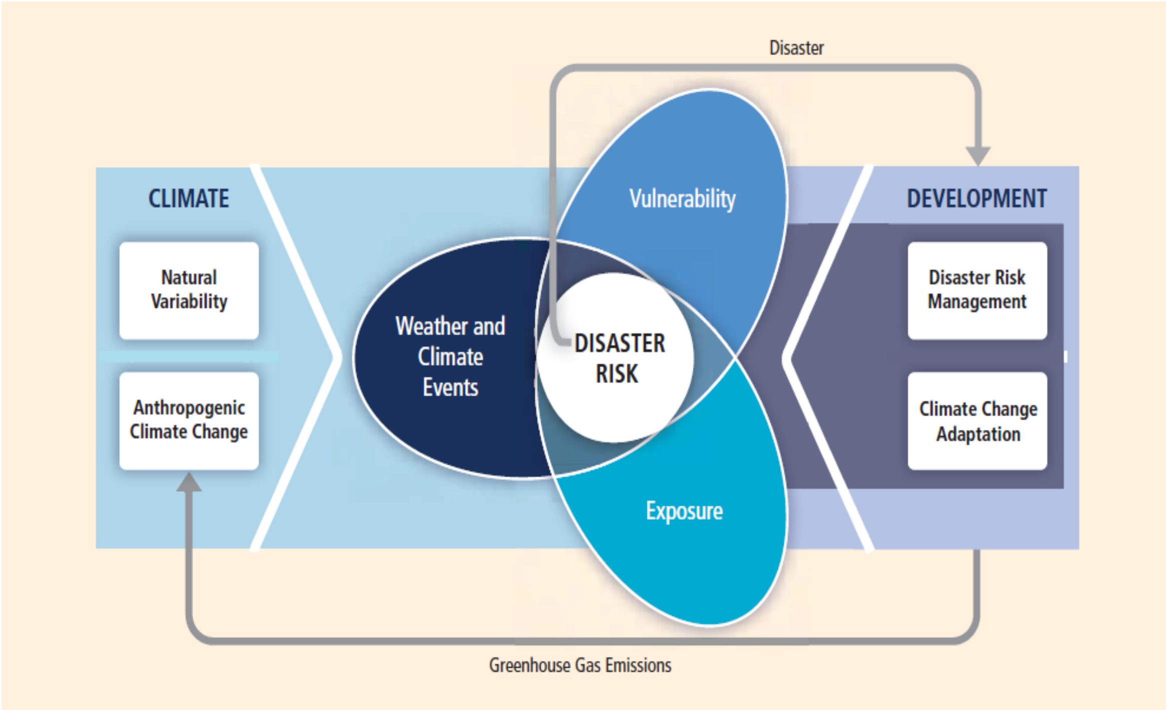

Figure 1: Illustration of the core concepts of Special Report on Managing the Risks of Extreme

The reality of climate change in many parts of the world is reflected in an increased volatility of extreme weather events. Between 1999 and 2018, about 495 000 people died worldwide and losses of US$ 3.54 trillion were incurred as a direct result of more than 12 000 extreme weather events (Global Climate Risk Index 2020). In its “Fifth Assessment Report” published in 2014, the Intergovernmental Panel on Climate Change (IPCC) has already predicted that risks associated with extreme events will continue to increase as the global mean temperature rises. It further reports that:

> *Economic, including insured, disaster losses associated with weather, climate, and geophysical events are higher in developed countries. Fatality rates and economic losses expressed as a proportion of gross domestic product (GDP) is higher in developing countries (high confidence). During the period from 1970 to 2008, over 95% of deaths from natural disasters occurred in developing countries. Middle-income countries with rapidly expanding asset bases have borne the largest burden. During the period from 2001 to 2006, losses amounted to about 1% of GDP for middle-income countries, while*

[2] Data from Statistical Yearbooks of the World Steel Association

> *this ratio has been about 0.3% of GDP for low-income countries and less than 0.1% of GDP for high-income countries, based on limited evidence. In small, exposed countries, particularly small island developing states, losses expressed as a percentage of GDP have been particularly high, exceeding 1% in many cases and 8% in the most extreme cases, averaged over both disaster and non-disaster years for the period from 1970 to 2006. (Intergovernmental Panel on Climate Change, IPCC 2014)*

A rare occurrence is seen among scientists reaching consensus on most things, yet they seem to agree that excessive carbon emissions contribute to global warming, as such are a concern to society and should be prioritised as it is shown to threaten human health, well-being, and economic productivity, as well as the world's biodiversity and natural ecosystems. Bansal *et. al*., (2016) and Daniel *et al.,* (2016) argue that there is compelling evidence for decisive action to reduce carbon emissions which are cited as the human induced cause for climate change.

The results of this study may assist to see how the BRICS countries in particular will behave as climate risks escalate in the future as they are forecasted to be the leading emerging group of the world. Given that most literature covers developed market economies as study that focused on the emerging markets to help understand the impact of climate change and its broader impact on modern society helps us formulate a view on the magnitude of future climate costs. These costs represent themselves as risks that need to be identified, before being quantified and managed.

2.3 Climate risks

Climate change culminates in climate risks which is a combination of the likelihood (probability of occurrence) and the consequences of an adverse event, such as climate hazard (Beer and Ziolkowski, 1995). According to the Adaptation Policy Framework (APF), major elements of risk are described as hazard, probability, and vulnerability. Climate risk can be assessed based on four approaches - a natural hazards-based approach, a vulnerability-based approach (biophysical or socio-economic), a policy-based approach (a new policy is tested for robustness to climate change) and the adaptive-capacity approach of climate-related risk.

A hazard is an event with the potential to cause harm. Examples of climate hazards include tropical cyclones, droughts, floods, or conditions leading to an outbreak of disease-causing organisms (plant, animal, or human). The element of probability simply refers to the likelihood of a hazard occurring. While vulnerability elements are the outcomes of climate hazards in terms of cost or any other value-based measure. Specific vulnerabilities include drought, flood, storm surge, and/or extreme temperatures. The optimum approach will be informed by a better knowledge of climate risks.

Some common events have extreme impacts, such as, hurricanes or tropical cyclones, they are referred to as extreme events because of the damage they cause, rather than through rarity of occurrence. Table 1 below shows a typology of extreme climate events from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) of varying types and their impact i.e., from simple to severe. The natural hazards-based approach is to fix a benchmark of hazard, such as a peak wind speed of 10ms-1, hurricane severity, or extreme temperature threshold of 35°C, then to see how that hazard affects vulnerability across space or time.

Table 1: Typology of climate extremes (based on Schneider and Sarukhan, 2001

Type	Description	Examples of Events	Typical method of characterisation
Simple	Individual local weather variables exceeding critical levels on a continuous scale	Heavy rainfall, high/low temperature, wind speed	Frequency/return period, sequence and/or duration of variable exceeding a critical level.
Complex	Severe weather associated with particular climatic phenomena, often requiring a critical combination of variables	Tropical cyclones, droughts, ice storms, ENSO-related events.	Frequency/return period, magnitude, duration of variable(s), exceeding a critical level, of impacts severity
Unique or Singular	A plausible future climatic state with potentially extreme large-scale or global outcomes	Collapse of major ice sheets, cessation of thermohaline circulation, major circulation changes	Probability of occurrence and magnitude of impact

Over and above the natural hazards, the expenses required to adhere to regulation and legislation, costs of cleaning up and lawsuits related to accidental spill and other uncontrollable events, and contingent environmental liability are the direct cause of uncertainty of future cash-flows (Hughes, 2000; Clarkson, Li & Richardson, 2004; Chapple, Clarkson, & Gold, 2009). At the Paris, climate conference held in December 2015[3], policy risk was sighted to being a policy priority for politicians and in international spaces such as the United Nations Framework Convention on Climate Change Conference where 195 countries signed a revised and ground breaking international climate deal. Countries agreed to make targeted efforts to reduce emissions by 2030 and some towards net zero by 2050 and limit warming to below 2 degrees Celsius. Climate policies may threaten cash flows in the short term were environmental regulation surrounding pollution increases the costs of operations, while also threatening profits in the long run when assets become stranded.

The study by Makololo and Seetharam (2020) explored the impact of economic policy uncertainty (EPU) among emerging market economies of the BRICS block in influencing firm performance with respect to financing decision in periods of uncertainty. And climate change does pose a condition of uncertainty. What they find is that an increase or decrease in EPU is determined by the way policymakers or investors act and the consequences of their decisions where EPU is deemed as a market characteristic that brings changes in prices and returns which requires investor attention to prevent negative issues. Zhang *et al.*, (2015) also came to the same conclusion that the way policy decisions are made and the implementation process, economic policies typically cause a large extent of uncertainty, which could impose insightful impacts on the financial market and companies' behaviours such as understating or overstating a decision that has been made. Cao *et al.,* (2013) concur with Zhang *et al.,* (2015) that policy uncertainty in business environments is caused by the time taken to implement new policies. It is worth noting though that the most affecting firms to policy risks or uncertainty are those with exposure to capital markets.

[3] http://ec.europa.eu/clima/policies/international/negotiations/paris/index en.htm

The trickledown effect of climate change beyond triggering policy shifts is its impact on business models. According to Tollefson (2016), and Pachauri *et al.*, (2014), world temperature averages are being surpassed with greater frequency than ever before with February 2020 by far being the warmest month on record, creating concern among scientists at NASA and NOAA[4]. This raised major concerns within communities as they became more conscious of the impact of global warming. The resultant pressure on firms has been growing for them to adopt their business processes to curb the carbonisation of the environment. The adaptation has technological cost implications, where failure to change has become a major risk to the going concern of many firms. Recently citizens have begun to take drastic actions against firms they deduce to be contrary to their community values. Recently in 2011 in Boulder, Colorado, where the community exercising their power of eminent domain, voted to authorise a takeover of Xcel Energy's power output capacity and distribution infrastructure by the municipality thereafter setting up a municipal run utility. These seemingly random political events bring into question assumptions' investors make regarding stable property rights as they can expose to the possibility of being stranded assets even without international climate policy (Jagannathan, Ravikumar & Sammon, 2017).

In 1996 according to a group of Science Policy Research Unit (SPRU) scientists the dominant "world view" considered technology inherently static; its extrapolation into the distant future inevitably led to resource depletion and environmental toxification. The newly emerging environmental movement also considered technology a major source of environmental degradation that would continue to generate unintended and unwanted side effects. Foray & Griibler (1997) these unintended consequences pose a threat to established business processes which some call disruption.

[4] CBS News March 17, 2016

2.4 Use of ESG portfolios in managing climate risks

With the rise in climate risks as shown above, investors have become more proactive in trying to deploy their hard-earned capital in ethical portfolios, such as those proxied by Environmental, Social and Governance (ESG) factors for example. The assets under management of professional investors who invest in ESG rated assets has grown from $13.3 trillion in 2012 to $39 trillion in July 2021[5]. While the investment mandate given to asset managers is profit maximisation, there is a growing call to ethical investing in ESG rated assets since the launch of the Principles for Responsible investment (PRI) in 2006 by the United Nations. Campaigns like NetZero2050 have seen even some corporate investors like BlackRock actively force boards to develop a compliance roadmap to keep them vested. Powers and Gunnemann (1969) made a call to high education institutions with endowment funds and other non-profit institutions to incorporate in their investment thesis a need for sustainable investment principles to reduce the social impact of corporate decisions from which these organisations earn a return of their endowment funds. Simon, Powers and Gunnemann (1972) suggested that institutions like Yale have taken the initiative in establishing an advisory committee in 1972 to monitor investor responsibility.

The 'E' in ESG has received the widest coverage as it speaks to more urgent concerns as world temperature averages are being surpassed with greater frequency than ever before. This has cash flow implications as already shared, which occur in the future. In most of the return generated value from 1926 to 2015 in the S&P 500 index, less than 30% of the average 10-year investment return was earned from dividends accrued over the ten years ex-post, along with capital gains being realised at the end of the 10 year period. These total returns are therefore dependent on investors' projections of the future (Jagannathan, Ravikumar & Sammon, 2017). It follows that a portfolio must therefore be future focused. As such one such future focused risk, Environmental concerns, could potentially place an investor's wealth at risk. To mitigate this risk, fund managers are allocating capital to firms that are well managed and take environmental, social and governance responsibility seriously (that is away from fossil fuels), ultimately reducing portfolio risk.

[5] https://www.iigcc.org/

Conversely, do fund managers estimate climate risk accurately? The impact of climate change risks on the general wider economy and more specifically on the capital markets, has sparked wide interest due and overall concerns. In 2017 and 2018 at the RFS Climate Finance Conference and at the Climate Risk Summit at the UN Foundation, the UN Secretary General, Ban Ki-Moon, remarked that ". . . investors need to know how the impacts of climate change can affect specific companies, sectors and financial markets as a whole," Ki-moon (2016). It is a common practice for investment managers to rate climate change risk exposures of corporations' based on their atmospheric greenhouse gas emissions (GHG), but as Hong *et al*. (2019) noted, ". . . climate change risks need not be so narrowly confined to carbon exposures". Climate risks pose vulnerabilities to production processes due to natural disasters which directly affect profits. As such all economic players are at risk not just the GHG emitters. This reality calls to question the fund managers' competency in correctly estimating these disastrous climate change risks in their portfolio mix. Given the economic significance of these funds to price setting in the market, this question requires an answer.

The implications of misestimation by presumably sophisticated investors of the disaster impact on firms and, the eventually trading in exposed firms based on this misestimation may adversely affect the proper incorporation of information into asset prices causing informational inefficiency on stock prices. Beyond adversely impacting fund returns, such stock price distortions, do affect the real economy through the inefficient allocation of capital (Subrahmanyam & Titman, 2001; Wurgler, 2000). The prominent thoughts on how an asset manager might inaccurately estimate the impact of a climatic disaster is drawn from academic finance and psychology literature which hypothesises that inaccurate estimation by a manager could potentially be driven by salience bias (Aloky, Kumarz & Wermers, 2020). Where salience bias is the propensity to over allocate probabilities based on current information which can be recalled easily (irrationally overweighting more readily available information). This bias sees an overestimation of the risk of salient events based on vividness, proximity, or emotional impact (Tversky & Kahneman, 1973).

In practise, fund managers exposed to a rare devastating climatic event tend to overweight the probability of such disasters in the future, and, conversely, underweight in their portfolios stocks recently impacted by these climatic events. By employing a difference-in-differences strategy and comparing the portfolio decisions of mutual funds situated within 100 miles of the headquarters of firms in the disaster zone (treatment group funds) to those located further away (control group funds), Alok, Kumar and Wermers (2020) find that managers within a major disaster region allocate less capital to disaster zone stocks than they do for those located far. This aversion is related to a salience bias rather than to superior information possessed by close managers, as such, it decreases over time and distance from the disaster. This approach can be detrimental to asset manager with respect to some salient disasters like hurricanes and tornadoes where a long-short strategy can exploit the overreaction to generate a significant adjusted return over the following 2 year period. The empirical research question that econometrically addresses climatic disaster lies in portfolios that capture exposure to climatic disaster like ESG or more specifically environmentally sustainable rated share portfolios.

2.5 Measuring climate variables

The economic activities of men have reached a scale where the global climate has been significantly affected. The climatic implications of these economic activities present themselves

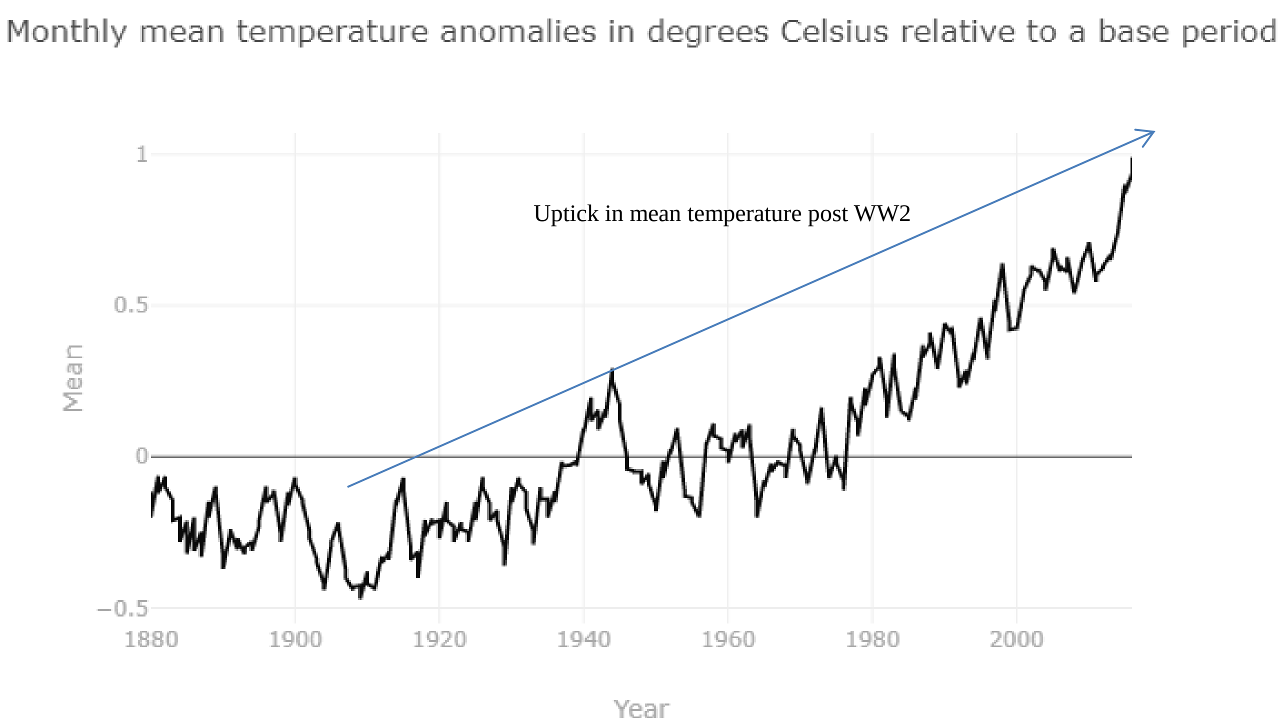

Figure 2: Global Temperature Time Series. Data are included from the GISS Surface Temperature (GISTEMP)

in carbon dioxide emissions. Combustion of fossil fuels leads to emissions of carbon dioxide into the atmosphere. Once in the atmosphere, the residence time appears to be very long, with approximately one-half of all industrial carbon dioxide still airborne. Based on the Special Report on managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), due to the selective absorption of radiation, the increased atmospheric concentration is thought to lead to increased surface temperatures as figure 2 above shows that the surface temperature has been increasing with a major spike in mean temperature beginning post the second world war when industrialisation was kicking off in the 1960s. The most careful study to date, Manabe and Wetherald (1975) predicted that a doubling of atmospheric concentrations of carbon dioxide would eventually lead to a global mean temperature increase of 3°C. The chart shows this may be breached as the spike post 1950s has been accelerating.

These temperature escalations are closely link to the Green House Gases (GHG) emissions growth that came with the industrial age. Now environmental economists are faced with trying to figure out the social cost of carbon (SCC) which is a new and important concept that has taken centre stage in economic and policy discussions about global warming. This term represents the economic cost caused by an additional ton of carbon dioxide emissions or its equivalent. It is calculated by optimizing the social welfare function (*W*) which yields a path of all variables. SCC is defined at time *t* as

$$\mathrm{SCC}\ (t) \equiv \partial \mathrm{W} \partial \mathrm{E}\ (t)\ /\ \partial \mathrm{W} \partial \mathrm{C}\ (t) \equiv \partial \mathrm{C}\ (t)\ /\ \partial \mathrm{E}\ (t) \qquad \text{Eq. 1}$$

Where the numerator is the marginal welfare impact of emissions at time *t*, and the denominator is the marginal welfare impact of a unit of aggregate consumption in period *t*; this gives the third term of equation 1, in which the SCC equals the economic impact of a unit of emissions in terms of *t*-period consumption as a numéraire. In actual calculations, discrete approximation is taken in equation 1 noting that the SCC is time-indexed because the marginal damage of emissions changes over time.

To circumvent the issues surrounding integrated assessment models that reference SCC, like the potential for highly skewed distributions of uncertain variables and potentially unbounded values of the SCC, Bansal *et al.*, (2016) use a temperature-augmented long-run risks (LRR-T) model built on the long-run risks framework of Bansal and Yaron (2004) and account for the interaction between climate change, economic growth, and risk. To account for the potentially severe consequences of global warming, the model features temperature-induced natural disasters in future output and growth. Since disasters are triggered when temperature breaches a threshold level (tipping point) and capture the idea of tail risk related to global warming as discussed in Pindyck (2012), temperature is therefore used in the LRR-T model. This approach is different from the standard integrated assessment (IAM) model, in which climate change is assumed to cause a deterministic loss in output. In the LRR-T model, temperature is a source of economic risk, where a persistent increase in temperature raises the likelihood of breaching the temperature tipping point and causing economic disasters.

Research by Choi, Gao, and Jiang (2019) used data sourced from a web search activity on Google Trends, which provides a Search Volume Index (SVI*)* of the search topic of "global warming." They downloaded the monthly SVI in each of the seventy-four locations from 2004 (when Google Trends began to provide data) to 2017. Using this data, they measured the public responsiveness to global warming if they lived in cities that had comparatively higher excess temperatures than other cities in the period under review. Da, Engelberg, and Gao (2011), in their research use aggregate search frequency in Google as a measure of attention for several reasons. First, Internet users commonly use a search engine to collect information, and Google continues to be the favourite. Indeed, as of February 2009, Google accounted for 72.1% of all search queries performed in the United States[6]. The search volume reported by Google is thus likely to be representative of the internet search behaviour of the general population. Second, and more critically, search is a revealed attention measure: if you search for a stock in Google, you are undoubtedly paying attention to it. Therefore, aggregate search frequency in Google is a direct and unambiguous measure of attention. Choi and Varian (2009) support this claim by providing evidence that search data can predict home sales, automotive sales, and tourism. Ginsberg et al. (2009) similarly find that search data for 45 terms related to influenza predicted

[6] Source: Hitwise (http://www.hitwise.com/press-center/hitwiseHS2004/google-searches-feb-09. php)

flu outbreaks 1 to 2 weeks before Centres for Disease Control and Prevention (CDC) reports. Similar trends are observed when the local excess temperature is high. In response investors tend to rebalance their portfolios based on the beliefs about global warming. They may sell stocks with higher climate correlations and buy stocks with lower climate correlations such that the later outperform the former. The Google Search Volume Index (SVI*)* is also applicable in measuring policy and technological shifts, as extreme weather increases the likelihood of politicians to speak, and firms increase activities aligned with the weather escalations. The timing is unusually high when weather is abnormal. Google makes the Search Volume Index (SVI) of search terms public via the product Google Trends (http://www.google.com/trends). The SVI is a weekly time-series average for a search term, which is the number of searches for that term scaled (Da, Engelberg & Gao, 2011).

Another approach is to build on measures of firms' environmental exposures produced by third-party ESG data providers. Indeed, there has been a growing interest in ESG investing among investors who are increasingly demanding assets that fulfil certain environmental ("E"), social ("S"), and governance ("G") criteria. Given this trend, measuring the ESG characteristics of firms has become an important task for investors, and firm level ESG scores are available from numerous providers that collect raw data gathered from sources such as firms' disclosures, SEC filings, and reports by governments or NGOs. The raw data is then translated into numerical ESG scores using proprietary algorithms. The study by Robert *et al.,* 2020 uses information on firm-level ESG scores from two leading data providers, MSCI and Sustainalytics. Both data providers construct various sub scores that evaluate firms on different aspects of their ESG performance. From these sub scores, they choose the broadest scores that plausibly proxy for firms' exposure to climate risk. It is important to note that the sub score receiving the most attention is the "E" environmental rating, and this aligns more with explaining climate risks.

Beyond the scope of traditional asset classes like stocks and bonds, investors are known to explore alternative investment products that have little to no correlation to hedge against equity market movements. The real estate market has been one of the firm contenders for investors' diversification approach. Even more so, here in South Africa, investment in infrastructure has gained momentum as far as pushing government to review the Regulation 28 policy to allow pension funds to deploy more capital towards infrastructure. In the valuation of real estate one notable source of risk comes from natural disasters, like floods, fires, and earthquakes. These risks are factored into observed real estate valuations which tend to be in the form of lower or higher insurance premiums. It follows then that an investor should be aware of the impact of climate change on real estate prices.

Conversely, Giglio *et al*. (2021) gives guidance on the appropriate discount rates to be used in valuing investments required for mitigating climate change to estimate the term structure of discount rates in real estate markets. The optimal policy response to climate change needs to be informed by quantifiable trade-offs between cost to remedy climate change and the potentially long-term benefits of meeting climate change emissions targets. It is therefore imperative to find an appropriate discount rate to give context to the present value of investments that pay off later. For context a policy that targets to reduce carbon emissions at a cost of US$4 billion to avoid future climatic damages with a face value of US$120 billion in 100 years from now, at a discount rate of 3%, will have a present value of US$6 billion. Given that the cost of US$4 billion is less than the present value of damages it is worth investing now to save US$2 billion. The reverse is also true where the discount rate is high, say at 5%, where we may see a negative premium than the cost of emissions now as we will not derive any benefit in trying to preserve the climate. Giglio *et al*. (2021) therefore provide insight into policy design by focusing on real estate to determine the term structure of discount rates that can help in measuring investments options that mitigate climate change abatements; given real estate long horizons are perfect for analysing climate change.

Earlier work on discount rates for climate change investments has been more theoretically inclined and/or inferential from realised returns of traded assets like private capital, equity, bonds and real estate. The case of the Dynamic Integrated Climate Economy (DICE) model by Nordhaus (2013) is most prominent, where a 4% discount rate is preferred as an estimate of the average rate of return on capital. This approach ignores the maturity and risk properties of these underlying traded assets, given asset pricing theory shows expected future cash flows discounts are driven by the state of the world in which they are realised.

2.5.1 OLS and VPR

In a non-time series context, we usually assume that the distribution of each e_t's is identical to and independent of the distribution of every other e_t. Such a process is called a "white noise" process. Under that assumption, OLS provides good estimates of a, b, and c. In the time series context, it is usually the case that there is some interdependence between the various e_t 's, so OLS may not be efficient (i.e., there may be other estimators that have smaller variance) for such models. In addition, the estimated confidence intervals of the parameters given by OLS may be optimistically small, and if one of the independent variables is a lagged dependent variable (i.e., $x_t = y_{t-1}$) then OLS may not be consistent. Even for very large samples, the OLS estimators may not converge to the true values of the coefficients (Beck, 1983).

Often researchers are interested in whether parameter estimates vary (in a discrete manner) over different time periods, either because they would like to believe that the results are time invariant or because they have theories that predict that results should vary systematically across various time periods. In many standard applications the specification of the alternative hypothesis is often straightforward; in the VPR case it is not. The most common alternative to be tested is the hypothesis that at least one parameter varies with time (Beck, 1983).

2.6 Relationships observed between climate risks and asset prices action

The resultant efforts employed by different measures of climate risks have shown a significant impact of the said risks on economic activity that has been reflected in asset prices. The study by Nordhaus (2013) on carbon emissions estimated social cost of carbon for the current time (2015) is \$18.6 per ton of CO_2 in 2005 US international prices with an expected SCC growth of 3% year-on-year until 2050. Estimates of the SCC are a critical ingredient in climate change policy.

They currently play two roles, first is they provide guidance as to the appropriate level of emissions controls or carbon pricing in policies to reduce emissions either at a national or at international level. And lastly, they are for rule making where countries do not have comprehensive policies covering all GHGs regulators might use the SCC in a calculation of social costs and benefits of policies involving energy or climate affecting decisions.

Bansal *et. al*., (2016) further posits that temperature risks affect aggregate wealth and asset valuations through the variation in expected growth rates and discount rates. A rise in temperature raises the marginal utility and lowers the current wealth to consumption ratio. Thus, temperature risks carry a positive premium, which is reflected in prices of forward-looking assets such as equities. In financial markets Choi, Gao, and Jiang (2019), find that stocks of carbon-heavy emitters underperform firms with low carbon footprint in excessively warm climate. Retail investors, unlike institutional investors, tend to vote with their wallets by selling carbon-heavy emitting firms in such weather. As such, return trends tend to be driven by investor sentiment towards the underlying asset rather than changes in the fundamentals of the asset. Jagannathan, Ravikumar, and Sammon (2017) finds that asset managers can reduce portfolio risk exposure by incorporating sustainable rated assets into their investment process as this can absorb sudden regulatory changes and shifts in consumer tastes, resulting in large asset price volatility which leave investors limited time to react. By incorporating ESG criteria in their investment strategy, money managers can tilt their holdings towards firms which are well prepared to deal with these changes, thereby managing exposure to these rare but potentially large risks.

Baldauf, Garlappi and Yannelis (2020) explored real estate to find out if house prices reflect belief differences about climate change. Real estate is positioned as the appropriate asset class to answer this question given its long-term holding period attribute which exposes it to long-run climate change risks. With the current homeownership rate of 63.6%[7], it is by far the most valuable asset for the majority of households. And the average household holds 40% of its assets

[7] U.S. Census Bureau 2017

in residential property, in compared to 30.5% invested in financial assets[8]. Further, real estate is a key component of the overall economy as it is an important source of household debt. They find that housing choice in an equilibrium model where agents derive utility from ownership in a neighbourhood of similar agents; prices show a variation in elasticities to climate risk. They find that houses perceived to be underwater in believer neighbourhoods sell at a discount relative to houses in denier neighbourhoods. Their results can be interpreted to mean that house prices show variability in beliefs about long-run climate change risks. These findings make intuitive sense as a believer neighbourhood would generally be hesitant to pay a premium for a home that they will potentially lose in the future than a believer who is open to paying a premium regardless of the potential threat to their asset. And these beliefs are reflected in the asset prices specifically, a 1-standard-deviation increase above the national mean in the percentage of climate change believers is associated with an approximate 7% decrease in house prices for homes projected to be underwater. Giglio *et al*. (2015) also find that when the fraction of property listings that mention climate change doubles, there is a 2% to 3% relative decline in the prices of properties that are in the flood zone compared to otherwise comparable properties in the same ZIP code that are not in a flood zone. This conclusion speaks to the idea that climate risks are incorporated in asset prices even in alternative asset markets were a wide range of controls including house characteristics, zoning restrictions, amenities, variation in climate-change awareness overtime, salience of flood risk, and house supply effects considerations are enforced.

Most notable studies mentioned above have covered developed markets and very little literature covers the emerging markets like BRICS countries in exploring the impact of climate risks on asset prices in these less developed markets relative to the US and Europe.

2.7 Summary of literature review

This chapter explored the pricing dynamics in relation to the broad topic of climate change as applicable to existing literature. It showed that given their increased severity and frequency,

8 SCF 2013

climate risks are more likely to cause sudden changes in regulations, technology, and consumer tastes. It introduced the evolution of climate change and the various climate risks and how they are measured. By using carbon emissions, temperature, policy, and adaptability proxies for measuring climate risk it showed how various literatures has previously analysed the varying relationships observed between climate risks and asset prices. The next chapter will discuss the research methodology explaining sampling and data collection.

CHAPTER 3
DATA AND METHODOLOGY

3.1 Introduction

As has been alluded to in the literature review, several methods are incorporated by authors in measuring climate risks studies. For this study, firms included in an Emerging Markets Climate Change Index, which is based on the MSCI Emerging Markets Index, its parent index, made up of large and mid-cap securities across 27 Emerging Markets (EM) countries are used. The index aims to represent the performance of an investment strategy that re-weights securities based upon the opportunities and risks associated with the transition to a lower carbon economy, while seeking to minimise exclusions from the parent index. These firms are regarded as well prepared to deal with sudden regulatory changes and shifts in consumer tastes, resulting in large asset price swings which leave investors limited time to react.

The MSCI Climate Change Indexes methodology broadly aims to categorise firms whose

Figure 3: MSCI Emerging Markets Climate Change Index Overview

business models promote a shift from fossil fuel based to a green model to reduce the investors' exposure to stranded assets and increase exposure to solution providers. With climate risks mainly related to the "E" rating which has received more emphasise lately, a filter of 13 key issues related to the E rating according to the MSCI Low Carbon Transition score and category to re-weight constituents of a parent index to increase exposure to companies participating in opportunities associated with transition and decrease exposure to companies exposed to risks associated with transition. The Indexes are rebalanced on a semi-annual basis, as of the close of the last business day of May and November, coinciding with the May and November semi-annual Index Review of the MSCI Global Investable Market Indexes. This study will use market-based measures, specifically index prices excluding dividends and climate risks proxies such as temperature, SVI outputs for policy and technological shifts. Section 3.2 looks at sampling, section 3.3 explores the data collection and methodological techniques, and section 3.4 will elaborate on the variables and then conclude the chapter.

3.1 Sampling

To determine the objectives, set out in this research, temperature data was sourced from the NASA Goddard Institute for Space Studies GISS Surface Temperature Analysis (GISTEMP) for each BRICS country. While the policy shifts data was collected from internet search activity on Google Trends, which provides a Search Volume Index (SVI) of the search topics of "environmental policy and climate policy". And an SVI for Technological changes search topics titled "green technology, eco-friendly technology". The daily SVIs are downloaded in each of the BRICS country from 2006 to 2020. We use topics instead of search terms because the former addresses misspellings and searches in different languages, as Google's algorithms can group different searches that have the same meaning under a single topic. Our idea follows Da, Engelberg, and Gao (2011), who use SVI of tickers to study investor attention.

The independent variable for each country will be environmentally sustainable rated shares based on the MSCI Low Carbon Transition score methodology which aims to represent the performance of an investment strategy that re-weights securities based upon the opportunities and risks associated with the transition to a lower carbon economy. The components used are shown on Figure 4 below for each of the emerging market countries. Only companies that meet these criteria will be included in the sample with a five equally and five value weighted portfolios formed for each of the five BRICS countries.

The share data will be collected from the Refinitiv database. The sample period is from January 2006 to December 2020 to capture the long-term effects of climate change risks on asset prices across different geographical locations given that abnormal temperatures require at least 10 years of data to calculate, the sample period will be a 14-year period. The sample group will be constituents of The MSCI Climate Change Index that meet the MSCI Low Carbon Transition score in Figure 4 below. The number of companies in the sample data is 1 276 for the above-mentioned years which are further filtered for BRICS countries making the total sampled companies 602. In total 10 portfolios are created with 5 equally weighted and 5 value weighted

Reduce Emissions	• Minimum 30% reduction in Greenhouse Gas (GHG) Intensity (Scope 1+2+3[1]) relative to the Reference Index • Potential emission intensity 30% lower • Neutral exposure to high impact sector[1] • Incentivize companies setting targets
Green Opportunities	• Increases weight in companies which see opportunities from climate transition • 3x category tilt score for companies in Solutions LCT Category (green companies) to the parent index
Decarbonization	• Annual decarbonization at 7% starting June 1st 2021 (base date)

Figure 4: MSCI Low Carbon Transition score

portfolios for each of the BRICS countries. The portfolios will be rebalanced annually with no overlaps to lower transaction costs. Further, to achieve the objective of this study, regressions will be run in R on sample data using the Ordinary Least Squares Regression (OLS) model. Thereafter the linear regression approach will be expanded to consider the Time-Varying Parameter regression (VPR) model in which the parameters vary systematically over time following the work of Beck (1983).

The sectors that are under observation vary across: Financials, Health Care, Consumer Goods, Basic Materials, Industrials, Consumer Services, Technology and Telecommunications, See figure 5 below.

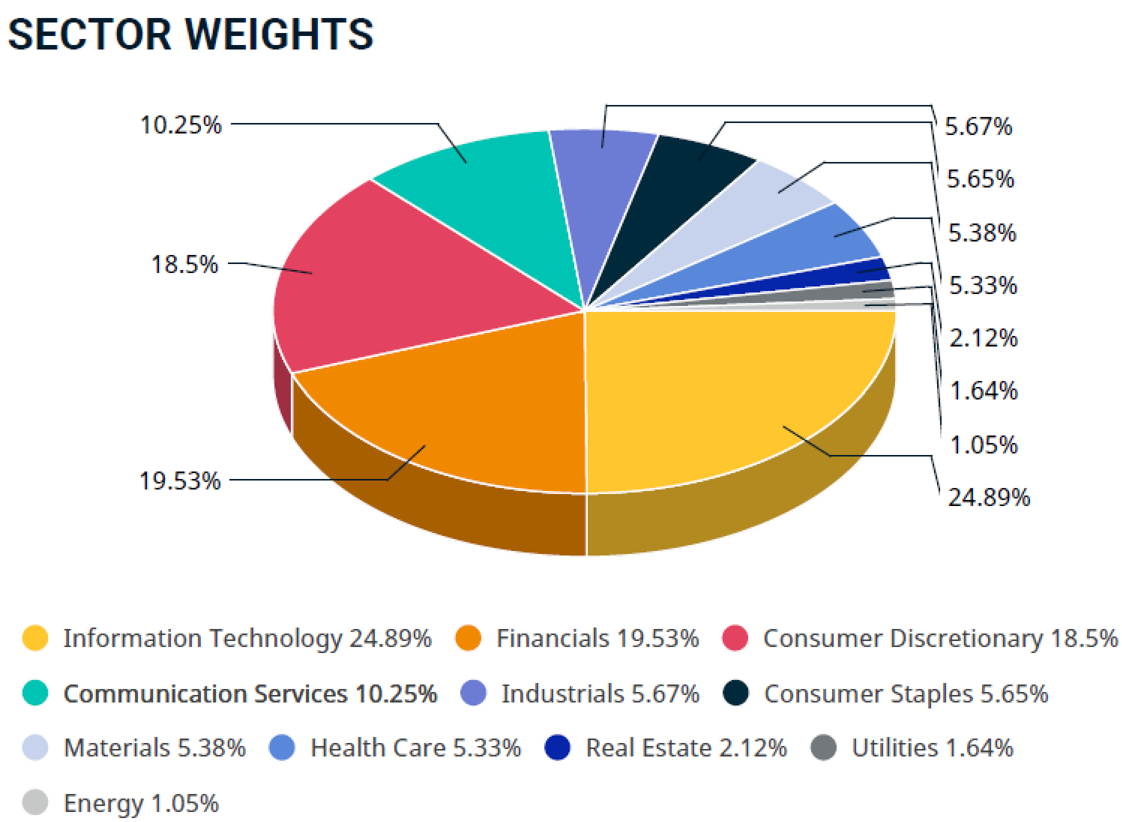

Figure 5: MSCI Climate Change Sectors

3.2 Data collection and methodological techniques

The objective of this study is to identify market reactions to climate risks caused by global warming in times of unusually warm local weather and the resultant policy shifts and technological adjustments. Given that climate change is a global phenomenon, the study is conducted for a broad international setting that is emerging markets to understand the market's collective beliefs and reactions. The international setting also gives us a classification opportunity given the view that extreme temperatures rarely occur simultaneously in both the Northern and Southern Hemispheres as noted by climate science research (Neukom *et al*. 2014). And this segmentation approach will be used to present the results in the next chapter.

To understand the impact of climate risks proxied by temperature, policy and technology shifts relative to daily abnormal returns which are the difference between share returns and expected returns for each E rated share portfolio for each country we run the following regression model:

$$ER_{it} = \alpha + \beta_1\, Temp_{it} + \beta_2\, Policy_{it} + \beta_3\, Tech_{it} + \varepsilon_{it} \qquad \text{Eq. 2}$$

Where ER_{it} are the log returns from the country i E rated share Portfolio at time t, $Temp_{it}$ is the daily % temperature change for country i and $Policy_{it}$ is the "environmental policy, climate policy" change in search topics count for country i and $Tech_{it}$ is "green technology, eco-friendly technology" change in search topic count. The focus is on abnormal changes in E rated share returns as proxied by the E rated portfolios per country and their relation to changes in temperatures and policy changes and technological shifts to comply with the climate change policies. We first find the share price returns which will be calculated from the share price of existing E rated share portfolios excluding dividends following the formula by (Curan & Moran 2007):

$$R_{it} = \ln \frac{P_{it}}{P_{it-1}} \qquad \text{Eq. 3}$$

Where R_{it} is the share return on firm i on day t and P_{it} is the share price on day t. Abnormal returns will be calculated to reflect the market's reaction to the climate risk. The calculation for abnormal returns will be the difference between share returns and expected returns to identify the unexpected returns surrounding the events.

$$AR_{it} = R_{it} - R_{mt} \qquad \text{Eq. 4}$$

Where AR_{it} is the unexpected return on day t, R_{it} is the share return on day t and R_{mt} is the market return on day t proxied by MSCI Emerging Markets Index.

To observe the time varying effect of climate risk to share prices across time, the Time-Varying Parameter regression (VPR) model in which the parameters vary systematically over time will be used to extend on the linear approach of the OLS which only shows us these affects at specific time intervals between the Y and X variables. However, a dynamic approach that considers regression coefficients as a flexible function of continuous time will help us evaluate whether and how factor associations change over time. This adjusts the OLS model with a parenthetical subscript *t* for time for all estimators as shown below.

$$ER_{it} = \alpha + \beta_{1t}\, Temp_{it} + \beta_{2t}\, Policy_{it} + \beta_{3t}(t)\, Tech_{it} + \varepsilon_{it} \qquad \text{Eq. 5}$$

The test to see if parameters vary is then an F-test of the null hypothesis that all the coefficients of t, on $\beta_1, \beta_2 and\ \beta_3$ are zero.

The price movement of the E rated share portfolios across emerging markets will be analysed to see if the movement can be explained by the climate risk factors. Like in Bansal *et al.,* (2019) If rising temperature has a long-run impact on the aggregate economy (that is, it increases future volatility or tail risk, or lowers growth), it should be reflected in current equity prices and the risk-return trade-off. Their empirical analysis shows that this is indeed the case. This research added two more climate risk factors and the intention is to see if these results hold and beyond the US as in (Bansal *et al.,* 2019; Chen & Gao, 2019; Engle *et al.,* 2018). The variables will be tested for multicollinearity and autocorrelations using a correlogram (ACF plot). Further, tests to identify the distributional properties will be done using the Durbin-Watson test and the Brock, Dechert, and Scheinkman (BDS) test will be used to test for linearity.

3.3 Conclusion

In this chapter, the report detailed the research methodology that will be employed by the author. The sampling and data collection sections further detailed the contents of the chapter. In the next section, the report will be looking at the results found, and a discussion of the results will be included.

CHAPTER 4
RESULTS

4.1. Introduction

This chapter deals with reporting the results and interpretation of the regressions output. R was used to conduct our research tests. The tests cover the BRICS countries, with each country specific tests being conducted. The chapter covers the descriptive statistics, linear regression and time varying parameter regressions to explore the hypothesis stated in the first chapter.

4.2 Descriptive statistics

The study conducted used a sample of 602 companies across five BRICS countries from January 2006 to December 2020 see Table 2 below. The figure below (Figure 6: Line graph of variables) shows summary plots of variables over time namely abnormal returns for equally and market cap weighted portfolios, temperature, Policy and Green technology shifts. Environmental Policy has been more prominent in Brazil, South Africa, China and India since the launch of the Intergovernmental Panel on Climate Change in 2006. High activity occurred as countries enacted policies to align with the Paris agreement. The same spike in activity is seen post the United Nations Framework Convention on Climate Change Conference of Parties held in Paris at the climate conference in December 2015. This is the same year green technology shifts started peaking with India showing the most amount of activity in the green technology space this was in response to the National Electricity Plan (NEP) framed by the Ministry of Power (MoP) which launched a 10-year detailed action plan in 2015 with the objective to provide electricity across the country, given the stats from the World Resource Institute Report 2017, India is responsible for nearly 6.65% of total global carbon emissions, ranked fourth next to China (26.83%), the USA (14.36%), and the EU (9.66%). One would also recall this is around the time electric vehicles started gaining momentum led by the listing of Tesla in 2014. Russia and China experienced the most temperature variability throughout the 14 years due to these country's vast sizes and their drastically different geographies ranging from extensive mountains, grasslands and deserts to tropical forests and low-lying coastal areas with a daily max change of 17 and 26

Degrees Celsius (See Appendix A1: Summary Statistics) this puts a lot of their operations at risk to climate change. Notwithstanding, these countries have been struggling to prevent even more pollution and natural disasters that stem, in part, from 30 years of unchecked economic growth.

Table 2: Sample Composition

Country	No of Companies
Brazil	49
Russia	410
India	86
China	20
South Africa	37
Total	**602**

4.3 Empirical Results

4.3.1 Linear regressions results

The linear regression plots below correspond to equation 1 in the research methodology. Two regressions are done using the portfolio return and market cap weighted return. Notably

Figure 6: Visual presentation line graph of Temp, Policy and Tech shifts variables over time

temperature has maintained a steady variability across Brazil, India and South Africa while China and Russia experiences wide temperature fluctuations between warm and cold, while Policy variations are most prominent in Brazil and South Africa and China in the earlier and later periods. Conversely, technological shifts in relation to green technology advancement has seen recent growth across all five countries in the later periods as climate change gone mainstream with China showing the most growth.

Hypothesis 1, following the main objective

Null - there is no climate risk effect on share price performance of environmentally sustainable rated shares portfolios

Alternative - there is a climate risk effect on share price performance of environmentally sustainable rated shares portfolios.

Table 3: Linear Regression results for BRICS countries for climate risks variables Temp, Policy and Technological shifts

Regressors	Brazil Regression Results		Russia Regression Results		India Regression Results		China Regression Results		South Africa Regression Results	
	AR	**AR_C**	**AR**	**AR_C**	**AR**	**AR_C**	**AR**	**AR_C**	**AR**	**AR_C**
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
TEMP	0.002	0.013	0.001	0.0002	0.013	-0.006	0.001	0.001	-0.001	0.001
	(0.009)	(0.009)	(0.001)	(0.001)	(0.010)	(0.010)	(0.002)	(0.003)	(0.003)	(0.003)
POLICY	-0.0003	-0.0003	-0.004**	-0.006**	0.003	0.001	0.001	0.001	-0.0003	-0.0004
	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)	(0.001)	(0.002)	(0.001)	(0.001)
TECH	-0.001	0.001	-0.003	-0.004	-0.001	-0.0001	0.003	0.013	-0.001	-0.003
	(0.010)	(0.011)	(0.016)	(0.018)	(0.001)	(0.001)	(0.008)	(0.017)	(0.004)	(0.004)
Constant	-0.0002	-0.0005*	-0.000	-0.0003	0.0001	-0.0004**	0.00003	-0.0002	-0.00004	-0.0002
	(0.0002)	(0.0003)	(0.0002)	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0002)	(0.0002)
N	5,421	3,646	5,344	3,643	5,477	3,703	5,476	3,512	5,52	3,742
R2	0.00003	0.001	0.001	0.001	0.001	0.0002	0.0002	0.0003	0.0001	0.0003
Adjusted R2	-0.001	-0.0003	0.0004	0.001	0.0001	-0.001	-0.0004	-0.001	-0.0005	-0.001
Residual Std. Error	0.017 (df = 5417)	0.015 (df = 3642)	0.016 (df = 5340)	0.017 (df = 3639)	0.014 (df = 5473)	0.012 (df = 3699)	0.013 (df = 5472)	0.016 (df = 3508)	0.012 (df = 5516)	0.011 (df = 3738)
F Statistic	0.047 (df = 3; 5417)	0.617 (df = 3; 3642)	1.637 (df = 3; 5340)	1.756 (df = 3; 3639)	1.183 (df = 3; 5473)	0.210 (df = 3; 3699)	0.357 (df = 3; 5472)	0.336 (df = 3; 3508)	0.129 (df = 3; 5516)	0.314 (df = 3; 3738)
Notes:	***Significant at the 1 percent level.									
	**Significant at the 5 percent level.									
	*Significant at the 10 percent level.									

4.4 Discussion of OLS results

The linear regression results show that Policy is statistically significant at the 5% level only in Russia. As such we fail to reject the Null hypothesis that there is no evidence of impact on asset returns from temperature changes, technological shifts in the green economy for Brazil, Russia, India, China and South Africa. However, there is some evidence of policy impacts on asset returns in Russia which does not seem to hold in the rest of the BICS countries as there is no evidence. For robustness the time varying parameter regressions (VPR) are also used, and the results are plotted are as shown below in figures 7 to 11.

4.5 VPR regressions results

The table 4 below shows summary statistics of variables over the 14 years based on the time varying parameter model, where temperature, Policy and Green technology shifts were modelled against equally and value weighted portfolios. Environmental Policy has been more prominent in Russia, India, and China with a 50% average search volume around about the launch of the Intergovernmental Panel on Climate Change in 2006 while Brazil and South Africa hardly showed any policy shifts. A greater degree of activity occurred as countries enacted policies to align with the Paris agreement which saw a spike in activity post the United Nations Framework Convention on Climate Change Conference of Parties held in Paris at the climate conference in December 2015. Russia and China had the lowest daily temperature variability of -27, -16 degrees Celsius and highest daily temperature variability between 17 and 26 degrees Celsius making the two countries the most susceptible to climate change risk. The green revolution led by renewables like solar, wind and hydrogen fuel cells have taken centre stage across the world and all emerging countries sampled showed a high degree of search volume variability throughout the 14 years. And this trend will most likely continue as capital flows shift from fossil fuels to sustainable technology.

Table 4: Varying Parameter Regression Summary Statistics for climate risks variables Temperature, Policy and Technological shifts for BRICS countries

	Brazil				Russia				India				China				South Africa			
Statistic	N	Mean	Min	Max	N	Mean	Min	Max	N	Mean	Min	Max	N	Mean	Min	Max	N	Mean	Min	Max
TEMP	5,474	0.65	-0.148	0.128	5,35	0,15	-0,27	0.174	5,478	0,3	-0.106	0,39	5,478	0.26	-0,168	0.264	5,522	28	0,17	0,39
POLICY	5,474	10	0	100	5,478	67	0	100	5,478	47	0	100	5,478	12	0	100	5,522	5	0	100
TECH	5,474	46	0	100	5,478	36	0	100	5,478	26	0	100	5,478	34	0	100	5,522	46	0	100

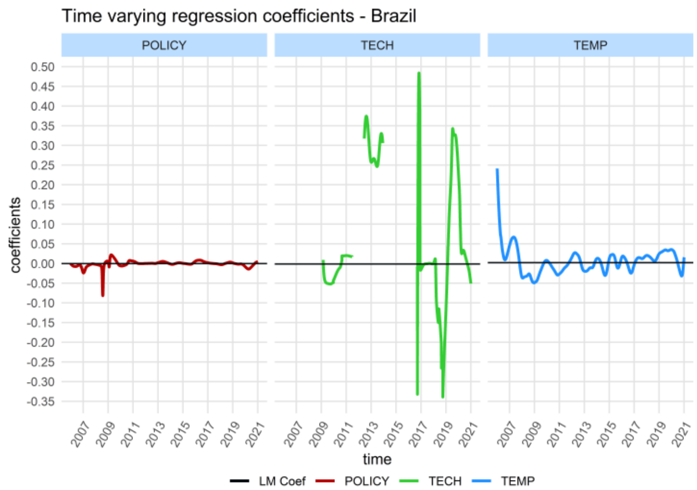

Figure 7: Time Varying Parameter Regressions Brazil over 14 years

Figure 8: Time Varying Parameter Regression Russia over 14 years

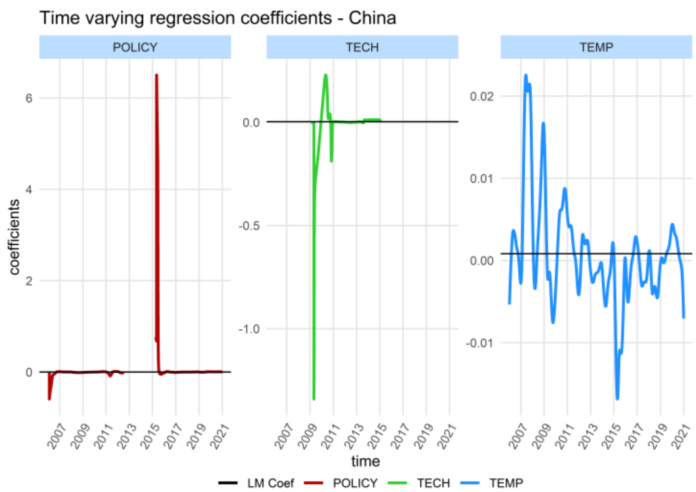

Figure 9: Time Varying Parameter Regression China over 14 years

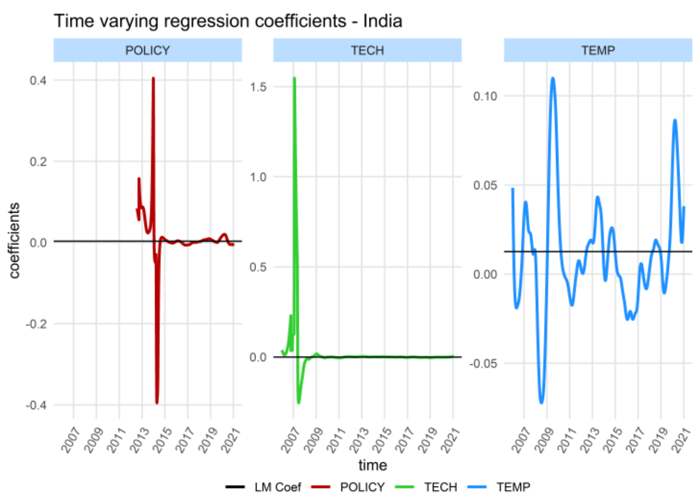

Figure 10: Time Varying Parameter Regression India over 14 years

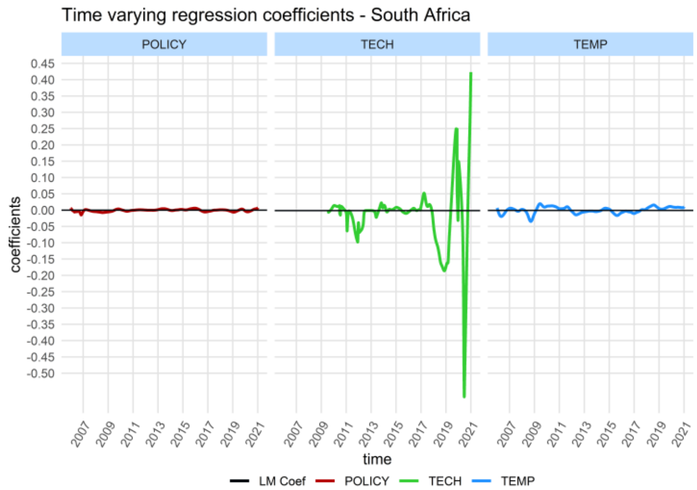

Figure 11: Time Varying Parameter Regression South Africa over 14 years

4.6 Discussion of VPR results

The VPR plots in Figure 7 to 11 shows that through time there was significant visual variation in variables that impacted asset returns with the most notable being technological shifts across all five countries. The graphs above show that the coefficients are not constant through time. The policy coefficients hover around 0, temperature changes are slightly larger, going above and below the OLS estimate by a magnitude of around 0.05. Interestingly, the coefficients start out high at 0.25, then dramatically dropping to zero in a short space of time with respect to policy across all BRICS countries with the sporadic spikes around 2015 which coincides with the Paris agreement session on sustainable investing. Most countries globally were most active around about this time after the summit hence the high volume of activity which shows strong evidence of impact on asset prices. Brazil and South Africa however showed little to no evidence of policy shifts impacting asset prices over the sample period. The technological shifts coefficients hovered above and beyond zero for most countries showing strong evidence of asset return influence and the statistical results on table 4 below show significant across all countries. And lastly, the impact of temperature on asset returns looks to be more pronounced in four of the five countries with South Africa showing the least evidence while the rest of the countries show strong evidence of returns being impacted. The VPR regression statistics below show that most of the coefficients except for temperature for South Africa are statistically significant. As such we reject the Null hypothesis as stated that there is no evidence that policy changes, technological shifts and temperature have an impact on asset returns in Brazil, Russia, India, and China respectively. However, there is no evidence that temperature and policy impact asset return in South Africa which does not seem to hold in the rest of the BICS countries as there is no evidence from the results.

Table 5: Varying Parameter Regression results for BRICS countries

	Brazil		Russia		India		China		South Africa	
Series	**xsquared**	**pvalue**	**xsquared**	**pvalue**	**xsquared**	**pvalue**	**xsquared**	**pvalue**	**xsquared**	**pvalue**
TEMP	12.776215	0	19.42897	0	23.724953	0	9.861749	0.00000	1.389638	0.164695
POLICY	-6.086436	0	-12.85306	0	6.806074	0	6.108978	0.00000	-17.331390	0.000000
TECH	22.527299	0	14.38271	0	8.530301	0	-3.078033	0.00211	-10.227732	0.000000

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

4.7 Model Diagnostics

The model diagnostics are conducted by extracting the residuals and fitted values and then plotted to see if any residuals explain any of the asset returns variation better than our variables. By observing if they form a visible distribution of points scattered randomly about 0 which seems to be the case for all BRICS countries as show in figures 12 to 16 in Appendix B1. This gives support to the model given low R^2 that the model does not fit as all residuals scatter around the zero mark across equally and cap weighted portfolios.

4.8 Test for Autocorrelation in residuals

The test for autocorrelation using the value of Durbin Watson Statistic he Durbin-Watson test statistic tests the null hypothesis that the residuals from an ordinary least-squares regression are not auto correlated against the alternative that the residuals follow an AR1 process. Given the results in table 5 below show that statistics are largely greater than 2, therefore, the residuals in this regression model are slightly auto correlated.

Table 6: DW Test for Autocorrelation in residuals

Country	Durbin Watson Test (eq1)	Durbin Watson Test (eq1_cap)	Durbin Watson Test (eq1_cap$residuals)	Durbin Watson Test (eq1)	Durbin Watson Test (eq1_cap)	Durbin Watson Test (eq1_cap$residuals)
	D-W Statistic	D-W Statistic	D-W Statistic	p-value	p-value	p-value
Brazil	2.128412	2.014666	2.014666	0	0.634	0
Russia	2.250475	2.18035	2.18035	0	0	0
India	2.771757	2.004444	2.004444	0	0.876	0
China	2.084612	1.962734	1.962734	0	0.312	0
South Africa	2.248728	1.938671	1.938671	0	0.062	0

4.9 Pre – regression ACF Plots Test – Variables

As the visual ACF plots show in Appendix C1 the correlations seem to die down as there is no correlation in the variables.

4.10 Multicollinearity

The variance inflation factors (VIF) can also be used to check for multicollinearity. The results as shown in Appendix D1 from the estimate it confirms that correlation between the variables is low, except the correlation between the two y variables, equally weighted and value weighted return, which is expected.

4.11 Summary

The overall results are not surprising given that Environmental issues peaked after the Paris climate session of 2015. The period after this session shows some price action from climate variables with particular respect to policy in Russia being more significant. The results from our VPR models show that climate variables are being priced into asset returns over different time horizons across most countries in our sample. These results are aligned with other asset classes like the real estate, equities of carbon intensive firms as highlighted in chapter two. Bansal *et. al.*, (2016) posit that temperature risks affect aggregate wealth and asset valuations through the variation in expected growth rates and discount rates. A rise in temperature raises the marginal utility and lowers the current wealth to consumption ratio. Thus, temperature risks carry a positive premium, which is reflected in prices of forward-looking assets such as equities and our results suggest this to be true for BRICS countries. In financial markets Choi, Gao, and Jiang (2019), that stocks of carbon-heavy emitters underperform firms with low carbon footprint in excessively warm climate. Retail investors, unlike institutional investors, tend to vote with their wallets by selling carbon-heavy emitting firms in such weather. As such, return trends tend to be driven by investor sentiment towards the underlying asset rather than changes in the fundamentals of the asset (Jagannathan, Ravikumar, and Sammon, 2017). These prior studies are conducted in the US market where much lobbying takes place by environmentalists, as such, investors tend to be more fluid in their investment approach.

CHAPTER 5
CONCLUSION

This research sought to understand the price impact of climate risks (herein proxied by temperature, climate change policy and green technology shifts) on asset returns in particular, those portfolios that are rated to meet strict environmental sustainability ratings across the BRICS countries. The findings show that there is a price impact (that is, climate risks are being priced into asset returns as shown by statistically significant results over the fourteen-year time horizon, since the launch of the United Nations Principle for Responsible Investing in 2006. These results are not surprising given sustainability issues have become prominent and investors are more socially conscious and tend to vote with their wallets. Further, our results align with other research papers, in particular the debt markets which are also seen to be robust in pricing in climate risks as shown by Chen and Gao (2019). Who find that climate risks are positively associated with cost of capital measures, more specifically the implied cost of equity and the cost of debt? This is intuitively sensible, given that these firms can be directly evaluated for their risk exposure in relation to their operations.

A key pillar of the efficient market hypothesis on which many financial models are built is the market's ability to quickly assimilate all available information and reflect this new information through the share price of the listed stocks (Agrawal *et al.,* 1992). This notion here is supported as material climate risks are being reflecting in asset returns. This study seeks to contribute to the area of asset pricing in emerging markets in identifying the key drivers of asset variability in the light of climate change risks.

The limitations of this study are that it uses environmentally sustainable rated shares for each designated country in the sample with no perfect index that filters for the environment factor apart from the ESG indices; it was a challenge to rate shares individually to fit the sample criteria.

An area for future research could be to establish if E-rated share portfolios provide any hedging benefits for climate risks, as one would hope. To further build on the portfolio diversification strategies given climate change issues are only starting to manifest and better portfolio construction approaches are needed to achieve alpha in a volatile world. Most notable study mentioned above have covered developed markets and very little literature covers the emerging markets like BRICS countries in exploring the impact of climate risks on asset prices in these less liquid markets relative to the US and Europe. Future research can draw comparisons between emerging markets and developed markets to see how asset prices are pricing climate risks.

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Appendix A: 1: Summary Statistics

Brazil

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
AR	5,421	-0.0002	0.017	-0.294	-0.005	0.005	0.161
AR_c	3,646	-0.0005	0.015	-0.139	-0.006	0.005	0.160
TEMP	5,474	0.00001	0.027	-0.148	-0.016	0.018	0.128
POLICY	5,474	0.001	0.197	-2	0	0	2
TECH	5,474	-0.0002	0.023	-1	0	0	1

Russia

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
AR	5,469	-0.00001	0.016	-0.143	-0.006	0.006	0.161
AR_c	3,733	-0.0003	0.017	-0.137	-0.009	0.008	0.161
TEMP	5,35	0.003	0.256	-2.730	-0.063	0.061	0.174
POLICY	5,478	-0.001	0.102	-2	0	0	2
TECH	5,478	0.0003	0.013	0	0	0	1

India

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
AR	5,477	0.0001	0.014	-0.160	-0.005	0.006	0.141
AR_c	3,703	-0.0004	0.012	-0.067	-0.005	0.003	0.116
TEMP	5,478	0.00002	0.019	-0.106	-0.010	0.010	0.091
POLICY	5,478	-0.0005	0.068	-1	0	0	2
TECH	5,478	-0.001	0.216	-2	0	0	2

China

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
AR	5,476	0.00003	0.013	-0.092	-0.004	0.002	0.095
AR_c	3,512	-0.0002	0.016	-0.090	-0.008	0.006	0.093
TEMP	5,478	-0.0001	0.108	-0.868	-0.050	0.055	0.264
POLICY	5,478	-0.0004	0.128	-2	0	0	1
TECH	5,478	-0.0002	0.024	-1	0	0	1

South Africa

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
AR	5,52	-0.00004	0.012	-0.091	-0.005	0.004	0.103
AR_c	3,742	-0.0002	0.011	-0.072	-0.005	0.004	0.102
TEMP	5,522	0.00004	0.056	-0.351	-0.028	0.034	0.335
POLICY	5,522	-0.001	0.227	-2	0	0	2
TECH	5,522	0.0002	0.038	-1	0	0	1

Appendix B:1: Model Diagnostics Residual vs Fitted

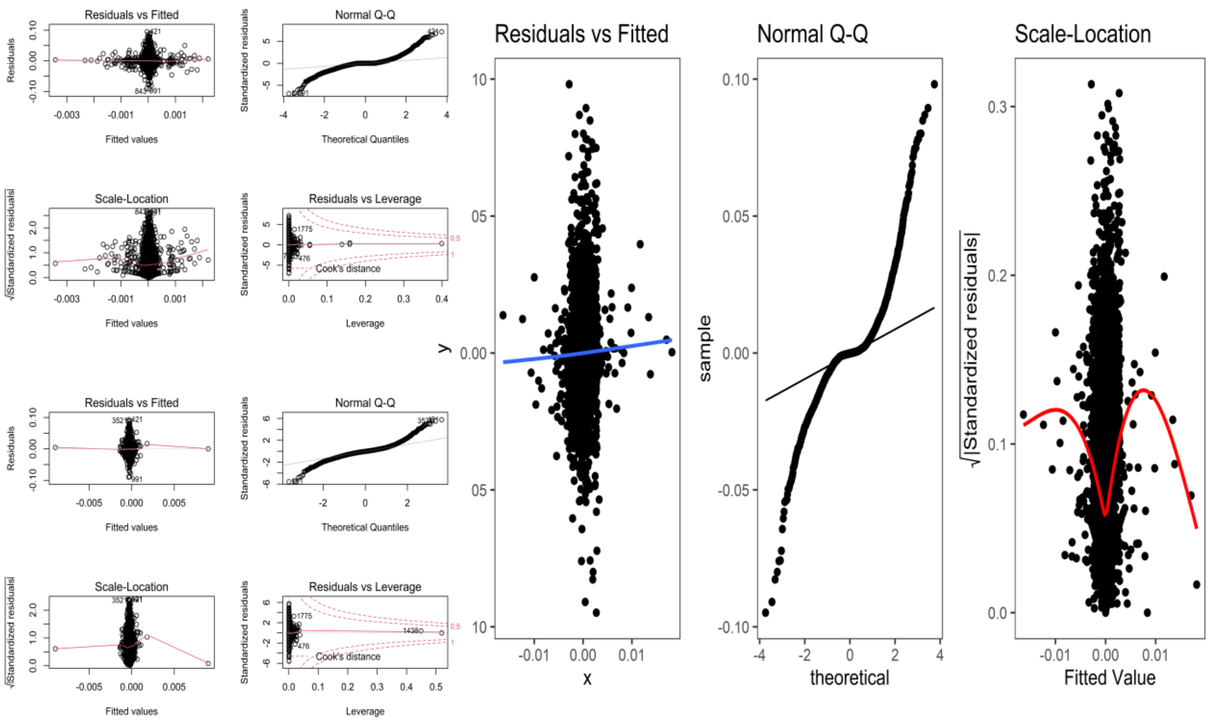

Figure 13: Model Diagnostics Residual vs Fitted - Brazil

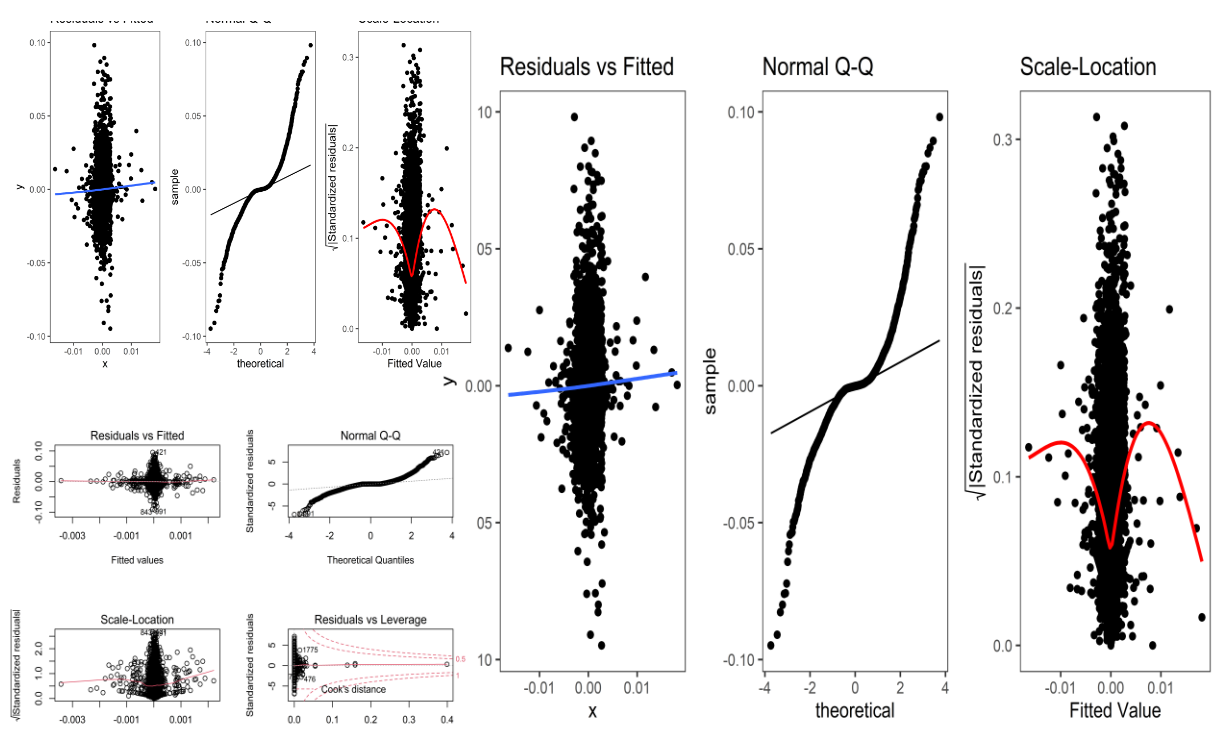

Figure 12: Model Diagnostics Residual vs Fitted - Russia

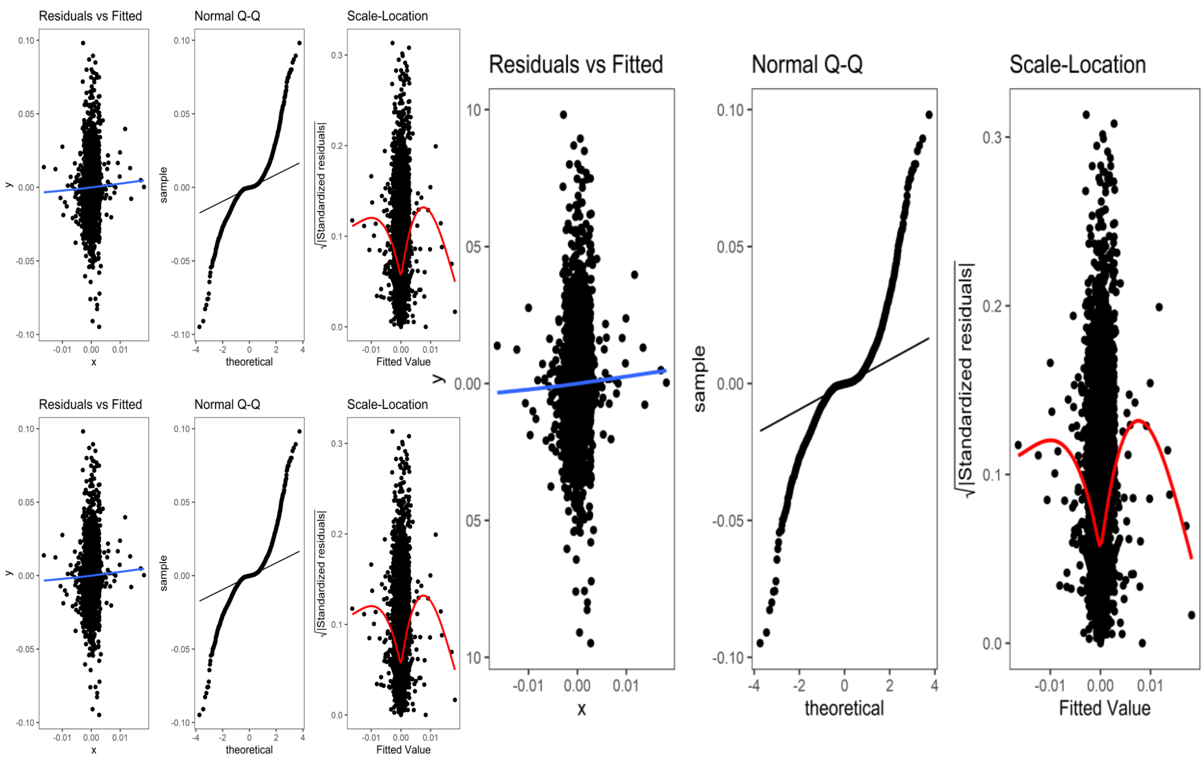

Figure 15: Model Diagnostics Residual vs Fitted - India

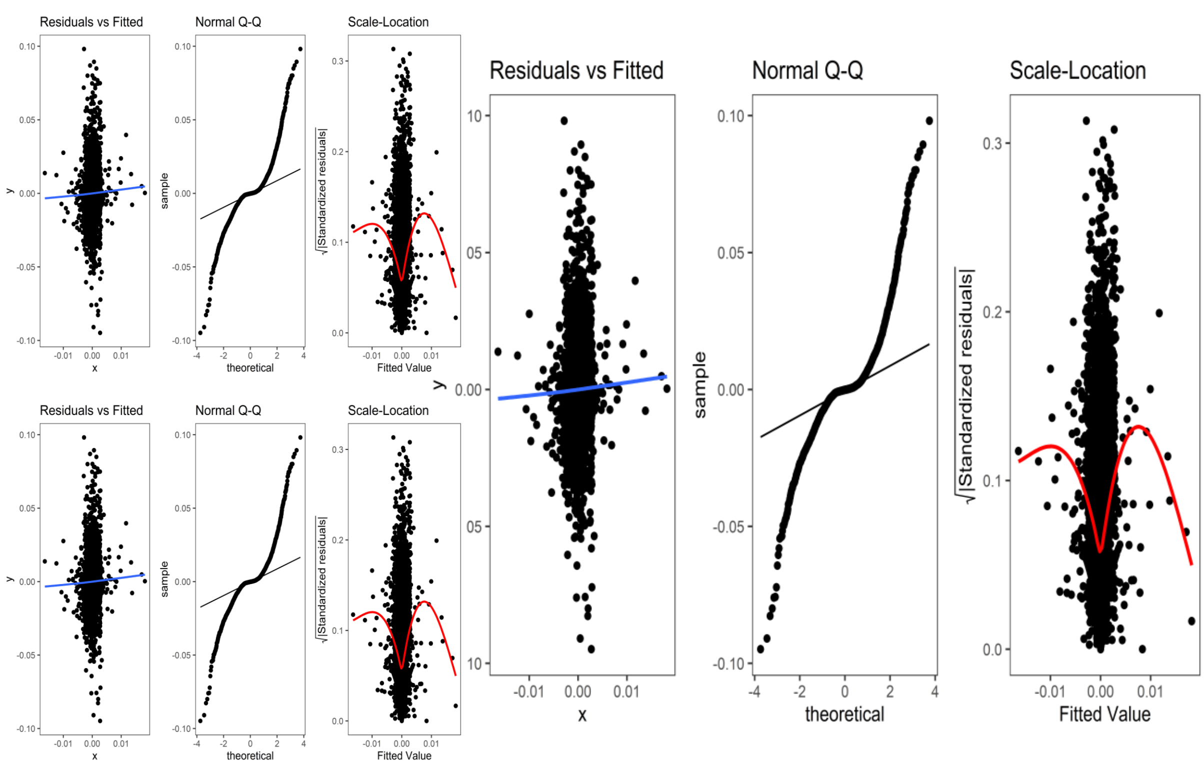

Figure 14: Model Diagnostics Residual vs Fitted - China

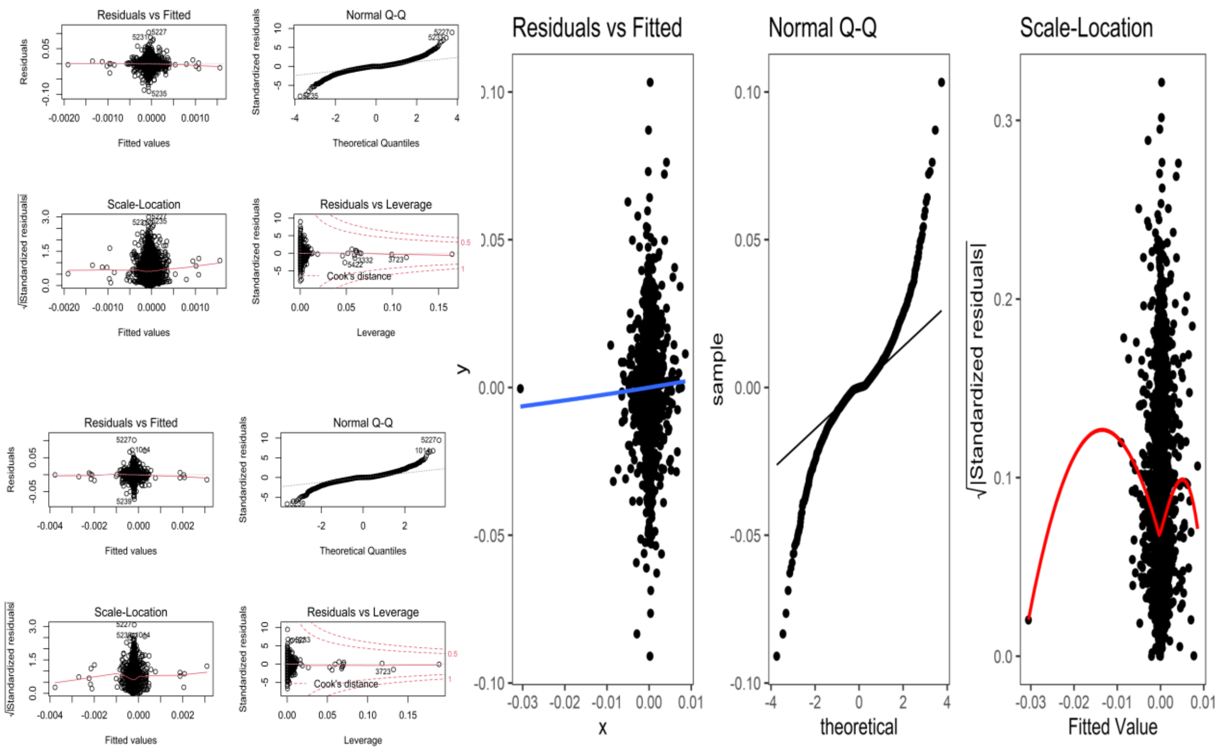

Figure 17: Model Diagnostics Residual vs Fitted - South Africa

Appendix C: 1: ACF

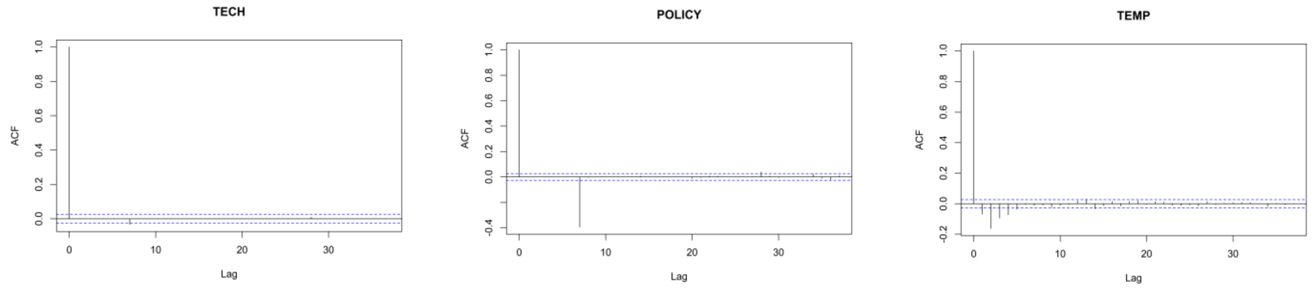

Figure 20: ACF - Brazil

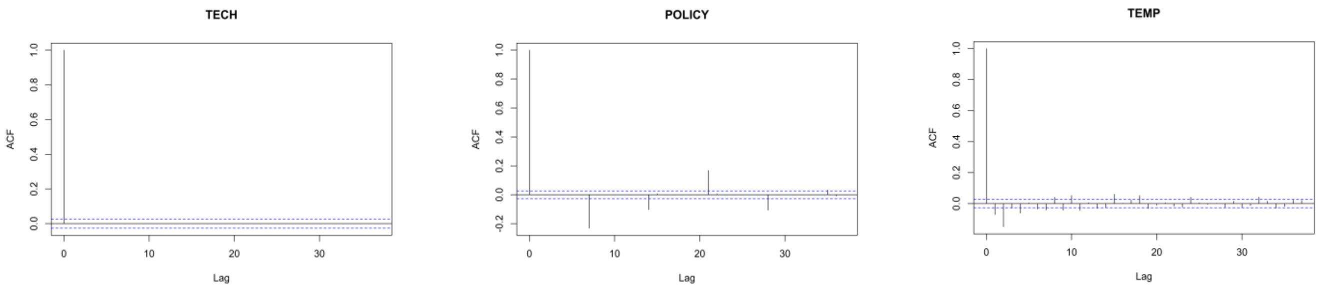

Figure 19: ACF - Russia

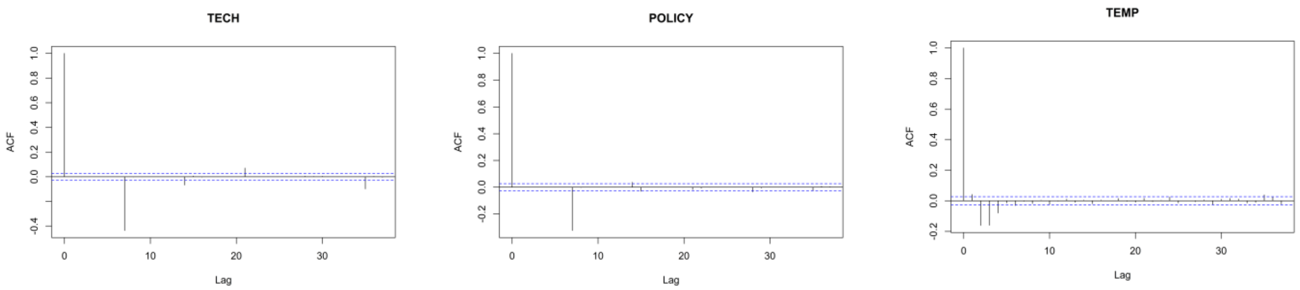

Figure 18: ACF - India

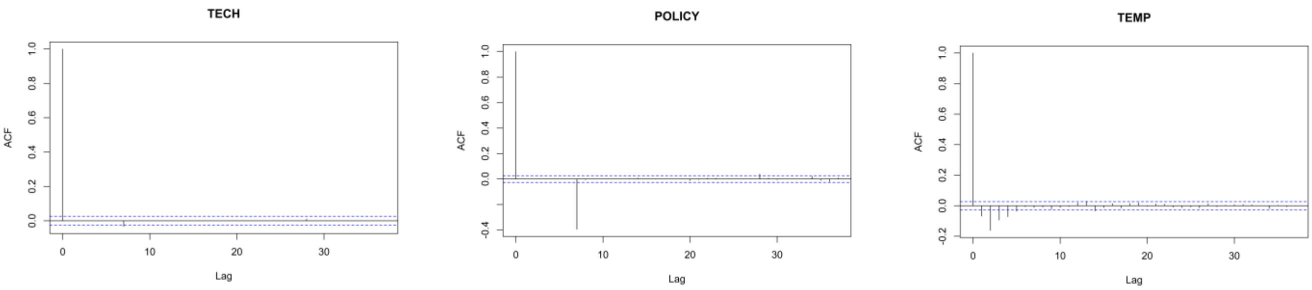

Figure 22: ACF - China

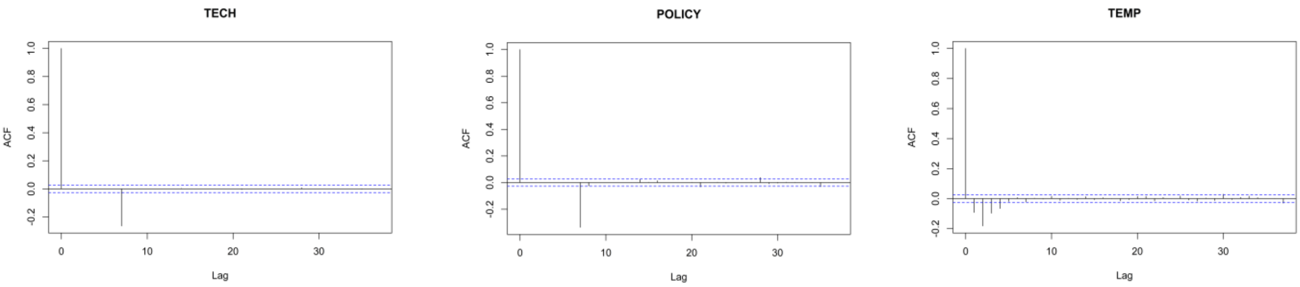

Figure 21: ACF - South Africa

Appendix D: 1: The variance inflation factors (VIF) results

Table 7: The variance inflation factors (VIF) results

Brazil - $estimate					
	AR	AR_c	TEMP	POLICY	TECH
AR	1.000000000	0.856722908	-0.013021906	0.005582049	-0.004256113
AR_c	0.856722908	1.000000000	0.022608024	-0.006533602	0.004088397
TEMP	-0.013021906	0.022608024	1.000000000	-0.004232077	0.016331380
POLICY	0.005582049	-0.006533602	-0.004232077	1.000000000	-0.138115570
TECH	-0.004256113	0.004088397	0.016331380	-0.138115570	1.000000000
Russia - $estimate					
	AR	AR_c	TEMP	POLICY	TECH
AR	1.0000000000	0.958956848	0.016258877	0.013655940	0.0003284244
AR_c	0.9589568483	1.000000000	-0.014645539	-0.023777290	-0.0012967849
TEMP	0.0162588774	-0.014645539	1.000000000	0.004848103	0.0020659365
POLICY	0.0136559402	-0.023777290	0.004848103	1.000000000	-0.1958447037
TECH	0.0003284244	-0.001296785	0.002065936	-0.195844704	1.0000000000
India - $estimate					
	AR	AR_c	TEMP	POLICY	TECH
AR	1.000000000	0.799294142	0.016733567	0.015156670	-0.001607501
AR_c	0.799294142	1.000000000	-0.019671195	-0.007508027	-0.000301018
TEMP	0.016733567	-0.019671195	1.000000000	0.008434133	-0.019126535
POLICY	0.015156670	-0.007508027	0.008434133	1.000000000	0.104016968
TECH	-0.001607501	-0.000301018	-0.019126535	0.104016968	1.000000000
China - $estimate					
	[,1]	[,2]	[,3]	[,4]	[,5]
[1,]	1.000000000	0.983223513	0.005074289	-0.003695371	-0.015787874
[2,]	0.983223513	1.000000000	-0.003530791	0.004790562	0.017947509
[3,]	0.005074289	-0.003530791	1.000000000	0.003052871	0.003486898
[4,]	-0.003695371	0.004790562	0.003052871	1.000000000	0.028028712
[5,]	-0.015787874	0.017947509	0.003486898	0.028028712	1.000000000
South Africa - $estimate					
	AR	AR_c	TEMP	POLICY	TECH
AR	1.000000000	0.878101771	-0.002302463	0.007775851	0.009902157
AR_c	0.878101771	1.000000000	0.003998939	-0.011139479	-0.014333707
TEMP	-0.002302463	0.003998939	1.000000000	0.010363094	-0.017486401
POLICY	0.007775851	-0.011139479	0.010363094	1.000000000	0.060426124
TECH	0.009902157	-0.014333707	-0.017486401	0.060426124	1.000000000