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Unhedgeable risk

How climate change sentiment impacts investment

UNIVERSITY OF CAMBRIDGE
Cambridge Centre for Climate Change Mitigation Research

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The opinions expressed in this report are the authors' own and do not represent an official position of the University of Cambridge CISL, the ILG or of any of their individual members.

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Executive Summary

Short-term shifts in market sentiment induced by awareness of future, as yet unrealised, climate risks could lead to economic shocks, causing substantial losses in financial portfolio value within timescales that are relevant to all investors.

Factors, including climate change policy, technological change, asset stranding, weather events and longer-term physical impacts may lead to financial tipping points for which investors are not presently prepared.

This research shows that changing asset allocations among various asset classes and regions, combined with investing in sectors exhibiting low climate risk, can offset only half of the negative impacts on financial portfolios brought about by climate change. Climate change thus entails "unhedgeable risk" for investment portfolios.

While the response to action aimed at limiting warming below 2°C is shown to be negative in its short-term economic and financial impacts, the benefits of early action lead to significantly higher economic growth rates and returns over the long run, especially when compared to a worst-case scenario of inaction. The present study shows that certain types of portfolio benefit more than others.

Even in the short run, the perception of climate change represents an aggregate risk driver that must be taken into consideration when assessing the performance of asset portfolios. Our analysis provides investors with a general guide to minimising their exposure to climate sentiment risk and has the potential to stimulate a constructive dialogue between investors, governments and regulators to examine the conditions necessary to build more resilient financial markets under unprecedented environmental change.

Commissioned by the University of Cambridge Institute for Sustainability Leadership (CISL) and the Investment Leaders Group (ILG), this report looks at the economic and financial impacts of climate risk over the next five years in order to identify opportunities for reducing climate-related investment risks through portfolio construction and diversification across different asset classes, regions and portfolios.

While the most significant physical impacts of climate change will probably be seen in the second half of this century, financial markets could be affected much sooner, driven by the projections of likely future impacts, changing regulations and shifting market sentiment. This study employs a unique approach to address these short-term implications of our long-term climate problem in relation to portfolio risk. The complex analysis presented here is the fruit of a collaborative effort between three research entities within the University of Cambridge, namely the Cambridge Centre for Risk Studies (CRS), the Cambridge Centre for Climate Change Mitigation Research (4CMR) and the Cambridge Judge Business School.

Both regulators and financial markets react in light of new information about climate change, including major events such as storms, floods and droughts; policy decisions; and the success and failure of companies. While such changes are partly visible in the present, they are likely to accelerate **as** the physical impacts of climate change become deeper and more regular. This will influence financial market behaviour gradually in the first instance (led by the most informed investors) and then, potentially, in a more disorderly fashion as markets seek to shed at-risk assets. Some of the economic losses incurred by investors in this transition can be avoided or hedged through mere reallocation strategies, while others require system-level intervention in the form of policy or regulatory action. While we cannot model the psycho-social dynamics of financial markets despite the ready availability of risk information, we can model physical impacts and consequences for the macroeconomy under different scenarios of climate change mitigation identified by the Intergovernmental Panel on Climate Change (IPCC) climate science. In doing so, our study characterises in detail the multi-faceted impact of climate change on different asset classes and geographies.

The results of this analysis show that, on a worst-case No Mitigation basis, 47 per cent of the negative impacts of climate change across industry sectors can be hedged through industrial sector diversification and investment in industries that exhibit few climate-related risks. Similarly, shifting from an aggressive equity portfolio to one with a higher percentage of fixed-income assets makes it possible to hedge 49 per cent of the risk associated with equities. However, these two "halves" are not cumulative, such that no strategy will offer more than 50 per cent coverage. This gives rise to the conjecture that, even in the short run, climate change will constitute an aggregate risk system-wide action in order to mitigate its economy- wide effects.

We adopt an approach that – as far as we are aware – has not been applied to analysis of the financial implications of climate change: stress testing representative portfolios using economic and market confidence shocks derived from climate change sentiment scenarios. This study quantifies the potential financial impacts of a shift in market sentiment driven by significant changes in investor and consumer beliefs about the future effects of climate change, modelling the impact of three market sentiment scenarios on four portfolios with different asset allocations.

The scenarios reflect differing beliefs about the likelihood of government action to limit warming to 2°C, as recommended by the IPCC, the actual emission levels anticipated, as well as physical climate change impacts, the probable stringency of regulation and levels of investment, including the types of technology likely to be developed. The scenarios, aptly named Two Degrees, No Mitigation, and Baseline, were developed according to well-recognised risk modelling techniques, drawing on the latest IPCC climate change projections and employing analysis of historical market shocks that offer meaningful parallels to interpret and model parameters within a climate risk framework.

The asset allocations employed are representative of pension funds (Conservative, Balanced and Aggressive) and insurance companies (High Fixed Income). Portfolios were stress tested by applying shocks based on different levels of carbon taxation, energy investment, green investment, energy and food prices, energy demand, market confidence, bond market stress and housing prices. Impacts are modelled over five years at the portfolio, asset class, sector and regional levels. This analysis enables the quantification of impacts for each scenario across different asset classes, industrial sectors, countries and portfolio structures.

The macroeconomic analysis shows that the transition to a low-carbon economy carries increased economic costs in the short term, but that longer term discounted benefits make a transition more than worthwhile. The sheer scale of structural change required for the global economy to shift away from a future dominated by fossil fuels towards a low-carbon economy requires tremendous investment in new capital infrastructure, in research and development, and in new business models. This transition period lasting years will be costly to the global economy. However, the alternative may well be worse: results from the macroeconomic analysis show that the No Mitigation scenario triggers a global recession for three consecutive quarters, shrinking the global economy by as much as 0.1 per cent each quarter.

By comparison, the Two Degrees scenario grows at just 0.3 per cent per quarter, whereas the Baseline model offers the fastest near-term growth, reaching 0.7 per cent per quarter. Over a longer time horizon (2015-2050), however, the Two Degrees scenario is shown to outperform the Baseline by 4.5 per cent with a discount rate of 3.5 per cent. While the degree of benefit varies by portfolio type, all portfolios experienced short-term losses and long-term benefits in this scenario. Clearly, it is only after the learning process, technological progress and construction of new infrastructure systems are complete that the positive benefits of the new low- carbon economy begin to accrue. Again, this process contrasts with the No Mitigation scenario, where economic output never recovers, but is supressed indefinitely below Baseline.

Turning to the impact of these horizons on market players, our results show that the High Fixed Income portfolio carries the least risk from financial market disruption, but also experiences low performance across all scenarios. In comparison, if no action is taken to limit warming to 2°C, a Conservative portfolio with a 40 per cent weighting to equities (typical of a pension fund) could suffer permanent losses of more than 25 per cent within five years after the shock is experienced.

Sectoral analysis shows that some hedging of climate risk is possible by targeting low risk equity investments across different regions and sectors of the economy. Overall, emerging markets are the worst affected. Results from the models suggest that approximately half of the impact on returns attributable to climate change can be hedged through cross-industry and regional investment in low climate risk sectors. At the multi-asset portfolio level, only half the negative impact of climate change on returns can be hedged by changing asset allocation.

Our analysis – alongside data tables generated for all our scenarios – provides investors with guidelines for minimising their exposure while, at the same time, stimulating a dialogue that goes beyond mere reallocation of resources to build a more sustainable capital market in an economy that is subject to environmental change.

1 Introduction

As awareness of climate-related risks grows and gains traction, prudent asset owners and asset managers are beginning to question how global environmental trends – such as increasing pressure on agricultural land, food security, soil degradation, local water stress, and extreme weather events – will affect the macroeconomic performance of countries and sectors, and how this will play out in financial markets.

To address these questions, and on behalf of the Investment Leaders Group (ILG), the Cambridge Institute for Sustainable Leadership (CISL) has commissioned this research from three Cambridge institutions: the Cambridge Centre for Climate Change Mitigation Research (4CMR), The Cambridge Judge Business School and the Centre for Risk Studies (CRS) therein. 4CMR has notable capacities in climate change research, whereas the Centre for Risk Studies, located within the Cambridge Judge Business School, has considerable expertise in the simulation of financial and economic impacts of various types of risk.

1.1 Investor risk

Climate change poses a major risk to the global economy affecting the wealth and prosperity of all nations around the world. It will have major impacts on the availability of resources, the price of energy, the vulnerability of infrastructure and the valuation of companies. This collaborative report studies how global trends arising from the possible impacts of climate change will lead to a shift in market sentiment in the short term. The study quantifies the economic impacts across regions, sectors and different asset classes, and models the estimated change in value for different asset portfolios. In principle, the financial impacts resulting from different forms of risk exposure can be hedged through strategic asset allocation and portfolio construction. However, some portion of said risk exposure remains effectively 'unhedgeable' due to the inherent systematic risks associated with different climate change scenarios. Avoiding systematic risks will require system-wide approaches such as climate change mitigation and adaptation measures at the local, regional, national and global levels.

Appendix A presents a collection of articles that have been published over the past decade that range from identifying climate change as an emerging risk, to addressing climate risks in the economy and portfolio management (Mercer, 2015; Rogers et al., 2015; Stathers and Zavos, 2015; Kraemer and Negrila, 2014; Committee on Climate Change, 2014; Mercer, 2014; Guyatt, 2011; Wellington and Sauer, 2005).

1.2 Study aim and objectives

The most significant geophysical impacts of climate change will most likely be observed in the second half of this century. As the climate continues to warm, global impacts will accumulate over time resulting in higher long-term risks, particularly if global average temperatures rise above 3°C (Pachauri, 2014). Financial markets, however, could show the impact of risk aggregation much sooner, as the effects of climate change will be driven by the projections of likely future impacts, changing regulation and shifting market sentiment. Therefore, investors should not be deterred from identifying and managing impending climate-based sentiment risks in present-day financial markets based on long-term climate change projections. In fact, investors who act now may benefit from first-mover advantage, or at the very least, minimise their exposure to such risks which could evolve even more rapidly than anticipated (possible if climate science advances allow the timing of 'tipping points' for climatic instability to be predicted).

This study models the effect of market behaviour and how financial investment decisions will be made under different climate change sentiment scenarios. Anticipating how the market may respond to long- term climate risks attempts to bridge the gap between the geophysical impacts of climate change over the longer term and the potential effects that climate risk may have on the economic and financial markets today. Therefore the aim is to identify and quantify the financial impacts that may arise from a shift in market sentiment driven by significant changes in investor and consumer beliefs about the future effects of climate change. Given certain conditions about future expectations of climate risk, market players will be prompted to change their behaviour today to reduce their exposure across different asset classes.

This study intends to shed light on the vulnerability and resilience of different asset portfolios to climate change related risks. With this information, investors will be able to hedge risk and invest in assets with lower potential of being affected by climate change risk.

While this document is meant to focus on the results of our analysis, we provide further details and background on our methodology in the Appendix. Appendix A provides a literature review. Appendix B introduces climate change as an emerging risk to asset owners and managers. Appendix C describes the methods and stress test scenario modelling approach that was adopted. Appendix D introduces the long- term climate change impacts on different sectors and regions of the world. Appendix E discusses the selection process for our stress testing scenarios, to which we turn next, and Appendix F provides further background information on the underlying macroeconomic model.

2 The sentiment scenarios

We use a triplet of (i) selected radiative forcing levels, (ii) socio-economic pathways and (iii) climate policy assumptions to develop three different sentiment scenarios, namely Two Degrees (Section 1.3), Baseline (Section 1.4) and No Mitigation (Section 1.5). The fundamental assumption of these scenarios is that public expectations and economic sentiments provide a bridge between the future geophysical impacts from climate change and the markets today. Scenarios do not model changes in the evolution and dynamics of policy implementation as each scenario unfolds over time. Rather, we assume the markets behave in a way that is consistent with each future scenario coming true. In sociology this is often referred to as the problem of reflexivity and occurs when the observations or actions of observers in the social system affect the very system they are observing. We remove this contradiction by only looking at the behaviour of the markets under the condition that the markets believe a particular future scenario is going to come true. In this way the present day reactions of the market are consistent with the belief of each future scenario unfolding, leading to the fulfilment of the scenario. For example, in the No Mitigation scenario the reactions of the market are consistent with the belief that there will be no mitigation and the impacts of climate change will be substantial. As a consequence, we do not account for the fact that under the No Mitigation scenario there is a higher chance that governments will react more strongly and will therefore avoid the worst effects of climate change.

2.1 Two Degrees

Two Degrees describes a world collectively making relatively good progress towards sustainability, with sustained efforts to achieve future socio-economic development goals. In this analysis it is defined as being similar to RCP2.6 and SSP1 from IPCC AR5. Resource intensity and dependence on fossil fuels are markedly reduced. There is rapid technological development (including clean energy technologies and yield-enhancing technologies for land), reduction of inequality both globally and within countries, and a high level of awareness regarding environmental degradation. The world believes that global warming will not raise the average temperature by more than 2°C above pre-industrial temperatures, but not without significant expense.

With this in mind, the economy gears up to make a transition away from fossil fuels and towards a low- carbon economy. However, a shift in long-term investment decisions from several key technology and financial institutions causes volatility and uncertainty in the financial markets leading to a short period of turmoil and lower growth. The economy goes through an arduous period of divesting away from fossil fuels, where nearly half of coal and oil assets are predicted to become stranded (HSBC, 2013). As the economy successfully restructures toward renewables, investors slowly regain confidence and the market recovers over the medium term.

Regulation: The level of global cooperation for mitigation is high, well-coordinated and early (within the next five years from 2016 to 2020). For example, the effort of climate policies aimed at reducing GHG emissions is reflected by the carbon tax imposed internationally on fossil fuel-dominant energy supply; a global carbon budget is allocated and set at 20 per cent of the total underground carbon reserves (Carbon Tracker Initiative, 2013).[1] Most major countries adopt the following carbon mitigation targets:

- $100[2]/tonne CO_2 of carbon tax to reflect the strength of climate policies aimed at reducing greenhouse gases (GHG) emissions
- Carbon budgets set at 20 per cent on existing reserves
- 80 per cent more investments[3] in low-carbon technologies
- No further investment (or subsidies) for fossil fuel extractions

Direct impacts: Carbon taxes are implemented as an additional tax (i.e. not revenue neutral), thus they will be passed on to businesses and consumers, thereby reducing purchasing power, productivity, investment, and the economy's total output (Congressional Budget Office, 2013). However, these carbon taxes may be used to offset budget deficits or invest in research and development boosting long-term productivity and have an overall positive effect on the economy in the long run (e.g. the Congress of the United States estimates a carbon tax of $20/tonne CO_2 would raise $1.2 trillion in revenue during its first decade).[4] Rapid improvements in energy efficiency, a decrease in the cost of renewables and the development of new agricultural technology leads to a significant reduction in carbon intensities and higher yields from agriculture. The short term economic outlook

1 Unburnable Carbon 2013: Wasted capital and stranded assets (Online) http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/02/PB-unburnable-carbon-2013-wasted-capital-stranded-assets.pdf [Accessed: 14 Jan 2015]

2 Centre for Energy and Climate Economics (Online) Available: http://www.rff.org/centers/energy_and_climate_economics/Pages/Carbon_Tax_FAQs.aspx [Accessed: 10 Feb 2015]

3 Financing a low-carbon future (Online) Available: http://static.newclimateeconomy.report/wp-content/uploads/2014/08/NCE_Chapter6_Finance.pdf [Accessed: 11 Feb 2015]

4 Congressional Budget Office, 2013. Effects of a Carbon Tax on the Economy and the Environment. https://www.cbo.gov/sites/default/files/44223_Carbon_0.pdf

remains in a state of turmoil while the economy goes through a phase of readjustment and capital is reinvested in a new energy system. This leads to a period of low short-term growth caused by high volatility, stranded assets and uncertainty in many long-term investments. This rocky period does not persist for long, and the long-term outlook for the economy remains positive.

- Negative 3 per cent sentiment shocks across each of the major economies for one year
- Negative sentiments taper back to zero and rise into the positive zone as markets regain confidence over the five-year period.

2.2 Baseline

Baseline is a world where past trends continue (i.e. the business-as-usual BAU scenario), where there is no significant change in the willingness of governments to step up actions on climate change. However, the worst fears of climate change are also not expected to materialise and temperatures in 2100 are only expected to reach between 2°C and 2.5°C. It is most similar to the IPCC's RCP6.0 and SSP2. There is some progress towards reducing resource and energy intensity (compared to historic rates), while the economy slowly decreases its dependence on fossil fuel. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. In general, global population continues to rise, especially in low-income countries. However, due to the lack of unified expectations regarding the future of either regulation relating to GHG emissions or real economic activities, there is little hope that any significant changes will occur to the existing economic conditions or climate policies over the short term (e.g. 2016 – 2020).

Regulations: Global climate policy actions are delayed beyond the modelling period, with only intermediate success in reducing vulnerability to climate challenges.

- No carbon or oil tax
- World fossil fuel energy supply/production remains unchanged
- Fossil fuel-dominant energy investments remain unchanged
- No technological advances to renewable energy sources

Direct impacts: None in the near future but become increasingly significant beyond 2060.

2.3 No Mitigation

In the No Mitigation scenario, the world is oriented towards economic growth without any special consideration for environmental challenges, rather the hope that pursuing self-interest will allow adaptive responses to any climate change impacts as they arise. This is most similar to RCP8.0 and SSP5. In the absence of climate policy, the preference for rapid conventional development leads to higher energy demand dominated by fossil fuels, resulting in high GHG emissions. Investments in alternative renewable energy technologies are low but economic development is relatively rapid, driven mainly by higher investment in human and knowledge capital.

The initial market volatility is high due to significant uncertainty around the future impacts of climate change. But as the world progresses under conventional development, there is growing realisation that the majority of wealth generated from strong economic performance was squandered on short term consumption. Thus, market confidence as to the future performance of the economy is adjusted downward, initiating a widespread down-grade in stock price valuations reflecting a future of low growth and economic output.

Regulation: Global mitigation, man-made drivers of climate change is low and delayed, with no coordinated action in attributing pricing strategies to GHG emissions and land use change. In the absence of climate policies within the five-year modelling period (i.e. 2016 – 2020):

- No carbon or oil tax
- 50 per cent increase in world fixed investment for energy extraction[5]

Direct impacts: Fossil fuels remain the dominant source of energy, incentivising rapid technological progress in large-scale energy and natural resource exploration and extraction, significantly driving up the price of fossil fuel energy. As the markets recognise the high growth potential in fossil fuel based assets, investment in fossil fuel companies increase; this capital is then spent on further exploration and extraction by these companies (ultimately leading to the High climate change scenario). Climate change - induced environmental degradation and water stress reduce agricultural yields across many parts of the world. The increased water stress, resource constraints, and other environmental factors further strain production capabilities as well as regional social cohesion.

- 10 per cent per year increase in global demand for carbon energy sources
- 10 – 20 per cent per year[6] increase in world agriculture prices due to higher cost and lower land-use availability
- Sentiment shocks of up to Neg. 5 – 8 per cent across the major economies

2.4 Potential scenario triggers

Many potential triggers may initiate a financial tipping point brought about by climate change and unravel in a similar fashion to one of the scenarios described above. These triggers illustrate the different types of signals that serve as leading indicators of the instantaneous sentiment shocks in each scenario; where an indicator is nationally located, the trigger would be the emergence of a significant number of countries exhibiting that indicator. In Table 1 we highlight five categories from which financial tipping points may result in one or more triggers are: new scientific evidence and technology, new policy announcements, new legal developments, increased social awareness, and economic factors.

5 Fossil Fuel Euphoria (Online) Available: http://www.tomdispatch.com/post/175760/tomgramper cent3A_michael_klare,_the_latest_news_in_fossil_fuel_addiction/ [Accessed 11 Feb 2015]

6 FAO Food price index (Online) Available: http://www.fao.org/worldfoodsituation/foodpricesindex/en/ [Accessed 11 Feb 2015]

Table 1: Potential triggers that may lead to the development of each scenario

Trigger	Two Degrees	No Mitigation
News cientific evidence and Technology	• New technological breakthrough in low-carbon technology (e.g. fusion, solar) • Increased accuracy in the monitoring and measurement of emissions for attribution	• New scientific evidence on the unstoppable and runaway effects of climate change • Thermohaline circulation shuts down • Permafrost melts releasing vast quantities of methane into the atmosphere • Greenland and Antarctica ice sheet begins to melt • Glaciers begins to disappear
New policy announcements	• Announcement of global agreement to limit GHG with a tax or a cap • Election of new political party that pushes climate change mitigation • Forced nationalisation of selected state assets • Commitment to stop the implicit subsidy of fossil fuels	• Chaos and breakdown in global discussion on GHG policy • Continued subsidy and government action to open new oil fields • Rollback on the price of carbon from all major economies (e.g., China, Europe, USA)
New legal developments	• Introduction of new case law on the legality of emitting CO_2 emissions based on existing law • Increase in the number of lawsuits and liabilities placed against companies that emit CO_2 or with disregard for the environment	• Climate change mitigation legal challenges defeated in court
Increased social awareness	• Increasing social awareness on the risk of GHG emissions and increasing reputational risk for companies that emit GHG • Increased social awareness and pressure from shareholders, employees and activists to reduce emissions	• Increasing social awareness of changing growing seasons and lower agricultural yields • Increase mechanisation and carbon-intensity on farmlands for fear of failed crops
Economic factors	• Achievement of price parity between renewable technology and fossil fuels • Stranded fossil fuel assets	• Persistent low fossil fuel prices • Clean technology bubble collapse

3 Macroeconomic analysis

The effects of human activity over the next two decades will either put the earth on a path to limiting an increase in temperature below 2°C compared to pre-industrial era temperatures, or commit the planet to temperature increases above 4°C or more. While the most likely scenario will be somewhere between these two extremes, it is nonetheless important to conduct 'what if' analysis to understand the implications for what these scenarios might indicate for the economy. Cost-benefit analysis is the most common approach used within the literature for estimating the discounted future costs of climate change, and attempts to estimate all potential future costs and benefits across different climate change scenarios before discounting these estimates into present day dollars. These estimates are often used to calculate the marginal cost of emitting a tonne of CO_2. In this analysis we do not conduct a cost-benefit analysis, nor do we use an Integrated Assessment Model (IAM) to estimate the costs and benefits of different climate change scenarios. Instead, this report draws on several other studies (Ackerman and Stanton, 2006; The Economist, 2015; 2008) to inform the development of the sentiment scenarios and for conducting the macroeconomic analysis. As part of the long-term economic impacts of each sentiment scenario, a net present value (NPV) calculation is completed to compare the long-term impact on global GDP with respect to the Baseline scenario. At a discount rate of 6 per cent and for the period 2015-2050 the Two Degrees scenario has an economic benefit over Baseline of 3.2 per cent, while the No Mitigation scenario has a long-term cost to the economy of approximately 14 per cent.

We use sentiment indicators as surrogates for awareness or perception of the economic impacts of climate risk by the public, policymakers and investors alike, in order to drive the macroeconomic analysis. The ambiguous concept of economic sentiment is usually neglected by mainstream macroeconomics because it is not a variable easily observable or quantifiable (van Aarle and Kappler, 2012), and often dismissed as a psychological or subjective component of beliefs (Arias, 2014). Nevertheless, the effect of sentiment shifts on the macroeconomy can be significant. In this analysis we attempt to capture market sentiment using plausible stress test scenarios. A significant part of the sluggish recovery following a downturn can also be attributed to the pessimistic view held by markets. Negative or risk averse actors play a significant role during recessions, e.g. during the hyperinflation period of the 70's and beginning of the 80's. The pessimistic wave of weak confidence reinforces the downturn by further driving growth rates downwards, even though economic fundamentals may have already recovered (Arias, 2014).

3.1 The Oxford Economics' General Equilibrium Model (GEM)

We use the Oxford Economics' GEM,[7] a quarterly-linked international econometric model, to examine how the global economy reacts to shocks of various types. It is the most widely used international macroeconomic model with clients including the IMF and World Bank. The model contains a detailed database with historical values of many economic variables and equations that describe the systemic interactions among, the most important economies of the world. Forecasts are updated monthly for the five-year, 10-year, and 25-year projections.

The Oxford Economics' GEM is best described as an eclectic model, adopting Keynesian principles in the short term and a monetarist viewpoint in the long term. In the short term, output is determined by the demand side of the economy; and in the long-term, output and employment are determined by supply side factors. The Cobb-Douglas production function links the economy's capacity (potential output) to the labour supply, capital stock and total factor productivity. Monetary policy is endogenised through the Taylor rule, when central banks amend nominal interest rates in response to changes in inflation. Relative productivity and net foreign assets determine exchange rates, and trade is the weighted average of the growth in total imports of goods (excluding oil) of all remaining countries. Country competitiveness is determined from unit labour cost.

7 The Oxford Economics' Global Economic Model (GEM) is a rigorous quantitative modelling tool for forecasting and scenario analyses. http://www.oxfordeconomics.com

3.2 Variable descriptions

Using the Oxford Economics GEM, three independent scenarios simulating market sentiment shifts are modelled: Two Degrees, No Mitigation and the Baseline. The Baseline sentiment scenario is the projection trajectory updated regularly by Oxford Economics; it acts as the control in this study and represents the reference economic projection for comparing Two Degrees and No Mitigation.

Table 17 in Appendix F shows the shocks applied to the eight macroeconomic variables, which are existing parameters across countries and regions contained as part of the Oxford Economics' GEM, in terms of magnitude of the shock and the extent of spatial impact across each scenario.

Some countries are illustrated as having larger macroeconomic shocks applied as compared to others because they are subjected to higher impacts due to varying exposure levels for a given mean global temperature change. Moreover, developed countries have greater capital stocks and infrastructure to better withstand temperature rises, thereby increasing their resiliencies and correspondingly reducing the magnitude of shocks applied. While most macroeconomic variables are shocked across the five-year modelling period to simulate the shift in consumer behaviour, consumption, and policy, higher volatility parameters such as confidence and house price indices are shocked for one year. Thus, the model simulates both longer-term behavioural changes, policy impacts and the instantaneous effects of rapid shifts in market behaviour.

3.3 Macroeconomic results

In this section, we present the macroeconomic outputs in the short term, 2015-2020, based on the GDP@Risk calculations for each of the three sentiment scenarios. A simple long-term macroeconomic analysis, from 2015-2050, is given in Section 1.10 followed by a comparison between the short and long- term outcomes in Section 1.11.

Macroeconomic and financial market results were derived using the Oxford Economic Model driven by a set of exogenous macroeconomic input shocks. These input shocks represent changes in commodity prices, shifts in climate policy and shifts in market sentiment from each of the scenario narratives. The sensitivity of our results to the market confidence parameter is explored further in Box 1 below.

Table 2 summarises the key macroeconomic impacts of climate risks for each of the sentiment scenarios: growth rates and GDP figures. By definition, the technical indicator of a recession is two consecutive quarters of negative economic growth commonly measured by GDP. Table 2 illustrates a global recession occurs for up to three quarters in the No Mitigation scenario, where the global economy shrinks by up to 0.1 per cent (Q-on-Q) compared to the baseline quarterly growth projection of 0.7 per cent.

The main macroeconomic output modelled from GEM is a year-on-year projection of the global economy. The impacts of each sentiment scenario are compared with the baseline projection in which no crisis occurs. The difference in economic output over the five-year period between the baseline and each sentiment scenario represents the GDP@Risk.

The primary figure representing the impact of this catastrophe is the GDP@Risk metric, which represents the total difference in GDP between the baseline and the scenario-specified projections. The total GDP loss over five years, beginning in the first quarter of 2016 during which the shock of climate risk is applied and then sustained through to the last quarter of 2020, defines the GDP@Risk. This is further expressed as a percentage of the total GDP. Table 2 also provides the GDP losses for each scenario globally and across selected countries, both as the potential total lost economic output over five years, and and as a percentage of the total economic output from 2016 to 2020.

Table 2: Summary of macroeconomic impacts across the sentiment scenarios modelled

Macroeconomic Impact	Sentiment Scenarios				
	Baseline	Two Degrees		No Mitigation	
Global variables					
Min. quarterly growth rate (Global Recession Severity)	0.7 %	0.3 %		-0.1%	
Global Recession Duration	N/A	N/A		3 Qtrs	
Economic output	5-yr GDP (US$ Tn)	GDP@Risk (US$ Tn)	GDP@Risk (%)	GDP@Risk (US$ Tn)	GDP@Risk (%)
Global	407.3	8.9	2.2%	19.1	4.7%
United States	91.4	3.0	3.2%	7.6	8.4%
United Kingdom	14.3	0.3	1.7%	0.8	5.8%
Germany	19.3	0.3	1.5%	0.7	3.8%
Japan	29.5	0.1	0.4%	0.6	2.3%
China	51.1	2.4	4.7%	4.6	9.0%
Brazil	12.3	0.4	3.5%	0.8	6.3%

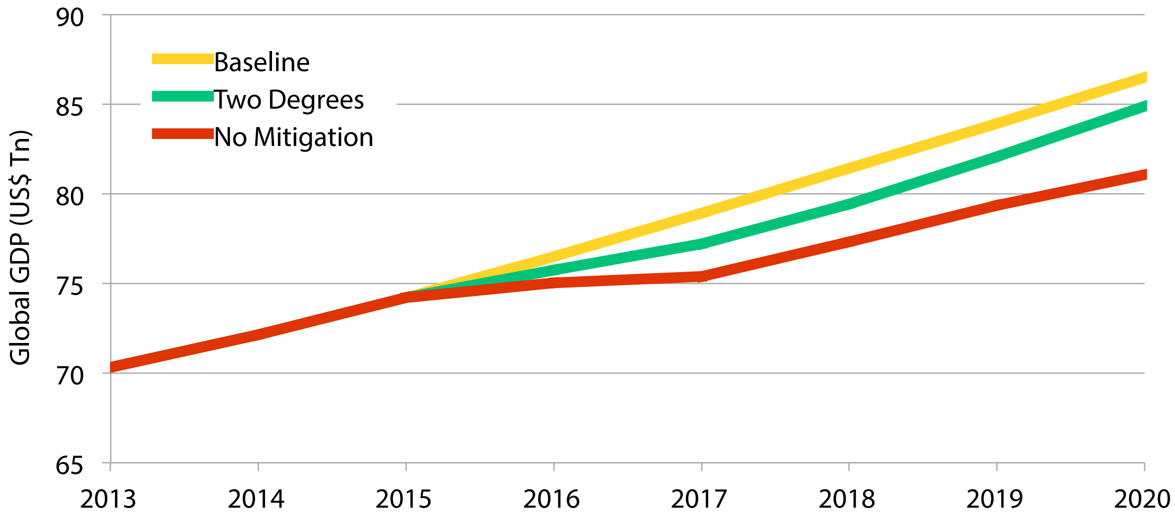


Figure 1: Modelled economic output between 2015 and 2020 for each sentiment scenario

3.4 Long-term impacts

The long-term economic impacts for each sentiment scenario were also analysed based on the underlying assumption that the sentiment shift in each case is consistent with the subsequent physical change in climatic conditions. The starting point for estimating long-term impacts includes running the GEM for a further five years to 2025. This allows the GEM, which is a general equilibrium model, to re-equilibrate to a new long-term growth trajectory based on the new economic conditions brought about in the initial five years.

From 2025 to 2050 we assume the annual growth rate of the global economy remains stable at year 10 (2025) annual growth rates. This compounding economic growth rate is then used to estimate annual global GDP levels to 2050. The further into the future economic output is projected, the greater is the uncertainty of those estimates. Therefore, maintaining economic growth at the best long-term estimate is a good first order approximation absent any additional information.

The long-term annual growth rates estimated from year ten are 3.5 per cent, 2.9 per cent and 2.0 per cent for the Two Degrees, Baseline and No Mitigation sentiment scenarios, respectively. Obviously higher annual growth drives higher long-term cumulative outcomes, which we give details next.

The results of this analysis are shown in Figure 2. Over the longer time horizon from 2015 to 2050, the divergence between the different sentiment scenarios becomes very pronounced. In fact the initial sentiment shock to the global economy cumulated over the first five years is negligible relative to the longer term cumulative impacts of climate change. We show that over the longer term, a rise in average global temperatures of not more than 2°C is beneficial to the global economy due to a higher annual economic growth rate than the Baseline No Mitigation scenarios. The long-term cumulative costs and benefits for each scenario over the 35-year period between 2015 and 2050 are shown in Table 3. When compared to the Baseline scenario using a discount rate of 3.5 per cent, the Two Degrees scenario is shown to have a 4.5 per cent beneficial global impact on cumulative output, while the No Mitigation scenario would have a negative impact of 16 per cent.

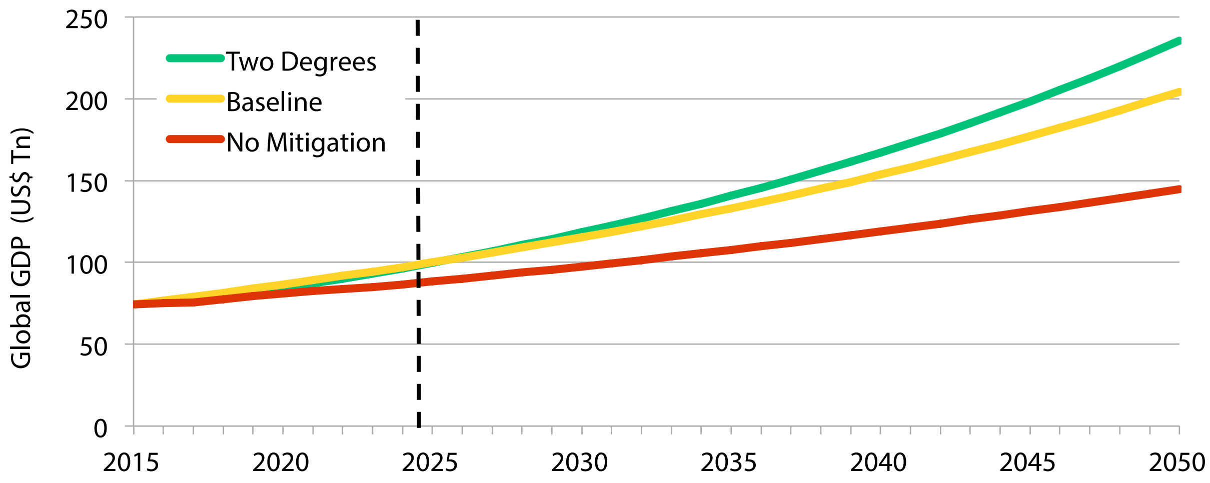


Figure 2: Comparison of the long-term GDP projections for each sentiment scenario

Table 3: Long-term impact with respect to baseline

	Long -term Impact of Scenarios with Respect to Baseline		
Scenario	No Discount Rate	3.5% Discount Rate	6% Discount Rate
Two Degrees	6.5%	4.5%	3.2%
No Mitigation	-19%	-16%	-14%

3.5 Economic conclusions

Although the physical effects of climate change will have limited impacts on the economy over the next five to 10 years, the effects of climate policy and market sentiment may cause significant economic disruption. The short-term economic impacts of both No Mitigation and Two Degrees result in negative consequences for the global economy. The No Mitigation scenario causes a global recession for the first three quarters of the analysis period, while the Two Degrees scenario does not cause a global recession but does cut economic growth in half when compared to baseline.

In the No Mitigation scenario the economy suffers an economic loss that continues indefinitely representing and ongoing loss to global economic output, while in the Two Degrees scenario the economy performs worse than Baseline for the first eight to twelve years, but eventually recovers and grows much faster than Baseline. Using a discount rate of 3.5 per cent over 35 years, the Two Degrees scenario outperforms the Baseline by 4.5 per cent, while the No Mitigation scenario against underpreforms the Baseline by 16 per cent.

4 Investment portfolio analysis

The macroeconomic effects of the climate impact sentiment scenarios will also inevitably impact financial markets. This section considers the market impact of the scenarios and corresponding consequences for investors in the capital markets.

The performance of bonds, equities and alternatives in different markets is estimated from the macroeconomic modelling, and compared with the performance at the start of the modelling period.

4.1 Valuation fundamentals

The goal is to estimate how the fundamentals of asset values are likely to change as a result of various market conditions. This analysis is not a prediction of daily market behaviour and does not take into account the wide variations and volatility that can occur in asset values due to trading fluctuations and the mechanisms of the market.

4.2 Passive investor assumption

Fundamentally, the analysis assumes a passive and "traditional" financial portfolio investment strategy, in which the proportions of different types of assets are fixed in advance, and are held constant via real-time rebalancing throughout a given period. This assumption is knowingly unrealistic, as an asset manager is expected to react to changing market conditions in order to rebalance risk across sectors and geographies within an asset class, and asset owners across asset classes, yet it is a useful exercise to consider what might happen to a fixed portfolio. It also provides a necessary benchmark representation against which active fund managers can compare the performance of dynamic strategies as well as informing what drives the behaviour of a fixed portfolio at different times. This draws investors' attention to whether improved portfolio management processes are required and gives greater insights into designing the optimal investment strategy.

4.3 Standardised investment portfolios

This study considers four typical high quality investment portfolios designed in consultation with the advisory panel and representatives from the financial services industry and insurance. They are fictional representative portfolios that mimic features observed in the investment strategies of insurance companies (High-Fixed Income Portfolio) and pension funds (Aggressive, Balanced and Conservative). For example, the Conservative Portfolio structure has 59 per cent of investments in sovereign and corporate bonds, of which 95 per cent are rated A or higher (investment grade), 40 per cent in equity markets and commodities make up the remaining 1 per cent of the portfolio structure.

The portfolio structures cover several asset classes and are geographically diverse. Investments spread across the developed markets of the US, UK, Germany and Japan, as well as the emerging markets of Brazil and China. The 40 per cent allocated to equity investments correspond to investments in stock indices. The Wilshire 5000 Index (W5000), FTSE100 (FTSE), DAX (DAX) and Nikkei (N225) are used to represent equity investments in the developed markets, while the Boverspa (BVSP) and SSE Composite Index (SSE) represent emerging markets. The maturity for long-term fixed-income bonds is assumed to be 10 years, while that of the short-term bonds either three months or two years, limited by the macroeconomic model outputs for each country.

4.4 High Fixed Income portfolio

Details of the High Fixed Income Portfolio are shown in Table 4, Figure 3 and Figure 4.

Table 4: Summary of the High Fixed Income portfolio asset allocation

Asset Class	USA	UK	Germany	Japan	Brazil	China	World	Total
Government 2 yr	8.0%	6.0%	4.5%	2.5%	1.5%	1.5%	0.0%	24.0%
Government 10 yr	7.0%	7.0%	5.5%	1.5%	1.0%	1.0%	0.0%	23.0%
Corporate 2 yr	3.0%	3.0%	3.0%	2.0%	1.5%	1.5%	0.0%	14.0%
Corporate 10 yr	6.0%	7.0%	3.0%	2.5%	1.5%	2.5%	0.0%	22.5%
RMBS 2 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RMBS 10 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equities	3.0%	2.5%	3.0%	1.0%	1.0%	1.0%	0.0%	11.5%
Cash	4.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%
Commodities	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	1.0%
Total	31.0%	25.5%	19.0%	9.5%	6.5%	7.5%	1.0%	100.0%

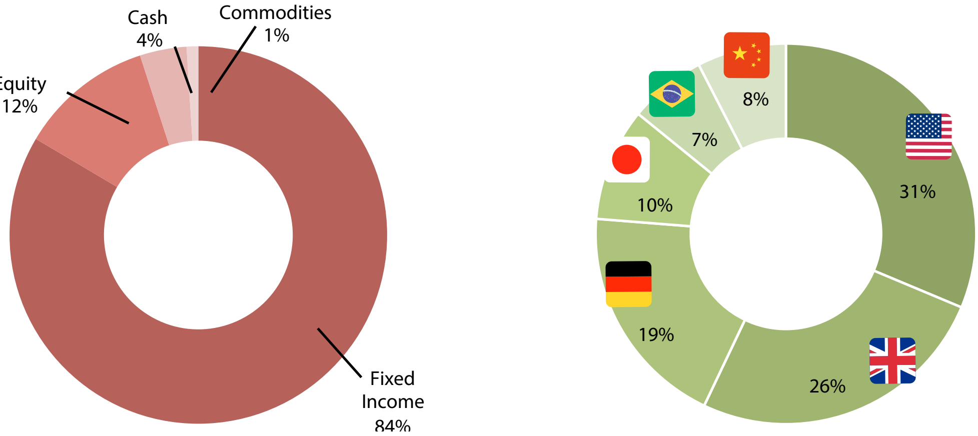


Figure 3: Asset class composition and geographic market spread in the High Fixed Income Portfolio structure

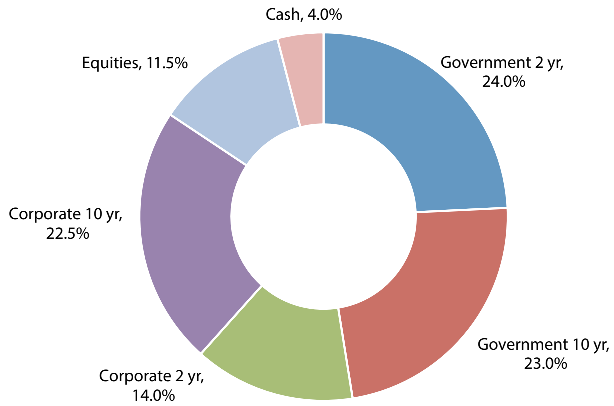


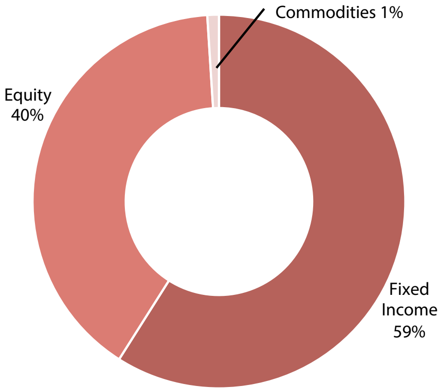
Figure 4: Idem detailed asset class breakdown of the High Fixed Income Portfolio structure

4.5 Conservative portfolio

Details of the Conservative Portfolio are shown in Table 5, Figure 5 and Figure 6.

Table 5: Summary of the Conservative portfolio asset allocation

Asset Class	USA	UK	Germany	Japan	Brazil	China	World	Total
Government 2 yr	4.0%	2.0%	3.0%	0.0%	1.0%	1.0%	0.0%	11.0%
Government 10 yr	3.0%	2.0%	3.0%	1.0%	1.0%	1.0%	0.0%	11.0%
Corporate 2 yr	5.0%	4.0%	5.0%	2.0%	1.0%	1.0%	0.0%	18.0%
Corporate 10 yr	5.0%	4.0%	5.0%	3.0%	1.0%	1.0%	0.0%	19.0%
RMBS 2 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RMBS 10 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equities	19.0%	8.0%	8.0%	5.0%	0.0%	0.0%	0.0%	40.0%
Cash	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commodities	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	1.0%
Total	36.0%	20.0%	24.0%	11.0%	4.0%	4.0%	1.0%	100.0%



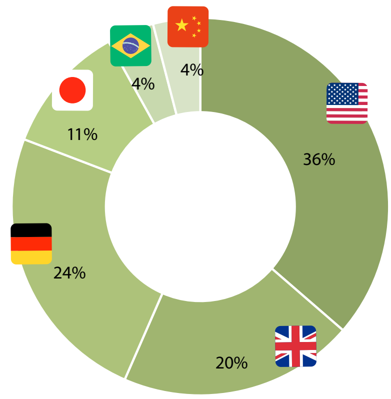


Figure 5: Asset class composition and geographic market spread in Conservative Portfolio

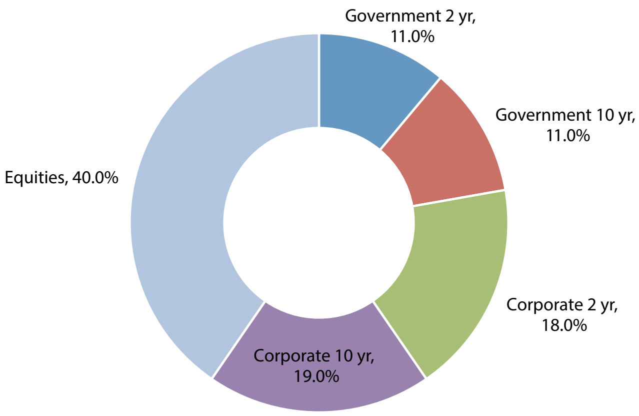


Figure 6: Detailed asset class breakdown of Conservative Portfolio structure

4.6 Balanced portfolio

Details of the Balanced Portfolio are shown in Table 6, Figure 7 and Figure 8.

Table 6: Summary of the Balanced portfolio asset allocation

Asset Class	USA	UK	Germany	Japan	Brazil	China	World	Total
Government 2 yr	3.0%	1.0%	3.0%	1.0%	0.5%	0.5%	0.0%	9.0%
Government 10 yr	3.0%	1.0%	3.0%	1.0%	0.5%	0.5%	0.0%	9.0%
Corporate 2 yr	4.0%	3.0%	5.0%	2.0%	0.5%	0.5%	0.0%	15.0%
Corporate 10 yr	5.0%	2.0%	5.0%	1.0%	0.5%	0.5%	0.0%	14.0%
RMBS 2 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RMBS 10 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equities	23.0%	9.0%	9.0%	4.0%	2.0%	3.0%	0.0%	50.0%
Cash	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commodities	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	3.0%
Total	38.0%	16.0%	25.0%	9.0%	4.0%	5.0%	3.0%	100.0%

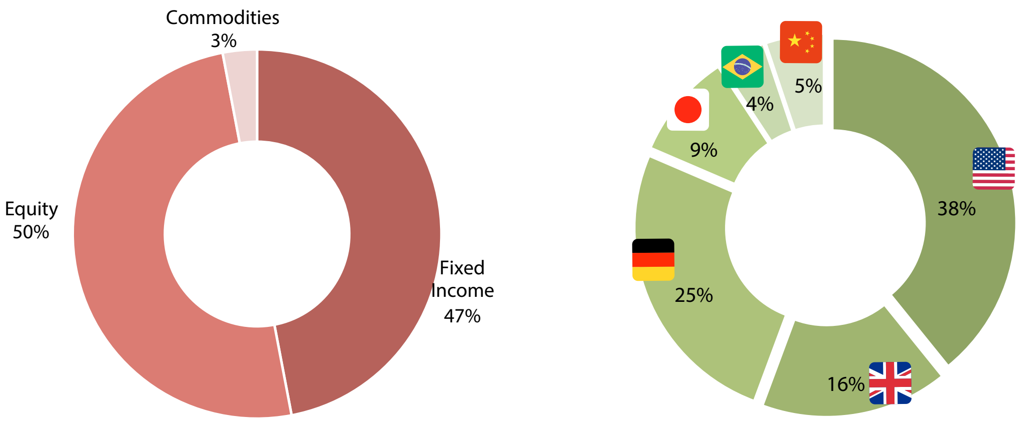


Figure 7: Asset class composition and geographic market spread in Balanced Portfolio

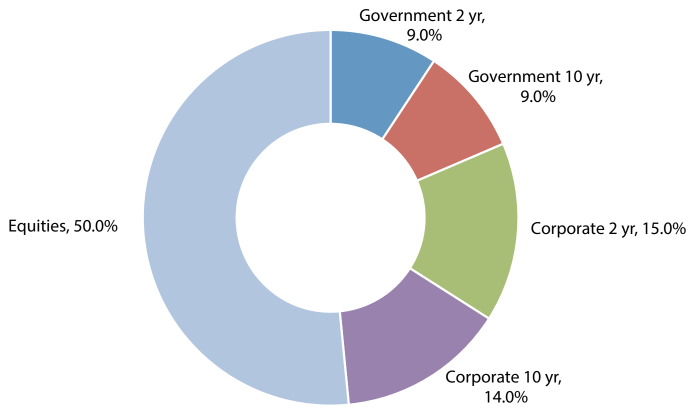


Figure 8: Detailed asset class breakdown of Balanced Portfolio

4.7 Aggressive portfolio

Details of the Aggressive Portfolio are shown in Table 7, Figure 9 and Figure 10.

Table 7: Summary of the Aggressive portfolio asset allocation

Asset Class	USA	UK	Germany	Japan	Brazil	China	World	Total
Government 2 yr	2.0%	1.0%	1.0%	0.5%	0.5%	0.5%	0.0%	5.5%
Government 10 yr	2.0%	1.0%	1.0%	0.5%	0.5%	0.5%	0.0%	5.5%
Corporate 2 yr	4.0%	2.5%	2.0%	1.5%	1.0%	1.0%	0.0%	12.0%
Corporate 10 yr	4.0%	2.5%	2.0%	1.5%	1.0%	1.0%	0.0%	12.0%
RMBS 2 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RMBS 10 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equities	26.0%	11.0%	10.0%	5.0%	4.0%	4.0%	0.0%	60.0%
Cash	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commodities	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	5.0%

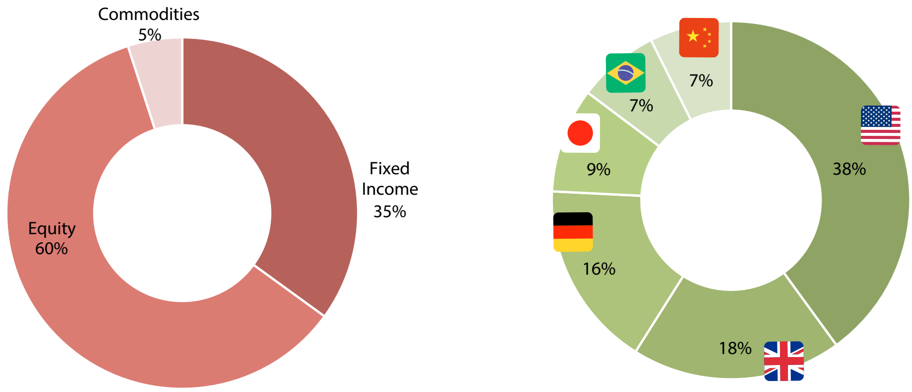


Figure 9: Asset class composition and geographic market spread in Aggressive Portfolio

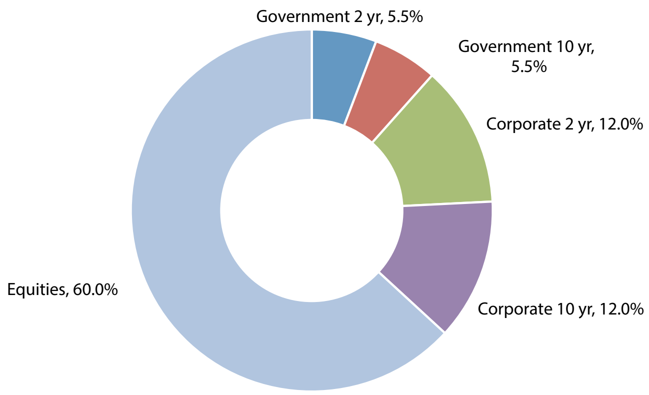


Figure 10: Detailed asset class breakdown of Aggressive Portfolio

4.8 Computation of returns

Portfolio returns are estimated using the following method.

Market price changes or Mark to Market (MtM) are calculated for all government bonds using equation (1) and for corporate bonds and RMBS using equation (2):

1 $\Delta MtM_{Gov,t} = (D_b)(-\Delta I/100)$

2 $\Delta MtM_{Corp,t} = (D_b)(-\Delta I/100) + (SD_b)(-\Delta CS/100)$

Here, D_b is the bond duration, for which we assumed the following values: D_b = 7 for ten-year bonds, D_b = 1.8 for two-year bonds, and D_b = 0.4 for three-month bonds. SD_b represents the spread duration. The change in interest rates, ΔI on government and corporate bonds and the change in credit spreads, ΔCS, are taken from the output of the macroeconomic analysis discussed in the previous chapter.

Government bond yields are estimated using a representative quarterly yield while corporate and RMBS yields are estimated using a representative quarterly yield and the period averaged credit spread.

Market prices for equities are calculated using the change in equity value from the macroeconomic modelling. Dividends are estimated using a representative quarterly yield. Exchange rate effects are taken into account to ensure all reported portfolio returns are illustrated in US dollars.

4.9 Portfolio returns

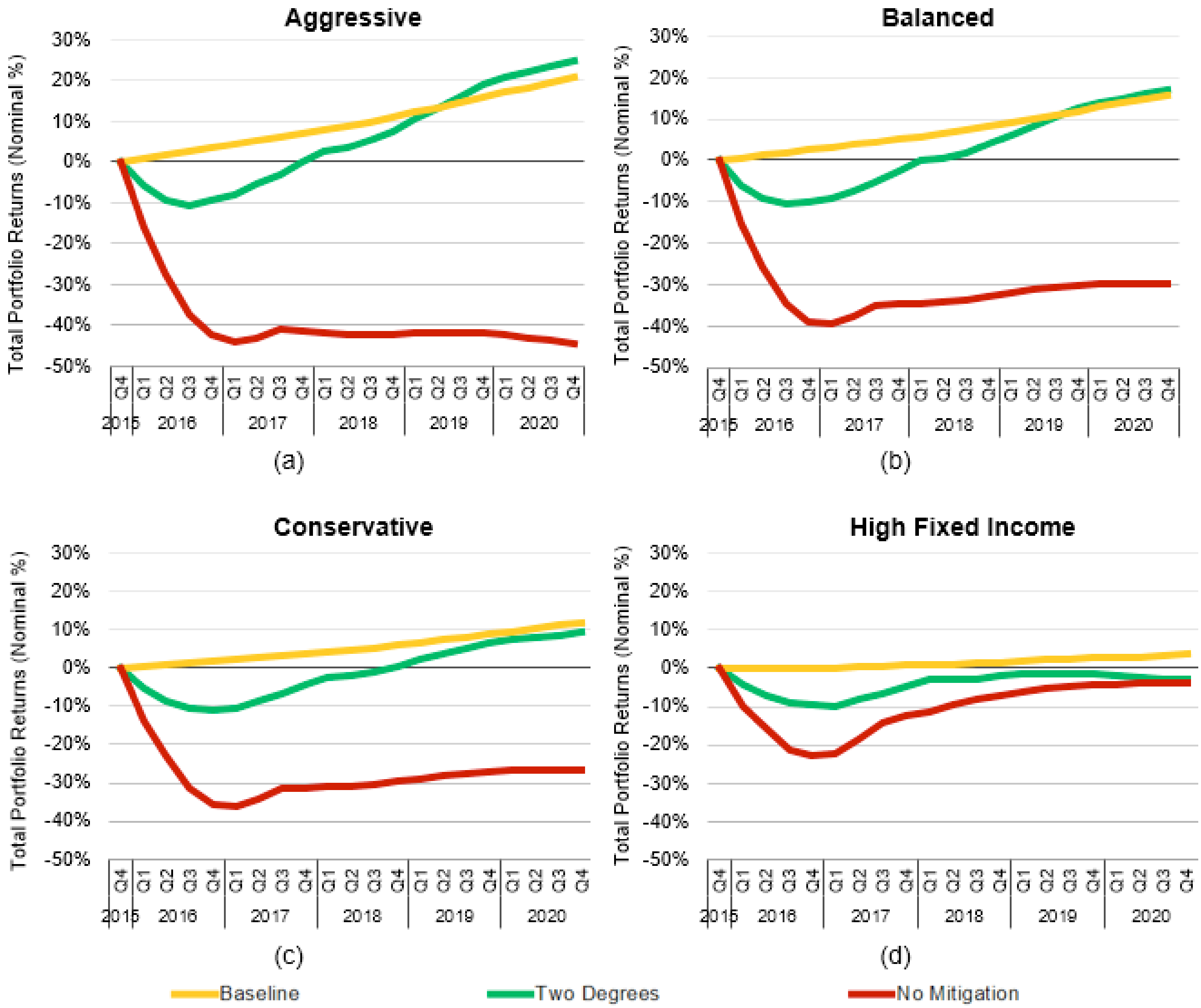


Figure 11: Comparison of total portfolio returns across sentiment scenarios

Figure 11 shows the scenario impacts by variant across all portfolio structures. We compared the impacts of the scenarios in terms of total portfolio nominal returns. Across all portfolio structures and scenarios, there are significant deviations from the baseline projections during the first year of the economic shocks, applied over a five-year period starting in 2016 Q1.

In the No Mitigation scenario, the Aggressive portfolio performs worst, recording a maximum loss of negative 45 per cent and registering a permanent loss with returns not being restored to baseline projection levels. This is consistent with economic theory on climate change, which also projects a loss into perpetuity. What is different in this result is that these losses are real and generate an immediate impact on the balance sheets of companies rather than representing a hypothetical future value discounted into present day values.

On the contrary, the Aggressive portfolio recovers relatively quickly, despite suffering the largest loss in the Two Degrees scenario, and its total returns are above and beyond the baseline projection levels by the end of the modelling period. This trend is consistent with expectations regarding asset class performance: economic shocks have the largest impact on equities, causing the Aggressive portfolio to react the most, as it has the largest equity allocation weights.

Regardless of the sentiment scenario studied, the High Fixed Income portfolio will be least at risk of any financial market disruption. However, this portfolio also experiences low performance and small overall gains.

4.10 Impact on returns – by asset class and geography

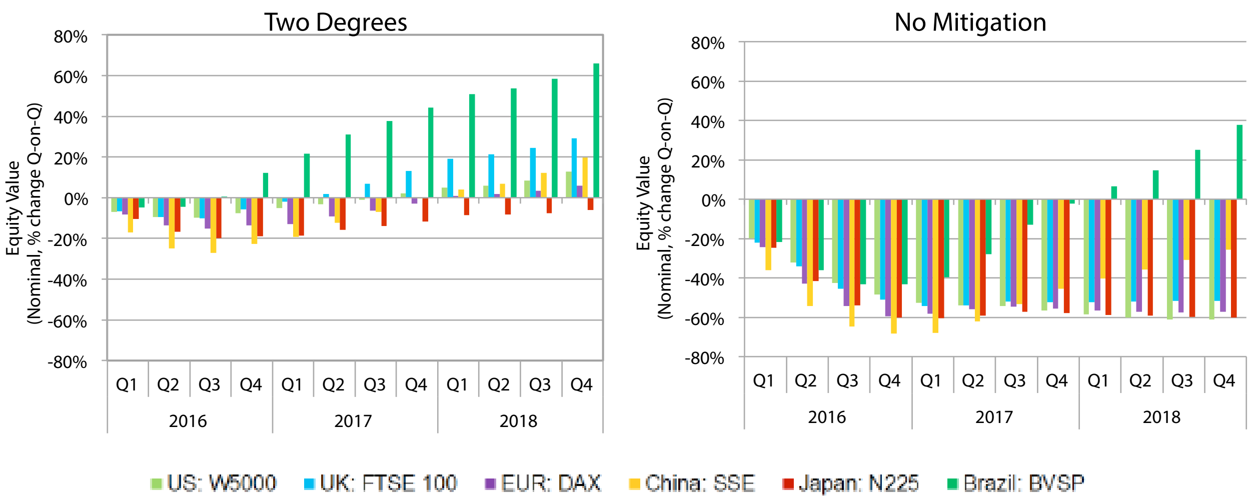


Figure 12: Comparison of equity performance by geography in nominal per cent change across sentiment scenarios

Figure 12 shows market impacts on equity performance by geography, primarily resulting from the degree of vulnerability of each country's economic fundamentals and responses to the applied shocks. In the Two Degrees scenario, the US (W5000), UK (FTSE), Europe (DAX) and Brazil (BVSP) recover quickly from losses to generate positive returns by the second year. However, across both scenarios, the Chinese (SSE) stock index is the most negatively impacted in the short run – and does not recover after three years – whereas the Japanese (N225) stock index is the most heavily affected on average (and also in the long run).

Figure 13 shows the market impacts on fixed income performance by geography. Overall, the negative impact on fixed income is not as significant as that experienced by equities – with the largest negative fixed income loss recorded at 36 per cent, as compared to almost twice as much (68 per cent) for equities. This suggests that equities are more volatile than fixed income assets in these scenario analyses, making the aggressive portfolio react the most across the sentiment scenarios.

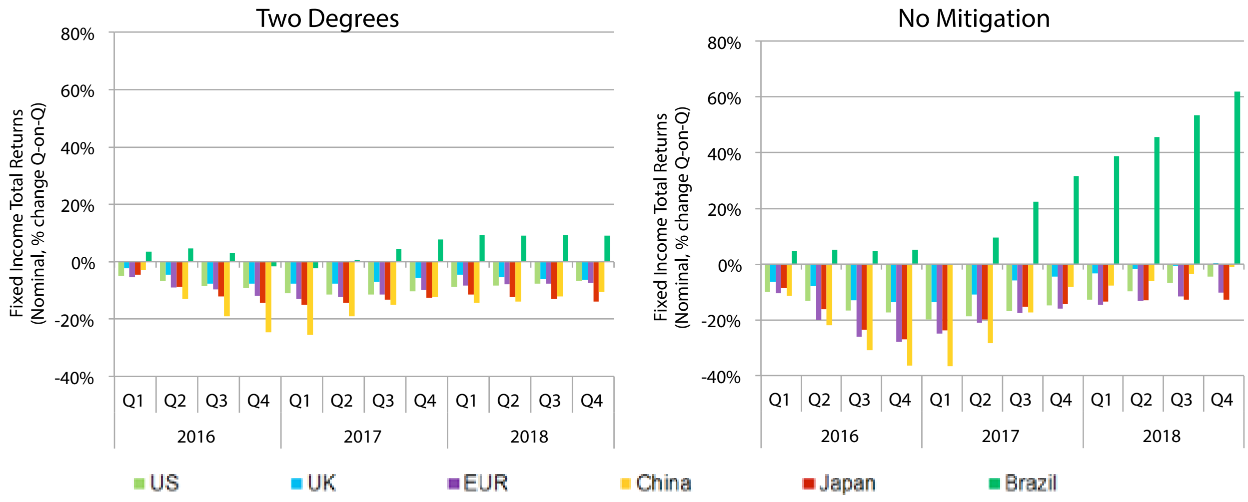


Figure 13: Comparison of fixed income performance by geography in nominal per cent change across sentiment scenarios

4.11 Impact on returns – by industry sector

The impact on equity returns by industry is calculated based on the respective sectors' betas, which represent volatility compared to the respective market indices. Both levered and unlevered beta values are compiled annually for each industry and across countries by Professor Aswath Damodaran from the Stern School of Business at New York University. These are then retrieved online[8] and analysed to better model sectoral impacts.

Beta is a measure of a sector's volatility, or unsystematic risk, in comparison to the market as a whole. In this study, we explored the impacts on industry sectors due to climate risks through shocks applied to the beta values. The region-specific climate damage functions, obtained in Section 5 Appendix D, are translated into shocks to the industry betas accordingly, so as to vary their volatility consistent with each scenario.

For example, in the No Mitigation scenario, agricultural productivity falls significantly due to global warming acceleration, leaving the agriculture sector in general subjected to greater climate risks and hence volatility, resulting in significantly larger beta values. These shocks then propagate through sectoral equity performances and are used to provide clarity and comparison across countries and sectors, as well as between the Two Degrees and No Mitigation.

Finally, within each market, the equity performance by industry (Table 8 and Table 9) is measured based on the notional Value-at-Risk (VaR), defined in this study as the drop in performance in the worst impacted quarter over the five-year modelling period (i.e. the worst one of twenty quarters, hence the notional 5th percentile).

The top three worst performing sectors are the same in both scenario variants, which shows that systematic effects (i.e. economy-wide effects) dominate over the short term (Table 8). In developed economies, the worst performing sector is Real Estate, closely followed by Basic Material, Construction and Industrial Manufacturing. In emerging economies, the worst performing sectors are Energy/Oil and Gas, Consumer Services and Agriculture. Theoretically, it is possible to hedge risk by switching investments from the worst-performing sectors to the better performing ones, e.g. Real Estate to Transport or Agriculture in developed markets in the No Mitigation Scenario (Table 9).

8 Damodaran, A. (2015) Current dataset for levered and unlevered betas by industry. [Online] Available on: http://people.stern.nyu.edu/adamodar/New_Home_Page/datacurrent.html (Assessed 24 Feb 2015)

Table 8: Worst performing industry sectors across both developed and emerging economies

	Sentiment Scenarios	No Mitigation		Two Degrees	
	Countries	Developed	Emerging	Developed	Emerging
Worst performing sectors across countries	Real Estate	-36%	-38%	-19%	-24%
	Basic Material	-26%	-36%	-14%	-23%
	Construction	-26%	-31%	-14%	-20%
	Energy / Oil & Gas	-24%	-77%	-13%	-51%
	Consumer Services	-20%	-44%	-11%	-30%
	Agriculture	-17%	-40%	-9%	-25%

Table 9: Best performing industry sectors across both developed and emerging economies

	Sentiment Scenarios	No Mitigation		Two Degrees	
	Countries	Developed	Emerging	Developed	Emerging
Best performing sectors across countries	Transport	-17%	-27%	-9%	-17%
	Agriculture	-17%	-40%	-9%	-25%
	Consumer Retail	-20%	-26%	-11%	-18%
	Health Care	-21%	-23%	-11%	-15%
	Industrial/Manufacturing	-25%	-26%	-13%	-16%
	Technologies	-21%	-27%	-11%	-16%

The box plots presented in Figures 14 to 17 show the distribution of returns for each sector. For example, in Figure 19, the “box and whiskers” representing Real Estate is built from the 20 quarterly return figures for the Real Estate sector in the No Mitigation Scenario, hence the top and bottom of the range are the best and worst quarterly return figures, respectively, over five years. We define the bottom of the range as “notional VaR”.

Figure 14 and Figure 16 are for the US (representing the developed economies) while Figures 15 and 17 are for China (representing the emerging markets). In the developed countries, Real Estate represents the most impacted sector for both No Mitigation and Two Degrees. However, the notional VaR for Real Estate in the No Mitigation scenario is -35 per cent while the notional VaR for the Two Degrees scenario is -20 per cent. This analysis shows that heavy users of fossil fuel resources are particularly vulnerable to movements in fossil fuel prices. Thus, it is not surprising to note that basic materials, construction and industrial manufacturing are among the worst performing sectors in the No Mitigation scenario, especially in developed markets, ranked in terms of notional VaR.

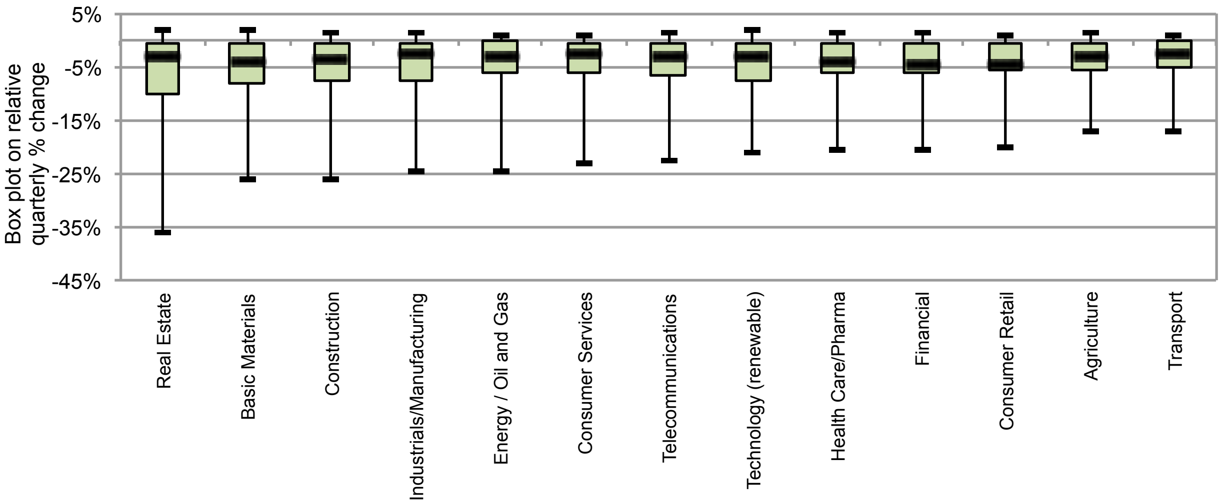


Figure 14: US market equity performance across industry sectors – No Mitigation scenario

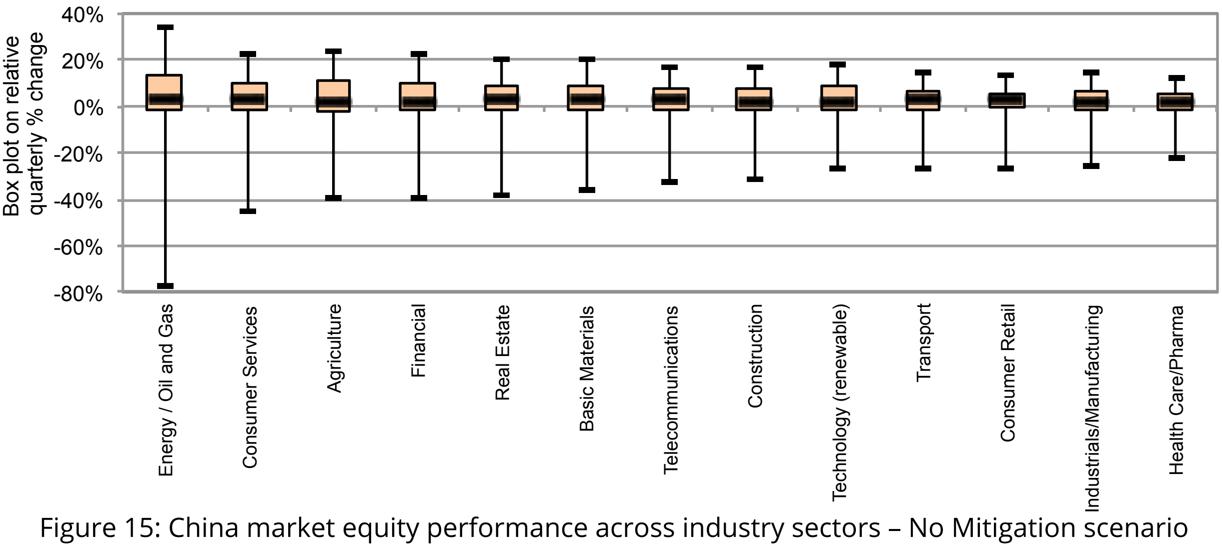


Figure 15: China market equity performance across industry sectors – No Mitigation scenario

Another sector worth emphasising is the Energy/Oil and Gas sector, which is among the worst performing sectors in emerging markets for both sentiment variants. In the No Mitigation scenario, a preference for higher energy demand dominated by fossil fuels leads to a decrease in volatility for energy stocks over time, limiting their recovery. Further, energy stocks are relatively more volatile in emerging markets than developed economies resulting in amplified losses as equity indices relatively underperform when economic shocks are applied. Hence, even though energy stocks better perform in developed markets, these stocks are generally underperformers when compared to the rest of the sectors.

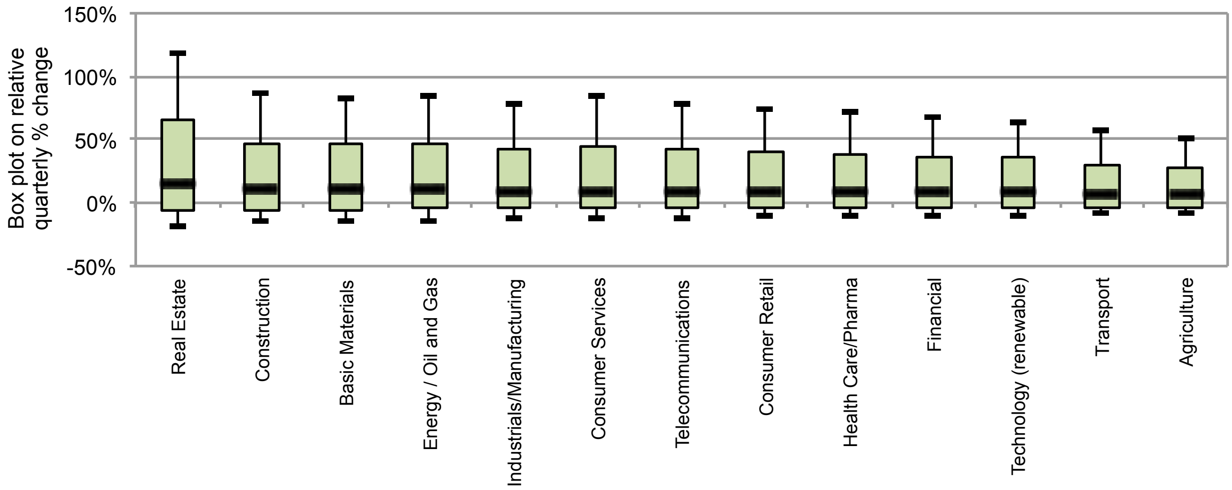


Figure 16: US market equity performance across industry sectors – Two Degrees scenario

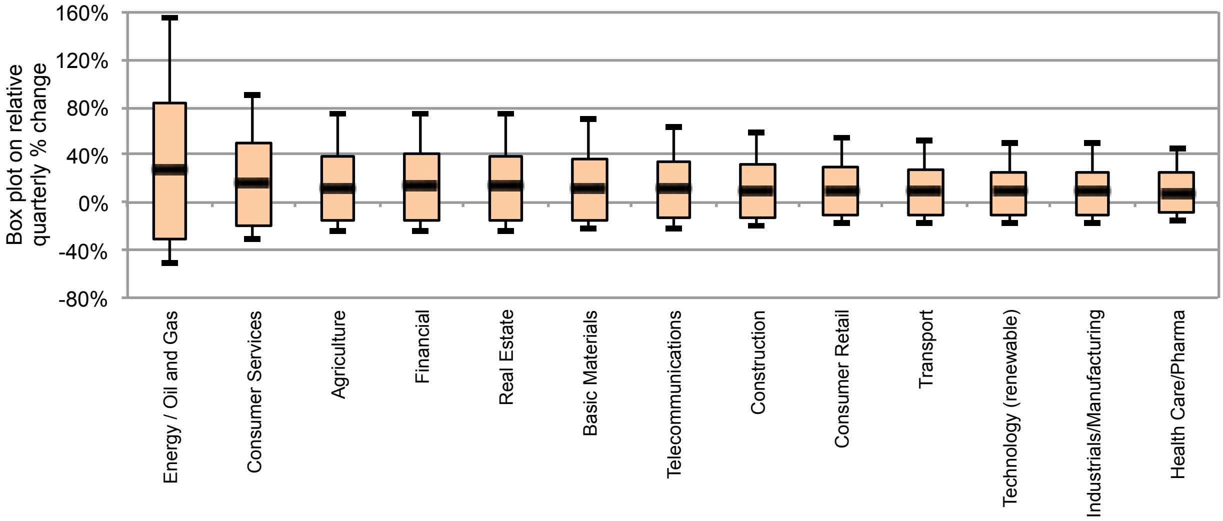


Figure 17: China market equity performance across industry sectors – Two Degrees scenario

4.12 Financial conclusions

Our analysis enables us to quantify the impact of climate risk scenarios on different asset classes, sector industries and regions. In particular, we can assess to what extent standard portfolio reallocation would enable investors to shield themselves from different scenarios.

By analysing sectors in developed and emerging markets (in Figure 14 to Figure 17), we can reveal the hedging potential of cross-industry diversification and investment in sectors with low climate risk. We find that under No Mitigation, the worst-case scenario, it is possible to cut the maximal loss potential by up to 47 per cent by shifting from Real Estate (in developed markets) and Energy/ Oil & Gas (in emerging markets) towards Transport (in developed markets) and Health Care/ Pharma (in emerging markets).

This implies that just slightly less than half of the returns impacted due to climate change can be hedged through cross-industry and regional diversification.

Table 10: Summary of portfolio performance measured by the 5 per cent VaR by structure and scenario, nominal per cent

Portfolio Structure	Baseline	Two Degrees	No Mitigation
High Fixed Income	0	-10%	-23%
Conservative	1%	-11%	-36%
Balanced	1%	-11%	-40%
Aggressive	1%	-11%	-45%

Table 11: Summary of portfolio performance (long-term impact after 5 years) by structure and scenario, nominal per cent

Portfolio Structure	Baseline	Two Degrees	No Mitigation
High Fixed Income	4%	-3%	-4%
Conservative	12%	9%	-26%
Balanced	16%	17%	-30%
Aggressive	21%	25%	-45%

Interestingly, we find a similar magnitude for the hedging potential of different portfolio allocations. Table 10 and Table 11 consider the notional VaR and long-term impact by portfolio structure and scenario. From this we can infer that, under No Mitigation, 49 per cent (=(45-23)/45) can be hedged by shifting from more equity-loaded portfolios (Aggressive) to a fixed income-heavy portfolio (High Fixed Income). Contrasting this to the portfolio's longer-run performance, portfolio managers can use the hedging potential across portfolio structures to maximise gains up to 28 per cent by shifting from a high fixed income investment to an equity-loaded structure (Aggressive) under Two Degrees.

An investment manager wishing to hedge climate risks for both Two Degrees and No Mitigation scenarios is advised to adopt the High Fixed Income portfolio containing assets from developed markets. Even though long-term returns are low in this case, downside losses are minimised. In the event of a Two Degrees scenario, there is little opportunity to hedge downside climate risk through portfolio construction. In the event of a Two Degree scenario an Aggressive portfolio offers the best positive returns over the long term. In the event of a No Mitigation scenario, the High Fixed Income scenario offers both the best protection against downside risk and the best long-term performance.

5 Conclusion

This study has quantified the implications of climate risk on investment portfolios over the short term. As far as we are aware, this is the first time that research addressing this question has been attempted. Previous studies have analysed the direct physical effects of climate change over the long term, typically in the latter half of this century, when the effects of climate change will have already started to have major impacts. These studies then discount the future impacts of climate change and provide an estimate in net present value terms. However, financial markets could be affected much sooner by market sentiment, which may change as new information comes to light about the effects of climate change.

The innovative approach adopted in this research allows us to simulate 'what-if' scenarios relevant for the next five years. The effects of climate change on markets will be driven by the projections of likely future impacts, for instance from new technology, changing regulation, indirect climate change impacts and shifting market sentiment. The scenarios we developed are coherent, quantifiable narratives. Although highly unlikely, they still are plausible for describing how expectations about future climate trajectories may have an impact on economic and financial markets over the next five years. This study therefore quantifies the potential financial impacts of a shift in market sentiment, driven by significant changes in investor and consumer beliefs about the future effects of climate change.

We find that, even in the short term, climate risks pose a significant threat to investment portfolio performance. In the worst-case scenario, a global recession occurs during the first three quarters of the shock and the global economy never recovers, losing an estimated 16 per cent of economic output by 2050. In the alternative scenario, action to limit warming to within 2°C will have negative short-term costs, lowering economic output for over a decade when compared to baseline. However, the long-term benefits make the transition worthwhile, increasing aggregate output to 2050 by up to 4.5 per cent above baseline projection levels. Investors are therefore encouraged to take a long-term perspective when considering climate risk in investment portfolios.

Nevertheless, investors cannot entirely shield themselves from the exposure to climate change. Although we have shown that 47 per cent and 49 per cent of impacts due to climate change can be hedged through cross-industry and portfolio construction, these two "halves" are not cumulative such that no one strategy is able to offer more than 50 per cent coverage of "hedgeable" risk. Climate risks therefore will remain an aggregate risk driver that requires system-wide action to mitigate its economy-wide effects.

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Appendix A Literature review

Table 12: Summary of climate risk-related research papers and reports

Year	Report	Contributor(s)	Nature of Contributor
2015	Investing in a time of Climate Change	Mercer	Global investment consultant
2015	From boom to bust? Climate risk in the golden state	Risky Business Project	Economic research firm
2015	Responding to Climate Change Risk in Portfolio Management	Schroders	Asset management company
2014	Climate Change is a Global Mega - Trend for Sovereign Risk	Standard and Poor's	Financial services company
2014	Managing Climate Risks to Well - Being and the Economy	Committee on Climate Change	Independent advisory to the UK Government
2014	Asset Allocation Survey: European Institutional Marketplace overview	Mercer	Global investment consultant
2011	Climate Change Scenarios – Implications for Strategic Asset Allocation	Mercer	Global investment consultant
2005	Framing Climate Risk in Portfolio Management	Ceres and World Resources Institute (WRI)	Non-profit organisations
2015	The cost of inaction: Recognising the value of risk from climate change	The Economist Intelligence Unit	Popular economic journal

Appendix B Climate risk

B.1 The climate science

Climate change is not a new phenomenon and dates back to the 18th century when Joseph Fourier (1768 – 1830) provided a mathematical proof demonstrating the effects of terrestrial and atmospheric radiant heat that drive the so-called green-house-effect. Building on this early work, Svante Arrhenius (1859 – 1927) showed the importance of atmospheric CO_2 in trapping heat and warming the earth's surface (Labatt and White, 2007, p.3). Arrhenius was the first scientist to publish estimates on the climate sensitivity metric, which represents the amount of heating that will be caused by a doubling of CO_2 levels in the atmosphere. He predicted that a doubling of CO_2 would cause an increase in global average temperatures of between 1.5 to 5.0°C, an estimate not too dissimilar from recent climate model projections. Since the Industrial Revolution the amount of CO_2-eq[9] in the atmosphere has increased from roughly 280ppm to 400ppm today, representing an increase of approximately 40 per cent. This concentration is the highest in the last 800,000 years and is likely to be the highest level for the last 20 million years. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased to unprecedented levels, driven primarily through fossil fuel emissions and secondly from net land use change emissions due to human activity. Anthropogenic CO_2 emissions have been accumulating in the atmosphere, ocean and terrestrial ecosystems at an increasing rate since the industrial revolution. The latest climate science as reported by the IPCC Working Group 1 AR5 summarises the following:

The atmosphere and oceans have warmed, the amount of snow and ice have diminished, sea levels have risen, and the concentration of greenhouse gases have increased (Stocker, 2014).

Since the publication of the latest IPCC reports (AR5) climate models have improved considerably. The models are now able to reproduce observed continental, scale surface temperature patterns, rapid warming since the mid-20th century and cooling immediately following volcanic eruptions. The attribution of climate change to human influence has been confirmed across many climate systems, making it extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century (Alexander et al., 2013).

B.2 Looking ahead

If left unchecked, continued emissions of green-house gases will cause further changes in all components of the climate system and lead to warming of 0.3-4.8°C[10] across the range of Representative Concentration Pathway[11] (RCP) scenarios. The global oceans will continue to warm and become increasingly acidic, affecting marine life. Warming oceans may also affect ocean circulation currents and weather patterns. It is extremely likely that Arctic Sea Ice cover will continue to shrink and thin, opening up the North West shipping route. Under RCP8.5 it may even become ice-free by the middle of this century. Spring snow cover will decrease as global mean surface temperatures rise. Glaciers across the world will continue to melt, potentially decreasing in volume between 15 per cent and 85 per cent. Global mean sea level will continue to rise and will very likely exceed the rates of increase experienced over the period 1971-2010, most ocean warming and increased loss of mass from glaciers and ice sheets. The likely range in sea-level rise will be between 0.26-0.82m across the different RCP scenarios (Table 13).

Table 13: Projected change in global mean surface air temperature and global mean sea level rise for mid and 21st century relative to the reference period of 1986-2005

		2046 -2065		2081 -2100	
	Scenario	Mean	Likely Range	Mean	Likely Range
Global Mean	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
Surface	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6

9 CO_2-eq are the total Green House Gases given in equivalent CO_2 units
10 Based on CMIP5 ensemble using a 5-95per cent confidence interval (Alexander et al., 2013)
11 Representative Concentration Pathways (RCPs) refer to the levels of radiative forcing in the atmosphere caused by increasing anthropogenic GHG emissions. The IPCC has published details on four RCP scenarios to represent the range of alternative possible climate change trajectories in the future

Temperature	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
Change	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
Global Mean Sea	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
Level Rise (m)	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Source: IPCC AR5 WG1, Summary for policy makers (Alexander et al., 2013) .

B.3 Opportunities for stabilisation and climate change commitment

The effects of climate change to come over the next century are largely determined by the cumulative stock of CO_2 emissions in the atmosphere. Given the capacity of the earth-climate system to reabsorb anthropogenic CO_2 emissions takes a very long time, the majority of emissions that are created this century will stay in the atmosphere for many centuries to come. It is estimated that between 15 per cent and 40 per cent of total emitted CO_2 will remain in the atmosphere for 1,000 years or more (Stocker, 2014). Therefore most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped and no attempt is made to remove the stock of emissions already in the atmosphere.

B.4 Climate change adaptation

Adaptation is the process of managing climate change impacts. While climate change mitigation attempts to prevent the worst of climate change from occurring, climate change adaptation attempts to minimise the worst impacts through building resilience to climate change as it occurs. Adaptation strategies therefore have the potential to minimise some of the worst effects of climate change. Wealthy first world countries will benefit the most from adaptation, while poorer developing countries will be the most affected without the means to prevent the most damaging impacts (Field, 2014). Weather events can have enormously varying impacts for different populations depending on vulnerability and capacity to cope. If correctly implemented, adaptation measures have the potential to reduce some of the risks that climate change poses to human populations. However, some of these measures, like geoengineering, have unknown and potentially uncertain dangerous side effects (Heyward, 2013). Geoengineering solutions that block radiant energy from entering the earth do not solve other problems like changes to the terrestrial carbon cycle and ocean acidification. Other studies have concluded that geoengineering is not a magic bullet and the acceptability of such solutions will be driven as much by social, legal and political issues as by scientific and technical factors (Shepherd, 2012).

B.5 The economics of climate change

It is now unequivocal that climate change is occurring and that human activities are a major contributory factor. Over the last decade there have been significant advances in the ability of climate models to simulate the impacts of CO_2 emissions on the world's ecosystems. As these models have evolved and grown in sophistication the impacts of climate change have become increasingly acute. In the seminal work by Sir Nicholas Stern (2007), climate change was shown to not just be a scientific concern but also pose a serious economic threat. Stern estimated that unabated climate change could cost the economy between 5 per cent and 20 per cent of annual global GDP if not tackled soon. The financial implication of such a large decrease in global productivity is evident. By acting promptly and avoiding the worst impacts Stern estimated the costs could be as low as 1 per cent of GDP. The range in economic costs being estimated show the challenges that must be faced by investors who wish reduce their exposure to climate risk and alleviate such potential losses.

Many economists describe climate change as one of the greatest market failures known to man. The inability of the market to effectively put a price on carbon means there are no incentives for driving a change in behaviour, thus increasing the overall risk of climate change. Most notably, if climate change continues unabated, it will be the future generations who will be burdened with a greater share of these risks.

B.6 Climate change risks

Unlike pollution, acid rain or contaminated land, climate change is a global phenomenon and has potential to affect all companies, sectors and countries across the world. Climate change is therefore one of the most financially significant environmental concerns facing investors today. Complicating matters further, climate risks are not all equal. Different sectors, regions and assets will be affected to varying degrees depending on their geographic location, energy intensity and proximity to climate induced extreme events. Modelling the differences in impacts across regions, sectors and assets is therefore critical to finding solutions and adopting strategies that can be used to minimise the risks of climate change and reduce aggregate losses.

On the basis of the IPCC results, an increase in temperature of 2°C (~400ppm) above pre-industrial levels is thought to be the maximum 'safe' level that can be reached without causing excessive environmental harm. Although this target has been officially endorsed and scientifically justified, some scientists argue that the danger threshold is actually much lower (Tschakert, 2015). Hansen (2005) argued that a 2°C limit inappropriately accounted for climate sensitivity and climate feedback processes and committed the planet to significant warming. Hansen instead advocated for a temperature increase of 1.5°C (~350ppm). The 2°C limit also fails to protect many of the world's poorest countries and ignores the potential for tipping points or points of no-return where climate change impacts would be much more severe.

A number of research studies have been completed that identify the risks which are amplified by the effects of climate change. While most risks are region specific, the overall consequences of climate change are negative.

Direct risks

- Increases in the frequency of extreme weather events. Increased risk of flooding
- Increased risk of droughts
- Increased risk of water stress
- Increased number of extreme temperature events
- Changes in the distribution and activity of parasites
- Altered agricultural productivity

- Changing fish stocks and migratory patterns
- Disturbance of complex ecological systems

Extreme weather events are one of the most prominent and talked about impacts of climate change (Bouwer, 2010). The IPCC finds that the frequency of heavy rainfall and heat waves has increased, that the area affected by drought has increased in many regions and that tropical cyclone activity has increased in the North Atlantic Ocean (Solomon et al., 2007). Unfortunately weather extremes are generally omitted or included in a very crude manner (Tol, 2006). Therefore the cost of extreme weather events is under-represented in most cost-benefit analysis of global climate policy, downplaying the magnitude of potential impacts. There are several reasons for this obvious oversight that mostly come down to the uncertainty in estimating the complex interactions that occur between hazards, exposure and vulnerability (van den Bergh, 2009).

Indirect risks

Aside from economic impacts, other indirect risks associated with climate change are often overlooked, but have potential to cause some of the most significant social and economic disruption. For example, *Risky Business*, a report published on the risks of climate change in the US, focuses exclusively on the direct physical effects of climate change and their impacts but ignores the indirect consequences that may result from a changing climate. Most climate change studies focus on impacts that occur within a country's territory, but other factors also make those countries susceptible to climate change. The world is highly complex, and countries are interdependent, relying heavily on global markets for access to critical resources. Indirect risks can be broadly classified into four distinct categories, namely: trade, finance, people and bio-physical (Benzie, 2015).

Bio-physical: transboundary ecosystems such as international river-basins, forests, oceans and the atmosphere may have impacts on other countries. For example, scarce water resources may cause one country to dam a river basin or divert valuable water for irrigation, resulting in significant impact on downstream countries and people.

Trade: indirect risks that occur through the trade pathway are transmitted through disruptions to global supply chains. For example extreme weather events in one country may have far reaching effects elsewhere around the globe. One countries response to climate change at home by protecting markets or placing export restrictions may trigger price shocks and have negative impacts in countries elsewhere around the world.

Finance: indirect risks on financial pathways affect the movement of capital and the exposure of both public and private assets held overseas that suffer lower yields and devaluation as a result of the impacts from climate change.

People: the movement of people across international borders due the effects of climate change represents a growing risk and potential humanitarian disaster. Many climate-related factors may cause people to migrate, these include: sea-level rise, desertification, tourism and human health risks amongst others.

B.7 The financial and economic risks

A carbon-constrained future presents a significant challenge for corporates and investors alike. The level of exposure experienced by different companies depends on the geographic location and the sector within which businesses operate. Competitive dynamics are also created by the various climate policies and the possible physical manifestations of climate change (Labatt and White, 2007, p.11). There are four climate risks that impact business, these are: physical risks, regulatory risk, business risk and financial market risk.

Regulatory risk

A company's exposure to regulatory risk depends on the stringency of greenhouse gases (GHG) policies that are being implemented. The level of exposure a company faces from regulatory risk is found on all three levels of the company's value chain:

1. Emissions from the company's own operations
2. Indirect emissions from the company's supply chain - especially energy derived from fossil fuels
3. Emissions linked to the use of the company's goods and services

The introduction of climate policies in different regions at different times will mean the impacts of climate policies will have uneven, heterogeneous effects. The power sector is particularly vulnerable, as fossil fuels remain a primary source of combustibles for most power generation companies. Within the power sector there are also significant differences between firms depending on the age and efficiency of generating assets, the company's share of renewables and its market position. Other sectors, like transport may see greater efficiency standards or new cleaner technologies start to dominate.

Physical risks

Physical risks arise from the direct risks of climate change such as droughts, floods, storms and rising sea levels. The sectors particularly exposed to these risks include agriculture, fisheries, forestry, health care, tourism, water, real estate and insurance. Extreme weather events have the potential to cause significant damage to assets and infrastructure paralysing productive economic activity.

The physical effects of climate change can also have a serious influence on the health and well-being of a population. Extreme temperatures can cause death and illness when experienced for extended periods. There is also increased risk from vector-borne diseases associated with changes in temperature and precipitation patterns. Respiratory-related illnesses and a decrease in the number of life-years, are also linked to an increase in particulate matter in the atmosphere; a by-product of burning fossil fuels.

Several studies have tried to quantify the potential increased costs from direct physical impacts of climate change. Usually these methods involve the development of stochastic models to predict changes in the frequency and severity of extreme weather events as no single event can be directly attributed to climate change. One study, completed by the Association of British Insurance (2005), concluded that there would be an increase in average annual losses of around $27 billion a year from three major types of events – US hurricanes, Japanese typhoons, and European windstorms. This represented a two-thirds increase by 2080 compared to the base-period average. Similarly in a study completed by the Centre for Risk Studies looking at World City Risk (Coburn et al., 2015), an increase in the frequency (10 per cent) and severity (5 per cent) of extreme weather events in 300 of the world's cities places an additional $32 billion per annum at risk of lost economic output.[12]

Business risk

At the level of the corporation, business risks include legal, reputation and competitive risks. Legal risks occur when litigation attempts are brought against companies for breaching their legal obligation to meet certain climate change related obligations, or have the potential to cause harm or breach a duty of care. Legal claims can be brought against a company by customers, competitors, investors or the State. Reputational risks occur when corporations respond to climate change related matters that alter the perception of brand value to

12 The study completed by CRS represents aggregate losses to GDP from extreme weather events, while the study completed by ABI represents losses to capital infrastructure

customers, staff, suppliers and investors. Corporations might suffer a backlash or be viewed in a negative light because of decisions that were made with regard to internal carbon management policies, products and processes. Reputational risk is particularly important in industries with high brand value, such as the automotive and airline industries where up to 50 per cent of brand value may be at risk.

Risk to a company's competitive position in a market depends on how the company responds to changing regulatory frameworks and other climate-related risks. Operational and market based risks may put constraints on existing assets and capital expenditures. Increases in the cost of inputs due to climate policies or supply chain disruption may change the competitive landscape. All of these factors affect the investment valuation of the company.

Financial market risk

The performance of individual companies is linked to the overall performance of the economy and the level of confidence placed in the financial markets. Large movements and a collapse in prices are usually the first signs that the markets are under stress. Falling prices then lead to lower confidence and even lower prices. During the chaos of a financial market collapse, traders attempt to salvage their investments before prices reach rock-bottom. How might the risk of climate change precipitate such a collapse? Primarily through price adjustments to the valuation of companies expected to be worst impacted by climate change. For example, agriculture in developing countries and asset owners of climate vulnerable infrastructure will be affected by changes to the growing season and extreme weather events. The share price valuation of a company reflects the earning potential of that company into the future, subject to some form of discount rate. The companies likely to experience the most significant adjustment in price are those most usceptible to being affected by a particular climate change scenario.

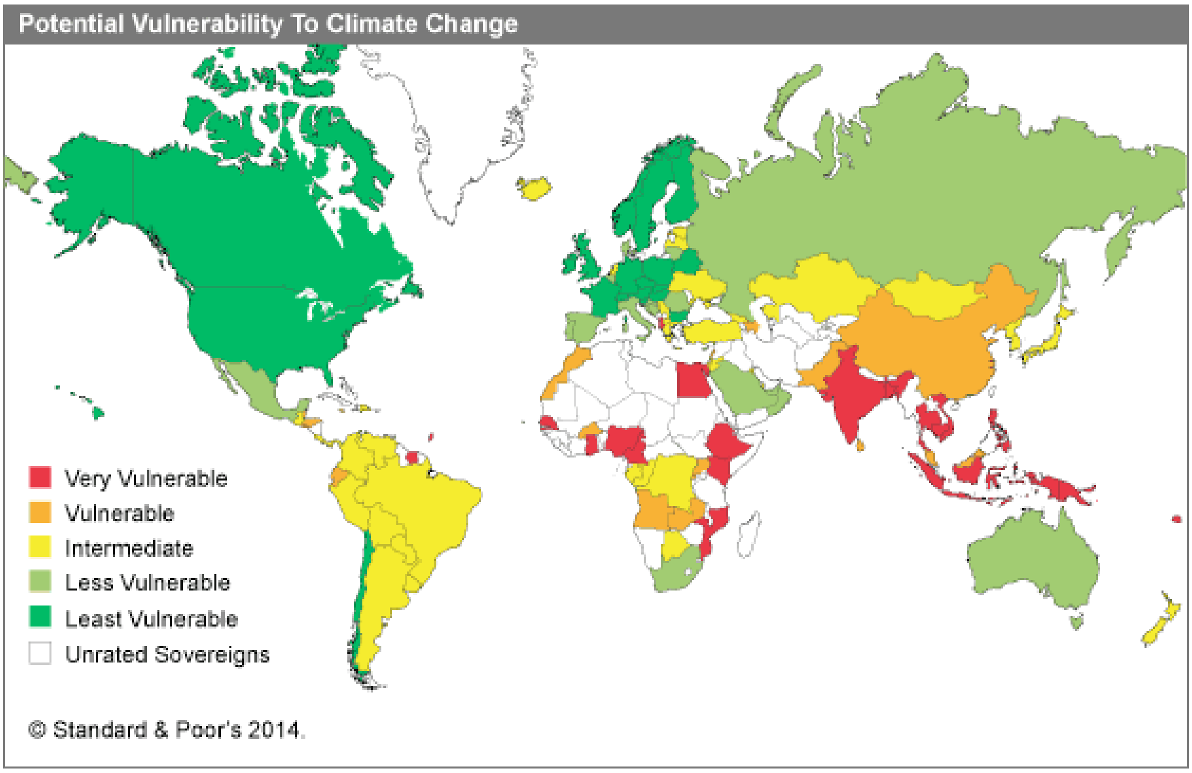

Figure 18: Climate change country credit risk, figure from (Standard and Poor's, 2014)

In 2014 Standard & Poor's carried out an assessment on trends in sovereign risk vulnerability due to climate change. The study concluded that climate change was a global mega-trend that would negatively impact sovereign credit-worthiness. The impact on credit worthiness would be transmitted through several channels, including economic growth, external performance and public finances. As shown in Figure 18, the vulnerability of different countries to climate change is uneven, with the poorer and lower rated country's hit hardest.

Appendix C Modelling and methods

C.1 Developing a framework for analysis

The aim of an institutional investor is to invest capital in a way that minimises risk and maximises return. Standard portfolio theory suggests that investment in diversified assets reduces overall risk while maintaining a given level of expected return. In this regard, it is not just the expected return of a portfolio that is important to an investment manager but also the volatility or VaR (Value at Risk) of an investment or portfolio. Large and unexpected negative downturns in specific asset classes over relatively short periods can have serious consequences for investors. One way of reducing portfolio volatility is through diversification of investments. Diversification is helpful when asset returns across different asset classes do not necessarily move in parallel under the same economic conditions. For example, when external effects are disregarded, bonds and stocks generally move in opposite directions, providing a certain level of protection (volatility reduction) for the portfolio overall. In general, however, the price of different asset classes depends on the underlying performance of the overall economy, so the price of different assets tends to move in the same direction as the economy. In portfolio theory, this aspect of risk is called 'systematic risk' and cannot be diversified away. Unsystematic risk is risk that can be reduced through diversification. An investor who owns stocks in different companies and sectors as well as other types of securities, such as Treasury bonds, will be able to reduce risks when impacts are isolated to particular industries or investment types.

The analysis contained in this report is based on the premise that climate change will cause both systematic and unsystematic risk to investment portfolios. Systematic risk occurs when the effects of climate change and any policies to combat its impacts cause a structural shift in the overall macro environment of the economy or market (e.g. the global economy degrades). As the macro environment adjusts to new beliefs about future output, systematic risk is created across the entire economy, affecting energy prices, national income, health and agriculture among others. Unsystematic risk occurs when there is additional risk to specific assets or securities that can be explained above and beyond general movements in the underlying economy. For example, the returns on equity investments are determined by a company's underlying financial performance, profitability and future return on invested capital. Stock returns are also affected by the performance of the industry as a whole. Under a scenario of extreme climate change, economic performance across the board will be impacted, lowering expectations about the future and reducing overall growth. However, some parts of their economy will be impacted more severely than others. For example, real estate in developed countries will experience more volatility in price as an increasing number of properties will be at risk of flooding. Thus it is possible to reduce overall portfolio risk by divesting from assets that perform worse and have higher volatility. A primary question of this research project therefore asks:

What proportion of climate sentiment risk can be diversified or hedged through portfolio structure and how much climate risk is systematic and therefore linked to macro-scale market and economic conditions?

C.2 Modelling timeframe

The emphasis on short-termism in the financial markets is well recognised (Bolton et al., 2006 Dallas, 2011;), where there is an excessive focus on speculative short-term results potentially at the expense of long-term value creation. In the current context, together with consultation with our advisory panel of experts,[14] this study concentrates on sentiment scenarios that have immediate financial effects and corresponding actions by prudent rational investors and asset managers over the next five years (i.e. 2016 to 2021). These sentiment shifts and consequential market impacts are years and perhaps decades in advance of the more severe climate change impacts that will be realised in the latter part of this century. This analysis, therefore, does not attempt to estimate the physical impacts of climate change over this short time frame, but instead asks how investors today may react to growing certainty over the potential future effects of different climate change trajectories. The analysis therefore considers how present day markets may react to the discounted future impacts of climate change across different countries, sectors and asset classes. Under an extreme climate change scenario, vulnerable assets that are expected to provide a return on investment over the medium to long term are expected to de-value which would then have much wider effects on market sentiment. A change in overall market sentiment then drags down the entire economy - over the short term - as prospects about future economic conditions and output are re-evaluated.

C.3 Modelling process

In order to understand and model the future impacts of climate change on present day financial markets, a new modelling approach was co-developed jointly by 4CMR and the Centre for Risk Studies, illustrated by the flow chart below (Figure 19).

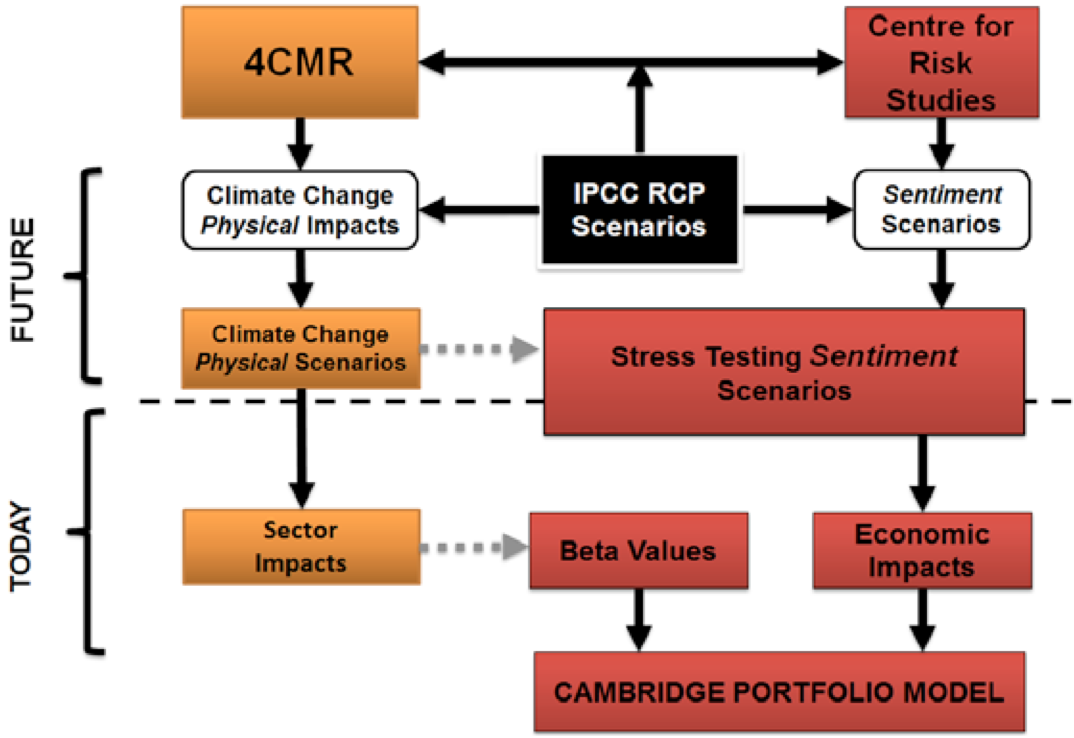

Figure 19: Conceptual links between 4CMR and CRS in the co-developed structural modelling methodology framework.

13 The members of the advisory panel are: Rob Lake (Independent Advisor), Richard Lewney (MD, Cambridge Econometrics), Dr Mike Maran (Chief Science Officer, XL Catlin), Rick Stathers (Head of Responsible Investment, Schroders), Raj Thanotheram (RI consultant), John Ward (Director, Vived Economics), Michael Sheren (Senior Advisor, PRA Bank of England) and Tomi Nummela (Head of Implementation Support, Principles for Responsible Investment)

The future climate change regional physical impacts inferred from the IPCC RCP scenarios by 4CMR do not directly measure the sentiment shocks in the stress testing scenarios, but provided CRS indications and magnitudes for developing meaningful scenarios and sectoral beta analysis. This process was conducted according to a number of steps as described below:

Step One – development of climate change scenarios

The process begins with the identification and development of three climate change sentiment scenarios. These three scenarios describe how different climate futures might unfold over time. They include assumptions about technology, policy and socio-demographics pathways and are based on the existing RCP (Representative Concentration Pathway), SSP (Shared Socio-economic Pathway) and SPA (Shared climate Policy Assumption) frameworks developed by IPCC. Further details on terminology are available in Appendix E: Defining the Scenarios. Two of these scenarios were chosen to represent futures that lie within the tails of the distribution of all possible climate futures and were therefore targeted to have a probability of occurring of around 5 per cent. These scenarios represent two opposing futures, one in which the rise in average world temperatures remains below Two Degrees Celsius out to 2100, the other where there is No Mitigation, and the temperature rise is four or more degrees by 2100. Note that there is large uncertainty in estimating the probability of particular scenario occurring, and this is only amplified when speculating as to the likelihood of a corresponding sentiment shift. It does, however, illustrate an important point namely, that the scenarios being modelled are not 'likely' or 'best guesses' but illustrative of the potential tail risk created by climate change.

Step Two - sectoral impacts from future climate change

The second step involves the synthesis of existing research on the future impacts of climate change under different climate change scenarios. For each climate change RCP scenario, the impacts across different countries and sectors are approximated based on the regional climate impacts modelled by 4CMR, which are used as intelligent proxies to the spatial extents and magnitudes of model parameter shocks in the subsequent economic and financial analyses modelled by CRS. This information is used to inform an analysis of how present day market participants might react.

Step Three – development of sentiment scenarios

Outputs from Step One and Step Two are used as inputs into the further refinement of each of the sentiment scenarios. This process takes impacts that occur in the future and translates them into how financial markets may react today. This involves a consequential analysis of how financial markets over the next five years will react to the perceived future impacts of climate change.

Step Four – macroeconomic modelling

Qualitative and quantitative data from each of the previous steps are then used to determine the relative size of the macroeconomic shocks to be applied to the Oxford Economics' General Equilibrium Model (GEM). The size of the shocks applied to different macroeconomic variables is calibrated, using the historical catalogue, to provide a plausible set of shocks in each scenario. Sensitivity analysis is then performed on each of the shocked economic variables to understand its effect on overall results; an iterative process is then followed to define and narrow the bounds of the magnitude for each of the shocks.

Step Five – calculation of beta values for sectoral impacts

One of the outputs of the Oxford Economics' GEM is an equity index for each country being analysed. Historical beta values, derived from a standard CAPM model, are used to describe sector level performance with respect to the underlying equity index for each country. Historical beta values for each industrial sector are then adjusted by the expected shock estimated under each climate change scenario. This has the effect of increasing sectoral volatility with respect to the underlying equity index, which is assumed to adjust to this new 'climate beta' over a period of five years. For example, assume the beta value for agriculture to be β=1.3 and suppose we shock the beta value by the inverse of the expected shock derived from the climate science models (e.g., agriculture output will decrease by 20 per cent). In this way, we assume the financial markets recognise the long-term performance of sectors, and this has a direct effect on the financial markets today through increased volatility proportional to the long-term effects of climate change. Thus, in this instance the beta value would increase from 1.3 to 1.63 (=1.3/(1-0.2)), indicating increased volatility and uncertainty about the performance of the agriculture sector.

Step Six – portfolio analysis

The relative performance of fixed income, equities and commodities for each country is provided as an output from the Oxford Economics' GEM. These are used to describe quarterly shifts in mark-to-market values over a five-year period in the Cambridge financial portfolio model. Four financial portfolios are constructed: High Fixed Income, Conservative, Balanced, and Aggressive. Each portfolio makes different assumptions about the relative proportion of assets that are invested in different asset classes and regions. These portfolios form the basis for determining how much risk can be hedged through reallocation across portfolios under different climate change scenarios.

C.4 Description of scenario stress testing analysis

The practice of using stress tests to assess the health of banks and economic institutions has earned increasing popularity in the wake of the 2008 financial crisis. This study designs a new suite of coherent stress tests to reflect current day sentiments to the economic and financial markets in advance of the physical impacts of climate change. The scenario stress testing approach, defined to conduct rigorous what-if analysis, looks at the implications of key economic risks and policy changes following the expected climate risks being studied. The approach seeks to illustrate the impacts of three different climate change scenarios defined by the international science community as 'bracketing' the range of possible climate impacts, and how these scenarios may have an impact on present day markets.

The choice of scenarios, to follow, and the calibration of their impacts are informed by established research in climate science, macroeconomic modelling and financial modelling. More generally, catastrophe types can be identified in advance on the basis of historical records, for instance the Cambridge taxonomy of macro-catastrophe threats provides a check-list for potential causes of future shocks (Coburn et al., 2014a) or drawing on perspectives of experts on the most significant long-term risks (World Economic Forum, 2015).

C.5 Complex risks and macroeconomic impacts

These climatic threats are of interest because they are complex risks – they impact networks of activities that underpin the global economy, disrupting interrelationships that drive business and cause losses in unexpected ways. They have multiple consequences, in causing severe direct losses, but also operational challenges to business continuity, cascades of effects on counterparties and the macroeconomy in general, and on the capital markets and investment portfolios. However, the exact timing of climate change impacts cascading into economic and financial risks remains highly uncertain, making the threats even more difficult to quantify and prepare for, potentially making them more harmful. In the three sentiment scenarios presented in this report, we explore how these effects might occur, tracing the flow of consequences from initial losses to macroeconomic impacts and then to financial market effects in terms of portfolio returns.

C.6 Developing coherent scenarios

It is important to identify the capacity and capability for these scenarios to trigger various cascading consequences that are the main causes of any catastrophic loss. These consequences are intertwined into complex risks. For stress tests to be useful, they need to be coherent (i.e. all described effects are consistent amongst one another in that they follow a logical sequence relying on causal mechanisms, and represent meaningful correlations across multiple dimensions of impacts). The development of a coherent scenario requires structural modelling, a scientific consideration of the causality along the chain of cause and effect and a holistic appreciation for the internal consistency within the scenario.

C.7 A structural modelling methodology

To develop a coherent stress test, we formulated a methodology for guiding the general processes to understand our scenario consequences, as summarised in Figure 20.[14] This guide involves sequential processing of the scenario, from defining the scenarios aligned to the appropriate assumptions, to several stages of modelling iterations to obtain results for the economic and financial impacts analyses. The construction of a scenario using structural modelling techniques presents various challenges before the requirements for a coherent stress test can be fulfilled:

- Can we construct an extreme fictional scenario that has never occurred and make it plausible?
    - We have attempted to do this through using evidence-based precedents of similar case studies (since the extreme events have not occurred in today's world), and detailed analysis of how similar past events would play out today, under the assumed conditions.
- Can these scenarios meet the criteria of being useable by businesses, investment managers or policy-makers for use in risk management?
    - We have worked with key users (a team of Advisory Panels of experts in responsible investment, risk modelling and economic consulting) to shape the scenarios so as to meet the management needs for stress testing, and are still constantly seeking additional ways to get the scenarios tested further and more broadly accepted

We believe it is important to create a robust and transparent process, and have tried to achieve this through detailed recording of assumptions, described in the following sections of this report, and sensitivity tests assessing the relative importance of one input on another.

In the macroeconomic stages of the modelling, we are conscious that the calibrated macroeconomic models are pushed beyond the comfort zone of normal economic behaviour for use in modelling extreme events. Thus, in working with an existing macroeconomic model, we have relied on economic model experts to understand the useful limits of the model and identify the boundaries of the model's functionality.

14 Methodology makes references the Cambridge Centre for Risk Studies' four main threat scenarios: China-Japan geopolitical conflict (Bowman et al., 2014b), São Paulo virus pandemic (Coburn et al., 2014b), Millennial uprising social unrest (Bowman et al., 2014a), and the Sybil logic bomb cyber catastrophe (Ruffle et al., 2014)

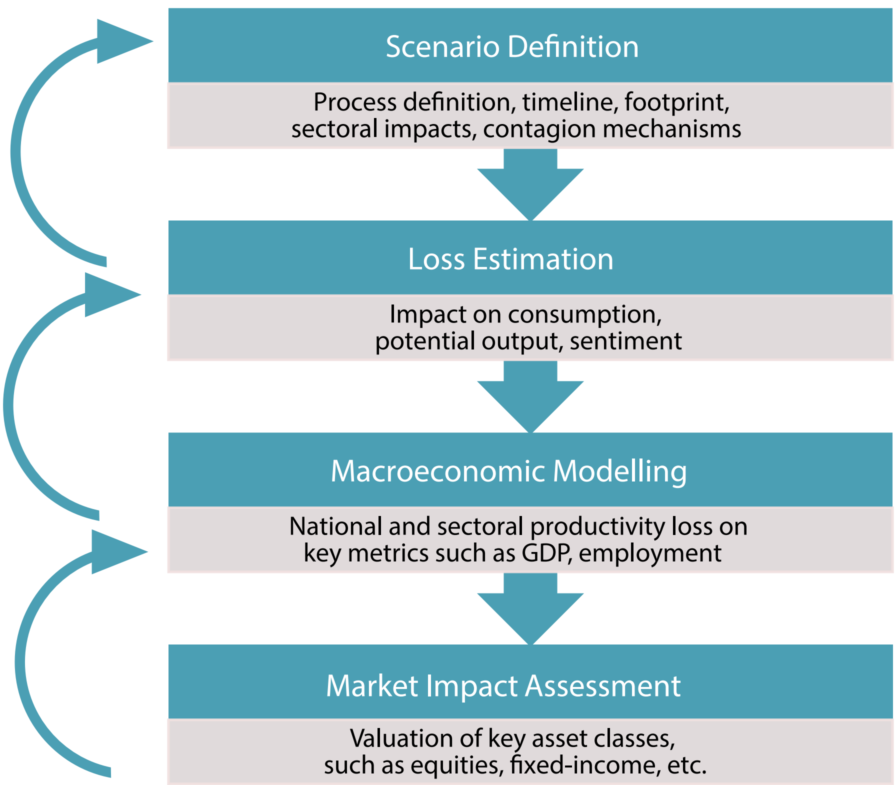

Figure 20: Structural modelling methodology for developping coherent stress test scenario

C.8 Assumptions and limitations

The economic estimates presented in this analysis are subject to the assumptions imposed during the narrative development and how the scenario unfolds over time. The modelling and analysis completed are also subject to several sources of uncertainty. A best attempt has been made to ensure the macroeconomic interpretation of the narrative is justified on historical grounds and follows sound macroeconomic theory and principles. However, the unusual and unprecedented nature of these particular scenarios introduces several layers of uncertainty in final model outputs that cannot be completely ruled out.

C.9 Macroeconomic assumptions

Several assumptions have been made regarding how sentiment shifts could play out. Firstly, the trigger for these scenarios originates from a collapse in the level of confidence due to the uncertainties accompanying the expected future impacts of climate change, and climate change-related policy. This initial shock sends tremors through markets around the globe. This shock travels through linkages between asset classes as well as cross-border financial integration and trade relationships. Moreover, the ongoing recovery of the economy hinges on how quickly financial markets and consumers regain their confidence in the economy. In the Two Degrees scenario, the impacts are less severe and the markets recover faster compared to the No Mitigation scenario. This is understandable, given the positive outlook of well-coordinated global actions in the face of climate change (i.e. policy certainty) and renewed hope in new technologies and future opportunity. The magnitude and duration for each of the macroeconomic shocks is given in Appendix F, Table 17.

Appendix D Climate change impacts

D.1 Background

The severity of the impacts of climate change depends strongly on the degree of change experienced, but also on the level of vulnerability of a region and/or economic sector. Both exposure and vulnerability vary across spatial scales, creating a need to explore the geography of climate impacts on key sectors. While it may be possible to hedge some risk by limiting exposure of assets, other risks will require system-wide action, both to mitigate climate change and to reduce vulnerability.

D.2 Zonal climate statistics

Weather describes the atmospheric conditions at a specific place at a specific point in time. Such forecasts depend critically on the initial state of the atmosphere, and tend to be accurate for up to one week. Climate models, however, are not predicting day to day weather systems. Instead, they take a longer-term view, predicting climate averages for a given location and timeframe. As such, it is not plausible to use climate models to answer specific questions about the occurrence of a particular weather event at a given point in the future. However, they can be used to calculate aggregated weather statistics over periods of 30 years (i.e. climate statistics such as the frequency with which large storms might occur).

There are many types of model and techniques that can be applied to generating projections of future climate change, with different benefits and limitations. The climate model output used here is from coupled Atmosphere Ocean General Circulation Models (AOGCMs) and was generated for the Coupled Model Inter-comparison Project Phase 5 (CMIP5). Data was obtained through the KNMI Climate Explorer.[15]

AOGCMs are highly complex in their representation of environmental processes, but as they simulate global climate, there are limits to the spatial resolution they can reach. Fine-scale variations in land cover, albedo, soil moisture, etc. have an effect on local climate that these models cannot resolve. Downscaling methods (dynamical or statistical) can be applied if information about variability is required on such a fine scale (e.g. Duliere et al., 2011); however, as the goal of this research is to aggregate climate statistics over large regions for which sectoral impact information is available, such a level of detail in the climate simulations is not required.

Different climate models produce different results when forced with the same Representative Concentration Pathway (RCP). Therefore, the multi-model mean of the CMIP5 experiments is used to generate impact estimates. Availability of model data for each RCP is indicated in Table 2. Where multiple experiments were completed with the same model configuration, only one has been included in the calculation of the CMIP5 ensemble mean, to avoid biasing the mean.

However, it should be noted that multi-model ensembles are not a systematic sampling of the uncertainty space of future climate, and issues such as model dependence and bias complicate their interpretation (Foley et al. 2013; Knutti 2010; Tebaldi and Knutti 2007). Using the KNMI Climate Explorer, monthly average near-surface air temperature for each RCP is averaged over the year. A MATLAB script is then used to calculate the

15 http://climexp.knmi.nl/start.cgi?id=rtisdale@snet.net

mean annual temperature over the end-of-century and baseline periods, and obtain the difference between the end-of-century and baseline periods. This anomaly field is exported to ArcGIS, where the zonal mean temperature anomaly is calculated, based on the regions used to generate the damage functions for climate impacts. Representative results of projected climate change are given in Figure 21, using temperature increase (relative to the pre-industrial mean global temperature) as the climate variable.

D.3 Derivation of impacts and risks

The impacts of climate change on assets and production capacity in economies have been estimated using the combination of a climate emulator model to produce climate projections similar to those of the more complex models used in the IPCC analyses (reducing the amount of computation needed in the present study) and a set of 'impact factors' for different categories of assets and production capacity. The climate model is used to estimate the temperature and/or precipitation (rainfall) change by year under each climate scenario and in each region of the world, while the 'impact factors' show the amount of damage expected in each asset/production category under this amount of climate change. The 'impact factors' were taken from a review of the climate damage estimates in the latest IPCC report, specifically the Synthesis report, which draws on analyses performed by the different IPCC groups focused on the science of climate change, its impacts and potential mitigation options, with emphasis on the report concerning impacts.

It should be noted that the IPCC analyses of impacts are drawn both from specific assessments in countries, and from regional assessments. They do not result from detailed analyses and hence should be seen as averages of vulnerability across wide geographic areas rather than applying to a specific asset or production capacity. They should, however, represent best available scientific estimates of vulnerability to potential damages from climate change under the climate scenarios considered, based on current (2015) locations of assets and production capacity. In other words, they do not reflect potential shifts in the locations of assets and production capacity globally, since such shifts will be determined by investment decisions.

Representative results of projected climate change – taken from the climate model mentioned – are given in Figure 21, using temperature increase (relative to the pre-industrial mean global temperature) as the climate variable.

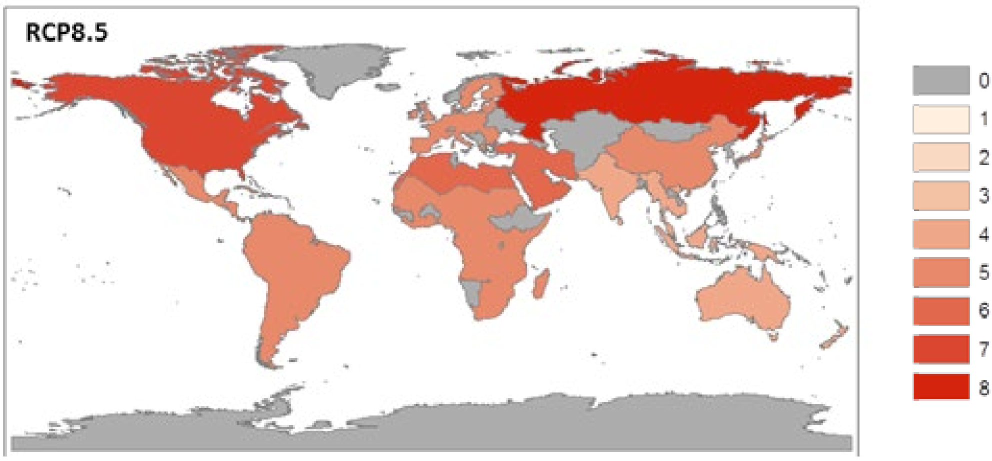

Figure 21: Regional mean temperature anomalies under RCP8.5 and RCP2.6, for the period 2071-2100 relative to the pre-industrial period.

The colour scale refers to the incremental temperature increase (in degrees C) relative to the temperature of the pre- industrial period.

The impact factors were developed for 10 regions of the world based on qualitative analyses of the regional results of the IPCC reports. These regions are: North America, Central America, and South America, Sub-Saharan Africa, the Middle East, European Union, Southeast Asia, China, Russia and Australia/New Zealand. Again, bear in mind that these are averages over very large regions, and hence 'hide' variability in climate impacts expected across a region. For example, the United States is expected to see significant differences in impacts between the Northeast and Southwest states. These differences are averaged out in the analyses performed by the IPCC, and hence here, and so the results should only be used to compare average, relative impacts between regions of the world as locations of assets and production capacity.

For each world region, damage was assessed for six sectors of the economy: Agriculture, Forestry, Land Transport, Buildings, Manufacturing and Energy. Again, these impacts should be seen as averages over a region within a category, for example the average impact to all Buildings within the region of North America, and so the results should only be used to compare average, relative impacts between categories of assets or production capacity in a world region. These impacts are then used in the development of the climate sentiment scenarios that describe how different sectors and regions of the world will be impacted under different climate change scenarios.

An example of the impact factors is shown in Table 14. The upper row is the temperature change in that region (rather than the mean global temperature change), expressed as the fraction of production capacity remaining after damage to assets in that region as a result of the change in temperature. For example, note that the value for North America under a temperature increase of 3°C is 0.85. This means the agricultural sector will experience an approximate decline of 15 per cent in production capacity, absent any adaptation measures. The temperature in North America has on average increased by 3°C. For details on other categories of assets and production capacity, please contact the research team.

Table 14: Remaining production capacity in the agriculture sector following any amount of temperature increase relative to pre-industrial revolution, for each of the world regions considered here

	Agricultural productivity							
	Temperature change (°C) relative to pre -industrial baseline							
	0	0.5	1	2	3	4	5	6
Region								
North America	1	1.05	1.00	0.95	0.85	0.70	0.60	0.40
Central America	1	1.04	1.02	0.98	0.80	0.70	0.58	0.42
South America	1	1.03	1.01	0.97	0.79	0.69	0.57	0.41
Sub -Saharan Africa	1	1.06	1.01	0.96	0.86	0.71	0.61	0.41
Middle East	1	1.04	0.99	0.94	0.84	0.69	0.59	0.39
European Union	1	1.03	0.98	0.93	0.83	0.68	0.58	0.42
Southeast Asia	1	1.06	1.01	0.96	0.88	0.72	0.61	0.40
China	1	1.06	1.01	0.96	0.88	0.72	0.61	0.40
Russia	1	1.10	1.05	1.00	0.90	0.75	0.65	0.45
Australia and NZ	1	1.04	1.02	0.97	0.78	0.72	0.60	0.44

Table 15: Summary damage ratio estimated from the climate model across defined sectors for 2080 – 2110: Combined effects of temperature and SPEI

Region	Sectoral Productivity (1 = 100%)					
	Agriculture	Forest	Land Transport	Building Assets	Production Assets	Energy Production
North America	0.62	0.72	0.91	0.93	0.91	0.84
European Union	0.59	0.69	0.90	0.92	0.90	0.81
Central America	0.64	0.75	0.95	0.97	0.95	0.87
South America	0.63	0.74	0.95	0.97	0.95	0.86
Sub -Saharan Africa	0.65	0.75	0.94	0.96	0.94	0.87
Middle East	0.65	0.76	0.97	0.99	0.97	0.88
Southeast Asia	0.68	0.80	0.90	0.94	0.92	0.93
China	0.68	0.80	0.90	0.94	0.92	0.93
Russia	0.71	0.82	0.90	0.94	0.92	0.96

Table 15 above reflects the respective regions' exposure to changes in temperature and rainfall levels across different sectors. However, exposure alone does not result in higher climate risks. Resilience provides another layer of understanding on how countries manage in the changing climate facing many uncertainties and challenges. Thus, subjected to varying degrees of climate risks, the six countries included in the study have different characteristics of resiliency listed below:

- **Preparedness.** Resilience involves the capacity to absorb the shock and then recover from the catastrophic event. Countries can do so by developing physical, economic, human, and/or social capital.
- **Adaptability.** In a changing world constantly evolving, countries that are able and willing to adapt to new conditions are relatively more resilient.

- **Experience.** Either by learning from home countries' experiences or studying the lessons of others' handling impacts of climate change, the knowledge gained makes it possible to better prepare and adapt the underperformers
- **Collective and coordinated response – interdependency.** Strong coordination and shared community values are make populations better able and willing to plan for and react to disruptive climate impacts.

Appendix E Defining the scenarios

E.1 Defining a climate risk sentiment scenario

We define a climate risk sentiment scenarios as a shift in market behaviour driven by beliefs about future economic and financial outcomes brought about by the physical processes of climate change, technology and climate change policy. Although the focus on the systemic aspects of climate risks looks at the impacts on a global scale, it is equally important to analyse impacts on individual countries, asset classes, or industry sectors for "hedgeable" risk management.

E.2 Selection process

To select extreme yet plausible scenarios, CRS referenced the scenario matrix architecture (van Vuuren et al., 2013) and modified it according to our research specifications (see Table 16). The potential outcome of climate change depends on three main factors:

1. Amount of radiative forcing levels (W/m2), given as the Representative Concentration Pathways (RCPs) in the IPCC analyses (Figure 22);
2. Shared socio-economic pathways[16] (SSPs) and;
3. Shared climate policy assumptions[17] (SPAs).

Figure 22 shows the expected range in estimates for each of the RCP scenarios as given by the IPCC, and also represents the range of scenarios chosen for this analysis.

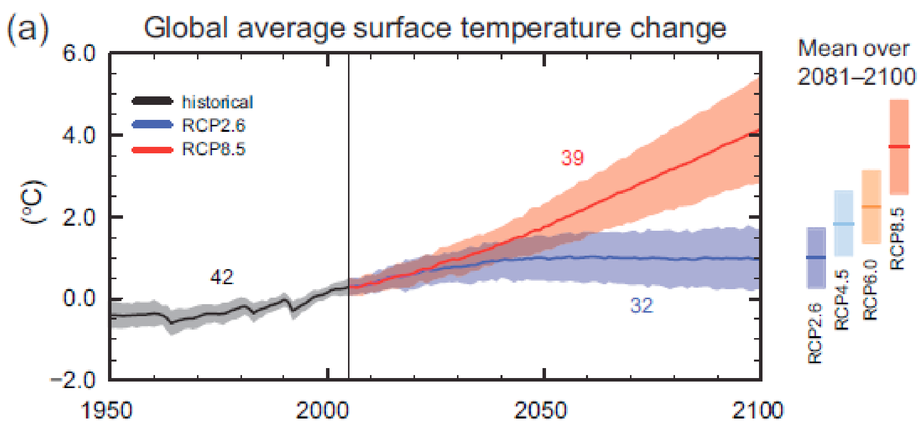

Figure 22: IPCC RCP scenarios (Source: Stocker, 2014)

16 Shared Socio Economic Pathways (SSPs) describe the social and economic assumptions for each country that underpin each of the RCPs

17 Shared Policy Assumptions (SPAs) are the regulations and agreements for different countries that underpin different RCP scenarios (e.g., carbon tax)

Table 16 below presents a two-dimensional matrix that extracts the specific RCPs with the corresponding SSPs, alongside the SPAs that are defined consistently with the mitigation challenges. The overview table illustrates that many alternative pathways are possible under different assumptions combining SSPs and SPAs to reach different levels of RCPs in the future. Thus, by implementing different climate policies (SPAs) it is possible to shift the forcing levels from one cell to another (depicted by the 'X's and dotted arrows in Table 16). This further shows that there is no fixed set of climate policies for each socio-economic pathway (SSP). Therefore the narrative will remain coherent as long as the overall pathway definitions and climate policy assumptions are broadly consistent.

Table 16: The extended scenario matrix architecture (Source: CRS)

Shared Socio-economic Pathways (SSPs)		SSP1 Sustainability	SSP2 Middle-of-the-road	SSP3 Fragmentation	SSP4 Inequality	SSP5 Conventional Development
Forcing levels (W/m^2)	8.5					X
	6.0		X	X	X	X
	4.5	X	X	X	X	X
	2.6	X	X	X	X	X
Example development (non-climate) policy	Economic	High	High	Slow; unequal	Slow; unequal	Very high
	Population	Low	Medium	High	Low to Medium	Low
	Urbanization	High	Medium	Medium	Low	High
	Education	High	Medium	Low	Unequal (very low to medium)	High
Shared climate Policy Assumptions (SPAs)		SPA1	SPA2	SPA3	SPA4	SPA5
Policy attributes	Mitigation: Level and start of global cooperation	High and early	Medium and mid-term	Low and late	High and early	Low and late
	Adaptation: Ability for capacity building	High	Medium	Low	Low	High
Example climate policy	Resource and Energy demand	Low	Medium (reducing)	High	Regionally differentiated (rich-poor divide)	High
	Carbon-based fuel demand	Low	Medium (reducing)	High	Regionally differentiated (rich-poor divide)	High
	Alternative energy Technology	High	Medium (increasing)	Low	Regionally differentiated (rich-poor divide)	Low
	Environmental	High	Medium (limited)	Low	Low	Low

Climate policy assumptions are not, by definition, included as part of the SSPs (O'Neill et al., 2013). In Figure 23, the traditional scenario matrix is therefore expanded to include a third dimension that incorporates climate-signals in a policy-context.

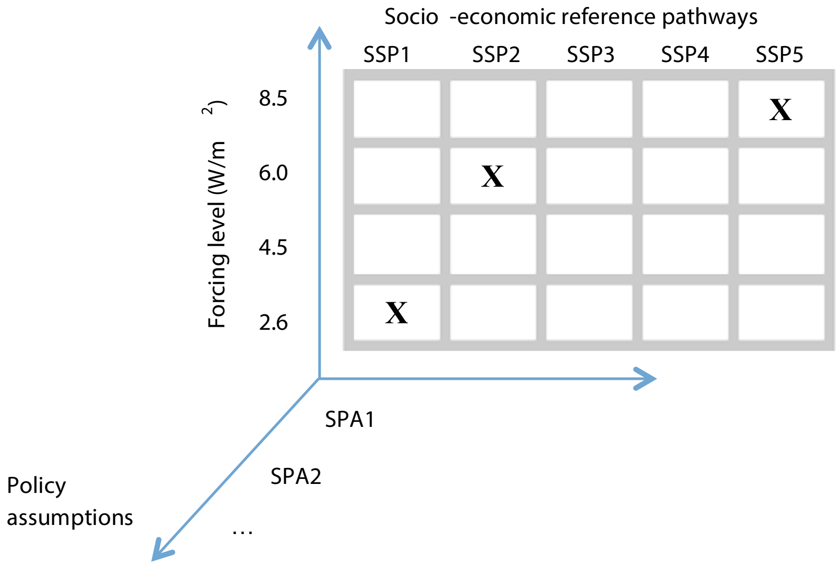

Figure 23: 3D scenario matrix approach (Adapted from van Vuuren et al., 2013)

Note that in the present analysis, as described in Section 3, RCP2.6 has been paired with SSP1; RCP 6.0 has been paired with SSP2; and RCP8.5 has been paired with SSP5. Shared climate policy assumptions (SPAs) usually provide information about new climate policies that are excluded from most socio-economic pathways (Kriegler et al., 2014). In essence, non-climate policies belonging to the traditional pathways mostly involve development (i.e. economic growth, improving energy access, urban planning, infrastructure, health services, population, and education). They are motivated in their own right, although they may affect climate policies or be affected by them. On the other hand, climate policies would not be implemented if there were no concern about climate change. Examples include policy that directly restricts or taxes the emissions of greenhouse gases (GHG), or supports technologies that remove or reduce GHG.

Appendix F Background on macroeconomic modelling

Table 17: Key input variables and their maximum shocks applied to the respective scenario variants

S/N	Macroeconomics Input Variable	Sentiment Scenarios			Shock duration applied
		Two Degrees	Baseline	No Mitigation	
1	Carbon Tax				
	Global	+ $100/toe^	Nil	Nil	5 years
2	World Investment for Fossil Fuel Extraction				
	Global	-80%	Unchanged	+50%	5 years
3	Non -Fossil Fuel based investments				
	Green investments	+80%	Unchanged	Nil	5 years
4	World Energy and Food Prices				
	Global	Unchanged	Unchanged	+100%	5 years
5	Global Energy Demand				
	Oil & Gas	-10%	Unchanged	Unchanged	5 years
6	Confidence Shock				
	United States	-3	Unchanged	-5	4 quarters
	United Kingdom	-3		-5	
	Germany	-3		-5	
	Japan	-3		-5	
	China	-3		-5	
	Brazil	-3		-5	
7	LongTerm Interest Rates				
	United States	2%	Unchanged	4%	5 years
	United Kingdom	2%		4%	
	Germany	3%		7%	
	Japan	3%		7%	
	China	5%		10%	
	Brazil	5%		10%	
8	Housing Price Index				
	United States	3%	Unchanged	20%	4 quarters
	United Kingdom	3%		20%	
	Germany	5%		35%	
	Japan	5%		35%	
	China	5%		50%	
	Brazil	5%		50%	

^ toe = tonnes oil equivalent

Table 17 shows the shocks that were applied to eight different macroeconomic variables that cut across countries and regions within the Oxford Economics' GEM. Shocks were carefully considered in terms of their magnitude, spatial impact and duration across each scenario variant. The remainder of this section further describes each of the variables and the underlying rationale for the respective shocks that were applied:

Carbon tax. Within the literature there is a huge range in estimates for the social cost of carbon (SCC). This spans from \$50/tCO_2 to well above \$300/tCO_2 (Stern, 2007; Tol, 2008). However, in order to stay within the 2°C limit by 2100 we anticipate that the price of CO_2 will be in the range \$250-\$300/tCO_2. In a study completed by Moore (2014) the upper bound cost of mitigation for avoiding dangerous climate change was estimated to be around \$300 tCO_2. This is equivalent to the modelled estimate of \$100/toe. This carbon price thus reflects the global response and policies of the Two Degrees Scenario. In the No Mitigation scenario no carbon tax has been applied.

World investment for fossil fuel extraction. In the Two Degrees scenario, high carbon taxes, the elimination of fossil fuel subsidies, investment in new renewables and low confidence in the performance of fossil fuels over the long term are all expected to drive down new investment in fossil fuel extraction by up to 80 per cent in the short term. In the No Mitigation scenario, high energy prices drive a positive long-term outlook in the performance of the fossil fuel-based industries; this in turn drives renewed interest in exploration and extraction, increasing investment in fossil fuel-based sectors by up to 50 per cent over the short term, thus increasing worldwide carbon-intensive energy sources.

Non-fossil fuel based Investment. In the Two Degrees scenario, the increase in spending for non-fossil fuel based investments is financed from carbon tax revenues. Within the literature this is commonly referred to as revenue recycling. The increase in non-fossil fuel investment also represents a shift in investment away from fossil fuels into non-fossil fuel based investments. In the No Mitigation scenario, non-fossil fuel based investments are modelled endogenously.

World energy and food prices. In the Two Degrees scenario, increased energy efficiency and lower concerns about the future effects of climate change mean that food and energy prices remain stable. In contrast, in the No Mitigation scenario, the long-term outlook for agricultural yields brought about by future climate change encourages hoarding and speculation about the future availability of food, driving up prices over the short term. Furthermore, increasing speculation about the possibility of future fossil fuel resource constraints (peak oil and gas) coupled with strong short-term demand and expectations that demand for fossil fuels will outstrip production capacity and supply will all serve to drive up energy prices over the short term.

Global fossil fuel demand. In the Two Degrees scenario, increases to energy efficiency, a shift to renewables and new taxes on carbon are expected to reduce global fossil fuel demand by 10 per cent. This assumes that the long-term transition to renewables takes much longer than the five year modelling period and that fossil fuels remain an important energy source - at least in the medium term. On the other hand, under the No Mitigation scenario, global energy demand for fossil fuels remains at historical rates over the five year modelling period. However, over the long-term as the economy becomes increasingly reliant on fossil fuels as a source of energy, global energy demand is expected to outstrip supply even though investments in fossil fuel extraction has increased. This is because the extraction of fossil fuels from increasingly remote locations drives up costs over the long term, increasing prices over the short term due to speculation.

Confidence shock. Confidence shocks are collectively applied across both developed and emerging economies and in both the Two Degrees and No Mitigation scenarios. The confidence shocks being applied reflect each country's level of vulnerability and resilience to climate change. The magnitude of confidence shocks applied reflects the level of expected financial market performance under each scenario. As a relativity check, the magnitude of the most severe confidence shock applied is approximately half the size of the confidence shock from the 2008 financial crisis.

Long-term interest rates. Long-term interest rates indicate stresses in the bond market, which reflect the weak expectations for future growth in countries most vulnerable to climate change. The shocks applied differ across developed and developing countries, primarily due to the different maturity of the bond markets and vulnerability to climate change impacts. In the Two Degrees scenario, interest rates increase because governments need to borrow to pay for new energy infrastructure, adding additional pressure to already strained government balance sheets. This has the effect of downgrading country credit ratings, putting positive pressure on interest rates over the short term. In the No Mitigation scenario, interest rates also increase, reflecting the chaos and uncertainty toward bond markets and the inability of governments to make any firm commitments to deal with the effects of climate change - particularly for those countries most impacted. In this scenario, governments also recognise the need to raise revenue to pay for future climate change adaptation strategies; as in the Two Degrees scenario, this places additional strain on already stressed government balance sheets.

Housing price index. In the No Mitigation scenario, the physical impacts from climate change, including rising sea levels, storm surges, extreme weather events, etc. will inevitably destroy homes and reduce the amount of viable land for building homes. Decreased availability of housing and the additional costs of recovery and reconstruction are expected to increase the cost of housing. Low supply and high demand will inevitably drive up prices, putting positive pressure on the house price index. The expected strong growth in the underlying house price index creates speculation in the short term for good quality homes not at risk from climate change, driving up prices. Furthermore, the rural to urban migration in searchthe quality amenities of cities better prepared for climate impacts also drives up prices particularly in urban environments. On the demand side, increasing numbers of climate refugees will increase the demand for new homes in less vulnerable places, exacerbating price increases even further. In the Two Degrees scenario, new household energy efficiency regulation will require that many homes be renovated to very high energy standards; many old inefficient homes will also need to be demolished. This is expected to drive up the cost of homes as speculation about the cost of new policy reaches the market. This effect is not thought to be as large as in the No Mitigation scenario and is benchmarked to historical fluctuations

Box 1: Sensitivity analysis in the macroeconomic model

Sensitivity analysis challenges the key quantitative assumptions by systematically changing the simulation computations to assess their effects on the final outcomes. For example, in this study, market confidence is one of the main economic drivers of the economic impact assessment; therefore the magnitude of the confidence level shock across countries being studied needs to be analysed. Here we perform a sensitivity analysis to show the effects of a confidence shock on the overall results.

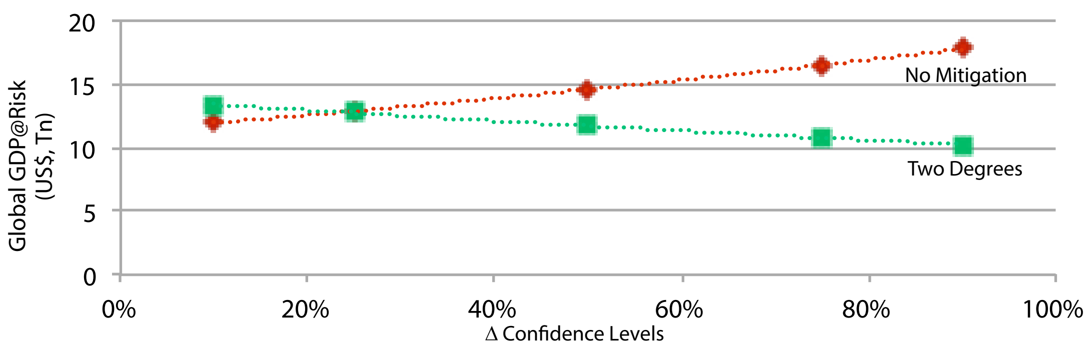

Figure F1: Sensitivity of GDP@Risk values with varying confidence levels

At a 10 per cent difference in confidence levels, keeping all other input parameters constant, the modelled economic impact (five-year global GDP@Risk value) due to the Two Degrees scenario is marginally larger than of the No Mitigation (Figure A1). This is consistent with the climate policy assumptions made in the scenario narratives should we not take into consideration the psychological effects of the market.

In the Two Degrees scenario, the transition to a low-carbon economy causes capital to be lost via stranded fossil fuel assets incurring immediate costs. This, combined with the implementation of carbon taxes and an uncertain transition period reduces total output productivity. Whereas, focusing only on rapid economic development in No Mitigation increases the profitability of fossil fuel investments with direct and immediate positive impacts on economic growth. Thus from an economic perspective with minimal sentiment effects, the potential output at risk is relatively higher in a rapid low-carbon transition scenario. However, significant negative sentiment shifts and shrinking consumption patterns in the No Mitigation scenario represent potential output at risk up to 40 per cent greater than, in the to Two Degrees scenario.

While this study does not quantify the correlation between economic sentiment and impact, it has validated that sentiment indicators are one of the main drivers of economic market performance. Therefore, market confidence is a necessary parameter for capturing the effects of human behaviour in modelling climate risk and assessing its economic and financial impacts. However, market confidence is just one of the drivers and by no means dominates the analysis.

Box 2: Oxford Economics' model validation and confidence shocks to markets

The Oxford Economics' GEM is often used as a tool for scenario analysis and stress testing. The GEM makes it possible to conduct rigorous "what-if" analyses, and to look at the implications of key economic risks and policy changes when there are extreme shifts in economic conditions. The Oxford Economics' GEM is a macroeconomic model widely employed by financial corporations, consultancies, and government departments. Multilateral organisations like the International Monetary Fund, the United Nations, and the World Bank have also used this model to conduct economic analysis. .

One example scenario produced by Oxford Economics is the Global Economic Scare Scenario, where financial markets across the world grow increasingly concerned over foreign growth expectations. Besides a marked slowdown in global activities, sentiments are shocked by 100 per cent across businesses, consumers, and investors to indicate a complete breakdown of confidence in the market and a decline in long-term economic outlook. The confidence shocks applied in the development of the climate change sentiment scenarios presented in this report always remain below 10 per cent, ensuring the scenario is both plausible and possible, even with a low likelihood of occurrence.

Another, more recent stock market crash occurred in China, and began with the bursting of the stock market bubble on 12 June 2015. The crash in the SSE index was estimated to have a peak-to-trough decline of over 40 per cent. Using the inverse of the volatility S&P index (^VIX), a suitable proxy for market confidence, we show a peak-to-trough decline of 57 per cent over the same period. We also show a close correlation between market performance and market confidence (R=0.64). While sentiment plays an important role in market performance, the magnitude of the confidence shocks applied in these scenarios are much lower than historical precedents, reinforcing the plausibility of the scenarios defined in this analysis.

Notes

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