The Economist Intelligence Unit

A report from The Economist Intelligence Unit.

The cost of inaction: Recognising the value at risk from climate change

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Written by

The Economist Intelligence Unit

EXECUTIVE SUMMARY

The asset management industry—and thus the wider community of investors of all sizes—is facing the prospect of significant losses from the effects of climate change. Assets can be directly damaged by floods, droughts and severe storms, but portfolios can also be harmed indirectly, through weaker growth and lower asset returns. Climate change is a long-term, probably irreversible problem beset by substantial uncertainty. Crucially, however, climate change is a problem of extreme risk: this means that the average losses to be expected are not the only source of concern; on the contrary, the outliers, the particularly extreme scenarios, may matter most of all.

To highlight the relevance of climate change to the asset management industry and beyond, this research estimates the value at risk (VaR)[1] to 2100 as a result of climate change to the total global stock of manageable assets (the *climate VaR*). The world's current stock of manageable assets is estimated to be US$143trn.[2] The resulting expected losses to these assets identified in our findings, in discounted, present value terms,[3] are valued at US$4.2trn—roughly on a par with the total value of all the world's listed oil and gas companies or Japan's entire GDP. This is the average (mean) expected loss, but the value-at-risk calculation includes a wide range of probabilities, and the tail risks are far more serious.

Warming of 5°C could result in US$7trn in losses – more than the total market capitalisation of the London Stock Exchange - while 6°C of warming could lead to a present value loss of US$13.8trn of manageable financial assets, roughly 10% of the global total.

These values are based on the discount rate of a private investor, a reasonable baseline as the affected losses mentioned above will be on the privately held pool of global assets. However, as climate change is also a systemic problem, with issues of wider societal concern, it is often appropriate to apply a lower discount rate, consistent with public-sector actors that have longer time horizons than individuals. When the expected losses are considered from the point of view of a government, employing the same discount rates as the Stern Review,[4] they rise dramatically. From the public-sector perspective, the expected value of a future with 6°C of warming represents present value losses worth US$43trn—30% of the entire stock of manageable assets. By way of scale, the current market capitalisation of all the world's stockmarkets is around US$70trn.[5]

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[1] Value at risk measures the size of the loss a portfolio may experience, within a given time horizon, at a particular probability.

[2] Our value for the stock of manageable assets is the total stock of assets held by non-bank financial institutions, as estimated by the Financial Stability Board. Bank assets are excluded as these are, largely, managed by banks themselves.

[3] Present value is a common financial metric used to assess the current worth of a future stream of cash flows given a specified rate of return. Future cash flows are discounted at the discount rate, and the higher the discount rate, the lower the present value of the future cash flows. The cost of capital is commonly applied as a discount rate by both private investors and public sector bodies.

[4] The Economics of Climate Change: The Stern Review. Available at: http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/independent_reviews/stern_review_Ûconomics_climate_change/stern_review_report.cfm

[5] World Federation of Exchanges.

While the value of future losses from the private sector is substantial, this is dwarfed by the forecast harms when considered from a government point of view. The long time horizon, coupled with private-investor discount rates, can lead to a remarkable tolerance for systemic environmental risk. The value at risk assessed by this research should be considered the expected losses to global assets if emissions fail to be substantially reduced, but fortunately, mitigation can greatly reduce these risks. Lower greenhouse gas emissions decrease the probability of temperature increases and thus the expected harms. Provided that warming from climate change can be kept under 2°C, the average projected losses can be cut in half, while the extreme losses, identified as tail risks, can be reduced by more than three-quarters. Although the mean projected losses are significant, the results also show that institutional investors are particularly at risk of lower probability but higher impact losses. Direct impacts vary geographically; economic sectors and asset classes that are concerned with physical assets or natural resources are the most vulnerable to climate change, such as real estate, infrastructure, timber, agriculture and tourism.

However, our analysis suggests that much of the impact on future assets will come through weaker growth and lower asset returns across the board. These indirect impacts will affect the entire economy, even though the direct damage will be more localised. Indirect damage is a particularly important portion of the overall risk in the more extreme scenarios (those with 5-6°C of warming). Asset managers cannot simply avoid climate risks by moving out of vulnerable asset classes if climate change has a primarily macroeconomic impact, affecting their entire portfolio of assets. In effect, total global output will be lower in a future with more climate change, rather than one with mitigation, and accordingly the size of the future stock of manageable assets will also be lower.

Thirty years is a common time frame for pension funds and other long-term investors. But if investors wait until these risks actually manifest themselves, then the options they will have to deal with them will be significantly reduced. This is a vital concern, as the scope of investments available to a future portfolio will be more limited in a world with severe climate change than in one which has successfully mitigated climate risks. This means that future pensioners may see the security of their retirement jeopardised as a result of the climate risk that the asset managers charged with their investments are currently carrying.

These findings indicate that climate change is likely to represent an obstacle for many asset owners and managers to fulfil their fiduciary duties. Fiduciary duty requires managers to act in the best interest of their beneficiaries. In practice this means they need to deliver the best, risk-adjusted returns possible. Unfortunately, too many investors currently overemphasise short-term performance at the expense of longer-term returns. If investment managers are aware of the extent of climate risk to the long-term value of the portfolios they manage, then it could be argued that to ignore it is a breach of their fiduciary duty. Indeed, fiduciaries arguably have an obligation to reduce the climate risk embedded in their portfolios. Yet to date few asset managers have measured the climate-related risks embedded in their portfolios, much less tried to mitigate them. According to estimates by the Asset Owners Disclosure Project,[6] only 7% of asset owners calculate the carbon footprint of their portfolios, and only 1.4% have an explicit target to reduce it.

The good news is that there are widespread opportunities to reduce systemic environmental risks, and many of them are clearly profitable. Some leading investors are already taking the

[6] Global Climate 500 Index 2015, Asset Owners Disclosure Project. Available at: http://aodproject.net/climate-ratings/aodp-global-climate-500-index

KEY FINDINGS

- The value at risk to manageable assets from climate change calculated in this report is US$4.2trn, in present value terms.
- The tail risks are more extreme; 6°C of warming could lead to a present value loss worth US$13.8trn, using private-sector discount rates.
- From the public-sector perspective, 6°C of warming represents present value losses worth US$43trn—30% of the entire stock of the world's manageable assets.
- Impacts on future assets will come not merely through direct, physical harms but also from weaker growth and lower asset returns across the board. The interconnected nature of the problem will reduce returns, even on investments unharmed by physical damage.
- Although direct damage will be more localised, indirect impacts will affect the entire global economy; accordingly, asset managers will face significant challenges diversifying out of assets affected by climate change. Institutional investors need to assess their climate-related risks and take steps to mitigate them; very few have begun to do this.
- Regulation has largely failed to confront the risks associated with climate change borne by long-term institutional investors. To enable meaningful risk analyses, public companies should be required to disclose their emissions in a standardised and comparable form.
- Carbon pricing is crucial to addressing climate change. Government inaction with respect to this market failure neglects an issue of systemic risk and global importance.

initiative by investing in projects that finance the transition to a lower carbon economy. Norway's Government Pension Fund Global runs an environmental fund of some NKr50bn (US$6bn) that is largely invested in alternative energy and energy efficiency; Aviva, the UK-headquartered insurer, is targeting a £500m (US$780m) annual investment in a low-carbon infrastructure over the next five years, and Allianz of Germany has committed €2.5bn (US$2.72bn) to renewable energy investments and plans to at least double its actual exposure in the medium term.

Others are seeking to reduce long-term climate risks by decarbonising their portfolios. This need not come at the expense of short-term performance. The Swedish public pension fund AP4, for instance, has identified the 150 worst performers, in terms of carbon intensity, in the S&P 500 index and divested its holdings in them. The remaining 350 stocks track the performance profile of the index closely but have 50% of its carbon footprint.

While proactive steps addressing climate risk can demonstrate leadership, isolated activities will ultimately be insufficient. This is a collective action problem that must be addressed if carbon emissions, and thus climate risks, are to be reduced. It is clear that government action is required to establish a firm, clear price that reasonably reflects its externality costs. Rather than opposing this, institutional investors can collectively influence the companies in their portfolios to adapt and prepare for a lower carbon future. Moreover, investors can actively engage with policymakers, encouraging them to address this market failure as something that is in their collective self-interest.

Although pricing carbon is essential, a carbon price alone is unlikely to completely solve the problem of climate change; complementary policies are necessary. The financial services sector has a vital role to play in managing the tail risks. To do so, better information and more thorough disclosure are needed by all market participants so that investors can make informed decisions.

Financial institutions, however, have an obligation to manage their tail risks, and institutional investors specifically must manage their funds with the long-term benefit of their beneficiaries in mind. For this to be possible, regulators should issue guidance explicitly recognising climate risks as material. This means that disclosure of carbon emissions and acknowledgement of climate-related risks by publicly listed companies should be mandatory. Institutional investors should be able to assess and, where feasible, mitigate their climate risks accordingly.

Imperfect data availability and patchy admissions on climate risk leave both regulators and institutional investors unable to adequately address these risks. Moreover, effectively co-ordinated regulation is necessary so that best practice can become standard practice. Without requirements to recognise climate risks as material, many organisations will choose to ignore them, creating "free riders" who shirk their own responsibilities while contributing to the long-term, systemic impact of climate change.

France is going further than issuing guidance. In May 2015 its National Assembly voted to require French institutional investors to disclose information on sustainability factors in their investment criteria, and to explain how they take into account exposure to climate risks and how they measure greenhouse gas emissions associated with assets held in their portfolios. This makes sense, because just as a particular institution may represent systemic financial risk, similarly climate risks may be concentrated but poorly assessed by institutional investors; regulators need clarity as to where these long-term risks are borne. For these assessments to be meaningful, regulators need to require companies to disclose their carbon emissions and related risks so that investors can make informed decisions.

To avoid sleepwalking into a climate crisis, large-scale efforts, such as France's, are needed from both the public and the private sector. Moreover, to bolster effectiveness and avoid regulatory arbitrage, there is a clear need for co-ordinated action by national governments, institutional investors, regulatory bodies and international financial organisations. The UN Climate Change Conference (Conference of the Parties, or COP21) due to take place in Paris at the end of this year offers a major forum for governments to address this market failure and to chart a path towards mitigating climate change. If there are no strong commitments to reduce greenhouse gas emissions and meaningful actions to price carbon, then this historic opportunity will have been wasted.

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The experts below have been kind enough to review the work conducted during the course of this research programme. Regardless, The EIU maintains full editorial control of this white paper; neither the reviewers nor their organisations necessarily support nor endorse the views expressed in the course of this report. We sincerely thank them for their time and participation.

Reviewers are listed below in alphabetical order by organisation:

- Howard Covington of the Alan Turing Institute
- Anthony Hobley of the Carbon Tracker Initiative
- James Leaton of the Carbon Tracker Initiative
- Mark Fulton of the Carbon Tracker Initiative
- Jonathon Porritt of the Forum for the Future
- Alex Bowen of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics
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ABOUT THIS RESEARCH

The cost of inaction: Recognising the value at risk from climate change is a report by The Economist Intelligence Unit (The EIU). The research depicts the scope of assets at risk from climate change from the present to 2100. This innovative achievement draws on a modelling endeavour that combines The EIU's long-term forecasts with a nuanced, integrated assessment model provided by Vivid Economics. The full methodology is provided in the appendix to this report. This white paper further discusses the possible consequences of climate change as well as how both investors and governments are measuring and responding to climate-related risks. The findings of this paper are based on detailed modelling, extensive desk research and interviews with a range of experts, conducted by The Economist Intelligence Unit.

The Economist Intelligence Unit would like to thank the following experts (listed alphabetically by organisation name) who participated in the interview programme:

- Tom Wilson, chief risk officer, Allianz, Germany
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- Gunnela Hahn, head of responsible investment, Church of Sweden, Sweden
- Philippe Desfossés, CEO, Établissement de Retraite Additionnel de la Fonction Publique (ERAFP), France
- Mats Andersson, CEO, Fjärde AP-fonden (AP4), Sweden
- David Blood, managing partner, Generation Investment Management, UK
- Al Gore, chairman, Generation Investment Management, UK
- Stephanie Pfeifer, chief executive, Institutional Investors Group on Climate Change, UK
- Sebastian von Dahlen, chairman, Global Systemically Important Insurers Analysts Working Group, International Association of Insurance Supervisors, Switzerland
- Jonathan Bailey, consultant, McKinsey & Company, US
- Dag Huse, chief risk officer, Norges Bank Investment Management, Norway
- Yngve Slyngstad, CEO, Norges Bank Investment Management, Norway
- Odd Arild Grefstad, CEO, Storebrand Group, Norway
- Tobias Reichmuth, CEO and co-founder, SUSI Partners, Switzerland
- Lauren Smart, executive director, Trucost, UK
- Nick Robins, co-director, Inquiry into the Design of a Sustainable Financial System, United Nations Environment Programme (UNEP)
- Rory Sullivan, senior research fellow, Centre for Climate Change Economics and Policy, University of Leeds, UK
- Mike Kreidler, commissioner, Washington State Office of the Insurance Commissioner, US

METHODOLOGY: MODELLING THE CLIMATE VaR

A core responsibility of asset managers and institutional investors is to manage risk, and the most commonly employed measure to assess it is value at risk (VaR). This measures the size of the loss a portfolio may experience, within a given time horizon, at a particular probability. In a pioneering endeavour to highlight the relevance of climate change to the investment community, this research estimates the VaR to 2100 of the global stock of manageable assets owing to the impacts of climate change, referred to in this report as the climate VaR.

In particular, the estimates of climate VaR comprise the effect of climate change this century on the global stock of manageable financial assets, in present value terms. The global stock of manageable financial assets today is quantified at US$143trn, which is the stock of assets held by non-bank financial institutions, according to the Financial Stability Board.

To estimate the effect of climate change to 2100 on the changing stock of manageable financial assets, The Economist Intelligence Unit (The EIU) and Vivid Economics have used a leading, peer-reviewed forecasting model of the impact of climate change on the economy, the DICE (Dynamic Integrated Climate-Economy) model. DICE is one of a small number of integrated assessment models (IAMs) that have been built to estimate the economic cost of future climate change. These models link economic growth, greenhouse gas emissions, climate change and the damages from climate change back on the economy, and they do so in an integrated, consistent framework. They are typically built by adding a simple model of climate change to an existing framework for modelling the macroeconomy, with carbon emissions and climate damages being the links between the two. DICE is the most popular of these models, having been used and cited in thousands of academic studies over nearly three decades. It is publicly available, and several evaluations have been performed of its forecasts. For example, it has been shown to produce forecasts of climate change in line with much more complex physics-based models, such as that held by the UK Met Office.

The traditional purpose of IAMs has been to estimate the size of the climate change externality—the social cost of greenhouse gas emissions—in order to inform policymakers in setting emission targets or carbon prices. A famous example of such an exercise is the Stern Review, which estimated the present value of the future social costs of climate change to be equivalent to 5-20% of global GDP. The US Environmental Protection Agency has also recently used a suite of IAMs, including DICE, to determine the social costs of carbon for federal regulatory impact assessments. Since the value of financial assets is intrinsically linked to the performance of the economy, the innovation of this study is to use the DICE model to estimate the impact of climate change on financial assets instead.

This modelling recognises that, since the present value of a portfolio of equities is just the discounted cash flow of future dividends, then in the long run—ie, over the course of a century—dividends in a diversified portfolio should grow at the same rate as GDP, because ultimately dividends are paid for from the output of the economy.[7] In well-functioning financial markets the same relationship with GDP growth should hold for cash flows from other kinds of assets, such as bonds. This relationship may not be observed over a relatively long time period, even decades, owing to business cycles; for example, corporate profits are currently at historical highs, while GDP growth is low. However, on average, to 2100, this relationship can be expected to hold up. The DICE model is then used to forecast the effect of climate change on GDP, and in turn on cash flows from assets.

The appendix further details an alternative approach, which uses estimates made directly by the DICE model of the impact of climate change on the stock of non-financial capital assets. These are then converted to manageable assets, based on estimates of the share of non-financial assets used to back financial liabilities, and the ratio of financial liabilities created per US dollar of non-financial assets.

This is an up-to-date version of DICE, which extends the model to incorporate direct damages from climate change to the stock of non-financial capital assets, as well as the more traditional route of modelling a reduction in the amount of goods and services that can be produced with given inputs of capital and labour. To estimate the climate VaR at different confidence levels, there are three key uncertainties, which the academic literature has identified as being particularly determinative of the impacts of climate change, that are assessed as part of this Monte Carlo analysis.

The first is the rate of productivity growth this decade, reflecting uncertainty over general macroeconomic conditions. This sets the magnitude of growth over the rest of the century, which exerts a strong influence on the size of assets in the future and, through the link between economic activity and carbon emissions, on the amount of warming along a path of uncontrolled emissions. After the initial decade productivity growth follows The EIU's long-term forecasts, which predict increasing productivity over the long term. An alternative approach based on a decreasing productivity scenario was used as a check for robustness; further details on this can be found in the appendix. The decreasing productivity scenario, in line with expectations of secular stagnation, yields a climate VaR that is even higher than that discussed in the body of this report.

The second key uncertainty is climate sensitivity, which is by how much the planet warms in response to a given increase in greenhouse gases in the atmosphere. Climate sensitivity captures key uncertainties in the climate system, in particular the role of feedbacks in the warming process, so the probability distribution is calibrated on the latest scientific consensus from the Intergovernmental Panel on Climate Change (IPCC). The third is the risk of catastrophic climate change, embodied in DICE's representation of economic damages. This probability distribution captures the divergence of views in the academic literature on the possibility of catastrophic impacts beyond warming of 3°C.

To discount future impacts of climate change on the stock of assets back to the present, two perspectives are taken. The first is that of a private investor, whose initial discount rate is representative of the rate of return on a diversified portfolio of assets with some undiversifiable, systemic risk, in line with the capital asset pricing model. This discount rate then moves in line with changes in GDP growth in the future, based on a premium to account for bearing undiversifiable risk. The GDP growth rate without climate change is used, as investors do not currently consider climate impacts in their asset valuations. This provides a conservative estimate of losses, as GDP growth with climate change will be lower, which should lead to a lower

[7] The Case for Forceful Stewardship (Part 1): The Financial Risk from Global Warming (SSRN, Covington & Thamotheram, January 2015) Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2551478

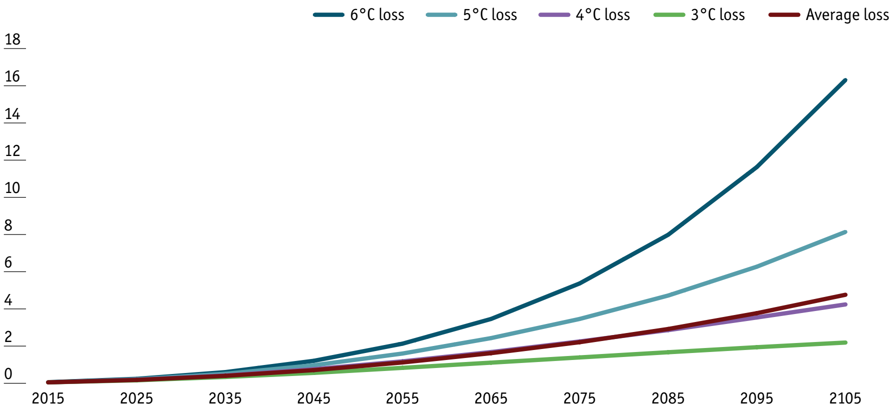
Table 1 - Value at risk

VaR due to climate change	Mean (average)	5°C	6°C
Present value from the perspective of a private investor	US$4.2trn	US$7.2trn	US$13.8trn
Present value from the perspective of a government	US$13.9trn	US$18.4trn	US$43.0trn

Table 2 - Percentage reduction in risk should warming be kept within 2°C

VaR due to climate change	Mean (average)	5°C	6°C
The perspective of a private investor	50%	63%	76%
The perspective of a government	57%	71%	85%

Figure 1: Losses are primarily incurred in the latter half of the century
Present value loss to current manageable assets (trillion $, 2015 prices)



Note: Losses are discounted at private sector discount rates. The losses over time are consistent with paths to the respective temperature levels being reached in 2105.

Source: Vivid Economics.

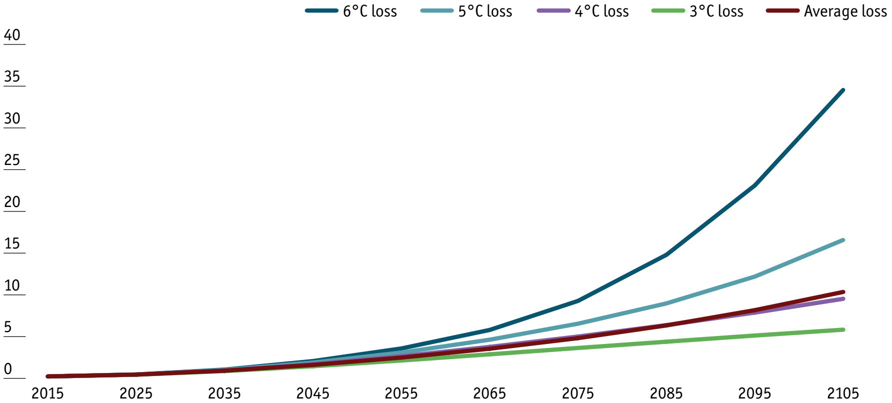
discount rate were investors to take this into account. Average private-sector discount rates begin at 5.5%, but fall to 4% towards the end of the century owing to slowing economic growth.

The alternative perspective takes the viewpoint of a public-sector regulator examining the social value of climate risk to financial assets. It is widely accepted that public-sector discount rates should be below private-sector discount rates, for reasons including a lower cost of capital as well as the avoidance of market distortions, such as taxation and externalities, which means that the gross returns on private investments are above their net social returns. This is modelled with the social discount rate applied by the Stern Review, which is appropriate for very long-run problems such as climate change, because it treats the wellbeing of future generations on a par with the wellbeing of current generations with some included uncertainty. The remaining justification for discounting in this framework is economic growth and its effect of reducing the marginal utility of consumption for future generations. Average government discount rates are initially 3.8% but fall to 2% towards the end of the century owing to slower economic growth.

The results show that the asset management industry is particularly subject to tail risks: lower probability but higher impact losses. Figures 1-4 show damage across the range of temperature levels over time. The damage increases over time, especially in the latter half of the century, when the effect of emissions released today begins to feed through to the climate. Even the average (mean) losses are significant. However, it is the risk in the “tails” of the distribution that is most severe, and this tail risk increases rapidly over time.

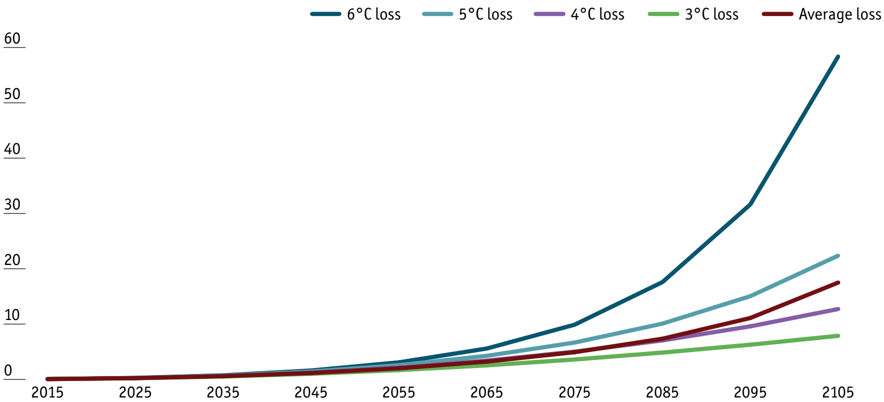
Our findings, when discounted back to their value in the present day, expect a mean (average) loss of US$4.2trn from the perspective of a private investor. However, this is only the mean; our value at risk calculation includes a range of probabilities, and the tail risks are far more

Figure 2: Losses to the capital stock are, like losses to current financial assets, primarily incurred in the latter half of the century
Damage to future capital stock (% loss in year due to climate change)



Note: Losses are not discounted. The losses over time are consistent with paths to the respective temperature levels being reached in 2105.
Source: Vivid Economics.

Figure 3: Range of expected losses discounted from a government perspective, in accordance with the Stern Review
Present value loss to current manageable assets (trillion $, 2015 prices)



Source: Vivid Economics.

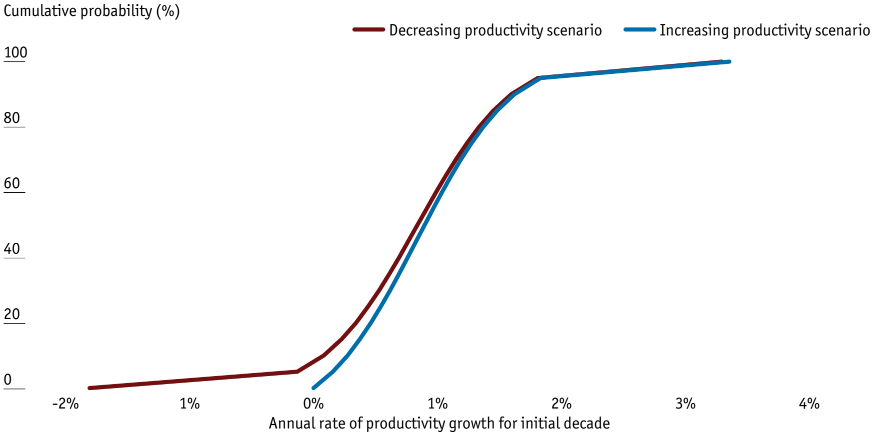
serious. Warming of 5°C is consistent with US$7trn in losses—more than the total market capitalisation of the London Stock Exchange—while 6°C of warming is consistent with a present value loss of US$13.8trn to manageable financial assets, roughly 10% of their global total. Table 1 highlights the extent of these losses.

Tail risks need to be taken very seriously when considering climate change. As highlighted by the 2008 financial crisis, tail risks are subject to miscalculation, but ignoring them can lead to exceedingly negatively outcomes. The estimated harms depicted in the modelling are conservative in nature, and the average result combines a range of unlikely but less damaging outcomes as well as the more extreme negative outcomes. This brings down the expected losses. It should be recognised that unless climate change is mitigated, the modelling depicts a permanent divergence towards a path of lower growth and diminished prosperity. Accordingly, it is important to recognise that losses from climate change do not merely represent market volatility or business cycles but permanent impairments to total assets.

Understandably, as the size of the expected losses is very heavily influenced by the discount rate employed, a discount rate more appropriate for the public sector regulators examining systemic risk would be significantly lower. For comparison, the climate VaR expected using the discount rates applied by the Stern Review are more than three times those of a private-sector investor. This may explain some of the unwillingness on the part of the private sector to address these issues. It does not, however, excuse government inaction on an issue of systemic risk.

This is particularly the case as there are opportunities to greatly reduce the risks from climate change. Table 2 presents the percentage reduction in the climate VaR of a mitigation scenario consistent with a 66% probability of remaining under 2°C of warming, relative to the

Figure 4: The distribution over initial productivity growth rates varies somewhat between the productivity scenarios



Note: The figure shows the cumulative probability of an annual rate of productivity growth being achieved in the initial decade, after which, this trend will evolve according to a scenario: its growth rate either increases or decreases.

Source: Vivid Economics.

baseline expected losses.[8] Increased mitigation reduces carbon emissions, and thus the likely array of future temperatures rises, occurring at different levels of probability. This lowers risks, and it reduces them most dramatically at the tail ends of the distribution where the worst potential outcomes lie.

These results are for total global assets, and DICE is a globally aggregated model that does not allow explicit disaggregation by asset class or by region. Nonetheless, impacts can be expected to vary by asset class and region. The impacts of climate change, at least for modest degrees of warming, can be expected to concentrate in sectors of the economy sensitive to weather conditions, for instance agriculture, energy, forestry and water. However, these sectors are connected with the rest of the economy through supply and demand linkages, and shifts in the prices of goods and services because of climate change will affect overall spending patterns and household incomes. Allied to the fact that at higher degrees of warming the impacts of climate change are expected to become increasingly economy-wide, this means that climate change poses a systemic risk, coming through weaker growth and lower asset returns affecting the entire portfolio.

As a result, asset managers may struggle to avoid climate risks by moving out of vulnerable asset classes and regions. This is because, at least under lower-probability and higher-impact outcomes, our findings suggest that climate change will primarily have a macroeconomic impact that affects the entire portfolio of assets. The interconnected nature of the problem is likely to reduce returns, even on those investments not actually harmed by physical damage. Given this result, asset managers will face significant challenges diversifying out of assets affected by climate change.

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[8] The minimal mitigation scenario is characterised by future inaction and stalemate on climate policies, which provides an emissions reduction of 6.5% in 2105 relative to a world of no further action whatsoever. Keeping global warming within 2°C as the "likely" outcome is the stated goal of the IPCC's mitigation analysis, and it uses the benchmark of at least 66% chance as the threshold.

THE NEED FOR FURTHER RESEARCH

This report is a major step towards understanding the impact of climate change on financial assets. However, there is substantial uncertainty embedded in any attempt to make such long-term forecasts, and the model itself necessarily presents an aggregated view of the world. Rather than detracting from the findings, which are significant, this highlights the need for further research.

While by no means comprehensive, below are some areas in need of further exploration:

- Geographical and sector-specific risk assessments. Ideally, this would lead to a comprehensive, bottom-up model covering all assets and assessing both direct and indirect impacts from climate change. Research should then aim to further disentangle the level of risk that cannot be diversified away.
- Investigations into the interaction between physical and financial assets. While financial markets have tended to be resilient to isolated natural disasters, the impact when affected at systemic level is less clearly understood.
- Detailed analyses need to explore the human and social costs of the more extreme potential outcomes. The substantial GDP and total asset impacts identified in this research suggest the likelihood of major dislocations to economies and societies around the world. This modelling endeavour is not able to depict this at a local or national level, but given the magnitude of the risks involved, further work is clearly merited.

THE IMPACT OF CLIMATE CHANGE

Since 1992, when the United Nations Framework Convention on Climate Change (UNFCCC) was first negotiated in Rio de Janeiro, much time has been lost without adopting mitigation policies to reduce the effects of climate change. Now, 23 years later, the 21st session of the Conference of the Parties to the UNFCCC (COP21), due to take place in Paris at the end of 2015, may provide a forum for governments to reach a substantive agreement on collective action to combat climate change.

According to current projections from the Intergovernmental Panel on Climate Change (IPCC), the earth's surface temperature is forecast to continue rising in the remainder of the 21st century; the global mean surface temperature increase for the period 2016–35 relative to 1986–2005 is likely to be in the range of 0.3°C to 0.7°C. Furthermore, heat waves will occur more often, extreme precipitation events will become more intense and more frequent in many regions, and oceans will continue to warm and acidify, while sea levels are expected to rise.[9]

Nevertheless, the precise impacts of these changes in climate and weather patterns are far from predictable. According to Rory Sullivan, senior research fellow at the ESRC Centre for Climate Change Economics and Policy at the University of Leeds, climate change-related risks must be assessed and managed in the same way as other risks, where attention must be paid to both probability and consequences.

Consider weather events such as storms. Mike Kreidler, Washington's state insurance commissioner, forecasts: "We're going to be looking at storms with greater intensity; we're going to face more problems related to wildfires and droughts; tornadoes that carry more of a punch; and hail that is larger and more damaging." Yet pinpointing where and when these events might occur, and predicting their individual impact, is not feasible with any degree of precision. And there is some uncertainty concerning the extent and the pace at which climate change will lead to these risks materialising.

Nick Robins, co-director of the Inquiry into the Design of a Sustainable Financial System at the UN Environment Programme (UNEP), points out that even as efforts to mitigate climate change bear fruit, there remains a probability of a highly destructive scenario outcome. While the risk of that outcome is low, the results may be catastrophic. "We wouldn't get on a plane if there was a 5% chance of the plane crashing," he says. "But we're treating the climate with that same level of risk in a very offhand, complacent way."

The effects of climate change are expected to be long-term, cumulative and probably irreversible. In North America and Europe, according to the IPCC, key risks include increased damages from river and coastal floods and from wildfires; in Asia, water and

[9] Climate Change 2014: Synthesis Report, Intergovernmental Panel on Climate Change, 2104. Available at: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

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> *Nick Robins,*
> ***co-director, Inquiry into the Design of a Sustainable Financial System, United Nations Environment Programme***

food shortages are a significant threat; and in Africa, risks include stress on water resources, reduced food security and a greater threat of vector- and water-borne diseases.

Keeping warming within 2°C as the "likely" outcome is the stated goal of the IPCC's mitigation analysis, and it uses the benchmark of an at least 66% chance as the threshold. Applying this threshold, the mean projected losses from the climate VaR—the value at risk (VaR) of global assets under management owing to the impacts of climate change—would be cut in half. More importantly, our findings indicate that mitigation has the potential to cut the projected harms of even the extreme losses identified as tail risks by more than three-quarters.

Global warming expected to 2050 is a result of past emissions; in other words, warming will occur even if further emissions are halted immediately. "Once the greenhouse gases are up in the air, climate change then is effectively irreversible," says Mr Robins of UNEP. "Unchecked, climate change will be very disruptive during this first half of this century. And then into the second half, it will be very destructive and potentially catastrophic." Owing to the delayed effect of carbon dioxide emissions, the full consequences of greenhouse gases emitted today may not be felt until long after they have entered the atmosphere.

As such, it is possible that any "tipping point" will not be recognised until after it has been reached. But positive action taken today will lessen the impact of climate change in the second half of this century. "I wonder whether ... the accumulated burden over time and the lack of willingness to directly address [emissions] in a meaningful manner is going to leave us in a position where it could be a catastrophe and we just miss the opportunity," says Tom Wilson, chief risk officer at Munich-based insurer Allianz.

A destabilising force

The effects of climate change on capital markets have the potential to destabilise the global financial system. In April 2015 the G20 group of major economies asked the Financial Stability Board, created by the G20 and hosted by the Bank for International Settlements (BIS) in Basel, to conduct an inquiry into the potential risks to global financial stability posed by climate change or regulation aimed at combatting the risks associated with natural disasters. "I believe natural disasters could affect global financial stability through different channels," says Sebastian von Dahlen, chairman of the Global Systemically Important Insurers Analysts Working Group at the International Association of Insurance Supervisors (IAIS) in Basel.

What is the scope of the economic cost of climate change? This report estimates the present-day climate VaR to be US$4.2trn. This is the mean (average) from the standpoint of a private investor. The tail risks are far more serious. Should there be warming of 5°C or 6°C, then the expected losses would rise to US$7trn or US$13.8trn respectively. These figures represent the harm to financial assets from the impacts of climate change if warming is not significantly mitigated.

When these risks are considered from the public-sector perspective, then a future with 6°C of warming represents discounted, present-day losses worth US$43trn, while 5°C of warming is consistent with losses of US$18.4trn. By way of scale, the current market capitalisation of all the world's stockmarkets is around US$70trn, while the current stock of manageable assets is around US$143trn, according to the latest estimates.[10]

The potential for climate-related destruction includes the risk of direct destruction of assets. In the US alone, climate change and severe weather patterns have the potential to put between US$238bn and US$507bn worth of coastal real estate under water by 2100 as sea levels rise, according to one estimate.[11] "Anything you can't move is of concern," says Mr Sullivan of Leeds University. "That's why sea-level rise is probably the most immediate risk for investors to be concerned about."

Climate change is expected to cause significant physical damage, in particular owing to the increased frequency of severe storms and flooding. Sea-level rise, in some of the more extreme scenarios, is likely to displace millions of people. To some degree this makes sense, as many of the world's most densely populated areas are located in low-lying coastal plains. While the human and the geopolitical implications that such disruption might cause are far from clear, the possibility of conflicts, refugee crises and widespread social dislocation would almost certainly increase.

[10] Our value for the stock of manageable assets is the stock of assets held by non-bank financial institutions, as estimated by the Financial Stability Board. Bank assets are excluded as these are largely managed by banks themselves. The value of the world's stockmarkets is taken from the World Federation of Exchanges.

[11] American Climate Prospectus: Economic Risks in the United States, October 2014. Available at: http://rhg.com/wp-content/uploads/2014/10/AmericanClimateProspectus_v1.2.pdf

The modelling endeavour undertaken in this research is only able to provide an aggregate view of the damages. However, at higher levels of warming the trillions of dollars in present value losses represent economic damages comparable with those seen in wars or civil conflicts. Unlike isolated events, however, climate change is global in scope and largely irreversible, presenting a permanent divergence towards a path of lower growth and diminished prosperity.

Similarly, increased frequency of droughts and severe storms will reduce food production and undermine water supplies in some locations. In aggregate, climate change is expected to undermine global food security, but if kept to a low level, this is likely to be manageable. Facing higher levels of warming, however, the IPCC's Fifth Assessment Report highlights that a large faction of the world's species will face an increased risk of extinction as a result of climate change.[12] For instance, most plant species are unable to shift their geographical range fast enough to adapt to unmitigated warming. The future following that sort of systemic collapse cannot be fully modelled.

There is also an increasing understanding that there will be direct impacts on human health, ranging from heat waves and fires to malaria and other vector-borne diseases. Poorer regions, less able to pay for adaptation measures, will suffer particularly acutely: the physical impacts alone will be devastating in many parts of the world.

Crucially, however, it is not just physical assets that are threatened with destruction from climate change. There is also significant scope for indirect destruction, for example through lower economic growth that will be a consequence of climate change; lower levels of savings will have a negative effect on investment levels; and lower returns on assets are likely to lead to poor performance of equity portfolios across the board. "If disasters are becoming more extreme, then I think it's not so much the question which asset classes are exposed, but rather, are there any assets which wouldn't be," highlights Mr von Dahlen of the IAIS.

Stranded assets

While leaving climate change unchecked will result in large-scale value destruction, it should be acknowledged that there is also scope for impacts on investor portfolios should major regulatory efforts to combat climate change be implemented. Among these is the impact of the stranding of assets—not least the substantial portion of known coal, oil and gas reserves which will probably remain unburned if climate change is to be limited—a scenario not currently priced into current valuations of these assets.

Owners and managers of assets in different countries are likely to be exposed to differing degrees of potential losses in their portfolios. In the UK, for example, the benchmark FTSE 100 share index holds a very substantial percentage of businesses that rely on carbon-intensive activities or assets, so that investors would face sharper potential losses if the prices of these assets were to experience a correction. At the same time, institutional investors in the UK, such as pension fund managers, favour index tracking more than elsewhere, meaning that ownership of carbon-intensive businesses is especially widespread.

[12] Intergovernmental Panel on Climate Change, Fifth Assessment Report. Available at: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

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>
> *Mats Andersson,*
> ***CEO, Fjärde AP-fonden (AP4)***

And there is no guarantee that any effects of climate change on the valuation of assets will be gradual or linear, so that a wait-and-see approach among investors potentially presents more risk to portfolios. "Regulations and restrictions on coal in 20 years' time: what would that do in terms of the current value of those stocks that we hold, and what do we think the path from here to there would look like?" asks Jonathan Bailey, a consultant at McKinsey & Company in New York. "There may suddenly be a consensus that shifts pricing." Inaction may leave investors holding such assets at particularly high risk.

This means that global investors are currently facing a stark choice. Either they will experience impairments to their holdings in fossil-fuel companies should action on climate change take place, or they will face losses to their entire portfolio of manageable assets should little mitigation be forthcoming. Charting a path away from these two options should be a strong motivation for long-term investors to engage with companies in their portfolios and to shift investments towards a profitable, low-carbon future.

ASSESSING PORTFOLIO RISK

What are investors doing to assess long-term risk in their portfolios? Only 7% of asset owners are currently calculating the carbon emissions embedded in their portfolios.[13] And in the US, just over 10% of insurers surveyed have published their climate risk management principles, according to a recent report.[14] The report's authors note that "most of the companies responding to the survey reported a profound lack of preparedness in addressing climate-related risks and opportunities."

It helps very little that the financial markets typically operate on a short time horizon. While in theory asset managers have an obligation to maximise risk-adjusted returns over the long term, in practice the tendency is to emphasise short-term returns. This is a problem more generally: if company executives' focus is too short-term, it can hamper those investments needed to ensure the long-term health of their companies; however, investors with longer-term horizons are required to focus on the long-term financial health of a company. But beyond general concerns, short-termism is a particularly acute problem for climate change owing to its exceedingly long-term nature.

This inevitably has implications for institutional investors with long-term liabilities such as insurers, pension funds and sovereign wealth funds. Norway's Government Pension Fund Global, for example, looks 30 years ahead. "We think of the firm on a much longer horizon than that, but realistically and practically 30 years is what we operate with," says Yngve Slyngstad, CEO of Norges Bank Investment Management, which runs the fund. Even this recognisably long-term horizon is a problem when addressing climate change, as actions taken in 2070 will be far too late to influence the level of warming from current trends.

[13] Global Climate 500 Index 2015–The Asset Owners Disclosure Project. Available at: http://aodproject.net/climate-ratings/aodp-global-climate-500-index

[14] Insurer Climate Risk Disclosure Survey Report & Scorecard: 2014 Findings & Recommendations, Ceres, 2014. Available at: http://www.ceres.org/resources/reports/insurer-climate-risk-disclosure-survey-report- scorecard-2014-findings-recommendations/view

Recognising that climate change represents a significant long-term risk to their portfolios, some leading institutional investors are starting to take decisive action—but they remain in the minority. “I think the most important thing is to get the pension fund asset managers to understand that climate is a risk,” says Mats Andersson, CEO of Swedish public pension fund manager Fjärde AP-fonden (AP4). “You can ask pension funds about traditional risk metrics, but ask them about their exposure to climate risk and I’m sure that 90% will say they haven’t got a clue.”

In recognition of the long-term systemic risks, a response to climate change should be incorporated into the legal duties of market participants, in particular, the fiduciary duty of asset managers. Laurent Clamagirand, chief investment officer of France’s AXA Group, asserts: “If ‘carbon’ is considered to be a risk, investors should attempt to identify, measure and reduce it on behalf of their beneficiaries.”

Consequently, climate change presents a significant challenge to the ability of institutional investors to fulfil their fiduciary responsibilities. Institutional investors with a long-term investment horizon are deeply implicated. “Many financial institutions, such as pension funds, aim to be around for many decades,” says Mr Robins of UNEP. “And in that context, their ability to continue to honour the promises they may have made to their beneficiaries will be profoundly impacted.”

Measuring carbon exposure

As a start, a number of investors are calculating the carbon footprints of their portfolios. In September 2014 the United Nations-sponsored Principles for Responsible Investing (PRI) launched the Montréal Carbon Pledge, whose signatories commit to the annual measurement and public disclosure of the carbon footprint of their investment portfolios. The goal is to attract at least US$3trn of portfolio commitment before the COP21 meeting in Paris at the end of this year. Currently 53 firms have signed the pledge, including Sweden’s Fjärde AP-fonden (AP4), with SEK295bn (US$36.3bn) of assets under management, and France’s Établissement de Retraite Additionnel de la Fonction Publique (ERAFP), with €21bn (US$23.8bn) of assets under management.

For leading investors, the motivation is there (See box: Motivations for investors to act), and many are calibrating their response. Mr Wilson, chief risk officer at Allianz, says that his firm is taking action: “We are exploring whether climate considerations and the regulatory implications of climate considerations should be influencing our asset-by-asset determination, not from an ESG [environmental, social and governance] perspective, but from an enlightened self-interest with regard to portfolio returns.”

MOTIVATIONS FOR INVESTORS TO ACT

As growing numbers of institutional investors address the climate-related risks in their investment portfolios, they are driven to act by risk management goals, financial returns and regulatory mandates. For those that have not yet taken steps to address the long-term risks they face, here are some reasons to do so:

- Yngve Slyngstad, CEO of Norges Bank Investment Management, which runs Norway’s Government Pension Fund Global, says that the mandate to manage the sovereign wealth fund clearly stipulates that the fund’s main driver is financial return. “Given the premise that it’s very long-term, we are now looking at sustainable business models,” he says.

- Storebrand Group is another asset manager which believes that sustainability is a prerequisite for securing long-term financial results. “To understand the risks and the opportunities that companies are facing over the long term is vital to making good investment decisions,” says CEO Odd Arild Grefstad. “And we believe that, over time, our sustainability research will contribute to higher quality and also positive returns.”

- Increasingly, says Philippe Desfossés, CEO of French pension fund Établissement de Retraite Additionnel de la Fonction Publique (ERAFP), asset managers may be called to account for not incorporating sustainability into the management of their portfolios, “because now it has really been made obvious that carbon is a risk, and it’s a risk for business,” he says. In case of legal dispute, he points out: “It’s now very difficult for anyone to say ‘Oh, I didn’t know it was a risk’.”

- In some cases, investment management mandates stipulate that funds must be managed with sustainability in mind but without sacrificing financial returns—especially in public pension funds. “We are regulated by law, and the law says that we should allocate capital on a 30-40-year horizon,” explains Mats Andersson, CEO of Swedish public pension fund Fjärde AP-fonden (AP4). “The law also states that we should take sustainability into account without giving up returns.”

Measurement needs to precede any effective mitigation, but this can take several forms. Dag Huse, chief risk officer at Norges Bank Investment Management, has been making efforts to understand the meteorological and geographical models used by reinsurers and how these models are incorporated into their research and their pricing. "All those geo-models produce a lot of statistics that the reinsurers use for setting their risk thresholds" he says. "Looking into this could be important when assessing changes in climate-related risk." Not surprisingly, perhaps, the reinsurers are reluctant to share proprietary models.

As part of its investment management activities, Storebrand of Norway has introduced a scoring method to help drive sustainability in its portfolios. An in-house research team compiles data to then assign a sustainability score from zero to 100 to each of the 2,500 companies in the firm's investment universe. "If the company has a higher rating, it will be a more attractive investment to different teams, whether it's a bond team or an equity team," explains CEO Odd Arild Grefstad.

Most investors appear to make use of ESG data sourced externally, often from specialist third-party information providers such as Corporate Knights, MSCI, South Pole Group, Sustainalytics or Trucost. For example, Trucost offers metrics to assess companies' carbon emissions, embedded carbon emissions from fossil-fuel reserves, water use, pollutants and waste generation. MSCI offers ESG indices, including low-carbon indices.

Investors caution that external data on sustainability measures are variable. Some industry sectors have long reported ESG measures, while others have not. Datasets sometimes combine reported company data and estimates. "We are constantly searching for good data on companies," says Mr Grefstad. "You need to know what you're doing if you're combining data from reported and estimated data and from different types of providers."

Accurate information is important for all companies, but particularly vital for fossil-fuel businesses and large energy consumers. Understanding the carbon intensity of their reserves or their consumption, respectively, ought to be clearly conveyed. Unfortunately, there is no standardised set of metrics or indicators for the disclosure of climate change-related information. This is despite calls from some leading investors for comparable and consistent information.

The fact that information on carbon emissions and climate risks is not readily available in a comparable form limits the ability of institutional investors to manage the risks within their own portfolios effectively. Despite an existing array of reporting schemes that address environmental information, most of these initiatives are voluntary in nature and limited in scope. This is clearly an area where financial regulators should have a role in laying out clear standards for all market actors.

Engaged asset managers are developing their own metrics for these issues, often relying on third parties' analysis or information to make up for the lack of market standards; however, most investors have not begun to approach climate risks in any systematic way.

> **It has really been made obvious that carbon is a risk, and it's a risk for business. It's now very difficult for anyone to say 'Oh, I didn't know it was a risk'.**
>
> *Philippe Desfossés,*
> ***CEO of French pension fund Établissement de Retraite Additionnel de la Fonction Publique (ERAFP)***

INVESTING, DIVESTING AND ENGAGING

For those investors who recognise and measure the long-term climate-related risks embedded in their portfolio, there are a number of options. A clear opportunity is to identify and invest in companies that are better placed to benefit from a transition to a low-carbon economy—and to shift funds from those that are more heavily dependent on carbon for returns. In many cases these investment opportunities have the potential to generate attractive returns, as well as representing an opportunity for institutional investors to mitigate carbon-related risks embedded in their portfolio. "The business case to invest in a transition to a low-carbon economy is becoming extremely compelling," says David Blood, managing partner of Generation Investment Management. "And that's what's going to drive change."

Furthermore, substantial financing is required as the world economy transitions towards a low-carbon future, presenting opportunities for investors to mitigate their risks, decarbonise their portfolios and diversify their returns. These opportunities include areas such as renewable energy and energy efficiency. "In the current low interest rate environment, investments in renewable energy infrastructure are an attractive investment proposition with stable distributions for institutional investors," says Tobias Reichmuth, CEO and co-founder of SUSI Partners, a Zurich-based company specialising in investing in sustainable infrastructure.

Indeed, the IPCC estimates that additional investment of between US$190bn and US$900bn is required annually in the energy sector alone if the rise in average global temperatures is to be capped at 2°C.[15] Based on International Energy Agency (IEA) data, Mercer, a consulting firm, estimates that additional cumulative investment in efficiency improvements, renewable energy, biofuels and nuclear and carbon capture and storage (CCS) could expand in the range of US$3trn to US$5trn by 2030.[16]

Felix Hufeld, president of Germany's Federal Financial Supervisory Authority (BAFIN), explains that the principles-based approach of new Solvency II rules for insurers, due to enter into force in the European Union in January 2016, could help to promote such investment. "All insurance companies which fall under Solvency II will have to comply with the famous Prudent-Person Principle, which does offer you more degrees of freedom to invest your money," he says. "That

[15] The Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report. Available at: https://www.ipcc.ch/report/ar5/

[16] Climate Change Scenarios—Implications for Strategic Asset Allocation, Mercer, 2011. Available at: http://www.mercer.com/insights/point/2014/climate-change-scenarios-implications-for-strategic-asset- allocation.html

A FREE OPTION ON THE MISPRICING OF CARBON

The Swedish public pension fund Fjärde AP-fonden (AP4) is governed by legislation that requires it to take sustainability into account, but without giving up returns. When AP4 decided to scrutinise the climate-related risks in its investment portfolio, it began by measuring the carbon footprint of the S&P 500 index. The pension fund's managers decided that, as they sought to mitigate the climate-related risk in their holdings in the index, they did not want to take any sector stances—specifically, they did not want to take any explicit bets against fossil fuels.

Instead, AP4 kept its S&P 500 holdings sector-neutral by divesting only those stocks that proved to have the heaviest carbon footprints among banks, retailers, automotive manufacturers, oil companies, coal companies and more. By taking out the 150 worst stocks on a sector-neutral basis, leaving AP4's holdings at 350, the firm continued to track the S&P 500 with a tracking error of between 0.7% and 0.8%.

"The surprising part of this was that we took down the carbon footprint by 50%," recalls AP4 CEO Mats Andersson. "So we will get a free option if carbon is wrongly priced, which I believe it is." He adds: "If I'm right, we've taken down the risk for our clients—the Swedish pensioners—in terms of climate risk in our portfolio, without jeopardising returns in the short term because we get more or less the same returns."

A further surprise was in store. After one year AP4's carbon-light S&P portfolio had outperformed the wider S&P 500 by some 70-80 basis points. "I still don't know why," says Mr Andersson. "One reason could be that companies that look after the carbon footprint will probably look after the rest of the business in the same manner. So this is actually a way to pick the good companies."

AP4 has now rolled out a similar model in Europe and plans to do the same in Japan. The management plans to decarbonise the fund's entire equity portfolio within two years. "I think that we will end up actually having within the span of 50% to 70% lower carbon intensity, and that is without giving up returns," Mr Andersson comments. "On the contrary—we get this free option."

The business case to invest in a transition to a low-carbon economy is becoming extremely compelling

David Blood,
managing partner, Generation Investment Management

does include infrastructure projects, which, from an investment vehicle point of view, are usually the main reactions to cope with climate change." As such, Mr Hufeld believes that Solvency II regulation is actually an opportunity for insurers.

Regulations affecting the asset allocation strategies of pension funds certainly play an important role, according to Mr Reichmuth. "The funds available for investment in clean energy and energy efficiency projects could expand greatly if infrastructure were more widely recognised as its own sector. Legislation in Germany has made this easier, but most countries simply treat infrastructure as part of 'alternative investments' despite their very different risk/return profiles", he states. This can impose limitations on investor exposure to certain asset classes.

Leading institutional investors are already positioning themselves favourably to gain from growth in renewable energy and energy-efficiency activities. Norway's Government Pension Fund Global, for example, manages an environmental fund of some NKr50bn (US$6bn) that is largely invested in alternative energy and energy efficiency; Aviva, the UK- headquartered insurer, is targeting a £500m (US$780m) annual investment in a low-carbon infrastructure over the next five years; and Allianz of Germany has committed €2.5bn (US$2.72bn) to renewable energy investments and plans to at least double its actual exposure in the medium term. France's AXA Group said in May 2015 that it would triple its green investments to €3bn by 2020 through green bonds, private equity and infrastructure investments. "Institutional investors are increasing their exposure to this space, but there is a need to better commodify the opportunities for clean infrastructure investment," says Mr Reichmuth.

In March 2015 EU finance ministers approved the regulation for the European Fund for Strategic Investments, which is set to unlock €315bn, the bulk of which is aimed at financing strategic infrastructure projects of European interest, including in the energy sector. Public institutions and development banks are set to shoulder some of the risk, paving the way for investment from pension funds, insurers and other institutional investors, according to Stephanie Pfeifer, chief executive of the UK-based Institutional Investors Group on Climate Change (IIGCC). "We have had a lot of discussions with the EU Commission on how to attract more investment into low-carbon infrastructure in particular," Ms Pfeifer asserts.

Engagement

Engagement is an important tool offering investors a path towards risk mitigation. In some cases, investors are removing the worst performers in each sector from their portfolios and are engaging with the remaining firms, especially where these are local and easily accessible, and where carbon-intensive activities make up a minority of the investee firm's activities. Storebrand has divested from all pure-play coal companies and some pure-play oil firms, for example, but remains an active owner of a local company involved in oil projects that are not a dominant part of their business, according to the firm's CEO, Mr Grefstad. "We've been a strong voice," he comments.

Institutional investors can use engagement as a tool to reduce the risk that stranded assets may hamper returns from the shares in their portfolios. Investors can push their portfolio companies to take action to mitigate their climate risks—wielding influence both through discussions with management and through the votes that their shareholdings entitle them to. For the growing volumes of equity funds under management that are managed passively through index tracking funds, engagement offers an opportunity for investors to bring influence to bear on strategy and capital decisions, points out Mr Bailey of McKinsey.

"As a company you are going to have to stop investing in further high-carbon assets and start either returning capital to shareholders and winding the business down, or pivoting towards lower-carbon business operations," explains Mr Bailey. "And so the question is what that path looks like." As an institutional investor, it becomes all the more important, Mr Bailey says, to understand the company's strategy, to engage with management and to identify the moment when they will need to pivot.

Investors are in a position to push companies to adapt for long-term growth. This includes advocating that businesses in their portfolios seek profitable means of reducing their carbon emissions or carbon intensity. This can be done in private meetings or through passing resolutions at shareholder meetings if a softer touch proves ineffective. "We see businesses already adapting and already changing their business models because they see that makes financial sense and they see they don't have a choice," Storebrand's Mr Grefstad says. While leading companies are responding to these issues, shareholders can exercise active stewardship throughout their portfolios.

AP4 is one pension fund that very actively engages with the management of the companies in which it is invested. "When we at AP4 are on a board nomination committee, we always fight for the board to have enough competence on sustainability," says Mr Andersson, the CEO of AP4. "We make sure we've got the boards with the competence to actually drive sustainability, and we make sure we've got the management to do it and a strategy that is aligned with what is possible."

In turn, institutional investors also have scope to influence the lobbying position that these companies take, points out Ms Pfeifer of the IIGCC. “Are they are in favour of, for example, reform of emissions trading schemes to support a robust carbon price or not?” she asks. Investors should have the right to know the lobbying position of companies in their portfolios and, more importantly, institutional investors can push to ensure that company activities are in accord with the broader interests of their shareholders.

The opportunities for engagement extend beyond companies held within an asset manager’s portfolio. Some leading institutional investors are recognising that it is in their own interest and that of their beneficiaries to advocate policy action on climate change. The IIGCC, for example, representing US$24trn in assets, has called on the finance ministers of the G7 to support a long-term global emissions reduction goal in Paris this year aimed at keeping emissions under 2°C.[17] It has further called for governments to submit short- to medium-term national emissions pledges and country-level action plans to achieve them.

Divesting high-carbon assets

Divesting has the potential to send a signal to company management and the public more broadly. While a company may not miss any single investor, Lauren Smart, executive director and global head of the financial services business at Trucost, points out that “with a critical mass of investors, there is a strong argument that the cost of capital for that company may go up.” At the same time, she argues that divestment sends a “very strong public policy signal” that policymakers and regulators may tighten rules around companies with a heavy carbon footprint, or else ease regulation or reduce the cost of capital for competitors to those companies, such as those developing alternative technologies.

But while divestment provides a clear means for investors to publicly express their concerns with climate change, it forgoes the substantial influence that share ownership provides. It may be that divestment is the best option only after engagement has failed or where a company’s core business model is fundamentally reliant on high carbon emissions.

Motivated investors have announced programmes to shed assets that represent significant long-term climate-related risk or carbon-related risk. Yet, given the significance of carbon-intensive assets in institutional portfolios, divesting is hardly straightforward. Bloomberg New Energy Finance estimated in an August 2014 report[18] that the stockmarket capitalisation of companies in the coal and the oil and gas sectors amounts to nearly US$5trn. Oil and gas companies, which accounted for US$4.65trn, are particularly large and widely held, making wholesale divestment a complicated process. As a result, asset managers with a mandate to hold a fully diversified portfolio may struggle to remove this sector from their portfolios entirely.

[17] IIGCC open letter to the Finance Ministers of the Group of Seven. Available at: http://www.iigcc.org/files/publication-files/Investor_CEO_letter_g7_final.pdf

[18] “Fossil fuel divestment: a US$5 trillion challenge”, Bloomberg New Energy Finance, August 2014. Available at: http://about.bnef.com/content/uploads/sites/4/2014/08/BNEF_DOC_2014-08-25-Fossil-Fuel-Divestment.pdf

However the stockmarket, value of coal companies in isolation accounts for less than US$250bn, and their carbon intensity is substantially higher than that of the oil and gas sector, presenting a clearer opportunity for investors seeking to divest. Indeed, coal is the most carbon-intensive energy source, and without carbon capture and storage it is fundamentally incompatible with emissions-reduction initiatives. In May, AXA Group announced that it plans to sell €500m of coal-related bonds and equities in order to reduce long-term climate-related risk. Norway's Government Pension Fund Global also has divested from a number of companies in recent years following financial assessments that include environmental and social factors. The list includes companies involved in palm oil production, coal mining and coal extraction for electricity power production. "It's around 130 companies that we've taken out of our investment universe," says Mr Slyngstad of Norges Bank Investment Management. The majority of those divestments are related to climate issues.

A nuanced approach to reducing the climate-related risks embedded in investment portfolios is possible – in particular for investors whose funds track equity indices. "Some [investors] are tilting their funds away from high-carbon assets with best-in-class and screening [approaches] and changing their benchmarks," says Ms Pfeifer. Swedish public pension fund AP4 is decarbonising its portfolio in this way. (See box: A free option on the mispricing of carbon).

THE STATE OF REGULATION

Regulation of the financial services sector has intensified enormously since the 2008 financial crisis. While national regulation has at times gone further, the Basel III regulatory framework covering banks set the new baseline. This raised capital requirements, further defined liquidity ratios and broadened the regulatory and supervisory review process. These efforts have reshaped wide swaths of the financial services sector in line with a stated goal by the G20 in 2009 to "generate strong, sustainable and balanced global growth". At the EU level, Solvency II has endeavoured to deliver similar outcomes with a framework covering insurers.

These reforms demonstrate clear regulatory concerns with regard to systemic risk. But in their focus on the excesses that provoked that crisis, most have overlooked an opportunity to address emerging risks to long-term financial and economic stability. Regulation has largely failed to confront risks associated with climate change, and in particular long-term climate-related risk borne by institutional investors. The insurance sector is particularly exposed as greater outlays will likely be required to cover natural disasters, while at the same time the overall portfolios which must fund their liabilities will be diminished.

LEADERSHIP FROM DEVELOPING MARKETS

While many developed markets have lagged behind, China and Brazil have arguably been leaders when it comes to including systemic environmental risk in their financial regulation. Both have explicitly recognised the materiality of systemic environmental risks as they relate to long-term financial stability.

Since 2012 the China Banking Regulatory Commission (CBRC) has required banks to monitor their borrowers' compliance with environmental regulations and to begin implementing loan contract changes so than environmental violations can trigger accelerated loan repayments. Moreover, the CBRC works to promote bank lending to environmentally sustainable economic activities through its Green Credit Guidelines.

These regulations integrate a range of environmental and social issues; they were informed and supported by the World Bank in 2012 and recognise the Equator Principles as a framework for international best practice. Funders are requested to collect data from renewable energy infrastructure and energy efficiency-related projects, among others, and turn them over to the regulator

Similarly, in 2014 the Central Bank of Brazil implemented a regulation establishing guidelines for financial institutions to consider the degree of exposure to the social and environmental risk of their activities and transactions. This not only covers financial institutions' own operations, but also the environmental and social risks within their asset portfolios. It further requires, at the risk of penalties, that banks publicly disclose their environmental and social risks.

Explicit statutory requirements to assess, disclose and mitigate long-term climate-related risks are largely absent from the regulatory frameworks of most major developed economies. Japan, for example, has "no regulations associated with climate change with regard to Japanese insurance companies currently, since Japanese insurance companies have low exposure to climate change in their portfolios," states an official of Japan's Financial Services Agency, which oversees the country's banking, securities and exchange, and insurance sectors. "We have no plans to introduce changes to the regulatory framework," the official affirms.

Nor are there clear plans for the European Insurance and Occupational Pensions Authority (EIOPA),the EU's insurance and pension fund supervisory body, to further scrutinise fund managers' climate-related risks. A March 2014 draft revision[19] of the EU's 2003 directive on supervision of institutions for occupational retirement provision included a requirement that institutions produce a risk evaluation for pensions, including "new or emerging risks relating to climate change, use of resources and the environment." Yet, in the September 2014 draft revision this reference had been scrapped. The final document is due before the European Parliament before the end of 2015.[20]

In December 2014 a group of members of the European Parliament wrote an open letter to Mario Draghi, president of the European Central Bank (ECB) and chair of the European Systemic Risk Board (ESRB)—part of the EU's European System of Financial Supervisors that is hosted by the ECB—urging the body to investigate how the exposure to high carbon investments the exposure to high carbon investments might pose a systemic risk to our financial system and what the options might be for managing this potential threat". As yet, they have received no official response.

Mr Hufeld of BAFIN believes that risks should be captured through the overall framework of any particular company's risk-management procedures and rules and regulations—and that it would not make sense to single out any specific type of risk. "You need to have a toolbox to supervise those sorts of challenges that is broad enough and flexible enough to cope with all those different types of phenomenon happening out there," he says.

Meanwhile, both listed companies and many financial institutions are subject to regulations that require them to disclose their material risks. One possibility is that climate-related risks may be encompassed in those statutes that already govern

[19] Available at: http://ec.europa.eu/internal_market/pensions/docs/directive/140327_proposal_en.pdf

[20] Available at: http://www.parlament.gv.at/PAKT/EU/XXV/EU/03/81/EU_38179/imfname_10493724.pdf

companies' general disclosure requirements. A case in point is the US Securities and Exchange Commission (SEC), which in 2010 issued guidance stating that the SEC requires companies to report material risks, which would include material climate-change risks.[21] While it did not amend any existing statutes, the SEC did draw attention to the fact that climate-related risks may fall under existing rules and regulations.

In particular, the SEC has highlighted that there are an array of requirements on businesses to disclose their risks. The SEC went on to suggest that companies may consider the impact of legislation and regulation, international accords, indirect consequences of regulation or business trends, and the physical impacts of climate change. Ceres, a Boston-based non-profit organisation advocating sustainability leadership, had previously cited breaches of disclosure rules when it lobbied the SEC for guidance.[22]

The SEC has clarified that this was not a rule change, nor did it explicitly alter the reporting requirements of US-listed companies. Critically, this guidance falls short of recognising that climate change risk is systematically material. This sharply underlines the reality that a great deal hinges on the interpretation of what constitutes a material risk.

Climate change presents an array of long-term risks; although the precise scope is understandably uncertain, this research suggests that it will likely be material for all companies. Perhaps more importantly, dramatically reducing overall carbon emissions will require the collective efforts of a critical mass of actors. Suffering free riders may undermine the efforts of the rest and impede the chances of meaningfully mitigating climate risks.

The beginnings of action

In a clear signal that climate-related risks may be a worry for financial regulators, the Bank of England has launched a probe into the risks that insurers face through climate change. Paul Fisher, executive director for insurance supervision at the Prudential Regulatory Authority, the Bank of England's financial services regulatory arm, warned last March that insurance companies "may take a huge hit" if their holdings in oil and gas companies lose value because of action to halt climate change.[23]

In December 2014, EU Directive 2014/95/EU on disclosure of non-financial and diversity information entered into force, amending the previous Accounting Directive 2013/34/EU. This covers disclosure of non-financial information by large companies and so-called public interest

[21] Available at: https://www.sec.gov/rules/interp/2010/33-9106.pdf

[22] Available at: http://www.ceres.org/press/press-releases/investors-environmental-groups-push-the-sec-to-require-full- corporate-climate-risk-disclosure

[23] "Confronting the challenges of tomorrow's world". Speech given by Paul Fisher, deputy head of the Prudential Regulation Authority and executive director for insurance supervision. Available at: http://www.bankofengland.co.uk/publications/Documents/speeches/2015/speech804.pdf

> **Putting a price on carbon is the best way to incorporate all of these risks where carbon is concerned into the investment process**
>
> *Al Gore,*
> ***chairman, Generation Investment Management***

entities (including banks and insurers) across the European Economic Area. This amendment requires disclosure of non-financial information including information relating to policies, risks and outcomes as regards environmental matters. EU member states must transpose the directive into national legislation by the end of 2016. [24]

In other cases, public sector action takes the form of increased requests for information, rather than compliance with specific regulation. For instance in the US, several states conduct an annual Insurer Climate Risk Disclosure Survey, which was created by the National Association of Insurance Commissioners and is mandatory for most sizeable insurers. The survey asks insurance companies what financial risks they face from climate change, as well as actions they are taking to respond to those risks. Furthermore, financial examiners in the US have been given guidelines so they may ask insurers about their exposure to climate-related risks, says Mike Kreidler, Washington's insurance regulator and co-chair of the NAIC's Climate Change and Global Warming Working Group.

And most significantly, in May, France's National Assembly voted on a series of amendments of the country's Energy Transition Law - providing a first glimpse of a statute explicitly covering climate-related risk. One amendment will require French insurance firms, pension fund managers and other institutional investors to disclose "information on the consideration of environmental, social and governance factors in their investment policy criteria." Investors will also be required to explain how they "take into account exposure to climate risks, including the measurement of greenhouse gas emissions associated with assets held" in their portfolios.

While effective regulation to combat climate change has been largely absent to date, regulatory attention is increasing and the new legislation in some quarters is beginning to focus more sharply on climate-related risks. However, while awareness of the issue is growing among financial regulators, few are taking action. This is despite the fact that few institutional investors have addressed this risk to date; just 7% are able to measure the carbon footprint of their portfolios and a mere 1.4% have an explicit target to reduce it. Regulators should require that companies disclose their carbon emissions so than investors can assess their risks with accurate and comparable data.

[24] Available at: http://ec.europa.eu/finance/accounting/non-financial_reporting/index_en.htm

A price on carbon

Many market participants insist that carbon pricing is essentially what is needed, among them Al Gore of Generation Investment Management. “Putting a price on carbon is the best way to incorporate all of these risks where carbon is concerned into the investment process,” he says. The best way to tackle the externality of carbon pollution “is to attach a price tag so that it can be more smoothly integrated into the routine assessment of asset values that people conduct and analyse in their portfolios on a constant basis.” While clearly accurate, emissions trading schemes have yet to deliver on expectations: getting the pricing right will be crucial.

It is clear that government action is required to establish a firm, clear carbon price that reasonably reflects its externality costs. It is the responsibility of governments to correct market failures, and climate change is potentially the world’s most important market failure. Without an appropriately functioning pricing mechanism it is incredibly difficult for climate risks to be addressed and for capital to be effectively allocated. This requires rigorous carbon taxation or carbon trading schemes.

In many jurisdictions this is already happening, either through carbon taxes or cap-and-trade schemes. To date, emissions trading schemes have not always lived up to their expectations and in many instances the price set for carbon emissions is too low to meaningfully capture the negative externalities associated with climate change. This is currently the case of the European Emissions Trading System, the world’s largest scheme, where the price of a tonne of carbon languishes below US$10. For his part, Mr Clamagirand of AXA Group says: "It is important that the regulators start considering a more realistic – i.e. higher – carbon price. This will then allow market participants to start incorporating it into their valuation models.”

Reasonable assessments of the price needed to meaningfully address emissions have generally ranged above US$30 per tonne. However, the challenges of several current schemes have more to do with a tendency of governments to oversupply the market, concede free quotas or provide other loopholes than with inherent failures of cap-and-trade as a system. Carbon taxes, once considered politically unpalatable, have also been implemented in markets ranging from Chile to British Columbia.

The choice of a carbon tax or a carbon trading scheme is less important than the need to ensure that a price mechanism is established, commensurate with the negative externalities that climate change is expected to bring. The inherent uncertainties and long-term nature of the problem make this difficult. However it is clear that for these policy measures to be effective, they must be firm, long-term and comprehensive. Moreover, by establishing a framework whereby the stringency will predictably increase over time, market actors will be able to respond while ensuring that mitigation measures are carried out in a cost-effective manner.

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Over the long term we have a self-interest in well-functioning markets

Odd Arild Grefstad,
CEO, Storebrand Group

Establishing this pricing signal is crucial for companies and investors to properly incorporate climate-related risks into their decision-making. But international cooperation to combat free riding and encourage greater action is similarly vital. The Paris Conference of the Parties due to take place at the end of this year will have wasted an important opportunity if concrete measures to price carbon emissions do not emerge. The precise tools employed may vary, but the direction of travel needs to be firmly set by governments at a national level and strongly reinforced though international agreements.

“The market is the most efficient way to allocate a rare resource, which is capital. If we think that’s the case, why is it not working?” asks Philippe Desfossés, CEO of ERAFP. “It’s not working because the market is not getting the right signals, and obviously we know that the problem is linked to the fact that this negative externality that is carbon is not priced.”

Correcting market failures

Regulation is required to address market failures, and the negative externalities of climate change clearly constitute a market failure. Moreover, addressing climate change is clearly a problem of collective action. “While responsible industry players will make commitments this year to contribute to the transition to a low carbon economy, these efforts may not reach the necessary scale,” warns Mr Clamagirand of AXA. “It will always be a story of a few responsible actors doing their best within a broader financial system that is not fully designed for sustainability.”

While pricing carbon emissions effectively is vital, complementary policies are necessary to mitigate climate risks. Indeed, reforms to the financial system may be needed to facilitate an orderly transition even in an economy in which carbon is effectively priced. “You’ll still need disclosure requirements and markets, you’ll still need to make sure that fiduciary responsibilities are aligned with climate security or that solvency rules are actually properly refined to enable long-term allocations to the green infrastructure, for example,” states UNEP’s Mr Robins.

Moreover, Mr Grefstad of Storebrand argues that regulation helps create a level playing field for investing companies. By imposing standards of behaviour on asset managers uniformly, regulation has the potential to provide industry with incentives to step up their fight against climate change.

Mr Grefstad argues further that regulation would be an advantage for the financial industry in general. “Predictability is good for finance because it’s easy to create returns when you have predictable financial markets,” he points out. “Climate and other resource and ecosystem changes are affecting that predictability.” Mr Grefstad reasonably concludes that “over the long term we have a self-interest in well-functioning markets.”

“The market is very good at innovation. But it doesn't deliver universality. So there is a role for policymakers to identify where there are market failures, identify best or good practice and turn it into customary practice," affirms Mr Robins. "We have extensive experience with voluntary disclosure, for example, but the market on its own will not deliver universal reporting,” he says. “That’s where regulation can step in.”

Regulators should explicitly recognise climate risks as material. This means that listed companies should be required to assess their own carbon emissions and disclose them. Institutional investors need to analyse the climate risks in their portfolios and actively look for ways of mitigating their exposure. This may be through shifts in their investment strategy or engagement with company management, but simply ignoring climate change risks failing to meet their fiduciary obligations.

One aspect of this is more effective co-ordination among the institutions that govern the world’s financial systems, including regulatory institutions and international bodies. “We need really to have better systems for risk management. We need to integrate issues like climate change, particularly into the prudential regulation of financial institutions, banks, insurers, pension funds,” according to Mr Robins.

The COP21 meeting, due to take place in Paris at the end of this year, may provide further impetus. The objective of the 2015 conference is to reach a binding and universal agreement on climate change by all participating nations. Regardless of the precise outcome, it is important that this chance to bring together a range of different stakeholders all concerned about the impact of climate change not only on themselves but on society and the economy more broadly, must not be wasted. Leading organisations need to do more than change their own investment strategies: they need to campaign both for a price on carbon and for a more level regulatory playing field.

RECOMMENDATIONS FOR ACTION

Governments must enact comprehensive carbon-pricing mechanisms that reflect their externality costs. Lacking a realistic price, efforts by market participants to limit climate change are inherently handicapped. Addressing market failures is fundamentally the responsibility of governments.

Financial regulators need to ensure that best practice becomes standard practice. This means recognising climate risk as material and requiring the disclosure of carbon emissions by market actors. Standards for comparable information are necessary to identify free riders and concentrations of systemic risk.

Stock exchanges should require disclosure of greenhouse gases by all listed companies. Clear accounting of carbon intensity is needed. Without accurate information, integrated into financial reporting, investors cannot manage their risks appropriately.

Institutional investors must integrate climate change into their risk management. Assessing and measuring the risks in their own portfolios is a necessary first step. This can lead to adjustments in investment strategy or to deeper engagement with company managers. Advocating that policymakers address market failures is in their collective self-interest. Complete inaction is a failure to act in the long-term interest of their beneficiaries and could risk future litigation.

Pensioners should insist that the fund managers responsible for their retirement savings seriously address the full spectrum of long-term risks they are facing. Concrete measures vary from promoting corporate engagement and public policy advocacy to potential legal action demanding that fiduciary responsibilities be met.

CONCLUSION

The potential impact of climate-related change on the assets owned and managed by institutional investors is significant. Our estimates indicate that asset managers can expect present-day losses of US$4.2trn to the US$143trn of current manageable assets as a result of climate change by 2100 at a private-sector discount rate, equivalent to the entire GDP of Japan. It is important to recognise that this is not a risk of volatility or temporary price movements but of permanent impairments and capital losses. Perhaps more seriously, the expected losses would more than triple (US$13.8trn) should global warming reach 6°C. Few institutional investors have addressed this risk to date; only a modest minority are even able to measure the carbon footprint of their own portfolios.

Governments have no excuse for inaction. The potential harm from a public-sector point of view is significantly above the private-sector average expectation should some of the more extreme outcomes be realised with present value damages of US$43trn consistent with a 6°C scenario. While the likelihood of that much warming is low, the results would be catastrophic. Regulation has not generally required owners and managers of assets to measure, disclose or manage the climate-related risks embedded in their own portfolios, despite the fact that these risks are both material and systemic. However, regulators should take note of the bold action taken by France, which in May of this year amended the law requiring asset managers to do so.

Even with little regulatory pressure, a number of leading institutional investors are beginning to address climate-related risks. Some are making efforts to engage with policymakers, encouraging them to address this market failure. A few are measuring the carbon footprint of their investment portfolios. Others still are divesting investments in carbon-intensive industries or engaging with companies to exert influence over their management. And more excitingly, a wide array of asset managers and owners are finding profitable opportunities to finance the transition to a lower carbon economy, including investments in renewable energies, new technologies and energy efficiency.

Despite the efforts of the private sector, there is substantial scope for regulators and governments to make a contribution. Not least, many market participants are looking for agreement on a meaningful price on carbon at the COP21 meeting, due to take place in Paris at the end of the year. However, even if a substantive agreement were to emerge, there is a clear need for co-ordinated action by regulators, governments and institutional investors in order to address the long-term, systemic risks at play. Climate risks need to be assessed, disclosed and, where feasible, mitigated.

THE VALUE OF GLOBAL ASSETS UNDER MANAGEMENT AT RISK DUE TO CLIMATE CHANGE

Final Technical Report

1. Introduction

Climate change can affect the asset management industry by putting assets at risk of direct destruction from events such as storms and floods, or by indirectly affecting asset returns. While climate change has long been seen as a threat to economic activity, the risks it poses to assets are not well understood. This is partly because the outcomes of climate change are subject to large uncertainties, and partly because the issue has not been brought to the attention of the industry. Yet the industry exists to manage risk, and has a commonly-employed measure to assess it: value at risk (VaR). In a pioneering attempt to highlight the relevance of climate change to the asset management industry, this report estimates the value at risk of global assets under management (AuM) due to the impacts of climate change, or the climate VaR.

VaR measures the size of the loss a portfolio may experience, within a time horizon, at a particular probability or confidence level, p. So, if for instance the VaR of a portfolio is $1bn over a one-year horizon at a confidence level p=95%, that means there is a 5% probability that the loss on the portfolio is at least $1bn. The climate VaR is the loss that can be attributed solely to the impact of climate change on the stock of assets. That is to say it compares the value of assets in a world with climate change relative to the same world without climate change.

VaR is a natural way of thinking about the impacts of climate change. This is because there are great uncertainties in the estimation of climate impacts (IPCC, 2014b; Millner, Dietz, & Heal, 2013; Tol, 2012; Weitzman, 2009). For example, future greenhouse gas emissions are uncertain, as is the climate response to emissions, and the impact on the economy of climate change. Furthermore, these uncertainties feed into each other, creating a 'cascade' of increasing uncertainty. This report extends typical analysis of climate impacts, to consider the impact of climate change on assets, rather than the more commonly studied impact of climate change on GDP. Therefore uncertainty must be clearly acknowledged, which VaR does by presenting possible losses at certain levels of probability, so is an appropriate metric for the impacts of climate change on the asset management industry. In particular, by considering events that occur 'at the tail of the distribution', such as events with a 5% or 1% probability of occurring, a VaR estimate focuses on the high impact, low probability outcomes that could result from climate change.

The climate VaR in 2100 is the focus of this report. Climate change is a long- term problem, with a considerable lag between the release of emissions and economic impacts. The full consequences of greenhouse gases emitted today will not be felt until around the end of the century. While this date may seem distant for many in the industry, the scale of future impacts, even in present value terms, is likely to be significant, and it is only by taking action today, far in advance of the worst effects, that we can prevent them from occurring.

This report focuses on the broader stock of manageable assets, rather than assets currently under management. Manageable assets are those the industry could potentially manage, rather than the share that is currently managed, which is estimated to have been 22-25% of the potential market in recent years (McKinsey & Company, 2012). The report takes this focus because its aim is to consider how the industry's overall prospects are affected by climate change, rather than on its ability to attract customers and increase its market share in the face of climate change.

2. Methodology

2.1 General approaches

The impact of climate change on the financial sector, let alone the asset management industry, has been the subject of limited research to date (Arent et al., 2014). The sector suffers from limited awareness of, or interest in, the issue (Covington & Thamotheram, 2014) and few modelling frameworks exist to assess the impacts (Vivid Economics, 2013). Indeed, the Prudential Regulation Authority in the UK was motivated by this lack of knowledge to request information from industry in June 2014 (Prudential Regulation Authority, 2014). However the concept of climate VaR has recently been introduced and demonstrated in a simple, yet powerful, way (Covington & Thamotheram, 2015).

There are two types of approaches that could be taken to estimating the climate VaR: bottom-up or top-down. A bottom-up approach would be built around a relatively detailed portfolio analysis model, which takes as its input various kinds of macroeconomic variables and goes on to model the returns to different asset classes in different countries or regions. This approach can be described as bottom-up[1] because the analysis of climate VaR must be built outwards by situating the portfolio analysis model within a system of other, linked models capable of providing it with the inputs it needs. In particular, this would include the effects of climate change on economic outcomes, as well as, perhaps, the direct effect of climate change on portfolio performance, via its effect on the co-variances between assets (in this way, the interaction between climate risk and other sources of risk is taken into account).

A bottom-up approach is model- and data-intensive, and it is unclear whether the uncertainty inherent in providing this high level of detail would provide particularly accurate estimates. One of the principal reasons for this is the famously poor state of knowledge of climate impacts (Pindyck, 2013; Nicholas Stern, 2013). For many of the causal processes in need of estimation as part of the bottom-up approach (for example, the effect of climate change on the covariance between equities and corporate bonds in the United States), there are simply no data, and it is unclear how to obtain convincing data. Given this, and the need, at this point in time, to explore the order of magnitude of climate impacts on AuM rather than the detailed consequences, a simpler, albeit less detailed, top-down approach is valid.

A top-down approach uses a simple macro-economic model that has been integrated with emissions and climate modules. A small number of so-called integrated assessment models (IAMs) of climate change exist, which have been built in order to estimate the economic cost of climate change. These link economic growth, greenhouse gas emissions, climatic changes and damages from climate change back to the economy in an integrated, consistent framework.

[1] Bottom-up is not to be confused with other senses in which the term bottom-up modelling has been used in related fields, for instance energy modelling, where it indicates that the model is built up from representations of individual energy technologies.

Famous examples include the DICE model of William Nordhaus (1993, 2008, 2014) as well as the PAGE model of Chris Hope (2006, 2013), which was used by the Stern Review (2007). These models have been built with public -policy objectives in mind, above all the quantification of the externality that climate change constitutes, for example the Stern Review's estimate that the costs and risks of climate change will be equivalent to losing 5-20% of global GDP each year, now and forever. This enables an assessment of what reasonable costs should be incurred to bring climate change under control, in total, such as the percentage of GDP to spend on mitigation, or at the margin, such as the level of a carbon tax per tonne of CO_2.

IAMs are not without their limitations. IAMs can be, and are, fairly criticised for not describing the full range, richness and uncertainty of scientific knowledge regarding climate impacts, for making value judgments, particularly in choices over discount rates, and for not using a sufficiently sophisticated representation of the economy (King, Schrag, Dadi, Ye, & Ghosh, 2015; Vivid Economics, 2013). They are also generally considered to be conservative in their estimates of damage. In this report we take great care to acknowledge and incorporate the scientific uncertainty, in particular regarding catastrophic climate change, lay out the value judgments that are made and test different discount rates, and extend the economic sophistication of the analysis to consider financial assets. Despite this, we acknowledge that the modelling faces limits and that the results should be interpreted as a guide to the likely magnitude of impacts.

However, IAMs remain the only way to quantify the aggregate economic impact of climate change within a consistent framework. There are no alternative modelling tools yet developed to quantify the economic cost of climate change within a consistent framework, as is required for this project (Vivid Economics, 2013). Other studies of the impacts of climate change in general, and especially work on the effects on financial assets, do not quantify the economic impacts; for examples see (AVOID, 2015; King et al., 2015; Mercer, 2015). Often the focus is on the physical impacts, such as the extent of flooding, or non-monetary losses, such as health impacts, or a qualitative discussion of economic impacts is provided. Such approaches avoid the criticisms of IAMs but also forgo the expositional benefit of aggregating impacts into a single dollar value, the magnitude of which can be easily understood – and these are currently unavoidable trade-offs.

While IAMs have not before been used to consider the impact of climate change on assets, they contain useful information to estimate the climate VaR. Depending on the precise approach to estimation, IAMs can estimate the impact of climate change on two parameters useful for estimating the climate VaR: i) GDP growth, which can be linked to the growth of dividends from manageable assets, and ii) the stock of capital. This gives rise to two approaches: the dividend approach and the capital approach.

These two approaches address different issues: the present value reduction in future dividends, in the dividend approach, and the effect of climate change on the future capital stock, in the capital approach. They are not alternative measures of the same thing. The dividend approach considers the effect climate change will have on the growth of dividends from the current stock of manageable assets, which was $143 trillion in 2013,[2] and the consequent reduction in the value of this stock, given that its value equals the discounted flow of future dividends. The capital approach considers the effect that climate change will have on the future stock of non-financial assets,[3] the economic capital used to produce output, which underpins many of the financial assets managed by the industry. These approaches are explained in more detail in the following Sections 2.2 and 2.3.

DICE is the most suitable model for our purposes. Among IAMs set up to estimate climate impacts, DICE is one of the very few based on the so-called 'Ramsey' growth model.[4] This makes it suitable for the task at hand as it has two relevant features that other established IAMs, such as FUND and PAGE, do not. First, the growth rate is determined within the model rather than assumed, which means that the effect of climate change on the growth rate is explicitly modelled. Second, DICE explicitly models the capital stock, which underpins the stock of manageable assets. DICE is widely used in academia and policy-making, in its original form and as the basis for other models, such as WITCH, and has been extensively peer-reviewed.

The impact of climate change on assets is distinct from 'stranded assets', which describes an effect of mitigation policy on assets. Recently, much attention has focused on the effects of climate change mitigation policy on the financial sector, as policy to limit emissions may prevent the currently -expected value of emission-intensive assets from being realised, thereby 'stranding' the asset. However, this is not the focus of this report, which is instead on the effect on assets of the physical impacts of climate change, should mitigation policy not succeed in limiting emissions.

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[2] Our value for the stock of manageable assets is the stock of assets held by non-bank financial institutions, as estimated by the Financial Stability Board. Bank assets are excluded as these are, largely, managed by banks themselves.
[3] Our value for the stock of non-financial assets is based on the stock in DICE, the model used to estimate the results of this report, with additional refinement based on EIU data.
[4] More precisely, this model has a lineage that begins with Ramsey (1928) and includes modern developments by Cass (1965) and Koopmans (1965), among others.

2.2 The dividend approach

In a new paper, Covington & Thamotheram (2015) present an approach to estimating the climate VaR using information on GDP growth under climate change. They calculate AuM as the present value of the flow of future dividends, and make a key assumption: in a diversified portfolio of equities, the growth rate of dividends is exactly equal to the growth rate of GDP. Then, drawing on other studies, they calculate the loss of GDP due to climate change at a range of confidence levels. Through the relationship between dividends and GDP, they then calculate the impact of climate change on assets at particular confidence levels, thereby estimating the climate VaR. Their work suggests that, in their worst case, 'the value at risk in 2030 may be equivalent to a permanent reduction of between 5% and 20% in portfolio value compared to what it would have been without warming'.[5]

Our dividend approach builds on this paper. We take Covington & Thamotheram's key insight, that there is a relationship between the growth rates of absolute dividends and GDP, and use this relationship to find the change in dividends arising from the change in GDP due to climate change, which DICE models directly. We assume that dividends from manageable assets grow at the same rate as GDP. This assumption, the same as Covington & Thamotheram's, is made because dividends are ultimately paid for from the output of the economy. So, if the share of output paid in dividends is, on average, constant in the long run, then GDP and dividends will grow at the same rate. This relationship may not be observed in data over a relatively long time period, even decades, due to business cycles; for example corporate profits are currently at historic highs while GDP growth is low. However, to 2100, the relationship should be expected to hold on average.

We provide two main advancements on Covington & Thamotheram's estimate. First, we estimate climate and GDP outcomes within an integrated framework, to give a consistent and more rigorous estimate of the VaR at different confidence levels. Second, as described below, we consider a broader portfolio of assets than equities.

The dividend approach considers manageable assets to be all non-bank financial assets. We take a broad definition of manageable assets, to cover all assets held by non-bank financial institutions, which was $143 trillion in 2013, as estimated by the Financial Stability Board (2014), as all these assets could, potentially, be managed. Bank and Central Bank assets, on the other hand, are largely managed by the institutions themselves and so are excluded. This broad definition not only provides a more accurate estimate of the magnitude of impacts, but it also makes the assumption that dividends from manageable assets grow at the same rate as GDP more appropriate, as the broader definition controls for cyclical differences in relative performance across asset classes.

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[5] However, when discounting their results to 2015 present values, Covington & Thamotheram find that the expected present value at risk in 2015 in their worst case is one-fifth of the value at risk in 2030: that is to say, it is equal to a permanent reduction of between 1% and 4% in portfolio value.

The dividend approach estimates the present value loss of future dividends from the current stock of manageable assets. This impairs the value of the current stock in 2015, given that its value equals the discounted flow of future dividends. As the dividend approach considers effects to a portfolio of manageable assets, the loss of future dividends is discounted from the perspective of a private investor, although it can also be discounted using government discount rates. These issues are discussed further in Annex 5.4.

2.3 The capital approach

The capital approach explicitly estimates the impact of climate change on the stock of assets. As mentioned, DICE explicitly models the stock of non-financial assets, known as 'capital' in the economics literature, so the impact of climate change on this stock can be estimated. In DICE, a generic capital asset is created when households save, so a stock of assets is built over time as savings accumulate, and declines with depreciation. Assets earn a return, which incentivises savings. In this report, the initial stock of non-financial assets is based on the stock in DICE, updated based on EIU data, and is $207 trillion in 2015. In our version of DICE, climate change affects the stock of non-financial assets in two ways: by lowering the rate of return and by directly destroying assets.

Climate change indirectly affects the stock of non-financial assets by lowering investment. The impacts of climate change drive a wedge between the output that could potentially be realised with given capital and labour stocks, and actual output. This lowers the output produced per unit of asset, thereby reducing the attraction of investment, which leads to a lower stock of assets. For example, climate change may destroy a fraction of the output of a farm, and as a result the assets employed on the farm will earn a lower return, meaning that the farmer has less incentive to hold a large stock of assets. Furthermore, since less output is available, households will have less to save, and therefore the stock of assets will build more slowly.

Climate change directly affects the stock of assets by destroying them. Dietz and Stern (2015) propose an extension to DICE, whereby, as well as driving a wedge between actual and potential output with capital and labour inputs given, a portion of damages also directly reduces the capital stock. An example of this kind of effect is storm damage to infrastructure. This extension is incorporated in the model used in this report.

Impacts to non-financial assets can be converted to impacts to manageable assets. Non-financial assets can be used to back financial liabilities. For example a corporation can take out a loan secured against a factory, or the flow of income the factory will provide. The financial liability of a debtor is a financial asset for a creditor, and this financial asset could be managed. So, if the stock of non-financial assets is reduced due to climate change, the stock of manageable assets will also decrease. To estimate the impact on manageable assets from the reduction in non-financial assets, two conversions are required. First, the share of non-financial assets that are used to back financial liabilities must be estimated.[6] Second, the financial liabilities created per dollar of non-financial asset must be estimated. The product of these two ratios converts a dollar of lost non-financial asset to a value of lost manageable assets.

6 Not all types of non-financial assets are typically used to back financial liabilities. For example, public infrastructure is rarely used to back government liabilities, and non-financial non-corporate businesses, such as sole traders, rarely issue manageable securities.

However, results for the capital approach are presented as a percentage reduction in the capital stock. As explained in Annex 5.1, this conversion does not cover all manageable assets and the ratios may vary over time. As a consequence, results in the capital approach are not converted into losses of manageable assets, but presented as a percentage reduction to the capital stock. If manageable assets are, on average, as vulnerable to climate change as the capital stock in general, then a similar percentage reduction to manageable assets would be expected.

3. Key issues in the estimation of the climate VaR

Estimation of the climate VaR raises a number of issues. Before proceeding to the results, it is important to describe a number of key issues in the estimation of the climate VaR. These issues concern: uncertainty, long- term prospects for productivity growth, discounting and mitigation scenarios. A short summary of these issues and their treatment in the modelling is provided here, with extensive discussion provided on each in the Annex.

The probability of a loss in the climate VaR is generated by uncertainty over three factors: the level of productivity growth, the climate sensitivity and the risk of catastrophic climate change. There are many uncertainties in the estimation of climate impacts. However, the academic literature has identified three parameters to which outcomes are particularly sensitive. The first, the level of productivity growth achieved in the initial decade, which sets the magnitude of growth for the century, reflects uncertainty over general macroeconomic conditions. After the initial decade, the trend then evolves according to a scenario: its growth rate either increases or decreases, explained below. The second, the climate sensitivity, defines the temperature increase for a doubling of greenhouse gas concentrations, which is uncertain due to the complexity of the climate system. The third, the risk of catastrophic climate change, reflects the divergence of views in the academic literature on the possibility of catastrophic impacts beyond a certain degree of warming. In this report, a probability distribution for each of these three parameters is defined using the best available evidence and Monte Carlo analysis is used to estimate impacts across the range of confidence levels. Further discussion is provided in Annex 5.2.

Scenarios are used to describe different prospects for long term productivity growth. The long term growth rate of productivity can either be increasing over time, so the global economy continues to grow at a relatively high rate, which is the EIU's view; or decreasing, so global growth slows, which reflects the idea of 'secular stagnation', the default setup in the DICE model. We use the EIU's projections of increasing productivity growth as the base case. However, as these alternatives present different prospects for future economic growth, and therefore the stock of assets, the secular stagnation view is tested as an alternative scenario. So the trend in productivity growth is treated as uncertain, as described above, but then whatever the trend, it either increases or decreases in the long run, depending on the scenario. Further discussion is provided in Annex 5.3.

The dividend approach is discounted from both the perspective of a private investor and a government. As the dividend approach considers effects to a portfolio of manageable assets, a discount rate is applied as is standard practice for a private investor. The discount rate is a function of the future GDP growth rate without climate change plus a premium to account for holding risky assets relative to a risk-free asset. The GDP growth rate without climate change is used as investors do not currently consider climate impacts. This results in a more conservative estimate of losses, as GDP growth with climate change will be lower, leading to a lower discount rate if investors took this into account. Average private sector discount rates are initially 5.5% but fall to 4% towards the end of the century, due to slowing economic growth.

The government discount rate used in this report follows the approach of the Stern Review. In addition to discounting from the perspective of a private sector investor, government discount rates are also applied to the dividend approach. This sensitivity is explored because governments have a duty to safeguard financial assets on behalf of society and regulate to fulfil this duty, so the value at risk from a government perspective is also relevant. It is widely accepted that public-sector discount rates should be below private-sector discount rates, for reasons including a lower cost of capital as well as the avoidance of market distortions, such as taxation and externalities, which mean the gross returns on private investments are above their net social returns. The government discount rate used in this report follows the approach of the Stern Review. This approach is appropriate for very long-run problems such as climate change, because it treats the wellbeing of future generations on par with the wellbeing of current generations with some included uncertainty. The remaining justification for discounting in this framework is economic growth, and its effect of reducing the marginal utility of consumption for future generations. Average government discount rates are initially 3.8% but fall to 2% towards the end of the century, due to slowing economic growth.

The capital approach provides undiscounted, future values. Results are not discounted in the capital approach, as the focus is on the state of the future capital stock, for which the calculation of present value equivalents is conceptually difficult.[7] Further discussion on discounting is provided in Annex 5.4.

A mitigation scenario consistent with a likely chance of remaining under 2°C of warming is compared with the base case of minimal mitigation. The base case is a scenario of minimal mitigation, as the climate VaR is the loss that can be attributed solely to the impact of climate change on the stock of assets, rather than the impact of (less) climate change and (more) mitigation. That is to say the base case isolates the effect of climate change by comparing the value of assets in a world with climate change relative to the same world without climate change; where both worlds have the same level of minimal mitigation. This analysis can be added to by finding the climate VaR in a world with high mitigation (and therefore less climate change than the base case) relative to the same, high mitigation, world without climate change. These two

[7] This difficulty arises because the value of the future capital stock cannot be discounted as if it were a private investment, unlike the future flow of dividends from manageable assets, as it contains items such as public infrastructure. The appropriate discount rate for the capital stock is therefore complex. On the other hand, presenting future, undiscounted, values in the capital approach is simple and clear – and therefore utilised.

climate VaRs, the base case and the mitigation scenario, can then be compared to show how the climate VaR is reduced due to mitigation. The base case has a minimal level of mitigation, an emissions reduction of 6.5% in 2105 relative to a world of no action whatsoever, to reflect existing policies, but can otherwise be characterised as a scenario of complete future inaction and stalemate on climate policies. The mitigation scenario is consistent with a likely chance of keeping temperature change below 2°C, the most stringent mitigation scenario the IPCC considers to be feasible (IPCC, 2014a), where a likely chance is defined by the IPCC as a 66% probability of occurrence. Further discussion is provided in Annex 5.5.

4. Results

The dividend and capital approaches estimate distinct climate VaRs. These approaches are not alternative measures of the same thing, but consider two issues that are of common concern to the asset management industry. The dividend approach considers the effect climate change will have on the growth of future dividends from the current stock of manageable assets and the consequent reduction in the value of this stock, given that its value equals the discounted flow of future dividends. The capital approach considers the effect that climate change will have on the future stock of non-financial assets, which underpins many of the financial assets managed by the industry. Due to this distinction, the results should be considered as measures of different impacts and not as alternatives, and are presented separately, with primary emphasis placed on the dividend approach as this is the approach presented in the EIU paper. The secular stagnation productivity scenario is also presented separately, as a sensitivity to the base case assumptions.

The losses are primarily incurred in the latter half of the century. Figure 1 shows how the presentvalue loss to current assets evolves over time along temperature consistent paths, as well as the average loss over time. To illustrate, if we were only concerned with losses over the next 40 years, to 2055, and believed that the world was on a path to 6°C of warming by 2100, then the consistent present value loss to current assets to 2055 would be $2 trillion (discounted using private sector rates); this is where the red line crosses the lowermost y-axis gridline at 2055. Losses after 2055 would of course still occur, but, given the 40 year time horizon, they would, in this example, be disregarded. As the figure shows, the losses are primarily incurred in the latter half of the century, as there is a lag between the release of emissions and temperatures increasing. It is only later in the century that the climate consequences of the majority of emissions are expected to be felt, although there is scientific debate over whether the climate response will be faster (Frölicher & Paynter, 2015).

EXPLAINING THE TERMINOLOGY OF THE RESULTS

Results for extreme outcomes are presented as damages consistent with temperature levels. The original purpose of this report was to present damages at particular levels of probability, such as the 95% confidence level, as is standard practice when estimating a Value at Risk figure. However, for expositional purposes, temperature levels are presented instead of probability levels. The temperature levels, such as 5°C and 6°C, occur with particular probabilities, approximately 10% and 3% respectively. The damages occurring with these probabilities are then presented at these temperature levels. These damage levels are consistent with these temperatures, as they occur with the same probability. However, we want to be clear that damage levels are not unique to temperature levels. For example the worst case damages at 4°C could be equal, or higher, than the damages that occur with the same probability as 5°C of warming (but that is because worst case damages at 4°C has a less than 10% probability of occurring). The presentation of damages consistent with temperature levels, rather than probability levels, is simply a choice about exposition: there is no modification of results – just a different choice of language. While this presentation may cause some confusion for any reader comfortable with probability levels, the editorial guidance is that this is outweighed by the benefit of reaching readers who more readily identify with temperature levels.

The average loss is the expected value of damages across the full range of temperature levels. This report estimates a probability distribution over the range of losses to manageable assets. That is to say that each level of possible damage has an associated probability of occurring. The average loss is the expected value of the distribution, which is found by weighting every outcome in the distribution by its associated probability and summing all of these values. For example, the expected value of a dice is 3.5, which is the sum of 1/6th of the numbers 1 to 6. The average loss does not have an associated temperature level, but is the (probability weighted) average loss that can be expected across the full range of temperature levels.

4.1 Dividend approach results

Climate change is expected to cause permanent, present value losses to current manageable assets of 3% on average and up to 10% at extreme outcomes, when discounted at a private sector discount rate. Climate change is expected, on average, to cause $4.2 trillion of present value losses to current assets, equal to 3% of current assets, when discounted at a private sector discount rate. Losses are much higher if more extreme outcomes are expected to occur, with $7.2 trillion and $13.8 trillion of present value losses consistent with warming of 5°C and 6°C respectively. This means that private investors are overvaluing manageable assets today by 3% of their current value if they consider the expected average impacts of climate change; while if they believe that 5°C or 6°C of warming will be reached by 2100, then assets today are overvalued by 5% and 10% respectively.

From a government perspective, current manageable assets are on average 10% overvalued, and up to 30% at extreme outcomes. When using Stern Review discount rates, which are lower than private sector discount rates, the mean average expected loss is $13.9 trillion, equal to 10% of current assets. At more extreme outcomes, losses from the government perspective are very severe. If 6°C of warming is expected, then the consistent level of present value losses at government discount rates is $43 trillion, equal to 30% of current assets.

These results are summarised in Table 1 and an explanation of the average and temperature consistent losses terminology is provided in Box 1.

Table 1 - The present day value of losses to current manageable assets due to climate change is 3—10% on average depending on discount rate, and 10—30% at 6°C of warming

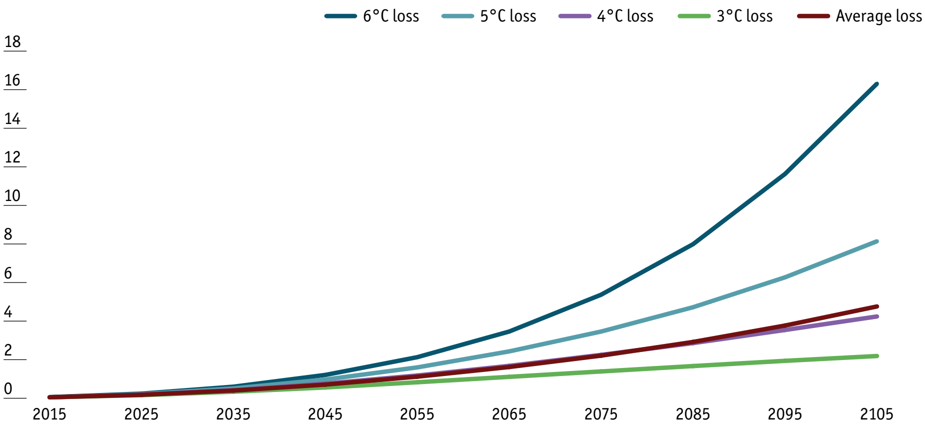
Present value loss to current manageable assets	Average loss	5°C loss	6°C loss
Private investor perspective	$4.2 trillion	$7.2 trillion	$13.8 trillion
Government perspective	$13.9 trillion	$18.4 trillion	$43.0 trillion

Note: The current stock of manageable assets is $143 trillion. Dollar values are in 2015 dollars. Losses are the cumulative loss to manageable assets to 2100 discounted to the present using private sector discount rates (5-7%, declining with the growth rate) and government discount rates, as per the Stern Review, respectively.

Mitigation consistent with a likely chance of remaining under 2°C of warming reduces average losses by at least half and losses at extreme outcomes by at least three quarters. Losses to manageable assets will occur even if warming is limited to 2°C. However, these losses will be greatly reduced if mitigation action is taken. Average losses from the private investor perspective are halved to $2 trillion. Losses at extreme outcomes are reduced even further, with damage consistent with 6°C of warming reduced by three quarters. The reduction in losses at extreme outcomes is very important for asset managers that must, due to regulation, be resilient to tail risks, such as insurance firms. The benefits of mitigation are even greater from the government perspective, as the lower discount rate increases the benefit of avoiding damage, in the same way that it increases the cost of suffering damage.

The losses are primarily incurred in the latter half of the century. Figure 1 shows how the presentvalue loss to current assets evolves over time along temperature consistent paths, as well as the average loss over time. To illustrate, if we were only concerned with losses over the next 40 years, to 2055, and believed that the world was on a path to 6°C of warming by 2100, then the consistent present value loss to current assets to 2055 would be $2 trillion (discounted using private sector rates); this is where the red line crosses the lowermost y-axis gridline at 2055. Losses after 2055 would of course still occur, but, given the 40 year time horizon, they would, in this example, be disregarded. As the figure shows, the losses are primarily incurred in the latter half of the century, as there is a lag between the release of emissions and temperatures increasing. It is only later in the century that the climate consequences of the majority of emissions are expected to be felt, although there is scientific debate over whether the climate response will be faster (Frölicher & Paynter, 2015).

Figure 1: Losses are primarily incurred in the latter half of the century
Present value loss to current manageable assets (trillion $, 2015 prices)



Note: Losses are discounted at private sector discount rates. The losses over time are consistent with paths to the respective temperature levels being reached in 2105.

Source: Vivid Economics.

4.2 Capital approach results

Climate change is expected to, on average, reduce the capital stock in 2100 by 9%, and up to 28% at extreme outcomes. The capital approach estimates the reduction in non-financial assets in 2100 due to climate change. This capital stock underpins many of the managed financial assets. Climate change is expected, on average, to reduce this stock by 9% in 2100. Losses are much higher if more extreme outcomes are expected to occur, with a 14% and 28% reduction in the capital stock in 2100 consistent with warming of 5°C and 6°C respectively. These results are summarised in Table 2.

Table 2 - Climate change could reduce the 2100 capital stock by 9% on average, and 28% at 6°C of warming

	Average loss	5°C loss	6°C loss
Percentage reduction in the 2100 capital stock	9%	14%	28%

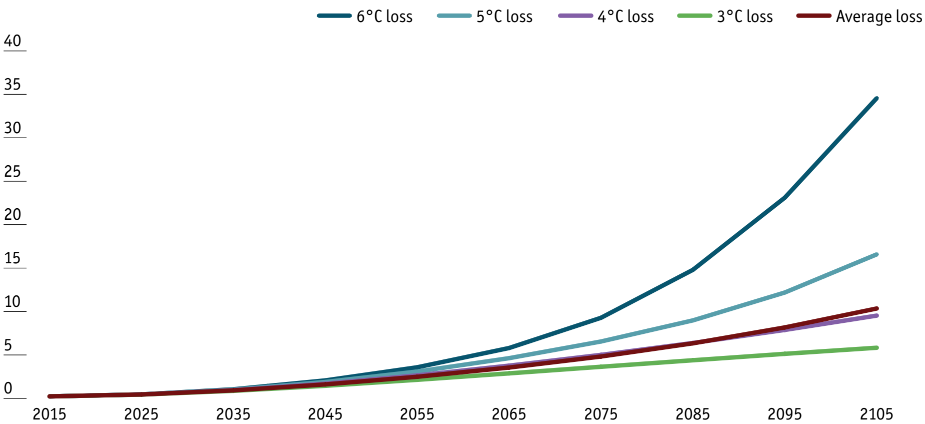
Note: The loss due to climate change of the capital approach measure is not discounted, but presented as the reduction to the capital stock in 2100.
Source: Vivid Economics

Mitigation consistent with a likely chance of remaining under 2°C of warming reduces average losses by two thirds and losses at extreme outcomes by 85%. The benefits of mitigation are greater in the capital approach than in the dividend approach because the capital approach focuses on the future capital stock, rather than present value losses, so the benefit is not discounted.

Losses to the capital stock are, like losses to current financial assets, primarily incurred in the latter half of the century. Figure 2 shows how the damage to the capital stock evolves over time along temperature consistent paths, as well as the average loss over time. Damage to the capital stock is not discounted, that is to say that the values represent the loss of capital in the relevant year. To illustrate, if we were concerned with losses to the capital stock in 2055, and believed that the world was on a path to 6°C of warming by 2100, then the consistent damage due to climate change would be a 4% reduction in the capital stock. As the figure shows, the losses are primarily incurred in the latter half of the century, for the same reason as in the dividend approach: that there is a lag between the release of emissions and temperatures increasing.

Figure 2: Losses to the capital stock are, like losses to current financial assets, primarily incurred in the latter half of the century

Damage to future capital stock (% loss in year due to climate change)



Note: Losses are not discounted. The losses over time are consistent with paths to the respective temperature levels being reached in 2105.
Source: Vivid Economics.

4.3 Secular stagnation scenario

Damages in the secular stagnation scenario are higher. Table 3 compares the results for the dividend approach between the base case and the secular stagnation case. The damages are high in the secular stagnation case for two reasons. First, as lower productivity leads to lower economic growth, the discount rate is lower, and therefore the present value of damages is higher. Second, as explained below, the temperature consistent damages are more extreme.

The temperature consistent damages are higher in the secular stagnation scenario because high temperatures are less likely to occur and so consistent damages are more extreme. Lower economic growth in the secular stagnation scenario leads to lower emissions. As a consequence, it is less likely that a scenario of secular stagnation will result in high temperature increases. Temperature consistent damages are therefore higher as they too are more extreme. To illustrate, 5°C and 6°C warming have a 10% and 3% respective probability of occurring in the base case, but a 5% and 1% respective probability of occurring in the secular stagnation scenario. Therefore the damages consistent with 6°C of warming occurring in the base case are damages occurring with 3% probability, while those consistent with 6°C of warming occurring in the secular stagnation case are damages occurring with 1% probability.

Table 3 - The secular stagnation scenario has higher present value losses as lower growth leads to lower discount rates, and because the probability at which higher temperatures occur is higher, so the consistent level of damage is more extreme

Present value loss to current manageable assets	Average loss	5°C loss	6°C loss
Increasing productivity scenario (base case)	$4.2 trillion	$7.2 trillion	$13.8 trillion
Decreasing productivity scenario (secular stagnation)	$4.7 trillion	$18.4 trillion	$37.9 trillion

Note: The current stock of manageable assets is $143 trillion. Dollar values are in 2015 dollars. Losses are the cumulative loss to manageable assets to 2100 discounted to the present using private sector discount rates.
Source: Vivid Economics

4.4 Conclusions

The results show that the asset management industry is, from a private investor perspective, at risk of extreme outcomes and that the government has a role in safeguarding society from average losses due to climate change, let alone extreme outcomes. The results suggest that private investors are overvaluing manageable assets today by 3% of their current value if they consider the expected average impacts of climate change. However, if they consider the tail risks, that 5°C or 6°C of warming will be reached by 2100, then assets today are overvalued by 5% and 10% respectively. These are present value losses, discounted at private sector rates. From a government perspective, with a lower discount rate, even the expected average impacts to manageable assets are of major concern, let alone extreme outcomes. The mean average expected loss is $13.9 trillion, equal to 10% of current assets, while if 6°C of warming is expected, then the consistent level of present value losses at government discount rates is $43 trillion, equal to 30% of current assets.

These results are for global aggregate assets, but impacts will vary by asset class and region. DICE, as a top-down model, can only estimate results for global aggregate assets. The few studies that have considered the impact of climate change at a more disaggregated level, often at the economic sector, asset class or regional level, tend not to quantify the impact, due to the greater uncertainty inherent in more disaggregated analysis. However, they find that, in general, economic sectors and asset classes that are concerned with physical assets or natural resources are the most vulnerable to climate change. For example, Mercer (2015) finds that real estate, infrastructure, timber and agriculture are the most sensitive to climate impacts, while Vivid Economics (2013), which surveys a range of models, also finds that tourism may be negatively affected by climate change. Developing, and to an extent, emerging economies, are more vulnerable to climate change, not just because these countries are, in some cases, more likely to face greater climatic changes, but because, due to their lower income, they are less able to adapt to climate impacts (IPCC, 2014b). This means that, in these countries, large scale economic consequences may follow from relatively small scale climate change. As a result, financial assets in these regions may underperform other regions, for example Mercer (2015) identifies emerging market global equities as a particularly vulnerable asset class. Furthermore, while around 70% of current manageable assets reside in Europe and North America (Financial Stability Board, 2014), the growth of emerging markets means that many future assets will be in these regions.

Our modelling suggests that much of the impact to manageable assets will come through lower asset returns, affecting the entire portfolio, rather than direct damage, which would be more localised. The capital approach can decompose the percentage reduction in the capital stock due to climate change into direct damage, from events such as storms and floods, and indirect damage, due to a decrease in asset returns, which reduces the accumulation of assets relative to a world of no climate change. Indirect damage, with 5% probability in 2100, is responsible for around 60-70% of the loss of capital, with the lower and upper values in the range from the decreasing and increasing productivity scenario respectively. While this result is driven by assumptions about which there is limited evidence[8], it indicates that asset managers may face a challenge in avoiding climate risks by moving out of vulnerable assets classes and regions. This is because, at least under lower probability, higher impact outcomes, the results suggest that climate change will have a primarily macroeconomic impact, which will affect the entire portfolio of assets.

In conclusion, this report finds that the impacts of climate change on the asset management industry are of a significant order of magnitude when put within its own risk management framework. The industry has limited awareness of the risks it faces due to climate change, despite an institutional focus on risk management and clear metrics for risk measurement. This report speaks to that ethos by putting climate risks into a VaR framework. It finds, by adapting an established economy-climate model, that the VaR due to climate change is significant. Climate change is expected to cause permanent, present value losses to current manageable assets of 3% on average and up to 10% at extreme outcomes, when discounted at a private sector discount rate, and puts at risk 9% of the 2100 capital stock on average, and 28% at 6°C. From a government, and therefore regulator, perspective the present value losses are even higher, at 10% of current manageable assets on average and up to 30% at extreme outcomes. However, mitigation consistent with a 2°C target reduces average losses by at least half and losses at extreme outcomes by at least three quarters. So action on climate change is likely to be in the industry's interest, as a way to manage its own risks.

[8] In particular, it is assumed that 30% of climate damage affects the capital stock, but there is currently limited research on the appropriate share (Dietz & Stern, 2015). This assumption is related to, but not equal to, the share of direct damage resulting from the model; for example the share of direct and indirect damage to capital is approximately equal at higher probability outcomes.

5. Annexes

These annexes provide detailed discussion on the main conceptual and modelling aspects of the report. These are: the definition of assets, key uncertainties, productivity scenarios, discounting, mitigation scenarios and the parameter values of key modelling assumptions.

5.1 Definition of Assets

This report focuses on the stock of financial assets that could potentially be managed. Manageable assets are financial assets that can be professionally invested on behalf of an asset owner for a fee. This stock is the potential market size of the asset management industry, rather than the stock of assets currently managed, which is estimated to have been 22-25% of the potential market in recent years (McKinsey & Company, 2012). We take a broad definition of manageable assets, to cover all assets held by non-bank financial institutions, which was $143 trillion in 2013, as estimated by the Financial Stability Board (2014). Bank and Central Bank financial assets are excluded as these are, largely, managed by the institutions themselves. Non-bank financial institutions are: insurance companies, pension funds and other financial intermediaries (such as money market funds, investment funds), plus public financial institutions, as their assets can be professionally managed by a third party. This definition is appropriate as this report focuses on how the industry's overall prospects are affected by climate change, rather than on its ability to attract customers and increase its market share in the face of climate change.

Financial assets, broadly speaking, consist of all financial claims[9], such as bonds, and shares or other equity in corporations. A financial asset is created by raising a liability that will be paid off from a flow of output. At a fundamental level, output results from a production process where (technology and human capital augmented) labour and non-financial assets, commonly referred to as economic capital, are combined. Non-financial assets can be fixed assets, such as machinery, natural resources, such as water, and ideas, such as patents. In a developed economy, the share of output earned by non-financial, fixed assets is typically 30%, and the remaining 70% is earned by labour.

The stock of financial assets depends on the flow of output, which in turn depends on the stock of labour and non-financial assets. For example a corporation can issue a bond and use its machinery to produce output sufficient to liquidate the bond when it becomes due, or a household can take out a car loan and repay it with wages. Financial assets can therefore be created from corresponding financial liabilities that are backed by non-financial assets or labour income, but not all non-financial assets or labour income need be used to create financial liabilities and assets.

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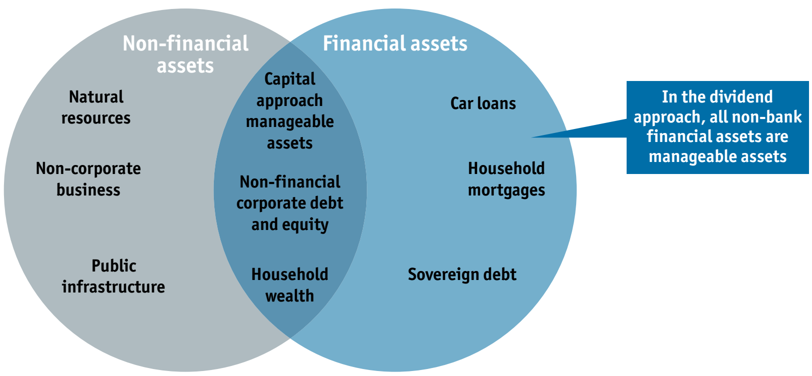
[9] The payment or series of payments due to the creditor by the debtor under the terms of a liability.

The relationship between non-financial and financial assets has two important implications for this report. First, the results of the capital approach, the impact of climate change on non-financial assets, can be converted into an effect on financial assets, as described below. Second, the assumption in the dividend approach: that dividends from manageable assets grow at the same rate as GDP, is based on the logic that the stock of financial assets depends on the flow of output, that is to say: GDP, which in turn depends on the stock of labour and non-financial assets.

The dividend approach takes into account all financial assets – those backed by both capital and labour – while the capital approach only considers financial assets that are backed by capital. As the relationship between dividends and GDP growth relates to dividends from all financial assets, the dividend approach estimates results for the full stock of manageable assets. Indeed, the broader the definition of financial assets, the more appropriate the assumption is, as this controls for cyclical differences in relative performance across asset classes. The capital approach, on the other hand, estimates the impact of climate change on the capital stock, so can only provide information on the impact of climate change to those financial assets that are backed by non-financial assets in the capital stock. This difference is illustrated by Figure 3. As explained below, not all non-financial assets can be used to create a financial asset, and not all financial assets are backed by capital, such as car loans or household mortgages[10], where the liability is met by labour income.

Figure 3: The capital approach focuses on a sub-set of manageable assets, those that are backed by non-financial assets, while the dividend approach focuses on all manageable assets



Note: The list of assets in the figure is not exhaustive.
Source: Vivid Economics.

[10] Note that while household mortgages are secured by a non-financial asset, real estate, the liability is metfrom the income of the mortgage holder. For example if a mortgaged house is destroyed, the mortgage still exists, and must be paid by the mortgage debtor.

In the capital approach, impacts to non-financial assets can be converted to impacts to manageable assets. To calculate the effect on manageable assets of a dollar loss of non-financial assets requires two conversions. First, the share of non-financial assets that are used to back manageable financial liabilities, and concurrent financial assets, must be estimated. This includes the non-financial corporate sector, which issues corporate debt and equity, and financial instruments arising from household wealth, such as pensions. It excludes the non-financial assets of the financial sector, which holds non-financial assets for risk and regulatory purposes, non-corporate businesses, as these rarely issue manageable securities against their non-financial assets, and (the majority of) government debt, as discussed below. Second, the financial liabilities, and therefore concurrent financial assets, created per dollar of non-financial asset must be estimated. The product of these two ratios converts a dollar of lost non-financial asset to a value of lost manageable assets. To illustrate, in the US, on average over the last decade, the non-financial corporate sector owned 25% of non-financial assets, and $1.7 of financial asset was created per $1 of non-financial asset in this sector (Board of Governors of the Federal Reserve, 2015). So a $1 loss of non-financial assets, will lead to a $1.7 loss of non-financial corporate manageable assets, 25% of the time, or a $0.43 loss of non-financial corporate manageable assets on average for every $1 of non-financial assets destroyed.

Data is insufficient to identify the value of government debt used for investment in non-financial assets. Some government debt is used to finance investment in non-financial assets, so would be included in the scope of manageable assets under consideration in the capital approach. However, a large proportion of government debt is used to finance consumption, the repayment of which is premised on future claims to tax income. Data on the share of government expenditure to acquire non-financial assets is available, for example IMF (2014). From this data, one could assume that the same share of government borrowing is used to finance this investment. However, data is not available over a long, or complete, time series, and suffers from significant variation over time, due to the financial crisis and ensuing recession. Therefore it does not provide a reliable enough basis to make assumptions about future patterns of government spending, especially to 2100.

There are two main issues with this conversion of loss to non-financial assets into manageable assets. First, it only estimates a sub-set of manageable assets; it does not capture the effect of climate change on financial assets that are backed by labour income, such as household mortgages, and taxes on this income, as many government bonds are. This is in contrast to the dividend approach, which considers all manageable assets. Second, data on the conversion rates is not available globally, and rates are likely to vary over the next century. As a consequence, results in the capital approach are not converted into losses of manageable assets, but presented as a percentage reduction to the capital stock. If manageable assets are, on average, as vulnerable to climate change as the capital stock in general, then a similar percentage reduction to manageable assets would be expected.

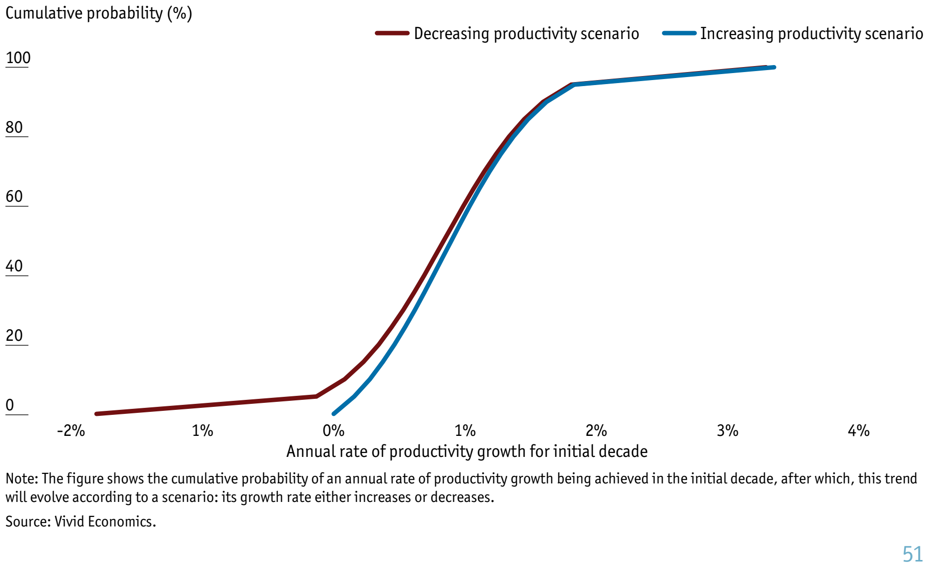
5.2 Key uncertainties

There are a large number of uncertainties associated with modelling the impacts of climate change. As IAMs combine three separate simplified models: economy, emissions and climate, they require many different inputs. There is no consensus on a single, definitive value for a wide range of these inputs and so it is appropriate to treat them as uncertain, i.e. define a probability distribution over the range of possible values, when estimating the impacts of climate change. Indeed, the most comprehensive study of uncertainty with regards to the DICE model randomises all 51 input parameters (Anderson, Borgonovo, Galeotti, & Roson, 2014).

Research suggests that only a small subset of the parameters in DICE have a significant impact on the key results. Large variations in most parameters do not significantly change the overall impacts of climate change. This suggests that, for computational simplicity, it is sensible to confine our attention to those that do. Dietz and Asheim (2012) and Nordhaus (2008) identify eight parameters as important for uncertainty analysis while other well-known studies, such as the US Government's InterAgency Working Group on the Social Cost of Carbon (2010), have focused on only one, climate sensitivity.

When estimating climate VaR, arguably three parameters are key and as a result, only these are treated as uncertain in this report. The first parameter is the level of productivity growth achieved in the initial decade, because it sets the magnitude of growth for the century. It therefore has a direct and considerable impact on the size of the future economy and thus, the income available to invest in assets. The second and third parameters impact the magnitude of damage that climate change causes. Climate sensitivity, the equilibrium increase in global mean temperature following a doubling in the atmospheric concentration of greenhouse gases, defines how much the planet warms in response to emissions, which is uncertain due to the complexity of the climate system. The third parameter, (part of) the curvature of the damage function, defines how much of output and capital is destroyed by a given temperature increase. So, taken together these two parameters define the amount of damage a given level of emissions causes. Uncertainty in each of these three parameters is introduced into DICE by modelling each as a random variable.

Figure 4: The distribution over initial productivity growth rates varies somewhat between the productivity scenarios



Note: The figure shows the cumulative probability of an annual rate of productivity growth being achieved in the initial decade, after which, this trend will evolve according to a scenario: its growth rate either increases or decreases.

Source: Vivid Economics.

The initial rate of growth in productivity is defined as a normal distribution. In a new paper, Dietz, Gollier and Kessler (2015) calibrate uncertainty around productivity growth based on nearly 200 years of data from the UK and US. They find that it is best modelled as a normal distribution with a mean of 0.84% annual growth and standard deviation of 0.59%. After the initial decade, the trend then evolves according to a scenario: its growth rate either increases or decreases, described further in Annex 5.3.

The distribution over initial productivity varies somewhat between the productivity scenarios. Figure 4 shows the cumulative probability of an annual rate of productivity growth being achieved in the initial decade, after which, this trend will evolve according to a scenario: its growth rate either increases or decreases. The cumulative distribution functions are different for each scenario. The distribution for the decreasing productivity scenario is based on Dietz, Gollier and Kessler (2015), as described above. The increasing productivity scenario is a modification of this former distribution. Specifically, it is truncated to have no negative values, resulting in a shift of some probability weight to positive values. This is because, in this scenario, an initially negative productivity growth rate would become increasingly negative over time. Such an outcome would imply that the global economy, of its own accord (rather than due to climate change), has a recession that leads to a negative spiral of decline, resulting in the collapse of the economy. This is (relatively) implausible and inconsistent with a scenario where productivity is increasing, i.e. negative productivity growth should not persist in such a scenario.

Climate sensitivity is defined as a log-logistic distribution. Parameters for uncertainty over the climate sensitivity are determined by large-scale climate models. We define climate sensitivity as a log-logistic distribution, following Dietz and Stern (2015) and Dietz, Gollier and Kessler (2015). It results in a probability distribution with an ~80% probability that value for climatesensitivity is between 1.5 and 4.5, consistent with the latest IPCC report (IPCC, 2013). The distribution has a mean of 3.6309°C of global average warming for a doubling in the atmospheric concentration of greenhouse gases and a standard deviation of 1.4215.

The risk of catastrophic climate change is modelled to take into account the range of views in the academic literature. Damage to the economy due to climate change is estimated by a damage function. This is a polynomial equation that converts a global average atmospheric temperature increase into economic damage. This equation is fitted to estimates from impact studies in the literature. It is very hard to estimate the effect on the modern economy of high levels of temperature increase, as there has been no experience of this. However, it is highly likely that damage will be increasing with temperature. The question is whether damage increases slowly or quickly, in which case the curvature of the damage function will be shallow or steep respectively. Different authors have taken different approaches to modelling the curvature of the damage function, particularly at higher temperature increases. A key issue is whether high temperature increases could lead to catastrophic climate change, which would result in a very steep damage function at these temperature increases.

In our version of DICE, the damage function is shallower or steeper depending on a random variable. In DICE, the damage function is defined as a polynomial of atmospheric temperature as set out in the equation below. Dietz and Asheim (2012) account for uncertainty in the curvature of the damage function through a random coefficient on a higher-order term: where is the atmospheric temperature at time t, are coefficients used to calibrate the function on impacts studies and is the random parameter. The rationale behind this approach is that can be used to effectively 'turn on or off' a catastrophic climate impact responsible for steeply increasing losses in GDP beyond a certain degree of warming. Weitzman has been the key proponent of the idea of catastrophic climate impacts at a macroeconomic level (Weitzman, 2012), but Nordhaus tends to dismiss it. Given that there is no compelling empirical evidence with which to discriminate (Tol, 2012), the calibration in Dietz and Asheim was undertaken such that the distribution of values of spanned the views of these two scholars. Since then, Dietz and Stern (2015) have introduced, as a 'high' scenario, a damage function of the same form as Weitzman (2012) but that is even more pessimistic. This damage function is used prominently in Covington and Thamotheram (2015), and is also the damage function used in this report.

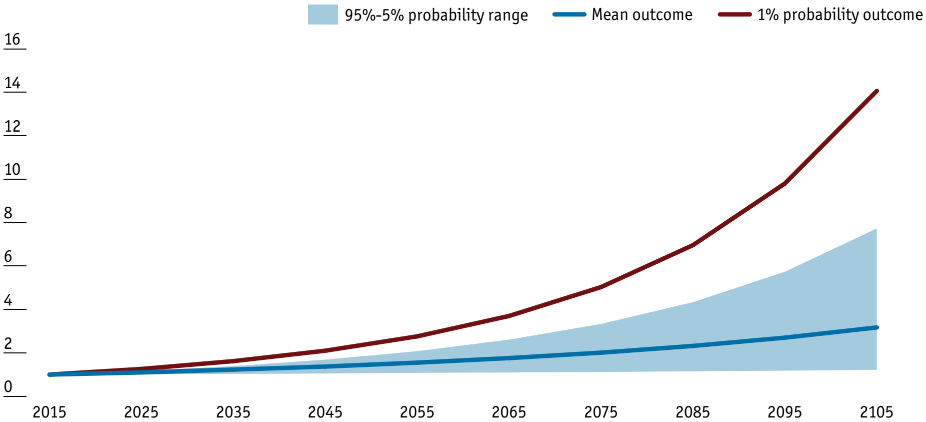
We model the curvature of the damage function as a normal distribution. To estimate the climate VaR, we take the broad approach of Dietz and Asheim in using to span the existing literature, but with Nordhaus and Dietz and Stern (2015) as the end-points of the range of views. This results in a normal distribution for with a mean of 0.12417 and a standard deviation of 0.04139.

5.3 Productivity scenarios

As productivity is critical to the main results, it is important to recognise that uncertainty exists about its evolution in two ways. We are uncertain about both the trend of productivity growth, and how this trend might evolve in the longer term. As discussed in Annex 5.2, productivity growth has a large and cumulative effect on future output and can significantly alter the climate VaR as a result. Thus, it is important to explore the impact that each of these uncertainties might have.

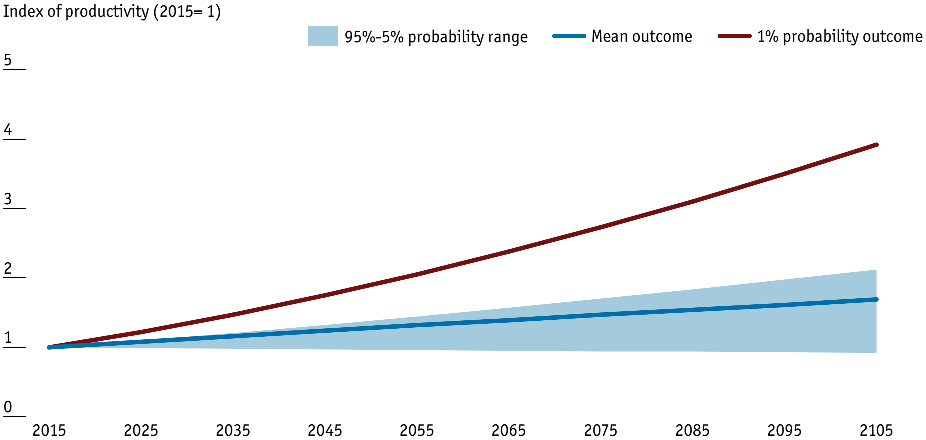
Uncertainty regarding the trend of productivity growth is bounded and so can be modelled as a random variable. As a large dataset of past growth rates exists, we can identify a reasonable range of values that the future growth rate could take. From this, it is also possible to estimate how likely it is that the growth rate will take specific values within this range. In the context of DICE, this allows us to define uncertainty over the initial rate of productivity growth by fitting a probability distribution over past data, as described in Annex 5.2.

Figure 5: In the increasing productivity scenario, the rate of growth in productivity increases, leading to higher overall growth
Index of productivity (2015= 1)



Note: Figure is for the increasing productivity scenario, where the growth rate of productivity increases over time.
Source: Vivid Economics.

Figure 6: In the decreasing productivity scenario, the rate of growth in productivity decreases, leading to lower overall growth
Index of productivity (2015= 1)



Note: Figure is for the decreasing productivity scenario, where the growth rate of productivity decreases over time.
Source: Vivid Economics.

Scenarios are used to describe different prospects for long term productivity growth. The long term growth rate of productivity can either be increasing over time, so the global economy continues to grow at a relatively high rate, which is the EIU's view; or decreasing, so global growth slows, which reflects the idea of 'secular stagnation', the default setup in the DICE model. We use the EIU's projections of increasing productivity growth as the base case. However, as these present different prospects for future economic growth, and therefore the stock of assets, they are presented as scenarios: the increasing productivity scenario (the base case scenario), where productivity continues to grow at an increasing rate; and the decreasing productivity scenario (the secular stagnation scenario), where the growth rate of productivity decreases over time. The increasing productivity scenario is calibrated to EIU projections of the capital stock, so that the capital stock in the mean outcome in 2100 aligns with EIU projections. The decreasing productivity scenario follows the default setup in DICE. So, the overall treatment of productivity is that the trend in productivity growth is uncertain over the initial decade, but then, whatever the trend, it either increases or decreases in the long run, depending on the scenario.

As Figure 5 and Figure 6 show, these scenarios produce very different levels of productivity in the future. In the increasing productivity scenario, there is a 5% probability that productivity will increase by at least ~7.5 times by 2100 – this probability being generated from the three uncertain parameters described in Annex 5.2, while in the mean case it increases by at least ~3 times by 2100. This is in contrast to the decreasing productivity scenario, where there is a 5% probability that productivity will increase by at least ~3 times by 2100, while in the mean case it almost doubles.

5.4 Discounting

To quantify the present value of the climate VaR, the future climate VaR must be discounted at an appropriate rate. Discounting is one of the most controversial issues in the economics of climate change. In this report, however, the primary point of view taken is that of a private investor, attempting to value the possible impacts of climate change on his/her asset portfolio. As a private investment problem, many discounting controversies can be avoided, because they relate to the social discount rate to be applied by governments to public investment.

One difficult issue that remains is the fact that the impacts of climate change are potentially 'non-marginal', requiring endogenous discounting. This means that impacts can be so large as to affect the rate of economic growth (Dietz & Hepburn, 2013; Gollier, 2012). The rate of economic growth is intrinsically linked to the discount rate: the faster the economy grows, the higher the discount rate, and vice versa. The difficulty presented by climate change being a non-marginal problem is then that no single discount rate will be appropriate for all scenarios, rather different discount rates will be appropriate for each scenario, depending on economic growth in that scenario. As the discount rate within a scenario depends on the economic growth rate of that the scenario, the discount rates are known as endogenous rates. The need to use endogenous rates rightfully precludes exogenous approaches to discounting, such as declining discount rates.

Endogenous discounting creates a paradox in the case of the capital approach. Climate change has the potential to significantly reduce the future stock of capital, compared with a counterfactual scenario absent climate change. But in this bleak future the economy grows much more slowly, meaning that, to calculate the present value of the climate VaR, a lower discount rate should be applied. The result is that, perversely, the present value of the stock of capital can be higher under climate change than without. This is not incorrect – it merely says that a smaller future stock of capital is more valuable today, given the prospect of a slow-growing world. However, it naturally presents difficulties in presentation and understanding, which means it can be more effective to simply estimate the future climate VaR in undiscounted terms.

The same issue affects the dividend approach, but can justifiably be avoided. In this case one can take the empirically-supported view that portfolio managers will nonetheless derive the present value of the climate VaR using a single discount rate for all scenarios, because that is standard practice (i.e. their practice does not take into account that climate change could be non-marginal). In particular, the discount rate tends to be based on historical returns, although it can also be calibrated on a growth path consistent with the DICE model.

The discount rate used in the dividend approach is calculated from the perspective of a private investor. The discount rate is a function of the future GDP growth rate without climate change, calculated each decade, plus a premium to account for holding risky assets relative to a risk-free asset. The GDP growth rate without climate change is used as investors do not currently consider climate impacts. This results in a more conservative estimate of losses, as GDP growth with climate change will be lower, leading to a lower discount rate if investors took this into account. Average private sector discount rates are initially 5.5% but fall to 4% towards the end of the century, due to slowing economic growth.

However, as a sensitivity, government discount rates are also applied in the dividend approach. This sensitivity is explored because governments have a duty to safeguard financial assets on behalf of society and regulate to fulfil this duty, so the value at risk from a government perspective is also relevant. The government discount rate used in this report follows the approach of the Stern Review. As noted above, such an approach is not without its challenges, but at least the challenges of the Stern Review approach to discounting are well-documented and, largely, well-understood. In the Stern Review approach, the government discount rate is a function of the future GDP growth rate with climate change, as the government should consider climate impacts, plus a pure rate of time preference of 0.1%, which means that impacts on future generations are only discounted according to the probability that future generations will not exist to experience the impacts.[11] The pure rate of time preference is also multiplied by a marginal elasticity of utility of 1, which means that impacts to people within a time period are valued equally. Average government discount rates are initially 3.8% but fall to 2% towards the end of the century, due to slowing economic growth.

[11] This takes into account the low but non-negligible probability that civilisation ends through some means unrelated to climate change.

5.5 Mitigation scenarios

The base case in the analysis follows a path of minimal emissions mitigation. The emissions trajectory in the base case is taken directly from the published version of DICE-2010 and represents a scenario in which no new climate change policies are adopted (Nordhaus, 2010); this can be interpreted as 'complete [future] inaction and stalemate on climate policies'. This scenario results in a reduction of 6.5% of total emissions in 2105 relative to a world in which there were not only no new climate policies but also no existing climate policies.

This is the relevant scenario as it allows the isolation of the impacts of climate change. When trying to estimate the climate VaR, we are trying to estimate the total assets that are at risk due to climate change in the future. The variable of interest is therefore the potential impact of climate change and not the response to this potential impact, that is to say greater mitigation. Therefore, it is most appropriate to compare scenarios with and without climate change, but also both without additional mitigation. If scenarios both with additional mitigation were to be used, it would not be possible to disentangle the impact of climate change itself from the offsetting impact that additional mitigation would have through reduced emissions. So the base case results present the value at risk in a world of minimal mitigation with climate change relative to a world of minimal mitigation without climate change.

Nonetheless, examining scenarios with additional mitigation can provide useful insights and is explored as a sensitivity. The scenario with additional mitigation is based on the 'LimT' scenario in the published version of DICE-2010 (Nordhaus, 2010) but it is recalibrated such that it limits global average temperature increase to 2°C with a 66% probability. This is consistent with a 'likely chance' of keeping temperature change below 2°C, the most stringent mitigation scenario the IPCC considers to be feasible (IPCC, 2014a)

The sensitivity calculates the difference in the climate VaR between the base case and the 2°C scenario employing the same methodology as the main analysis. For the 2°C scenario, the climate VaR is calculated for both the capital approach and dividend approach. Similar to the main analysis, this is done by comparing the value of the capital stock and of total dividends respectively in a world with and without climate change. The absolute value for the climate VaR is then compared with the equivalent climate VaR in the base case scenario. Therefore, this difference indicates how much less capital would be at risk from climate change if mitigation efforts were sufficient to limit the global average temperature increase to 2°C.

5.6 Key modelling assumptions

Table 4 - Table 4. Key assumptions in DICE for the calculation of the climate VaR

Name	Value	Source	Comment
Climate sensitivity	Log-logistic distribution: Mean = 3.6309 Std Dev = 1.4215 (truncated at 0.75)	Dietz and Stern (2015); Dietz, Gollier and Kessler (2015); IPCC (2013)	Distribution results in a probability distribution withan ~80% probability that value for climate sensitivity is between 1.5 and 4.5, consistent with the latest IPCC report.
Productivity growth rate in initial decade	Normal distribution: Mean = 0.0084 Std Dev = 0.0059	Dietz, Gollier and Kessler (2015)	Distribution is fitted to 200 year dataset on UK andUS productivity. The distribution is truncated at 0 for the increasing productivity scenario.
Curvature of the damage function	Normal distribution: Mean = 0.0084 Std Dev = 0.0059 (truncated at 0)	Dietz and Asheim (2012); Nordhaus and Dietz and Stern (2015)	Distribution reflects the wide range of views on the appropriate coefficient for the 'high-order' damage term seen in the literature.
Capital share of income (%)	30%	Nordhaus (2010)	Standard assumption in the literature and follows original calibration of DICE-2010.
Depreciation rate (% per annum)	10%	Nordhaus (2010)	
Share of damage to capital	30%	Dietz & Stern (2015)	
Initial yield on portfolio (% per annum)	2.76%	Dimson, Marsh, & Staunton (2011)	Estimates for the representative yield and rate of return on equities and bonds are taken from the real annualised yields and returns over the period 1900-2010. These are calculated as the geometric mean of the time series data.
Initial rate of return on portfolio (% per annum)	5.50%	Dimson, Marsh, & Staunton (2011)	

Source: Vivid Economics

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