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Title

Be prepared – exploring future climate-related risk for residential and commercial real-estate portfolios

Abstract

This paper explores how real-estate investors and lenders can assess and manage the physical risks of climate change through well-established risk models and climate scenarios. We propose a methodology that real-estate investors and lenders can use to improve their understanding and management of these risks. The methodology is applied to a sample of 12 real-estate portfolios with a total market value in excess of £2 trillion, spread across Europe, North and South America and Asia, investigating the impacts of climate change on losses from floods and winter storms (UK) as well as tropical cyclones (North America and the Pacific Rim). The estimated changes in risk, especially in the climate scenario most aligned with the current warming trajectory, raises important questions for investors, lenders, insurers and policymakers as to how these new levels of risk can be managed in the most cost-effective manner.

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1. Introduction

The changing climate poses new risks and challenges to investors and lenders. Much attention has focused on transition risk – the risks posed by rapid decarbonisation of the world economy – but at present, political agreements to cut emissions have not been matched by equivalent action on the ground. Instead, the world is currently on track to see substantial climate change throughout the 21st century (Climate Action Tracker, June 2019). This creates heightened risks to investors and lenders, the so-called 'physical risks' of climate change, which, among other impacts, may be seen in terms of higher temperatures, changes in flooding, drought water availability, and sea level rise.

Regulators, investors and lenders are increasingly aware of the possible implications of physical risks across different parts of the financial system but lack practical, analytical approaches to guide their decision-making. The Financial Stability Board (FSB)'s Task Force on Climate-related Financial Disclosures (TCFD) has recommended inclusion of physical risk disclosures in organisations' annual filings. In addition, at least 18 regulators and central banks from across Europe, North America and Asia, including the Bank of England, De Nederlandsche Bank and Banque de France have recently drawn attention to the direct risk climate change poses to investors, as well as the potential for contagion to other parts of the finance sector (NGFS, 2018). This is now accompanied by a growing body of guidance and advise – for example from the European Bank for Reconstruction and Development (EBRD) (European Bank for Reconstruction and Development, 2018), and the United Nations Environment Programme Finance Initiative (UNEP FI) (United Nations Environment Programme Finance Initiative, 2018).

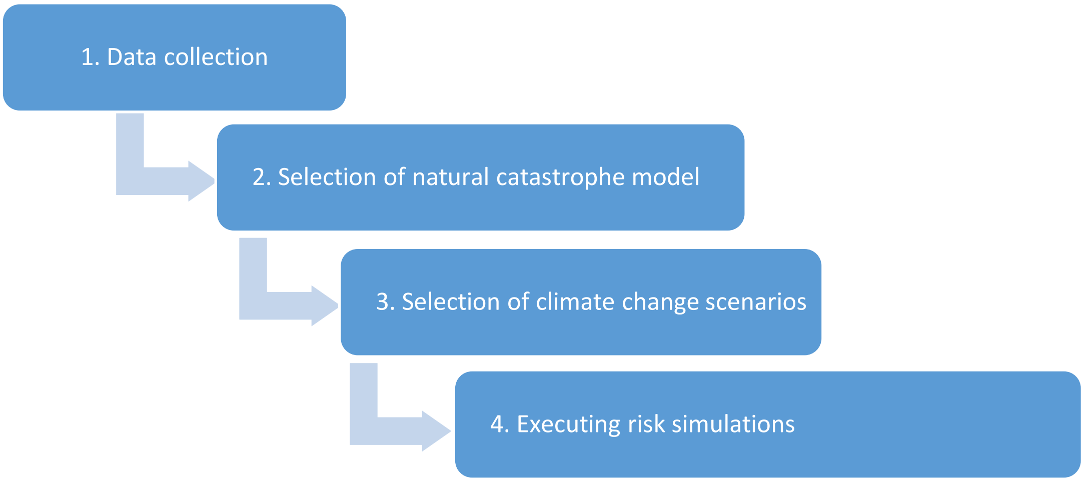
However, while there is a general perception that risk disclosure is important, there is still little understanding of how climate risks can be assessed, and therefore reported, managed and, ultimately, reduced. At present, the analytical ability to assess current and future physical risks, as well as assess opportunities, is generally limited: only a third of respondents to the TCFD's June 2019 survey reported using climate-related scenarios for physical risk, with lack of data and tools identified by the TCFD as a barrier. While the demand for physical climate risk analytics is increasing rapidly, largely in response to global initiatives such as the TCFD, the use of physical risk data and associated tools by investors and lenders remains very limited. Often, investment decisions proceed without any reflection of their exposure to physical risks (Surminski et. al. 2016; Surminski et.al. 2018). This is particularly concerning given global infrastructure needs, estimated to be up to US$90 trillion by 2030 (The Global Commission on the Economy and Climate, 2016).

This paper shows how investors and lenders can use risk modelling tools and associated metrics to better assess, manage, report and reduce their exposure to physical risks, particularly those from extreme weather events. Risk models have long been used by the insurance industry to assess and price extreme weather event risk, and hence help them and their clients manage these risks. Recently the Geneva Association, the leading international insurance think tank, recommended that climate science projections should be used within natural risk models to provide more forward-looking forecasts (Golnaraghi et. al. 2018) This paper shows how, in practice, outputs from climate models and climate scientists can be used in combination with natural risk models to assess risk under future climate scenarios. Used in this way, the insurance industry's risk models are powerful tools that can be used by investors and lenders within their scenario analysis to help quantify the physical risks of climate change, while recognising the inherent uncertainty surrounding the future incidence of climate events.

2. An analytical methodology for investors and lenders

In this paper we develop and apply a four-step process for analysing the physical impacts of climate change. This is set out in **Error! Reference source not found.**.

Figure 1. **Key steps for investors and lenders for modelling the physical risks of climate change**



Source: The authors, for CISL 2019

First, data on the physical assets ('exposure') is collated by investors or lenders. At a minimum, this data should include geographic locations and some information on asset class, such as a classification into residential, non-residential real estate or infrastructure. The more detailed the asset-level information can be – in terms of asset type, construction type and year, roof type, number of floors, occupancy and square footage – the more robust the associated results will be.

Second, investors or lenders need to decide which natural risk model(s) to use for their analysis. A number of factors will play into this choice. A critical one will be whether the modelling will be undertaken in house or sub-contracted to a commercial model vendor. The former might make use of an open source model. This may allow for more bespoke analysis to be undertaken and provide greater understanding of what drives any results, but these models may not have received as much investment and will also require reasonable technical skills to be confident that the work is being undertaken accurately. The advantages and disadvantages reverse for models from commercial vendors. For models supplied by vendors, the extent and transparency of model documentation is another important factor, since this will enable investors and lenders to understand and review the assumptions made in the modelling.

The third stage involves choosing the climate scenarios to model and defining how those climate scenarios might influence the probability and severity of extreme weather events. In order to account for uncertainty about the extent of global action on reducing emissions, scenarios chosen should cover a wide range of plausible futures. The scope of potential ranges in temperature increases, typically expressed in terms of temperature increases by 2100 above a pre-industrial baseline, might range from 1.5°C, the temperature target 'aimed for' in the Paris Agreement, to 4°C or more, which broadly reflects the temperature increases that would be expected given the current trajectory of emissions. For example, independent scientific analysis by the Climate Action Tracker in November 2017 estimated that current global commitments to emissions reductions have only a 10 per cent chance of being sufficient to limit temperature rises to 2°C (Climate Action Tracker, 2017). A recent sophisticated probabilistic analysis estimates that the most likely global mean temperature rise by the end of the 21st century is 3.2°C (Raftery et. al.2017) and analysis by Schroders suggests that warming could reach 4°C (Schroders 2018). The relationship between these temperature changes and the severity and frequency of disaster events within a region should incorporate the latest peer-reviewed developments in climate science and acknowledge/account for the uncertainty around these relationships. Some models already include effects of climate change on the frequency and intensity of the perils within their models; otherwise, collaborations with academics or specialist climate change impact modellers may need to be sought out in consultation with the model developer.

The final stage is model execution and interpretation of the associated results. Risk models can provide a wide range of different results of interest. Two of the most common outputs are Average Annual Loss (AAL) – the average expected losses from property damage through extreme weather events experienced by a portfolio per year – and annual probability of occurrence – the probability that, over the period of one year, a given asset experiences an extreme weather event of a given magnitude. Any results should be compared against a 'present day' climate scenario baseline and, where possible, these baseline results should be compared with and scrutinised against historical loss data. Forward-looking results should also be benchmarked against those from comparable studies, where available.

An optional stage in any analysis by investors and lenders is to explore how adaptation measures might reduce losses and asset value impacts. The flexibility provided by natural risk models' vulnerability modules can allow investors and lenders to understand the effect of some adaptation measures on expected losses. Adaptation measures reduce the vulnerability of properties to extreme weather events and can therefore alleviate some of the impacts of climate change . Examples of adaptation measures for flood risk are waterproof doors, windows and airbricks and measures that reduce damage if flood waters do ingress such as resilient flooring, plastic kitchens and raised power sockets. The effectiveness of such interventions will depend on the effectiveness of the measures themselves and the extent to which measures are taken up. Inside natural risk models, the effect of adaptation measures effects can be modelled, underpinned by assumptions about take-up rate of these measures (e.g.eg how many homes are fitted out). A comparison of expected losses with a 'baseline' and 'adaptation' damage curve provides an estimate of the effect of adaptation. Adaptation damage curves can be calibrated using data on historic losses for properties with adaptation measures or through engineering estimates of the effectiveness of the measures at given hazard intensities.

3. Application and findings

In this section we apply the above methodology to a sample of 12 real estate portfolios with a total market value in excess of £2 trillion, spread across Europe, North and South America and Asia, investigating the impacts of climate change on losses from floods (UK), European windstorms (UK and Europe), and tropical cyclones (North America and the Pacific Rim).

Of the 12 real estate asset portfolios analysed seven consist of UK residential mortgage assets held by large UK retail banks and building societies, whilst five are real estate investment portfolios held by specific financial institutions The latter portfolios mostly comprise offices and shopping centres, with assets across Europe, North America, South America and Asia. Data on the UK residential mortgage lending portfolios was derived from UK finance, data on the portfolios held by other financial institutions was made available to us for analysis by the portfolio owners. Table 2 provides further details. The analysis compares present-day Annual Average Losses of the portfolios from extreme weather events to their expected losses in the 2050s. Financial institutions with long-term investments, including banks and building societies providing new 35-year mortgages today, will have exposure to risks in this time period.

Table 1. **Two catastrophe models were used**

				Exposed to:		
Portfolio	Predominant asset class	Number of assets	Market value (UK GBP)	UK flood (Future Flood Explorer)	European winter wind storms (CLIMADA)	Tropical cyclones (CLIMADA)
1	Residential			✓	✓	
2	Residential			✓	✓	
3	Residential			✓	✓	
4	Residential			✓	✓	
5	Residential			✓	✓	
6	Residential			✓	✓	
7	Residential			✓	✓	
Sub-total		**7,200,000**	**2,093 bn**			
8	Commercial			✓		
9	Commercial			✓	✓	

10	Commercial			✓	✓	✓
11	Commercial			✓	✓	
12	Commercial				✓	✓
Sub-total		**1,251**	**36 bn**			
Total		**7,200,000**	**2,129bn**			

Source: The authors, for CISL 2019

The results derive from two natural risk models that are characteristic of those used in the insurance industry, CLIMADA (Aznar-Siguan&Bresch, 2019) and the Future Flood Explorer:

CLIMADA is an open-source and -access global probabilistic risk modelling and adaptation platform developed by the Weather and Climate Risk Group at ETH Zurich. In the present study, it is used to estimate losses from European winter wind storms and tropical cyclones worldwide. It follows the same structure as commercial natural risk models: a computation engine combines physical models of hazards, vulnerability calculations and financial data to produce estimates of the distribution of future losses caused by extreme weather events. These estimates can be made for present day conditions or, by making appropriate changes to CLIMADA's probabilistic hazard generation, for various climate change scenarios. CLIMADA is implemented in Python, freely downloadable and, thanks to comprehensive documentation and tutorials, can be run without deep technical expertise.[1] It has been used for a number of academic publications (e.g. Gettelman et al. 2018; Schwierz et. al. 2010). While the physical sophistication of hazard models in CLIMADA as used in this study does not match that of the commercial vendors, it has considerable value from being open source. This means all assumptions behind the model are visible and, with modifications to the source code and/or any parameter, can be adapted as required by advanced users.

The Future Flood Explorer (FFE) is a flood risk system model developed by Sayers and Partners to enable the influence of climate and socioeconomic changes on flood risk to be explored and how adaptation measures can offset these changes. It was used as part of the 2017 Climate Change Risk Assessment for the Committee on Climate Change (Sayers et al, 2015), the assessment of present and future social flood disadvantage in support of JRF climate just programme (Sayers et al. 2017) and in support of the National Infrastructure Assessment 2018 (Sayers et al. 2018), as well as for academic research (Sayers et al. 2016a,b). As set out in detail in these references, the FFE uses a combination of publicly accessible data (such as flood hazard analysis lead by national policy leads across the UK) governments), licensed data (on flood defences, property locations etc) and bespoke process analysis (representing the influence of defence failure for example) to develop an efficient representation of the UK flood system and its response to climate change and investment in defences and other flood management measures (including property-level measures). In this

[1] The Python source code and documentation for CLIMADA is available at https://github.com/CLIMADA-project/climada_python and https://climada-python.readthedocs.io/en/stable/, or Python.

analysis, the FFE is used to provide individual and combined estimates from coastal, fluvial and surface water floods to mortgage and non-mortgage assets in Great Britain.

The application explores Annual Average Losses in the 2050s in two climate change scenarios[2]: The first scenario is consistent with 4°C of global warming by the end of the century, an outcome in line with the warming implied by current trajectories of climate action.

The second scenario reflects the possibility that aggressive mitigation action and technological innovation leads to rapidly decreasing emissions levels and the global temperature rise being limited to 2°C by the end of the century. The two scenarios used therefore span much, if not quite all, of the range of possible temperature outcomes.

Climate models allow for an understanding of the links between global temperature scenarios and the frequency and severity of particular extreme weather perils at the regional level. These links are an area of active scientific research: There is more confidence in the relationship between temperature rise and extreme weather events for some perils (e.g. coastal flooding) than for others (e.g. hurricanes). For the purposes of this study, the following is assumed:

- For UK floods, changes in sea level rise, extreme rain events and precipitation from the UK Climate Projections 2009 (UKCP09) drive changes in flood risk.[3]
- Changes in tropical cyclone risk in North America and the Pacific Basin are based on published academic research by Knutson, Sirutis, and Zhao (Knutson, et. al.2015) who provide estimates for the effects of global warming on tropical cyclones at the end of the 21st century under a greenhouse gas emissions scenario consistent with a 4°C warming scenario. CLIMADA's tropical cyclone module scales the effects on intensity and frequency to the 2050s (and where required for a 2°C warming scenario) based on the total concentration of greenhouse gases expected in the atmosphere.
- For European winter wind storm risk, an ensemble of EUROCORDEX regional climate models is used to predict regional changes to storm intensity and extreme wind speed.

The results show that, for these particular portfolios, climate change could have large impacts on the losses that investors and lenders face from floods in the UK and tropical cyclones in North America and the Pacific Rim, but that their increases in losses from European winter wind storms are likely to be lower. Under a 4°C warming scenario, the modelling suggests the Average Annual Loss (AAL) caused by UK floods to residential mortgage assets could increase by 130 per cent. It also suggests a 40 per cent increase in the number of residential properties exposed to significant flood risk (defined as a 1.3 per cent or 1 in 75 annual probability of flooding or above), equivalent to 180,000 properties

[2] Climate change scenarios are sometimes defined in terms of emissions scenarios (for example the use of Representative Control Pathways in IPCC reports). In using climate change scenarios based on global mean temperature rises, we are following the recommendations of the UK Committee on Climate Change (UKCCC)'s Climate Change Risk Assessment 2017. As well as providing flexibility to use outputs of various climate models, stakeholder feedback to the UKCCC indicated that this description of climate scenarios is more easily understood by readers. 2°and 4° warming correspond to the mean predicted increase in temperatures from the CMIP5 ensemble of climate models in the RCP4.5 and RCP8.5 emissions scenarios, respectively.

[3] Updated climate projections were released in late 2018 ('UKCP18'), including projections at a higher spatial resolution and better modelling of extreme rainfall events. These outputs were not available at the time of analysis. The Met Office recommended continued use of UKCP09 until UKCP18 outputs were made public.

within the portfolios examined. These results are for large, geographically well-diversified portfolios; more regionally concentrated lenders may see larger increases. For investment portfolios, in a 4°C warming scenario, the increase in AAL from flood risk across four UK portfolios is modelled to be 70 per cent higher in the 2050s than today. Across the two portfolios with assets in North America and the Pacific Rim, the analysis based on best evidence suggests that the equivalent expected increase from tropical cyclone risk is 80 per cent. The portfolios examined face much smaller increases in risk from European winter wind storms.

The analysis also suggests that losses faced by investors and lenders are lower, but still substantial, if global efforts to reduce emissions are successful. For the UK residential portfolios, AAL from floods would increase by only half the amount of a 4°C scenario, while the modelling suggests that the number of properties within the portfolios at risk of significant flooding (1.3 per cent or 1 in 75 annual probability or above) might only increase by 25 per cent. For investment portfolios in the UK, the increase in AAL is 40 per cent, which is similar to the potential increase in AAL from tropical cyclone risk. Table 2 summarises. These results reinforce that it is paramount for governments, business and society to try and keep warming as low as possible, as underlined by the most recent IPCC analysis [2].

Table 2. **Modelling shows increased losses are expected across all perils, but they are lower if global efforts to reduce emissions are successful**

Peril	Asset type	Risk metric	2°C warming by end of century	4°C warming by end of century
UK flood risk	Residential mortgages	% increase in AAL by 2050s	61%	130%
		% increase in number of properties at significant risk of flooding (annual probability of 1.3% or above)	25%	40%
UK flood risk	Investment portfolios	% increase in AAL by 2050s	40%	70%
North America and Pacific Rim tropical cyclones	Investment portfolios	% increase in AAL by 2050s	43%	80%
European winter wind storms	Investment portfolios	% increase in AAL by 2050s	6.3%	3.6%

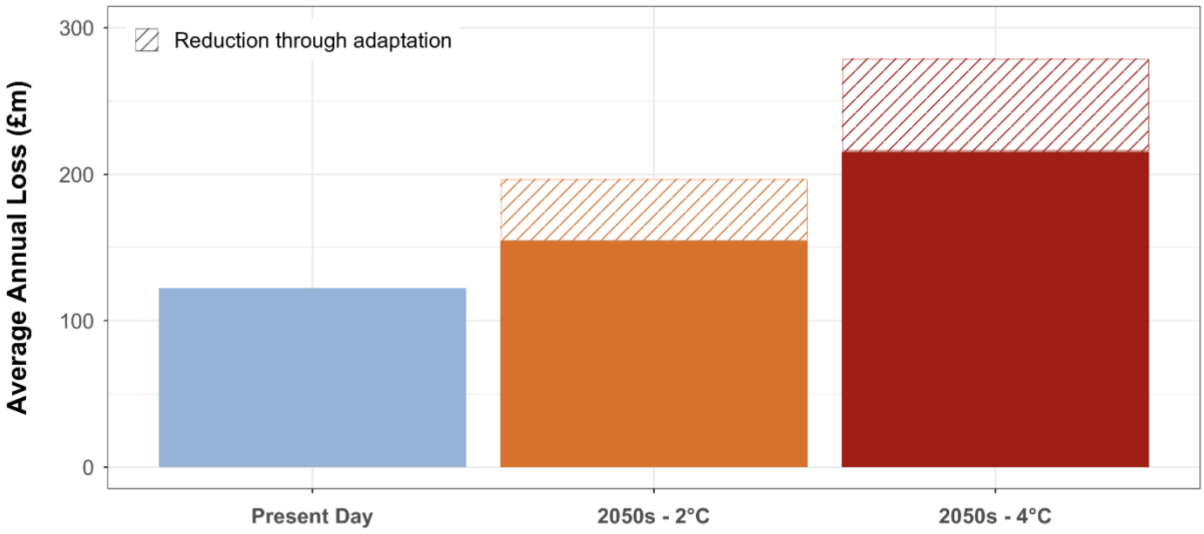
Source: The authors, for CISL 2019

Property-level adaptation measures can materially reduce climate change induced losses, and this is most effective when combined with global efforts to reduce emissions. In the UK, the modelling suggests that, under a 2°C scenario, around two thirds of the additional losses might be offset if half of at-risk households install flood protection measures. This includes measures to prevent flood ingress and measures to reduce damage if flood water does ingress, such as resilient flooring.

Further reductions in losses, and a reduction in the number of properties at significant risk of floods (annual probability of flooding above 1.3 per cent), could be secured by increased community-level flood adaptation measures.[4]

The analysis of tropical cyclone risk suggests that, in a 2°C temperature scenario, roof upgrades to properties at risk of tropical cyclones might offset around half of the increase in AAL. However, adaptation measures offset a smaller proportion of the increases in losses in higher temperature scenarios, when extreme weather events are expected to be more severe.[5]

Figure 2. **The modelling suggests that adaptation measures help reduce the Average Annual Loss from floods to properties in UK mortgage portfolios**



Source: The authors, for CISL 2019

These findings align with those from earlier studies. For instance, JBA found a 25–30 per cent increase in AAL for UK residential properties in the 2040s [6], while the UK's Climate Change Risk Assessment (Sayers 2015), also using the Future Flood Explorer as in this analysis, found a 30–62 per cent increase in AAL in the 2050s for UK residential properties. The smaller increases in AAL found in these previous analyses are likely to reflect differences in assumptions around community-based adaptation and in the portfolios examined, while in the case of the JBA analysis, also differences in model set-up and time horizon. Similarly, the relatively modest increases in AAL from wind storms match the findings of research carried out on behalf of the Association of British Insurers (ABI) regarding the effect of climate change on wind storm losses to UK assets (ABI., 2013). The ABI modelling exercise found the AAL from UK wind storms was expected to increase 11 per cent by the end of the century under a 1.5°C scenario and 25 per cent by the end of the century under a 4.5°C

[4] The analysis assumes spending on construction and maintenance of river and coastal defences continues to be implemented as effectively as experienced in the recent past.

[5] As discussed in Section **Error! Reference source not found.**, adaptation measures provide only limited resilience against the most extreme events.

scenario. It is likely that differences to our analysis are largely attributable to the different time horizon and scenarios considered, as well as some differences in the model set-up and the underlying climate models used to drive the results.

4. Discussion

The potential increases in risk, especially in a 4°C scenario, raise important questions for investors, lenders, insurers and policymakers as to how they can be managed in the most cost-effective manner. In cases where commercially provided insurance policies are held in relation to these perils, policyholders might expect to see, on average, increases in premiums, and insurance companies would need to purchase substantially more reinsurance to ensure solvency, in line with any increases in modelled uncertainty. For assets that have no insurance cover (such as some commercial properties), all of any increase in risk will be faced by investors and/or lenders.

These results also have important implications for the strategy of organisations set up to help address the insurance protection gap such as the UK's Flood Re. This not -for-profit reinsurance pool was developed by industry and government as an "innovative way to ensure the availability and affordability of flood insurance, without placing unsustainable costs on wider policyholders and the taxpayer" (DEFRA, 2013). The pool was launched in 2016 as an addition to the standard home insurance market rather than a replacement and is expected to encourage private carriers to write affordable flood insurance policies for high-risk properties. This is possible as it offers insurers a low-cost option to offset the costs of property insurance claims for flood damage (BMI Research, 2016).

In the specific case of the UK residential mortgage market, Flood Re is responsible for providing an affordable market for home insurance for properties built before 2009 that are at risk of flooding. Recent analysis suggests Flood Re's funding gap could increase, raising concerns about the sustainability of these arrangements (Surminski 2018; Jenkins et. al. 2017). There are also questions about the limits of insurability and what happens should cover be no longer available or affordable. Investors and mortgage providers have traditionally relied on insurance cover protecting homeowners from financial loss. A lack of access to affordable insurance would have adverse implications for homeowners living in those properties who may find that their properties suffer significant decreases in value, potentially leaving them in negative equity and either unable to sell their homes and/or unable to re-mortgage. This could have significant personal costs, as well as disrupting the liquidity and efficiency of the housing and mortgage markets. In turn, lenders may need to consider the increased risk of mortgage default, which is likely to be geographically concentrated, and ensure that their business strategies are robust to this risk

A crucial next step from this work should be for national regulators to explore in more detail the interlinkages between flood risk, insurance availability and the residential property market – with a particular focus on how these interlinkages could evolve over time. In the UK, this would build on the concern expressed by the Bank of England regarding the possible crystallisation of financial risks from greater flood risk to the UK residential mortgage market if flood insurance would become unaffordable (Bank of England, 2018) .

Furthermore, while there is expected to be a substantial overall elevation in physical risks in a 4°C scenario, not all lenders and investors are likely to be equally exposed. Especially in a 4°C warming scenario, the modelling finds significant differences in the risk of different portfolios of mortgage and investor assets. Under a 4°C warming scenario, the range of increase in expected losses across the seven UK residential mortgage portfolios varies between 108 per cent and 132 per cent. For the two portfolios of assets at risk of tropical cyclones in North America and the Pacific Rim, the range in the increase in losses is 17 percentage points, with much of this difference driven by the location of just a small number of assets. The modelling suggests that the spread in risk across different portfolios is substantially smaller if emission reductions are successful in moving the world onto a 2°C warming trajectory. Clearly there is a role for investors to support and invest in a low-carbon future to ensure that the pathway to 2°C is achievable, while also internalizing climate risks into their decisions: one of the most important ways that investors and lenders can influence their risk is through both strategic location investment decisions (which region/country/continent) and local asset-siting decisions; although any such changes should be done carefully, in a phased, managed way. Capital providers to investors and lenders will likely want to understand how such location decisions, intermediated by insurance availability (discussed above) and adaptation action (discussed below), are taking account of the physical risks of climate change. To the extent that investors and lenders do alter location decisions, it will be much less disruptive to the real economy if this happens over a long period of time rather than as an abrupt response to one or a series of particular events.

This analysis indicates there is a powerful opportunity for investors, lenders, the insurance industry and policymakers to target the uptake of adaptation measures in the most beneficial areas. Although it allows for rapid repricing of risk, the short time horizons created by the insurance industry's practice of one-year insurance contracts limits the ability for insurers to incentivise adaptation measures. However investors and lenders, combined with policymakers, may find it easier to take a longer-term perspective. They could work in concert with insurers to encourage the uptake of adaptation measures, for instance, by making both loans and insurance contingent on the installation of relevant adaptation measures. These efforts could help overcome 'first-mover risks' whereby households may be unwilling to introduce adaptation measures that similar households do not have, for fear that their abnormality, and the signal that the property may be exposed to physical risks, might reduce the value of the property.

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