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Climate Change, Flood Risk and Mortgages in the UK: a Scenario Analysis

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ABSTRACT

With rapidly increasing global average temperatures, physical risks originating from a changing climate may affect the financial health of households and the stability of the financial system. This article estimates the proportion of UK common equity tier 1 (CET1) capital exposed to flood related mortgage defaults under three climate scenarios: Present Day (2015), 2°C Low Population Growth (2080) and 4°C Low Population Growth (2080). The article finds that approximately 0.11% of UK CET1 capital is at risk of flood related mortgage defaults, whilst under the 2°C and 4°C Low Population Growth scenarios, 0.21% and 0.30% of CET1 capital is exposed to flood risk respectively.

Keywords: climate change, financial stability, flood risks, scenario-analysis

Introduction

It is widely accepted that climate change will have significant adverse effects on our economies in the coming decades. Since the early 1990s, neoclassical economic literature has attempted to measure and identify the potential threats of climate change by focusing on the general effects on the economy. However, much less attention has been paid to the effects that climate change would have on the financial system. It is only within the past five years that central banks, researchers and international organizations have started investigating the financial risks associated with climate change; in particular the United Nations Environment Programme, the Financial Stability Board, the G20, as well as Australian, British, French, Italian and Dutch central banks have issued warnings about the potentially destabilizing effects (Regelink et al. 2017).

Properties worldwide are threatened by the increasing probability of climate change and extreme weather conditions. The adverse effects that extreme weather conditions will have on the housing market will ultimately lead to sudden changes in banks' balance sheets, in particular banks' reserves and capital. However, there are a number of steps that must occur before we begin seeing such an impact on banks' balance sheets. Primarily,

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we expect to see noticeable changes in household borrowing and consumption (Campbell and Cocco 2007) and in turn see an increase in the exposure of financial institutions to climate-related risks which they have not yet considered (Dafermos, Nikolaidi, and Galanis 2018). The Dutch National Bank (Regelink et al. 2017) and BlackRock Investment Institute (2019) have attempted to quantify climate-related risk, with the former specifically looking at the impact of flood risk on Dutch financial institutions and insurers.[1] The latter looked at climate-related risks in the US municipal bond market and found results in agreement with Regelink et al. (2017). The results of both these papers are discussed in detail in Section 3. However, such research for the UK has not yet been conducted. More importantly, current Integrated Assessment Models (IAMs) do not consider the role of finance i.e. credit rating reductions, and thus such costs have not been included in the Social Cost of Carbon (SCC). Therefore, this paper aims to fill a gap in the UK ecological economics field by identifying how UK bank capital will be affected by 2080 by measuring how flood risk will impact the UK housing market.

In recent years, there has been growing recognition and evidence of the financial risks originating from climate change, however a survey conducted by the Bank of England found that just 10% of the firms were "taking a forward-looking view, grounded in long-term financial interest" (Rojas 2019). For that reason, this article aims to quantify the impact of flooding on the UK residential mortgage market, which represents 296% of UK tier 1 capital, by using a scenario analysis between 2015 and 2080. The scenario analysis builds upon Sayers's (2015) findings of Estimated Annual Damages (EAD). We chose to remain in line with Sayers's (2015) scenarios of Present Day (2015), 2°C Low Population Growth (2080) and 4°C Low Population Growth (2080) in order to increase the accuracy of the calculations.[2] From here we applied a multi-step process in order to identify the total value of mortgage-related Expected Annual Damages (EAD) in comparison to UK core equity tier 1 capital (CET1).

Our results show that approximately £52 million worth of UK residential mortgage-related damages are currently at risk exposing 0.01% of core UK capital to flood risk. However, in the event that the Paris Agreement is unsuccessful and we witness a 4°C rise in global average temperature by 2080, we can expect the total value of mortgage-related EAD to be £143 million, representing 0.03% of the UK CET1 capital. These results are rather stark, as we are only considering the impact of a single climate event on only one sector of the economy - the residential mortgage market.

Climate-Related Financial Risks: A Critical Discussion

The Bank of England (2017), United Nations Environment Programme Finance Initiative (UNEP 2018a,UNEP 2018b), Dutch National Bank (Regelink et al. 2017), Dafermos et al. (2018), and others have attempted to measure the financial risks originating from climate change. Climate change poses two primary risks for the financial system — transitional risks and physical risks.

Transitional Risks

Transitional risks are the threats associated with progressing to a low-carbon, greener economy and have been the focus of multiple studies. The transition to a low-carbon economy can affect financial markets via three channels: climate policy, technological progress, and consumer preferences.[3]

Indeed, certain sectors may experience large structural changes in asset values and higher operating costs.

[1] Regelink et al. (2017) used data collected by The National Flood Risk Analysis for the Netherlands, a project commissioned by the Ministry of Infrastructure and the Environment.

[2] A detailed analysis of Sayers (2015) methodology can be found in Section 4.

[3] See UNEP (2018a). Transitional risks have not been calculated in this article but have been briefly included in order to provide the reader with a holistic view.

UNEP (2018a) identifies that the transition will pose a threat to the value of investments held by banks and other financial institutions as certain industries become less profitable and more volatile. It is important to note that the severity of transition risks is dependent upon the speed of the transition. An abrupt transition would increase the financial risks as financial managers would not have time to adapt and align their portfolios with climate targets. If governments then proceed to keep pushing climate policies, this would lead to further growth in the misallocation between portfolios and climate targets (Scott, Van Huizen, and Jung 2017). This could subsequently lead to a "climate Minsky moment" (Prudential Regulation Authority 2018) which would materially damage financial stability as described by the Governor of the Bank of England, Mark Carney.

Physical Risks

Physical risks are the threats caused by the increase in extreme weather events such as flooding, droughts and storms (UNEP 2018b). Due to the complexity and unpredictability of natural events, identifying physical risks is substantially tougher and relies on a greater deal of human expertise than transitional risks.

The increase in severe weather events will have direct consequences on insurers if the damages and losses are covered. It is important to note that an increase in events covered by insurers would result in a higher premium for clients. However, there are multiple events which insurers do not cover, in this case the damages would have to be covered by households, firms or governments. This in turn could have second round effects on financial institutions as they are exposed to these agents through mortgages, loans, shares and bonds (Regelink et al. 2017). This reduction in the price of corporate bonds and the rise in debt defaults would induce climate-related financial instability which would adversely affect credit expansion and magnify the negative impact of climate change on financial activity (Dafermos, Nikolaidi, and Galanis 2018).

Moreover, the geographical focus of a firm's/individual's mortgage portfolio will play a crucial role in the impact of climate change. A firm found holding mortgages in a high physical risk location will experience an increase in the probability of default (PD) as the firm's capital is destroyed reducing their profitability and liquidity (Dafermos, Nikolaidi, and Galanis 2018). Also, residential locations may experience a reduction in loan-to-value (LTV) ratios as banks begin to include the cost of physical risks in their cost modeling (Prudential Regulation Authority 2018).

Analyzing the Risks

In order to measure the impact of physical and transitional risks on financial institutions, one must look at their balance sheet exposure to climate risk related sectors. It is very likely that financial institutions with no exposure to climate risk sectors face indirect effects regardless, as a result of financial interconnectedness.

Dietz et al. (2016) extrapolates traditional neoclassical theory in order to make an argument in favor of the significance of finance-related physical risks. Results from Stern (2007), Weitzman (2012), and Burke, Hsiang and Miguel (2015) are used to argue that since the performance of financial assets is derived from the overall performance of economic activities, the impact on financial assets will be significant if the general economic impacts of climate change are as significant as studies have shown. This gives rise to the urgency to conduct further research in order to quantify the total magnitude of climate-related financial risks. So far, all researchers have used scenario-based analyses with varying global mean temperatures above the pre-industrial level as their base variables for calculating transitional and physical risks.[4]

Physical risks, as stated before, are substantially more challenging to identify and calculate due to the unpredictable nature of naturally occurring events. UNEP (2018b) uses a combination of three timeframes

[4]It should be noted that the °C will impact transitional and physical risks differently. For example, a 2°C scenario implies a lot of transitional risks but not so many physical risks. Whilst under a 4°C scenario the physical risks are expected to increase more than proportionally.

and temperatures: 2020s - 2°C & 4°C, 2040s - 2°C, 2040s - 4°C. The scenarios are used across three climate-sensitive sectors: agriculture, energy, and real estate. This differentiation in sectors allows financial institutions to analyze the impacts of extreme weather events on borrower revenues and cost of goods sold by estimating changes in probability of default. The inclusion of real estate allows for the identification of potential changes in property values and LTV ratios as a result of extreme weather conditions.

The BoE (2017) and Regelink et al. (2017) have shown that a primary physical risk is flooding. Thailand witnessed approximately US$ 45 billion worth of flooding damages of which only a quarter was insured (Scott, Van Huizen, and Jung 2017). Flooding of such magnitude will increase as the global average temperature rises and this may impact the financial sector directly, for example through damages to offices, or indirectly through credit and investment portfolios. Regelink et al. (2017) identify three channels for the latter:

Firstly, financial institutions may face losses through exposure to the regions affected. The damage caused by flooding on commercial and residential assets will increase the credit losses of financial institutions' loans and investments.

Secondly, financial institutions may be affected by a reduction in the quality rating of government bonds. Flood damages to public infrastructure and emergency service costs will lead to substantial public costs. However, governments may not be able to finance these through tax revenue as people emigrate for protection. This results in the credit rating of the government bonds falling, impacting the portfolios of banks, insurers, and pension funds. Standard Poor's (2015) conducted research simulating direct damages to property and infrastructure occurring from extreme weather events which occur once every 250 years. From this it was found that €30 billion worth of damage to public infrastructure would decrease Dutch government bonds rating by half a credit rating.

BlackRock Investment Institute (2019) found results in agreement with Regelink et al. (2017) when looking at climate-related risk in the U.S. municipal bond market. With a total outstanding debt of $3.8 trillion, the municipal bond market is highly volatile to rising temperatures and sea levels. It was found that within a decade, more than 15% of the SP National Municipal Bond Index would be issued by Metropolitan Statistical Areas experiencing annualized losses of approximately 0.5% to 1% of GDP, which in turn would have a large impact on their creditworthiness.

Thirdly, the actual risk of flooding, whether it has occurred or not, will affect credit risk modeling which may lead to higher borrowing or lending costs on a range of the country's assets (Regelink et al. 2017).

Overall it is evident that quantifying finance-related climate risks still faces multiple challenges. The complexity and timeframe of climate change is seen to be one of the primary challenges, as agreed on by BoE (2017), UNEP (2018a,2018b), PRA (2018), ESRB (2016) and others. Although many researchers have looked into addressing both physical and transition risks, the case of the UK remains under-explored with regards to physical risks. The Bank of England has identified the possible threats originating from physical risks, but has not attempted to quantify them, which is the goal of this article.

Methodology

This article will focus on the direct effects of flooding on the UK's financial stability. As with all risks there are direct and indirect effects associated with them.[5] The direct effects of flood risk include physical damages to properties, reduction in property value, increase in Loan-To-Value ratio (LTV), and increase in mortgage default rates. Sayers (2015) estimated the annual damages resulting from flooding and will be discussed later on.

In order to measure flood risk, we implement a scenario-based model by using flood emulation scenarios per region which have been conducted by Sayers (2015). Sayers develops flood related damage estimations for UK regions under a 2°C and 4°C scenario in 2080.

[5] Indirect effects include reduction of neighboring property values due to contagion, declining performance of financial institutions with no exposure, and even reduction of bond ratings as discussed by Regelink et al. (2017). However, these are not the primary study of this article and will therefore not be discussed any further.

The analysis and estimation of properties at risk of flooding was calculated using the Future Flood Explorer (FFE), which uses existing data to create an emulation of the flood risk system. FFE relies upon nationally available datasets from each region and therefore provides a consistent UK wide view of changes in flood risk arising from different sources (Sayers et al. 2015). Additionally, FFE uses calculation areas in order to represent the real-world flood risk system. The calculation areas are split into two: (1) within river and coastal floodplains, and (2) outside of the fluvial or coastal floodplains. Therefore, it is assumed that any given calculation area within the floodplain responds either to coastal or fluvial flood sources but may still experience groundwater or surface flooding.

Sayers was then able to calculate annualized damages by using the Weighted Annual Average Damage (WAAD) approach based on the 2007 floods. The WAAD approach assigns an annual average damage to each property which fluctuates with the annual change in probability of flooding for that property. The WAAD calculation gives an Estimated Annual Damages (EAD) value per property i.e. a property that floods every 5 years with a WAAD value of £1,000 will have an average damage of £5,000 per flood event occurring. This value is then multiplied by the estimated number of properties affected in order to give the total value of EAD per region (Sayers et al. 2015: Appendix G).

There are certain limitations and assumptions of FFE that should be noted. Firstly, FFE relies on datasets provided by each country (England, Wales, Scotland, and Northern Ireland). Due to different collection methods and criteria used, the data provided varies across the UK and therefore produces statistical uncertainty. However, this data remains the most appropriate to use at the moment as it is the most detailed.

Secondly, the extent of the areas affected by flooding does not change with climate change implying that properties currently outside of the fluvial and coastal floodplain are assumed to remain outside the floodplain, regardless of the increase in global average temperature. The only variable that changes with climate change is the frequency of flooding.

Thirdly, inflation is excluded from the model and therefore the damages reported are at the 2014 price level. Also, it should be noted that the primary source of flooding considered is fluvial as it poses the greatest risk for the UK. Additionally, Sayers assumes a low population growth for both the 2°C and 4°C scenarios as EAD values show to be rather insensitive to population growth, something that may be due to continued adaptation (Sayers et al. 2015: Appendix B). In particular, current levels of adaptation can offset up to 50% of EAD values resulting from climate change and population growth (Sayers et al. 2015).

With regards to the changes in coastal flooding under the 2°C and 4°C scenario, UK climate projections were used from UKCP09 (Hadley Centre for Climate Prediction and Research 2007) which provides an assessment of Relative Sea Level Rise (rSLR) around the UK coastline. For the 2°C change in global average temperature scenario, the average values within each coastal region are taken directly without modification from the UKCP09. For the 4°C scenario, the projections rely on the values reported by the Environmental Agency (2011) as UKCP09 is known to exclude processes important to sea level rise at higher temperature changes.

Similarly, changes to peak river flows for England and Wales are based on FD2020 (Reynard et al. 2010) whilst Scotland is based on the CEH study (Prudhomme et al. 2013) which is equivalent to FD2020. However, for changes in peak river flows for Northern Ireland analogies with nearby regions of England and Scotland are used (Sayers et al. 2015: Appendix C).

Using Sayers's (2015) estimations of EAD will allow us to identify how higher global average temperatures will magnify flood related damages by 2080. The methodology can be broken down as follows:

Step 1: Re-categorization of Sayers (2015) regions

Sayers (2015) provides a very thorough scenario analysis by estimating the Expected Annual Damages (EAD) for selected UK cities. Mortgage data for each city that Sayers (2015) used are not available, we re-categorized them into their broader regions i.e. Central Greater London, East Midlands, North West, South West, etc as the majority of data relating to mortgages and property values were categorized as

Table 1: Re-categorization of regions

Sayers (2015) Regions	**Regions used in paper**
Hertfordshire & North London; South London; West Thames	Central & Greater London
Northants; Derbyshire; Nottinghamshire & Leicestershire	East Midlands
Lincolnshire; Cambridgeshire & Bedfordshire; Essex Norfolk & Suffolk	Eastern
Northumberland Durham & Tees	North East
Greater Manchester, Mersey & Chester; Cumbria & Lancashire	North West
Neagh Bann; North Eastern; North Western	Northern Ireland
Ayrshire; Clyde & Lock Lomond; Findhorn; Nairn & Speyside; Forth; Forth Estuary; Highland & Argyll; North East; Orkney; Outer Hebrides; Shetland; Solway; Tay; Tay Estuary & Montrose Basin; Tweed	Scotland
Kent; Solent & South Downs	South East
Devon & Cornwall; Gloucestershire	South West
Mid; North; South East; South West	Wales
Shropshire, Herefordshire & Worcestershire; Staff Warwickshire & West Midlands	West Midlands
Yorkshire	Yorkshire & the Humber

Source: Author's adaptations to Sayers (2015).

such. The re-categorization can be found in Table 1 below. It should be noted that since we do not have a complete collection of the cities within each region, as it can be seen for the South West, we assume that our calculations are indicative of the lowest possible damage hence in reality the magnitude will be much larger for such regions.

Step 2: Total property value per region

In order to identify the total property value per region we rely on data collected by HM Land Registry (2019) and ONS (2019). From HM Land Registry (2019) we obtained the mean residential property value per region[6], whilst ONS (2019) provided us with the total number of residential properties per region. These two datasets for each region were then multiplied together to provide us with the total property value per region, as denoted below:

$$\pi_{mean} * \nu = \beta \tag{1}$$

π_{mean} — mean residential property price per region
ν – total residential properties per region

[6]HM Land Registry (2019) values are based on last residential property transaction and not evaluator's estimation thus providing a more accurate result. However, the amount of time between the sale of a property and the registration of this information varies and typically ranges between 2 weeks and 2 months.

Step 3: Mortgage-related property value per region

Having obtained the total property value per region (β) we then quantified what proportion of the total property value is mortgage-related. Given the unavailability of data regarding the number or value of mortgage-related properties per region provided by UK financial institutions, this article used the value of residential mortgages outstanding per region, provided by UK Finance (2018). This is denoted below:

$$\frac{\alpha}{\beta} = \mu \tag{2}$$

α — value of residential mortgages outstanding per region
β — total property value per region

It should be noted that since the estimations are based on residential mortgages only and commercial real estate loans are not considered, this gives rise to two issues: (1) It underestimates the overall impact of mortgage-related EAD on the CET1 market, and (2) mortgage-related EAD in major regions such as Central Greater London can be even more underestimated since banks in big cities generally hold larger commercial real estate loans.

Step 4: Value of mortgage-related EAD

Having calculated the mortgage-related property value per region (μ) we are then able to quantify the value of mortgage-related EAD by using Sayers's (2015) findings. We must note that Sayers's (2015) EAD findings vary based on the scenario, i.e. the Present Day (2015) scenario for Central Greater London has an EAD of £75 million, whilst the 2°C Low population growth (2080) and 4°C Low population growth (2080) scenarios have an EAD value of £151 million and £233 million respectively. For that reason, we multiplied the percentage of mortgage-related property value per region (μ) by the EAD value of each region and scenario and denote it as:

$$EAD_{SR}\mu = \varepsilon \tag{3}$$

EAD_{SR} – EAD value per scenario and region
μ – mortgage-related property value per region

Step 5: CET1 capital ratio at risk

Having calculated the value of mortgage-related EAD per region we are then able to calculate the total value of mortgage-related EAD for the whole UK under each scenario. By acquiring the UK total we can then identify what proportion of CET1 capital ratio is at risk by using the following formula:

$$\frac{\varepsilon_{total}}{CET1} = \rho \tag{4}$$

ε_{total} – total value of mortgage-related EAD across the UK

Once the recategorization and equations 1 - 2 had been calculated we then had to calculate the remaining equations, 3 - 4, for each scenario. As stated before, we followed Sayers's (2015) scenarios: Present Day (2015), 2°C Low population growth (2080), and 4°C Low population growth (2080). For each scenario we expect to see a more than proportional increase in the impact of flooding. This is discussed in the results section below.

Results

This article will focus on the results found for the UK total before looking at Central Greater London and the South West. In particular, Central Greater London has a very large population sample along with being the capital of England and of the European financial centre, thus representing a key region for the analysis provided herein. The South West on the other hand is seen to have experienced the highest percentage increase in EAD between the Present Day scenario and the 2080 4°C Low population growth scenario. For each scenario, Sayers calculates the Estimated Annual Damages (EAD), Properties at risk > 1:75 and Properties at risk in deprived areas > 1:75. We did not use the findings for Properties at risk > 1:75 in our methodology as they were not directly compatible, however we have used them for comparison across regions in the Regional Impact subsection of the Results section. Additionally, we can assume that deprived areas would experience a more than proportional increase in mortgages at risk as the likelihood of default in such areas is usually higher. Additionally, we would also expect deprived areas to have a larger impact on public finance as a proportion of the properties would be state owned and therefore the costs of flooding would have to be covered by the local authority.

Impact on UK Capital Reserve

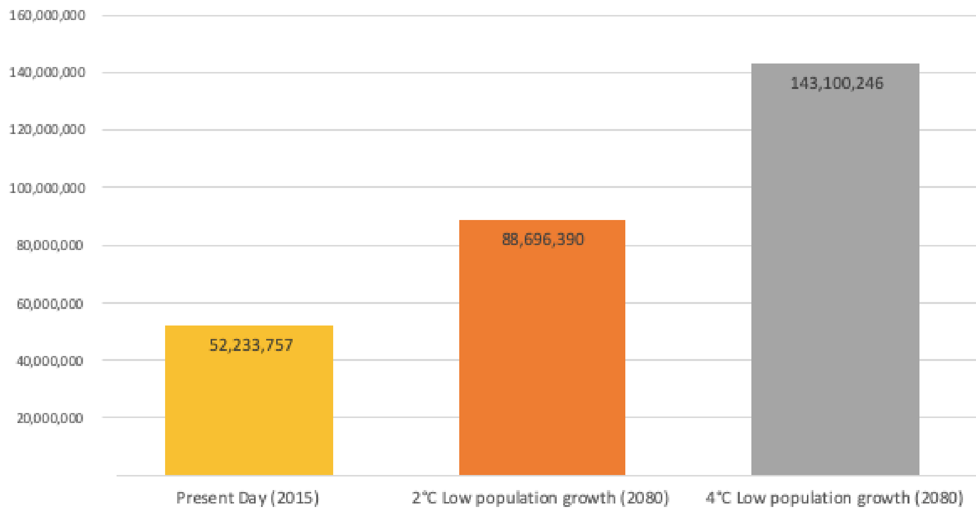
In order to calculate the magnitude of flood risk on the financial sector we have to look at the aggregate results. For this we used the common equity Tier 1 (CET1) capital ratio for the UK banking sector, which can be found using Bank of England (2019) – that being £439 billion. CET1 is used as it represents a bank's core capital along with common shares, retained earnings and stock surpluses occurring from the issue of common shares (Bank for International Settlements 2017). CET1 represents a minimum of 4.5% of a bank's capital reserve, providing us with a ball park figure for what proportion of assets can be lost before core loss-bearing equity runs out. In this case it provided us with an accurate proxy for how flooding will impact the UK aggregate capital reserve. It should be noted that whilst total capital (tier 1 and tier 2 combined) would have been more accurate as a measurement, it was not possible to acquire the total capital amount for all financial institutions. For that reason, CET1 was used as it provided us with the core capital across all UK financial institutions. Additionally, certain limitations or creative accounting actions should also be noted. For example, one issue that arises is that banks can influence their core capital by tweaking the asset number and thus undermine capital safety (Ford 2018).

Using the results from the total value of mortgage-related EAD for each region, we are then able to calculate the total value of mortgage-related EAD for the whole UK under all three scenarios. This can be seen in Figure 1 below.

Using equation 4, we can then identify what proportion of the UK CET1 capital is at risk under all three scenarios as seen in Table 2 below. At the Present Day scenario, we can see that the total value of mortgage-related EAD represents 0.01% of the CET1 capital, however this then steadily increases by an additional 1 basis points under the 2°C and 4°C Low population growth Scenario respectively. From this we can see that just over one basis point of the whole UK CET1 capital is at risk from flooding in the present day. It should be noted that no growth model was used for the UK CET1 capital therefore potentially leading to overestimated 2080 scenario results.

As it can be seen, the Present Day Scenario exposure is seen to increase threefold if the Paris Agreement is not met – a significant result. Certain schools of thought may claim that such risk has already been priced into existing assets and therefore no sudden change would be experienced by portfolio managers. However, due to the lack of human expertise with regards to climate change, and in particular flooding, we are sceptical

Figure 1: Total value of mortgage-related EAD



Source: Author's calculations, Sayers (2015), UK Finance (2018), HM Land Registry (2019) and ONS (2019).

Table 2: Percentage of CET1 capital at risk

	Present Day Scenario	**2080 2°C Low Population Growth Scenario**	**2080 4°C Low Population Growth Scenario**
Total value of mortgage-related EAD (£)	52,233,757	88,696,390	143,100,245
CET1 capital at risk (%)	0.01%	0.02%	0.03%

Source: Author's calculations and Sayers (2015).

of the Efficient Market Hypothesis (EMH), in particular the strong-form state. This is primarily because of the large time-frame we are dealing with, which makes it rather unlikely that market agents would be able to accurately price such distanced events. More importantly, current Integrated Assessment Models (IAMs) do not consider the role of finance, i.e. credit rating reductions and therefore such costs have not been included in the Social Cost of Carbon (SCC). Additionally, if the costs were large and included within IAMs and SCC, then the risk would be systemic and therefore uninsurable.

Therefore, the first step is to build our knowledge. We can do so by looking at how the severity and frequency of extreme weather events is shaped by a further increase in global average temperature and how that in turn creates risks for the financial sector. Also, adaptation techniques should be used to reduce the probability of flood damages i.e. improving defenses, managed realignment of the coast, and urban runoff management through sustainable drainage systems. The need for early adaptation is vital as significant increases in flood risk are expected to occur as early as the 2020s (Sayers et al. 2015).

In general, with an increase in global average temperature we do not solely expect an increase in flooding but instead an increase in all extreme weather events, as stated by UNEP (2018b), therefore implying that our results are merely the tip of what is to occur. We should also remember, that this paper only measures the first-round effects originating from flooding and does not take into consideration any second-round effects such as investor confidence and bond ratings which would ultimately magnify our results.

Additionally, this article only looks at the impact of a 2°C and 4°C increase in global average temperature by 2080, however the speed by which we experience a 2°C or 4°C increase in global temperature will play a vital role in the size of the flood impact and all other extreme weather events. Currently we are witnessing a 0.15°C – 0.20°C increase in global average temperature per decade (NASA 2019), however we can expect that if this increases to 0.20°C - 0.25°C per decade then we will see proportionally larger extreme weather events occurring. Such an increase in the rate of temperature change would be an issue as we would be experiencing events at a frequency that we have not experienced before. If the global average temperature keeps increasing at 0.15°C – 0.20°C per decade, this provides us with the opportunity to adapt our lifestyles and overall economy to such extreme weather events therefore minimizing the damages realized. For example, we would be able to adapt to the frequency of flooding by building properties further away from the source of flooding i.e. rivers. This would by no means reduce our environmental footprint or decrease the rate at which global average temperature is increasing. It would however reduce the extent to which the economy is affected and therefore give us more time to attempt to figure out how we can go about reducing our carbon footprint without reducing our economic growth.

Regional Impact

In order to be able to use Sayers's findings we first had to identify the total property value per region along with what percentage of it was mortgage-related. As seen below in Table 3, Central Greater London had the highest total property value of mortgage related properties and the fourth highest percentage of mortgage-related property value at £1.5 trillion and 16.4% respectively. The South West was found to have a total property value of £612 billion of which 13.1% is mortgage-related. The total property value and percentage of mortgage-related property value were calculated using the formulae from equations 1 - 2 respectively.

Under the Present Day scenario, Sayers (2015) provides us with an EAD of £75 million for the region of Central Greater London. This is the highest EAD figure amongst the regions and ultimately begs the question of how it is possible for central England to experience the highest EAD resulting from flooding. This is due to fluvial flooding being used as the primary measure of flood risk hence Central Greater London producing the highest EAD results under the Present Day scenario due to its close geographical location to the River Thames. Using Sayers (2015), it is projected that there are 217,000 properties at risk between 2015 and 2080, a figure that represents 6.67% of the total number of homes in the region (ONS 2019).

When comparing this to the 2080 2°C Low population growth scenario we can see an increase of 101%, resulting to an EAD of £151 million. As expected, an increase in global average temperature will lead to a more than proportional rise in EAD as it can be seen with the results from the 4°C Low population growth scenario. Under this scenario, Central and Greater London experience a total increase of 211% resulting in £233 million expected annual damages.

In turn, the properties at risk under the 2°C Low population growth scenario are seen to increase by 240,000 resulting in a total of 457,000 properties at risk between 2015 and 2080. This then increases to a total of 680,000 properties at risk under the 4°C Low population growth scenario, representing 20.9% of total number of households in Central and Greater London (ONS 2019).

For the South West it was found that there would be £17.3 million worth of EAD whilst 42,000 properties would be at risk, representing 1.78% of the total number of homes in the region (ONS 2019). Compared to the figures provided for Central Greater London above, we can see that the South West is comparatively at a lower risk both by EAD and by percentage of homes at risk. However, as will be seen later the EAD increases more than proportionally with an increase in global temperature.

Interestingly, regions such as the South East experience a proportionally smaller increase in EAD between the 2°C Low population growth scenario (2080) and 4°C Low population growth scenario (2080). This diminishing marginal effect on EAD results in a proportionally smaller increase in the value of mortgage-related EAD. This can be attributed to the fact that the majority of realized damages are predominately experienced at the 2°C level thus resulting in a proportionally smaller increase at 4°C. That being said this

Table 3: Total property value percentage of mortgage-related property value

Region	Total property value (£ billion)	% of mortgage-related property value
Central & Greater London	1,538	16.4
East Midlands	373	12.1
Eastern	747	8.4
North East	152	16.9
North West	497	16.3
Northern Ireland	102	20.5
Scotland	357	17.2
South East	1,170	14.5
South West	612	13.1
Wales	214	13.2
West Midlands	470	13.1
Yorkshire & the Humber	365	15.8

Source: Author's calculations, UK Finance (2018), HM Land Registry (2019) and ONS (2019).

does not imply that the extent of the damages will also be proportionally smaller at the 4°C level. What is more, it may also be possible that the 4°C scenario EAD figures are underestimated as we do not have complete knowledge of the links between global average temperature and severity or likelihood of flooding.

Concluding Remarks

This paper proposed a multi-step scenario analysis for quantifying flood risk in the UK financial services sector. To quantify the impact of flooding, we use the data found by Sayers's (2015) scenario analysis which provides us with the Expected Annual Damages (EAD) for three different scenarios: Present Day (2015), 2°C Low population growth (2080) and 4°C Low population growth (2080). From these findings we were able to identify the total value of mortgage-related EAD and therefore the proportion of UK CET1 capital at risk. Overall, our study suggests that under the Present Day scenario, 0.01% of CET1 UK capital is currently exposed to flood risk whilst under the 4°C Low population growth scenario (2080) the CET1 capital at risk triples to 0.03% — a significant result.

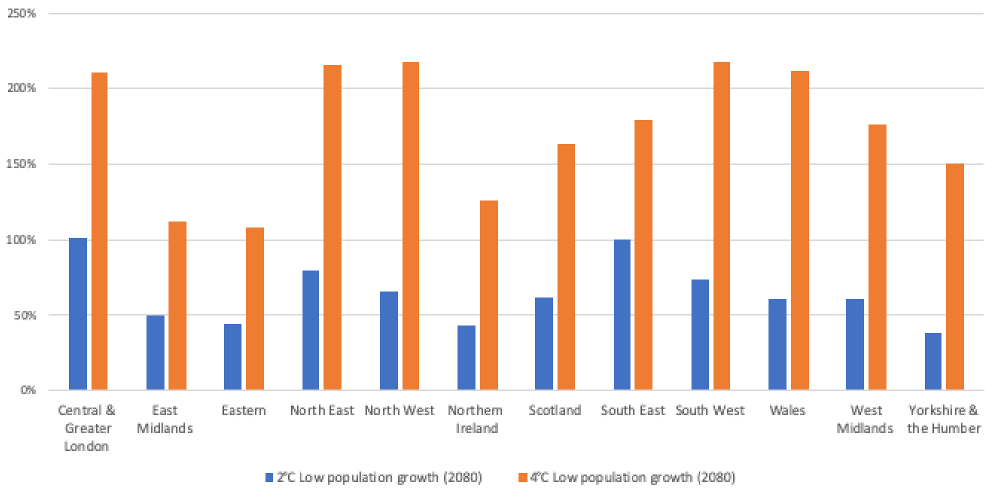
We must note that given the specificity of the study, the results are stark. This study only looked at one segment of the mortgage market being impacted by one effect of climate change. Therefore, a 0.03% unexpected loss in risk-free assets is incredibly substantial as it could potentially place banks beyond their CET1 capital buffer. Additionally, higher flood risk is likely to be combined with other extreme weather events therefore magnifying the final impact. What is more, our current measurements and understanding of flood risk and all other physical risks is rather limited therefore allowing us to safely assume that the risks that we are currently quantifying are merely the tip of the iceberg. Furthermore, the second-round effects may lead to a further reduction in property values once flood damages have been realized as investors stray away from high flood risk areas, something that has not been included in our model.

Table 4: Value of mortgage-related EAD per scenario

	Value of mortgage-related EAD (£ million)		
Region	**Present Day Scenario (2015)**	**2° C Low population growth scenario (2080)**	**4° C Low population growth scenario (2080)**
Central & Greater London	12.3 (-)	24.7 (101%)	38.2 (211%)
East Midlands	5.1 (-)	7.6 (50%)	10.8 (112%)
Eastern	4.3 (-)	6.3 (44%)	9.0 (108%)
North East	0.64 (-)	1.1 (79%)	2.0 (216%)
North West	3.7 (-)	6.2 (65%)	11.9 (217%)
Northern Ireland	1.7 (-)	2.4 (43%)	3.8 (126%)
Scotland	7.2 (-)	11.6 (61%)	18.9 (164%)
South East	4.8 (-)	9.5 (100%)	13.3 (179%)
South West	2.3 (-)	3.9 (73%)	7.2 (218%)
Wales	2.9 (-)	3.9 (60%)	7.2 (212%)
West Midlands	2.3 (-)	3.7 (61%)	6.3 (176%)
Yorkshire & the Humber	5.0 (-)	6.9 (38%)	6.3 (150%)

Source: Author's calculations and Sayers (2015). Numbers in bracket indicate percentage increase from Present Day (2015) scenario.

Figure 2: Percentage increase of mortgage-related EAD compared to Present Day Scenario (2015)



Source: Author's calculations and Sayers (2015).

Going forward, it would be beneficial to see more financial institutions either joining the 'Working Group' of UNEP (2018a,2018b) or conducting their own climate analysis such as BlackRock Investment Institution (BlackRock Investment Institute 2019) and Regelink et al. (2017). Additionally, it would also be useful if financial firms started incorporating such values in their core capital buffers or if such values were included in the Social Cost of Carbon estimates.

Recently, NGFS (2019) called for collective action of its members to draw policy recommendation for central banks, those being: achieving robust climate disclosure, and supporting the development of a taxonomy of economic activities. Over the next year they aim to prepare technical documents allowing for a greater understanding of climate-related financial risks. Increasing the number of financial institutions taking part in the study towards climate change will allow us to build a broader understanding of how climate change will impact financial stability. What is more, by increasing the number of participants we will also be able to compare and contrast findings across different industries and regions in order to identify how different sectors are impacted by climate change.

For this to occur we expect some form of government involvement in order to incentivize large financial institutions to start considering the long-term impacts of fossil-fuel financing. For instance, the US Congress has taken one of the first steps by questioning the seven largest financial institution CEOs on their environmental practices in the hopes that public pressure will force such institutions to change their approach (Washington Post 2019).

Finally, the purpose of this article was to contribute to the UK ecological economic literature by creating an adaptable multi-step process which can be used universally. By creating a universal model all climate-related events can be quantified, i.e. flood estimated annual damages can be substituted by estimated earthquake annual damages in order to quantify the magnitude of earthquake-related damages. Additionally, this model can be used to compare country specific climate-risk along with having the potential to aggregate all climate-related events and provide a proxy for climate change as whole.

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