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Feeling the Heat: Mortgage Lending and Central Bank Options*

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Extreme heat periods due to the changing climate are having a negative impact on many areas of the economy. In our study, we look at how much US mortgage lending is originated in the areas that are most vulnerable to future heat waves, and what central bank and supervisory authority actions could mitigate the resulting risk. From our results, we see that proportionally more lending flows into the areas that are likely to be most exposed to heat in the future. Population and economic output are relatively higher in these areas, and thus climate risk is less of a factor in lending decisions. However, lenders reject proportionately slightly more mortgage applications in the counties that are expected to be the hottest. Central bank and supervisory authority measures to support climate objectives are therefore of key importance. These could include, for example, central bank asset purchase programmes to support sustainable construction, especially in areas vulnerable to climate change, or the development of collateral management along similar lines. Coordination between the different authorities is also important because of the limitations of central bank actions.

Journal of Economic Literature (JEL) codes: E58, G21, Q54

Keywords: climate change, heat, mortgage lending, USA, central bank, supervisory authority

1. Introduction

Climate change is one of the greatest economic and social challenges of our time. According to climate scientists, there are a number of phenomena around the world that have not been seen in the past thousand, or even several thousand years.[1] Some of these are already irreversible. As average temperatures rise, heat days are

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[1] *Climate change widespread, rapid, and intensifying – IPCC*. Press Release, Intergovernmental Panel on Climate Change, 9 August 2021. https://www.ipcc.ch/site/assets/uploads/2021/08/IPCC_WGI-AR6-Press-Release_en.pdf. Downloaded: 8 February 2022.

becoming more and more frequent,[2] and they are harmful to both the economy and the human body. We also see changes in the water cycle. In addition to rising sea levels and retreating ice caps, the shift towards extremes should be highlighted, such as the increasing frequency of intense precipitation and droughts.

The relationship between the financial sector and climate change is complex and multifaceted (*FSB 2020*). On the one hand, through their financing activities, financial system actors can have an indirect impact on the process of climate change, depending on how environmentally sustainable their activities are (*Boros 2020*). On the other hand, climate change will not leave the financial sector untouched (*FSB 2020*). If climate risk is not sufficiently priced in – and the authorities responsible for financial stability have repeatedly voiced concerns about this[3] – possible rapid repricing events could have negative effects on the prices of a wider range of financial instruments and the stability of market participants. The sudden repricing and increase in risk premia may be due to a reassessment of physical risks, but may also reflect the temporary instability caused by the transition to a low-carbon economy.

These findings also apply to mortgage lending. Properties exhibit large differences in terms of their environmental impact (*Lützkendorf 2018*). Location is key in this respect as well. The environmental footprint of a building and the financial cost of its operation can also vary significantly from one location to another, and in the light of climate change, the question is how well the characteristics of buildings financed by mortgage lending today match the future climate of the area.

In many US states, housing construction rates are up to two to three times higher in zones which are at risk of flooding due to rising sea levels as compared to less at-risk neighbourhoods (*Climate Central 2019*), even though protecting against sea level rise is difficult and costly (*Leatherman 2018).* In addition, construction in such areas increases the risk of flooding, as the weight of buildings can cause tangible subsidence of the ground surface (*Parsons 2021*).

Central banks are also increasingly recognising that climate change may also have a negative impact on price stability and financial stability – i.e. fundamentally affect the goals set out in the central bank mandate.[4] Going beyond this, in Hungary the mandate of the Magyar Nemzeti Bank (the central bank of Hungary, MNB) already includes the promotion of environmental sustainability as a statutory goal (*MNB 2021a*).

[2] Climate Change Knowledge Portal. World Bank Group. https://climateknowledgeportal.worldbank.org/. Downloaded: 11 February 2022.

[3] Carney, M.: *Breaking the Tragedy of the Horizon – climate change and financial stability*. Speech given at Lloyd's of London, 29 September 2015. https://www.bankofengland.co.uk/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability. Downloaded: 30 September 2021.

[4] Lagarde, C.: *Climate Change and Central Banks: Analysing, Advising and Acting.* Speech by the President of the ECB at the International Climate Change Conference in Venice, 11 June 2021. https://www.ecb.europa.eu/press/key/date/2021/html/ecb.sp210711~ffe35034d0.en.html. Downloaded: 30 September 2021.

In this study, we look at US mortgage lending in areas subject to future heat waves. We study US data for reasons of detail and availability, and because in a country of this size there can be significant differences in the exposure of different areas to climate change. Precisely for this reason, the undoubtedly complex regional economic dilemmas of whether it is worth it to influence the spatial distribution or conditions of mortgage lending, and if so, how may be more relevant. Much of the literature has so far focused on real estate markets in flood risk zones, with little attention paid to real estate markets in areas exposed to future extreme heat. Previous studies have examined, among other things, the price effect (*Baranyai – Banai 2021*) or the impact on securitisation (*Baranyai 2021*), but, to the best of our knowledge, the relationship between extreme temperatures and the volumes of (mortgage) lending has not been studied in the literature.

In our study, we would like to draw attention to the fact that spatial inequalities in lending can also be examined from a climate change perspective, and that the options available to decision-makers should also be assessed from this perspective. Our analysis is mainly based on descriptive statistics – partly due to the nature of the research questions and partly to the lack of complete data – and lays the ground for further research that could, for example, explore the relationship between climate change and the denial of mortgage/loan applications in more detail.

Our research questions are the following:

1. Are more mortgages disbursed in counties in the US that are most vulnerable to future heat waves, relative to their land area, economic importance and population?

2. What do we know about supply and demand effects in lending patterns?

3. What can the central bank do to better understand and mitigate the climate risks associated with heat waves?

2. Overview of the literature

The analysis of our study is based on the theoretical assumption that heat can have negative economic, social and financial stability effects, and thus it is unfortunate to have a disproportionately high volume of mortgage originations in the most heat-prone areas. The negative economic and health impacts of heat are well documented in the literature. *Zivin – Neidell* (*2014*) detect lower labour productivity, *Jones – Olken* (*2010*) lower industrial output, *Addoum et al.* (*2018*) lower corporate profits, and *Dell et al.* (*2012*) and *Burke et al.* (*2015*) lower aggregate economic growth in the case of high temperatures. *Hajat et al.* (*2010*) found a relationship between extreme temperatures and higher mortality and morbidity, and *Deschênes* *and Greenstone* (*2011*) point out that the relationship is not linear, i.e. extreme increases need special attention. It is therefore not ideal, neither economically nor socially, to encourage construction and increased human and economic presence through mortgages in the places most exposed to extreme high temperatures.

The literature suggests that actors in the financial system are not sufficiently taking into account the risk of climate change, which may in turn raise financial stability concerns. In the real estate market, the expected temperature increase and the impact of extreme temperatures have not yet been studied, but sea level rise has. Several studies have demonstrated a small price effect (*Bernstein et al. 2019; Baldauf et al. 2020*), although some have found no such correlation at all (*Murfin – Spiegel 2020). Baldauf et al.* (*2020*) found that the extent of the price effect varies by area. Overall, the research results suggest that even in the case of sea level rise, it cannot be said that the risk is fully incorporated into real estate prices, which is probably also true for a less tangible risk (higher heat).

To reduce their risks, lenders can resort to various strategies which could also reduce the risk of instability in the financial system. The literature mainly focuses on whether a contemporary event related to climate change will induce lenders to change their behaviour. Here too, the picture is mixed. According to *Garbarino – Guin* (*2021*), for example, British credit institutions did not change any of the parameters studied after the 2013–2014 floods. However, *Duan – Li* (*2019*) find evidence that US lenders disburse less loans in areas that experience extreme heat today. The authors attribute this to a change in loan officers' expectations regarding climate change. *Ouazad – Kahn* (*2019*) found evidence that after natural disasters, the possibility of further disasters becomes more prominent in the minds of lenders. And at such times, they are even more eager to transfer this risk to companies closely linked to the state that support the US real estate market (government-sponsored enterprise: GSE).

Few studies have specifically examined the relationship between retail mortgage lending and future heat expectations, but their (preliminary) results suggest that at the aggregate level, lending behaviour is not independent of climate risk. According to *Baranyai and Banai* (*2021*), the more exposed a US area is to future heat, the higher the interest rate on local retail mortgages. The effect is a few basis points and is more significant in areas most exposed to extreme heat. *Baranyai* (*2021*) detects higher securitisation rates in these areas – which can be interpreted as lenders transferring part of their climate risks to the GSEs.

In the present study, we first investigate whether or not a proportionately large amount of credit flows to the places most exposed to heat waves. We are not aware of similar studies examining the relationship between future heat and volume of (mortgage) lending, but there have been other forward-looking analyses that examined the volume of today's activities in terms of climate exposure. The most relevant example is the analysis of housing construction rates according to flood risk exposure (*Climate Central 2019*), also taking into account the climate scepticism of people living in areas exposed to climate change (*Barrage – Furst 2019*).

Our analysis focuses on the macro-level decision-making perspective, including that of the central bank, and is thus related to the literature on the policy direction of climate finance. One of the key focuses of climate finance is financing the transition to a low-carbon, sustainable and climate-resilient economic model. Decision-makers around the world have already introduced measures that can be classified in this category; their effectiveness is evaluated by *Bhandary et al.* (*2021*). For an international perspective on the use of central bank toolkits in the context of climate change, see *MNB* (*2019; 2021a*); the potential role of central banks in the development of the green bond market is discussed by *Mihálovits and Tapaszti* (*2018*), while the challenges facing central banks and supervisory authorities in the context of climate change are discussed by *Campiglio et al.* (*2018*). They show that central banks are typically at the beginning of their journey towards risk management, and green aspects are emphasised mostly in their communication. As a first step, *Campiglio et al.* (*2018*) propose the development of a broad framework for risk mapping. So far, the US Federal Reserve has been amongst the central banks seeking to deepen its understanding of the risks, but looking ahead it is possible that there will also be measures to increase the climate resilience of the financial system (*Brainard 2020*). The MNB is now actively mainstreaming green considerations into both its supervisory and monetary policy toolbox, which makes it one of the pioneering central banks.

Possible central bank actions may differ depending on whether it is borrower or lender behaviour that underlies a particular territorial pattern of lending, and so we will examine this. However, it is beyond the scope of this article to establish in detail the extent to which the behaviour revealed is the result of a conscious attitude related to climate change.

3. Data and methodology

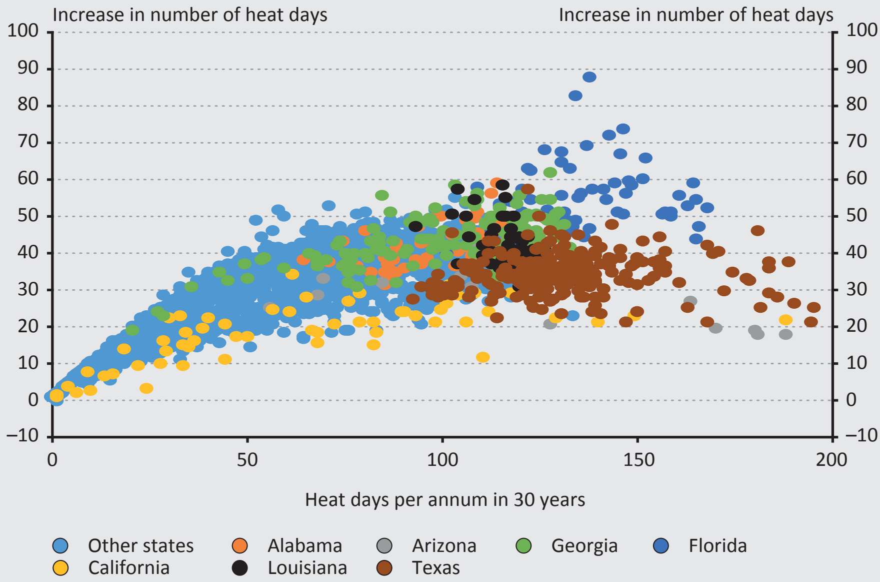
The most comprehensive publicly available database covering mortgage lending in the US is the Home Mortgage Disclosure Act (HMDA) database. It was created by the US Congress decades ago to help track how well lenders are serving the housing needs of local residents, to uncover potential discrimination and to help allocate public investments across the country (*FFIEC 2021*). Most banks and non-bank financial service providers engaged in lending are required to report HMDA data, with the exception of a few small institutions, mainly in non-metropolitan areas, which are not engaged in mortgage lending. The financial literature makes extensive use of this database (*e.g. Duan – Li 2019*). We also rely on this loan-level database for data related to US lending volumes, the characteristics of borrowers and lenders, as well as the loan-to-income (LTI) ratio.

The work of international climate research groups has been coordinated by the Coupled Model Intercomparison Project 5 (CMIP 5), and the arithmetic mean of the projections produced is also quoted in UN publications. A higher-resolution, US-wide version is available from the National Oceanic and Atmospheric Administration Applied Climate Information System (ACIS) database. We also use this database and its climate change projections.

Land area and population data are from the US Census Bureau, and regional economic performance data are from the Bureau of Economic Analysis. The survey is conducted at the county level by aggregating micro-level loan contract data. Our study does not cover Alaska and the so-called US territories (islands that are not linked to the US states).

Within climate change, we focus on the number of extremely hot days, when the daily maximum temperature exceeds 90°F, or 32.2°C. This cut-off value is also used in the ACIS database. We distinguish between future *levels* (the average of projections for 2041–2050) and the *change* compared to the most recent data (the difference between the average of 2041–2050 and the average of 2003–2012). Although our two heat variables are highly correlated, the highest increases in heat days are not always expected in the counties that are at the top of the heat list today. In some counties in California and Texas, for example, the projected increase is not outstanding, but they will nevertheless be among the hottest counties because they are already there (*Figure 1*). The number of heat days is forecast to increase most in the south-eastern part of the US (Florida, Georgia, Alabama, etc.).

Figure 1
Increase in the number of heat days and their future level



Note: Each dot represents a county. The X-axis shows the future level of heat (>90°F) days (average of projections for 2041–2050), while the Y-axis shows the projected change in the number of heat days (the difference between the averages of 2041–2050 and of 2003–2012). The counties in the states most exposed to future heat (either by X or Y heat variables) are highlighted in a different colour.

Source: ACIS

In the first part of the analysis, we compare the volume of disbursed loans and loan applications (flow) with population, GDP and land area data according to the area's exposure to heat (looking at both the level and the change). For lending data, we examine "vanilla" mortgages.[5]

In the second part of the analysis, loan denials rates will be constructed. The simple denials rate is the ratio of denied loan applications to the sum of disbursed loans and denied loan applications. This is used, for example, by *Duan and Li* (*2019*). We calculate rates based on both the volume of (mortgage) lending (flow) and the number of loan applications. We then generate sophisticated denials rates based on *Keys and Mulder* (*2020*), with the aim of filtering out the effects of known characteristics of loan applications and lenders. The following equation is used for loan application *i*, in county *j* and year *t*:

[5] The lending purpose is, for one (not more than one) family, to purchase or refinance a home; not for commercial purposes; no guarantee from the Federal Housing Administration, Farm Service Agency, US Department of Agriculture Rural Housing or Veteran Benefits Administration; the loan has no non-amortising features; the mortgage is not open-end or reverse.

$$
\begin{aligned}
Denial_{i,j,t} = {} & \alpha + \beta_{j,t} CountyYearDummy_{j,t} + \beta_1 Loan\ amount_i + \beta_2 Loan\ amount_i^2 \\
& + \beta_3 LTI_i + \beta_4 LTI_i^2 + \beta_5 \left(CLL_{j,t} - Loan\ amount_i\right) \\
& + \beta_6 \left(CLL_{j,t} - Loan\ amount_i\right)^2 + \beta_7 Ethnicity1_i \\
& + \beta_8 Ethnicity2_i + \beta_9 Ethnicity3_i + \beta_{10} Gender\text{-}dummy1_i \\
& + \beta_{11} Gender\text{-}dummy2_i + \beta_{12} Owner\text{-}occupied_i \\
& + \beta_{13} Local\ lender\ dummy_i + \epsilon_{i,j,t}
\end{aligned} \tag{1}
$$

Denial is a dummy variable with a value of 1 indicating denial of the application. CLL means the county and year-specific loan contract level cut-off value above which the GSEs will no longer purchase loans. LTI is the ratio of the loan amount to income. From demographic characteristics, we also take into account the ethnicity (White, Asian, Black, Hispanic) and gender (male, female, or male and female combined) of the loan applicant. This is important because, although we do not have information on debtor classification, it may correlate with certain characteristics, and skin colour, for example, may also play a role in the lender's decision – this is partly the reason why the HMDA database was set up (*FFIEC 2021*). Other control variables include the loan amount, the square of the loan amount and a dummy variable indicating whether the owner lives in the property. Finally, the literature suggests that lender behaviour may be affected by whether the lender is considered local, so we construct a dummy variable for this defining a lender as local in line with *Keys and Mulder* (*2020*) if it disburses at least 10 per cent of its annual lending in the county.

To construct the rejection index, $\beta_{j,t}$ values are added to the average denials rate calculated from the data so that the index values are between 0 and 1. Thus, our index is a measure of how application denials have evolved across counties and years, beyond the known loan-level characteristics. Data was available from 2017 to 2019.

Our key variables are summarised in *Table 1*.

Table 1
Main variables

Variable	Observations	Average	Standard deviation	P1	P25	Median	P75	P99
Number of heat days in 30 years	3,067	67.07	39.44	2.34	35.23	62.67	98.19	163.23
Increase in the number of heat days	3,067	29.9	11.83	1.59	21.98	31.91	38.03	55.51
Lending vs. territorial share	3,067	0	0.16	–0.2	–0.03	–0.02	–0.01	0.52
Simple denials rate (sum)	28,808	0.15	0.08	0.02	0.09	0.13	0.18	0.45
Sophisticated denials index	9,197	0.18	0.07	0.03	0.14	0.17	0.2	0.45

Note: The simple denials rate is for the years 2010–2019, while the sophisticated denials index is for the years 2017–2019.

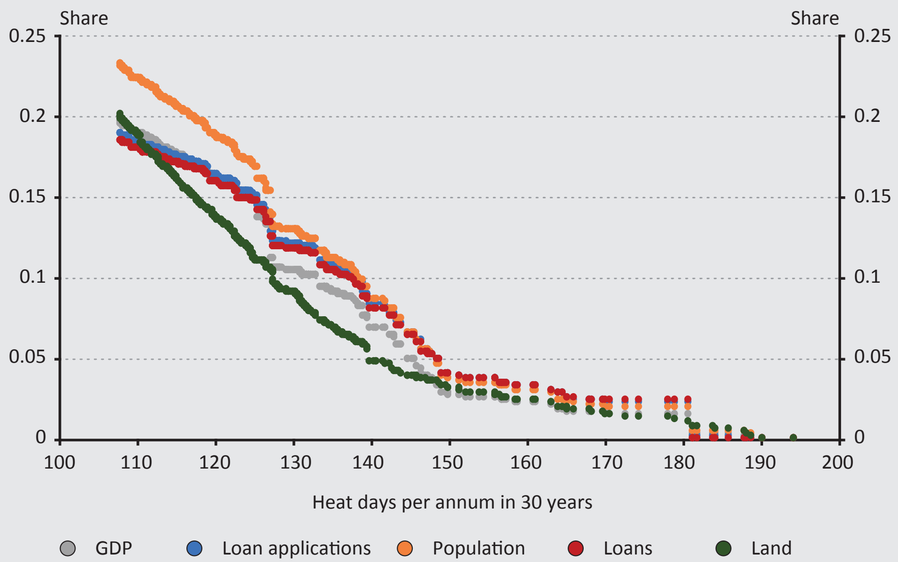
Source: ACIS, HMDA

4. Data analysis

4.1. Volume of (mortgage) lending and loan applications

The spatial distribution of the population and the country's economic performance is uneven. 13 per cent of the US population, 11 per cent of economic output and nearly 12 per cent of mortgage lending is tied to areas that will be in the hottest 10 per cent in 30 years (*Figure 2*). Similarly, areas that are expected to experience at least 140 heat days in the future, putting them in the hottest 5 per cent based on their land area, account for 7 per cent of total economic GDP and 8–9 per cent of population and loans disbursed (*Figure 2*). Focusing on the change in heat days over the next three decades, rather than future heat, gives a similar picture. The 5 per cent of the country's area with the highest projected increase in heat days covers 9 per cent of the country's population, 7 per cent of disbursed loans and 7 per cent of GDP (*Figure 3*).

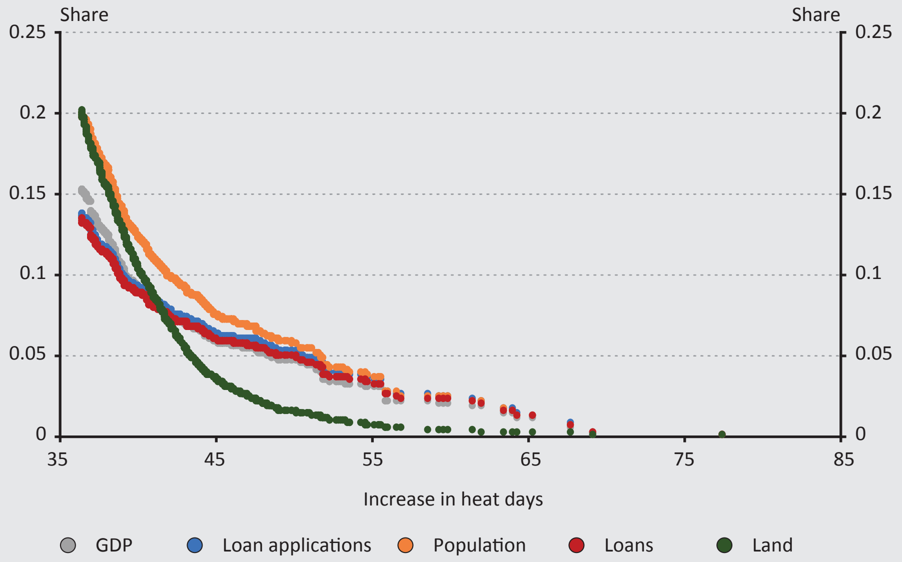
Figure 2
Mortgage lending in the area as a function of the number of "hot" days expected in 30 years – extremes



Note: The figure shows the share of the country's disbursed loans, population, GDP, loan applications and land area in 2019 that were in counties where x or more heat days (>90°F) are expected in 30 years (average of 2041–2050).

Source: ACIS, HMDA, US Census Bureau, BEA

Figure 3
Mortgage lending as a function of the expected warming of the area – extremes



Note: The figure shows the share of the country's disbursed loans, population, GDP, loan applications and land area accounted for by counties with x or more increase in the number of heat days (> 90°F) over the next 30 years (average of 2041–2050 minus the most recent historical data: average of 2003–2012).

Source: ACIS, HMDA, US Census Bureau, BEA

The question is whether the pattern is driven by a few (large) counties, or the statement is true for a wide range of counties. To answer this question, we first compare the territorial share of a county with its role in lending (*Table 2*, variable E). *Table 2* shows the counties with the largest difference in either direction. In particular, California's affluent regions benefit from a higher volume of lending relative to their land share, with the sparsely populated western US counties at the bottom of the list.

Table 2
Where does the role in lending differ most from the importance of land area?

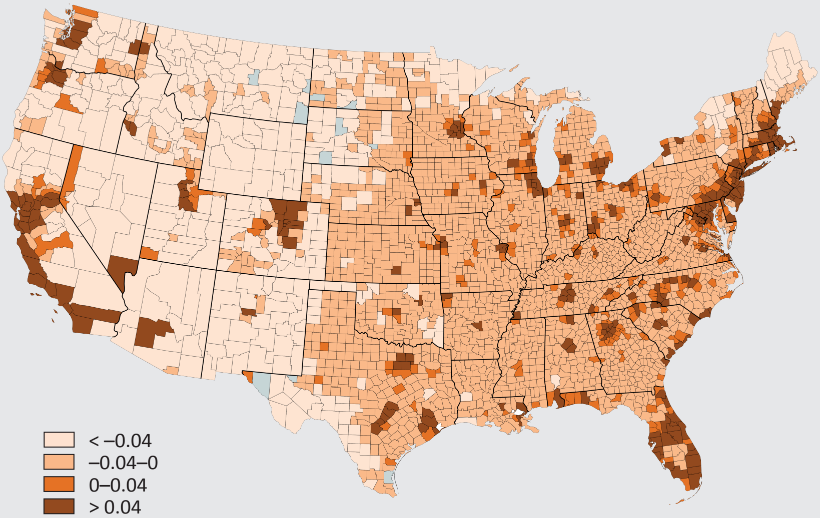
County	Share of county (per cent)				Lending % – Area %	Population % – Area %	GDP % – Area %
	Lending	Land area	Population	GDP			
	A	B	C	D	E = A – B	F = C – B	G = D – B
Highest volume of lending in relation to share of land area							
Los Angeles County, CA	4.95	0.14	3.08	3.87	**4.81**	2.94	3.73
Orange County, CA	2.36	0.03	0.97	1.27	**2.33**	0.95	1.25
Santa Clara County, CA	2.04	0.04	0.59	1.57	**2.00**	0.55	1.52
Maricopa County, AZ	2.24	0.31	1.38	1.25	**1.92**	1.06	0.93
San Diego County, CA	1.99	0.14	1.02	1.20	**1.84**	0.88	1.05
Lowest volume of lending in relation to share of land area							
Humboldt County, NV	0.00	0.38	0.02	0.01	**–0.38**	–0.36	–0.37
Malheur County, OR	0.06	0.45	0.07	0.03	**–0.40**	–0.39	–0.43
Inyo County, CA	0.01	0.59	0.02	0.01	**–0.58**	–0.57	–0.57
Harney County, OR	0.06	0.63	0.04	0.04	**–0.58**	–0.59	–0.60
Sweetwater County, WY	0.01	0.62	0.01	0.01	**–0.61**	–0.61	–0.61

Note: In line with the focus of the study, the calculations exclude Alaska and the islands not connected to the US (Territories of the United States) as well as 12 additional counties due to data limitations. CA: California, NV: Nevada, OR: Oregon, WY: Wyoming

Source: ACIS, HMDA, US Census Bureau, BEA

The difference between lending and territorial shares (variable E in *Table 2*) is also depicted on a map (*Figure 4*). We can see that, in addition to some counties in California, there is more lending in the northeast coastal region, Florida and around some large cities, relative to their area. It is also striking that this value is generally lower in the western half of the country. A similar pattern can be recognised in the population importance of counties (*Figure 5*; this is variable F in *Table 2*) and in the economic importance of counties (not shown separately in the study, variable G in *Table 2*). The relationship will be explored more formally below.

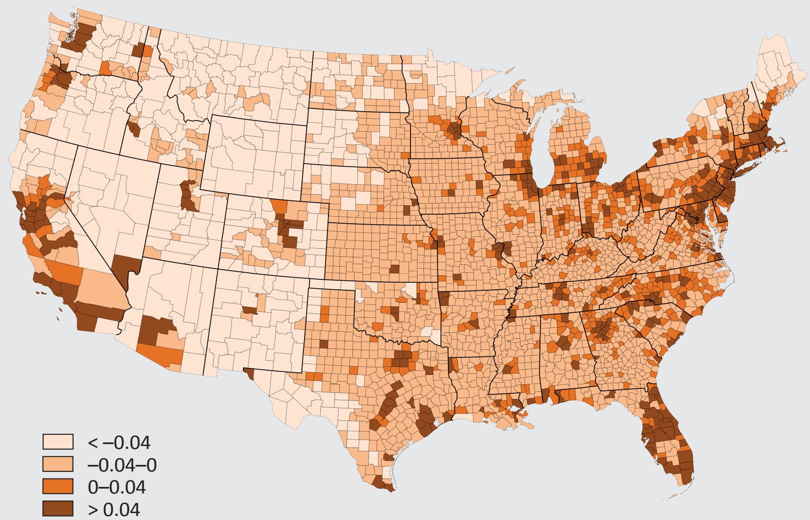
Figure 4
Relationship between land area and the volume of lending



*Note: The variable is the difference between the county's share of lending (A: amount of loans disbursed in the county / national volume of lending) and its geographical importance (B: land area of the county / land area of the country), multiplied by 100. Index = (A–B)*100. There are more than 3,000 counties. Gray indicates a lack of data.*

Source: HMDA

Figure 5
Relationship between land area and population



*Note: The variable is the difference between the proportion of inhabitants in the county (A: population of the county / population of the country) and its geographical importance (B: land area of the county / land area of the country), multiplied by 100. Index = (A–B)*100. There are more than 3,000 counties.*

Source: HMDA

On average, in lending, the weight of counties exposed to heat days exceeds that of less exposed counties (*Table 3*, examining variable E above). However, the difference is statistically significant largely only for heat variable 2 – the increase in the number of heat days. This is primarily due to the high level of lending activity in the south-eastern part of the country, particularly in several counties in Florida, where a significant increase in the number of heat days is expected. By contrast, some areas that are already hot (and will be among the hottest in 30 years), such as several counties in Arizona, have relatively low lending activity. *Table 3* shows, for example, that counties where the number of heat days is forecast to rise by at least 50 have an average difference of 0.042 percentage points between their share of lending and their share of land; in other counties it is approximately 0 (Test 5). The difference is not insignificant in economic terms either, since the average share of a county in both lending and land area is 0.03 percentage points (1/3,067 *100) in the 3,067 counties in our study, and such a difference between the counties' shares of lending and land area is not typical (in absolute value, the difference is less than 0.04 percentage points in 79 per cent of the counties and less than 0.03 percentage points in 69 per cent of the counties).

The spatial distribution of loan applications (*Figure 2 and 3*) is very similar to that of loans (*Figure 2 and 3*): thus, in the areas most exposed to climate change, proportionally more loans are applied for than the proportion of land area would justify, but not more than the economic activity and the population of the areas would explain. In other words, the expectation of how much a given area will change in the future in terms of livability does not seem to play a significant role in lending activity, either on the supply or on the demand side. In any case, a more formal analysis of the behaviour of lenders is conducted in the following.

Table 3
Importance of lending broken down by heat days

Test	Group	Observations	Average	St. error	Prob (T<t)
Number of heat days in 30 years					
1. >=130	0	2,871	–0.001	0.003	
	1	196	0.014	0.013	
	Diff (0–1)	3,067	**–0.015**	0.013	0.135
2. >=140	0	2,982	–0.001	0.003	
	1	85	0.037	0.028	
	Diff (0–1)	3,067	**–0.038***	0.028	0.088
3. >=150	0	3,015	–0.000	0.003	
	1	52	0.015	0.039	
	Diff (0–1)	3,067	**–0.015**	0.039	0.348
Increase in the number of heat days					
Test	**Group**	**Observations**	**Average**	**St. error**	**Prob (T<t)**
4. >=45 days	0	2,868	–0.001	0.003	
	1	199	0.012	0.006	
	Diff (0–1)	3,067	**–0.012****	0.006	0.032
5. >=50 days	0	2,989	–0.001	0.003	
	1	78	0.042	0.014	
	Diff (0–1)	3,067	**–0.043*****	0.014	0.002
6. >=55 days	0	3,034	–0.001	0.003	
	1	33	0.082	0.028	
	Diff (0–1)	3,067	**–0.083*****	0.028	0.003

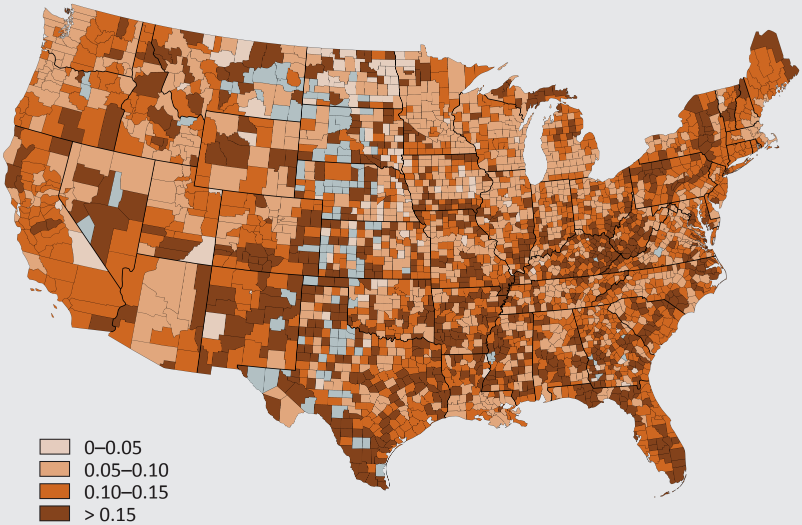
*Note: 2-sample t-test assuming different standard deviations. The examined variable is the difference between the role of the county in lending (A: volume of loans disbursed in the county / volume of loans disbursed in the country) and its geographical importance (B: geographical extent of the county / geographical extent of the country), multiplied by 100. Variable = (A–B)*100. Group 1 indicates the counties exposed to extreme heat based on the number of future heat days (cut-off values for Tests 1, 2 and 3: 130, 140 and 150 heat days, respectively), or based on the expected increase in the number of heat days (cut-off values for Tests 4, 5 and 6: +45, +50 and +55 heat days, respectively). Prob (T<t) indicates the significance level at which we can reject the null hypothesis that the mean value is the same in the two groups and accept the alternative hypothesis that the mean value of group 1 is greater than that of group 0. Statistically significant differences are marked also with asterisks: * significant at 10%, ** significant at 5%, *** significant at 1%.*

Source: ACIS, HMDA

4.2. Simple denials rate

We examine whether the relatively high volume of lending flowing to the counties most exposed to heat waves may be driven by lower denials by lenders, or the logic is that banks have a reduced preference for these areas because of future risks, but demand pressures still result in significant lending. We first look at this based on the simple denials rates. In many places, the rate values in the northern-central part of the country are low (or absent); these are areas less exposed to future heat (*Figure 6*). Many southern counties (Florida, Texas, some counties in New Mexico) have higher denials rates.

Figure 6
Simple denials rate

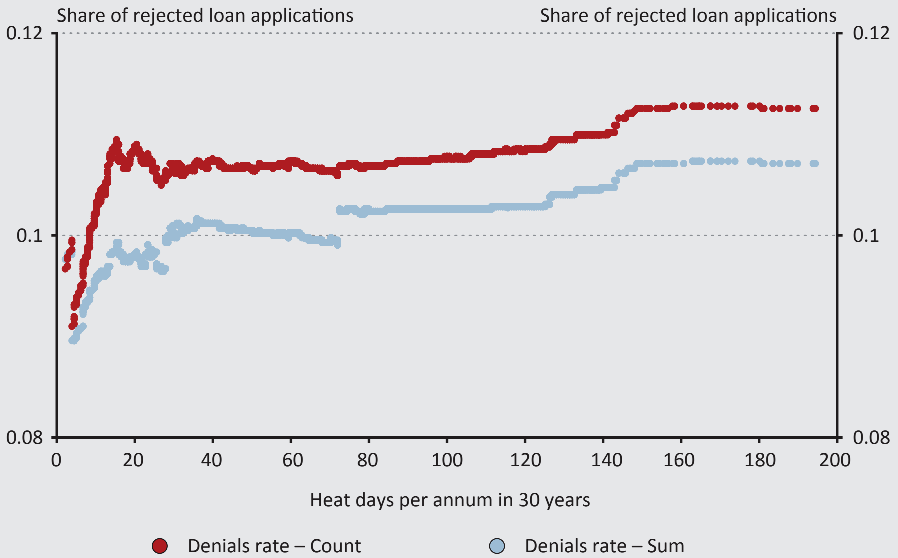


Note: The simple denials rate is the ratio of denied loan applications to the sum of disbursed loans and denied loan applications. No rate is calculated for fewer than 10 loan contracts (grey area).

Source: HMDA 2019, mapchart.net

In this context, we find that lenders' willingness to lend is slightly lower in places most exposed to climate change. More loan applications are denied in areas where, for example, more than 150 days of heat are expected in 30 years (*Figure 7*). *Figure 8* shows that in areas where the number of heat days is expected to increase only minimally, fewer loan applications are denied than in counties more exposed to climate change. In the northern counties in general, somewhat fewer loan applications are denied, which is reflected, among other things, in the low values of the X-axis in *Figures 7 and 8*. And at the high values of the heat variables, the southern counties with the highest denials rate and the highest exposure to heat appear in the cumulative denials rate. There may be reasons independent of climate change behind the pattern, but it is also possible that the future macroeconomic expectations used in the lender's decisions reflect climate change to some extent. *Figures 7* and *8* use lending data for 2019; in general, though not exclusively, a similar pattern characterises the various years in the past decade.

Figure 7
Cumulative denials rate as a function of the expected number of heat days in the area in 30 years



Note: The figure shows the proportion of loan applications that were denied by the lenders, based on the number of loan applications or the amount of loan applied for. For a given x, we calculate with the population of loan applications where at the location of the real estate (county) x or fewer heat days (>90°F) are expected in 30 years (average of 2041–2050). The figure reflects a total of more than 5 million loan applications, and the cumulative denials rates are shown from a minimum population of 50,000 loan applications. Lending data: 2019.

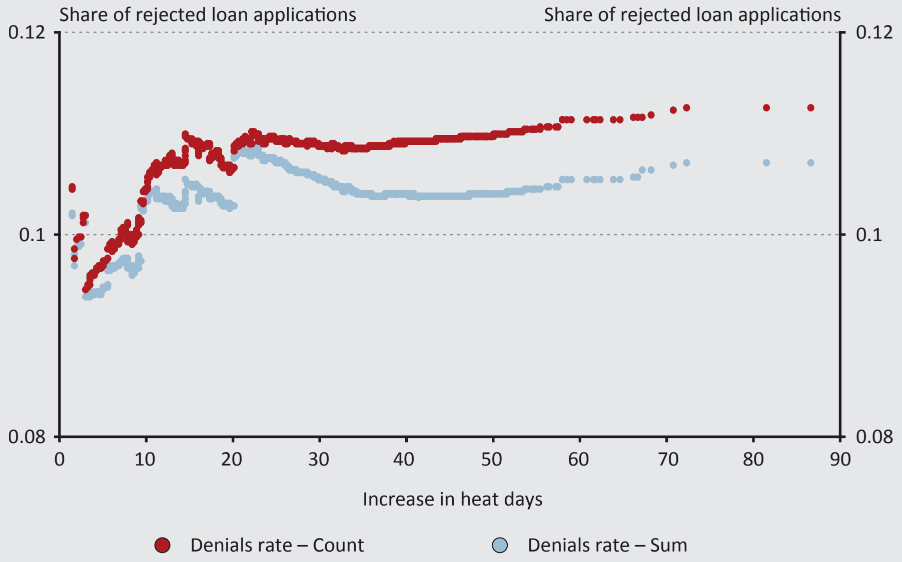
Source: ACIS, HMDA

4.3. Sophisticated denials index

The loan denial pattern in *Figure 7* and *8* does not necessarily reflect the willingness of lenders to lend, as there may be regional differences in the characteristics of loan applications. It is possible, for example, that in some areas loan applications have a higher risk and therefore there is a higher rate of denials, with unchanged willingness to lend. Spatial differences in the risk of loan applications may be the result of climate change-related or non-climate change-related causes. An example of the former is when wealthy people with good credit ratings move away from areas most vulnerable to climate change.

In the sophisticated denials index, we try to filter out the available loan application parameters, such as the demographic characteristics of the borrower or the size of the loan relative to income. Thus, using equation (1), we construct a county-level index and then examine the spatial distribution of the index values.

Figure 8
Cumulative denials rate as a function of the expected warming of the area



Note: The figure shows the proportion of loan applications that were denied by the lenders, based on the number of loan applications or the amount of loan applied for. For a given x, we calculate with the population of loan applications where at the location of the real estate (county) the increase in the number of heat days (> 90°F) is x or fewer over the next 30 years (average of 2041–2050 minus the most recent historical data: the average of 2003–2012). The figure reflects a total of more than 5 million loan applications, and the cumulative denials rates are shown from a minimum population of 50,000 loan applications. Lending data: 2019.

Source: ACIS, HMDA

Statistical tests continue to show that, on average, slightly more loan applications are denied in the counties most exposed to temperature change (looking at both future levels and changes) (*Table 4*). In areas where at least 150 heat days are expected in 30 years, the average value of the index is 0.23, which is 5 percentage points higher than the average for the rest of the country (*Table 4*, Test 3), and in the areas where the projected increase in the number of heat days is at least 50 days, the average value of the sophisticated denials index of 0.2 is 0.02 higher than the average of areas where heat waves are less expected to increase (*Table 4*, Test 5). Applying different cut-off values for the extreme level and change, there is a statistically significant difference between the average index values of the extreme and less exposed areas in all cases examined (*Table 4*, tests 1–6). It can be considered significant also in an economic sense if out of every 100 dollars of loan applications 2 to 5 dollars more are denied in the areas that are most exposed to future heat.

Table 4
Sophisticated denials index based on climate exposure

Test	Group	Observations	Average	St. error	Prob (T<t)
Number of heat days in 30 years					
1. >=130	0	8,621	0.178	0.001	
	1	576	0.210	0.004	
	Diff (0–1)	9,197	**–0.032*** **	0.004	0.000
2. >=140	0	8,945	0.179	0.001	
	1	252	0.223	0.006	
	Diff (0–1)	9,197	**–0.044*** **	0.006	0.000
3. >=150	0	9,043	0.179	0.001	
	1	154	0.232	0.009	
	Diff (0–1)	9,197	**–0.053*** **	0.009	0.000
Increase in the number of heat days					
Test	**Group**	**Observations**	**Average**	**St. error**	**Prob (T<t)**
4. >=45 days	0	8,610	0.179	0.001	
	1	587	0.197	0.003	
	Diff (0–1)	9,197	**–0.019*** **	0.003	0.000
5. >=50 days	0	8,966	0.179	0.001	
	1	231	0.203	0.004	
	Diff (0–1)	9,197	**–0.024*** **	0.004	0.000
6. >=55 days	0	9,098	0.180	0.001	
	1	99	0.201	0.005	
	Diff (0–1)	9,197	**–0.022*** **	0.005	0.000

*Note: 2-sample t-test assuming different standard deviations. The examined variable is the sophisticated denials index. Group 1 indicates the counties exposed to extreme heat based on the number of future heat days (Tests 1, 2 and 3: from 130, 140 and 150 heat days, respectively) or based on the expected increase in the number of heat days (Tests 4, 5 and 6: from +45, +50 and +55 heat days, respectively). Prob (T<t) indicates the significance level at which we can reject the null hypothesis that the mean value is the same in the two groups and accept the alternative hypothesis that the mean value of group 1 is greater than that of group 0. Statistically significant differences are also marked with an asterisk: significant at *** 1 per cent.*

Source: ACIS, HMDA

5. Central bank options

In the introduction and literature review, we described the economic and financial stability risks that climate change may pose, and from this perspective, we then examined the spatial pattern of the mortgage market activity in the US. Our results show that the areas highly exposed to climate risk experience significant lending outflows, even if their denials rates are relatively slightly higher. These facts underline the need for central banks, as state actors regulating and supervising the financial system, to address the impact of climate change on the financial system as a priority. In the following, we discuss potential climate change objectives, central bank actions and their context, using the above US mortgage lending example. The possible directions discussed here go beyond the dilemmas of just one dimension (heat waves) or one country (the US), but illustrate the problem that essentially all banking systems are facing or will face in the coming years.

In this chapter, we review, in a non-exhaustive manner, some possible objectives and related central bank[6] measures at different points on the path to mitigating heat wave risks. Some objectives and related measures are less controversial and closely in line with the traditional responsibilities of central banks (*Brunnermeier – Landau 2020*). Examples include the measurement, disclosure and incorporation of climate risk into the capital and liquidity requirements of financial system actors. Others, however, would proactively contribute to the cause of environmental sustainability in the fight against climate change. Legitimacy concerns of the latter measures can be reduced by a clear political mandate. There are already examples where the mandate of the central bank includes the promotion of environmental sustainability as a secondary objective (*MNB 2021a*).

In order to effectively promote environmental sustainability, optimally, there is coordination between the country's public authorities – central government, local authorities, central bank, etc. In this way, multiple incentives can push in the same direction, towards well-defined climate targets. The aim may be, for example, to improve public authorities' understanding of future exposure to heat waves or to build buildings in areas of extreme exposure appropriate from an environmental sustainability / climate exposure perspective.

Recognising the importance of climate risks, in the context of the Network for Greening the Financial System (NGFS), formal efforts are also made by central banks and supervisory authorities to share best practices and formulate recommendations to manage climate risks and promote the financing of sustainable economy (*NGFS 2021*). The NGFS – of which the Federal Reserve Board has been a full member since the end of 2020 (*Brainard 2020*) – has made the following recommendations to central banks (*MNB 2021a:16*):

- Expand the range and improve the quality of data;
- Integrate sustainability considerations into the central bank's own portfolio management;

[6] It varies from country to country whether the central bank responsible for monetary policy and the authority(ies) responsible for the regulation and supervision of financial institutions operate under the umbrella of the same institution. In the following part of this paper, the term central bank is used to cover both functions.

- Consider climate risks in financial stability monitoring and the supervision of institutions;
- Promote green financial awareness;
- Support the harmonisation of climate-related disclosures; and
- Support the development of international taxonomy.

In the following, we look at possible central bank measures that also fit the NGFS recommendations for arbitrarily chosen targets, but specifically related to exposure to heat waves (*Table 5*).

Table 5
Objectives and measures related to heat waves

	Possible objective	Possible central bank measure
1	Detailed information on the risk of heat waves	Supervisory data collection on the exposure of mortgage loans to heat waves
2	Market transparency regarding the exposure of financial actors to heat waves	Supervisory requirement to extend financial reporting
3	Understanding the risk of heat waves	Integrating the effects of heat waves into stress tests
4	Managing financial actors' risks related to heat waves	Amendment of the framework for capital and liquidity requirements for credit institutions
5	Build appropriate buildings in areas most exposed to heat waves	Changes to collateral policy, asset purchase programmes, changes to capital and liquidity requirements for credit institutions
6	Reduce construction rates as much as possible in areas most exposed to heat waves	
7	Reduce population in places most exposed to heat waves	Lending ban, collateral policy, capital and liquidity requirements

More information (*Objectives 1 and 2*)

Improving data coverage is a first and essential part of risk mapping, and is included in the NGFS recommendations. This can be done by combining climate projection data with data from financial actors, as used in this study, or by increasing data provision to supervisory authorities. In the former, we see that even the coverage of publicly available US mortgage data, which is internationally unparalleled in its detail, is not perfect. In addition, if the aim is to publish data, spatial resolution is also a key issue, since for certain risks, such as sea level rise, it is important to know the exact location, which may be subject to personal data protection restrictions.

Although the Financial Stability Board's Task Force on Climate-Related Financial Disclosures (TFCD) has been calling for progress on climate-related financial reporting for several years (*TFCD 2017*), implementation will take years and is not uniform across countries (*TFCD 2021*). Among the NGFS recommendations, we find that central banks are pushing for the development of standardised disclosures. Following from the example examined in the first part of our study, lenders could share in a uniform manner the proportion of loans disbursed in locations most exposed to extreme heat, as well as the environmental sustainability and resilience characteristics of the real estate used as collateral.

Understanding and managing the climate risks of financial actors (*Objectives 3 and 4*)

A growing number of central banks are exploring the possibility of incorporating climate change risks into bank stress tests in order to gain a deeper understanding of the implications for financial stability. Bank stress testing is a framework in which various shocks can be simulated over different time horizons to provide a complex examination of how specific scenarios might affect a credit institution (*Boros 2020*). Such a shock could be for example the withdrawal of a major agricultural company from the area due to heat waves, which could affect economic output, demographics and housing prices in the area.

Stress tests are suitable for assessing the impact of climate change precisely because of their forward-looking nature and their ability to deal with uncertainty around climate change through scenarios involving different assumptions. The first half of our study, for example, uses averages of temperature projections from international climate models, which are also available in UN publications and on the Climate Explorer website created for the US public. But the stress test can also be run based on climate models predicting more extreme heat waves. For example, as part of its green programme, the MNB is also using a long-term climate stress test to examine loan repayment rates under different scenarios (*MNB 2021b*). The largest banks emphasise this very feature of climate stress testing: they can perform sensitivity tests on the climate exposure of their assets (*UNEPFI 2018*).

Climate stress tests, while seemingly promising as a method to quantify risks, face a number of challenges (*Boros 2020*). These are partly due to the difficulties of quantifying the economic and financial aspects of physical-ecological knowledge. One major challenge is to capture long-term stress tests and the knock-on effects and feedbacks as fully as possible, as stress tests have so far mainly focused on a 2–3 year period. The field is relatively new and is attracting considerable attention in the financial world. When developing climate stress tests for heat waves, it is worth paying particular attention to the time horizon, as long-term negative socio-economic impacts can be incorporated into real estate market variables even in the short term (*Baranyai – Banai 2021*). A market consensus is forming regarding the local economic and demographic changes caused by future heat waves, regulatory actions and the behaviour of lenders; and in the long term, the knock-on effects and repercussions (in multiple circles) of the behaviour of the actors involved must also be taken into account.

Once risks have been stress-tested and quantified through other methods, it would be appropriate to integrate the climate dimension into the financial supervision framework (*Brunnermeier – Landau 2020*). In our case, for example, to ensure that an adequate capital and liquidity buffer is available to the financial actors that are exposed to heat waves.

Promote environmental sustainability (*Objectives 5–7*)

For the issue under study, the aim could be to encourage building in an environmentally sustainable way, especially in areas exposed to heat waves (*Objective 5*). A more radical objective could be to avoid an increase (*Objective 6*) or even achieve a decrease (*Objective 7*) in social and economic presence in the areas most exposed to heat waves.

The central bank can support environmental sustainability objectives with both prudential policy and monetary policy instruments (*Brunnermeier – Landau 2020*). A prudential policy tool is the discount applied to capital requirements that can be provided for certain activities considered sustainable (*Akbari et al. 2015*), such as financing buildings using sustainable cooling technologies (*Lundgren – Kownacki et al. 2018*). Such measures are controversial, as they can separate the riskiness of the activity from the appropriate level of capital, and the definition of sustainability is not clear. A monetary policy measure would be to narrow the range of eligible collateral and to tailor collateral values and asset purchase programmes according to environmental sustainability criteria. An example of this is when mortgages on real estate in areas exposed to extreme heat waves are excluded from the range of collateral accepted by the central bank.

A fundamental question is whether the central bank should reward environmentally sustainable activity or punish activity that goes against it. The MNB's green bond purchase programme is an example of a rewarding approach (*MNB 2021a*). The Swedish Riksbank's practice of only buying corporate bonds that are considered sustainable is an example of the latter.

Our analysis suggests that credit demand may be the main reason behind the higher disbursement of credit to the counties most exposed to heat waves relative to their share of territory. Supervisory measures, on the other hand, mainly affect the credit supply side. A simple lending freeze imposed on credit institutions may have many unintended side effects. If the supply of credit falls more steeply than demand, various less supervised shadow banking system players may step in to meet the demand for credit. The supervisory authority and the central bank should therefore act with particular caution and in cooperation with other authorities.

6. Summary

Climate scientists predict that our climate will change significantly in the coming decades, even if humanity takes rapid and effective steps to transition to a low-carbon economy. One aspect of this is that the number of heat days will increase in many areas.

High temperatures have well documented negative effects on the human body, productivity and the economy. And the most effective protection against heat available today – air conditioning – is environmentally unsustainable. It is, therefore, important where and with what technology the buildings and neighbourhoods that will face tomorrow's climate are built today.

Through the financing of buildings, via mortgage lending, the participants in the financial world also have an impact on the ecological footprint of human activities, and are themselves exposed to climate change. For both reasons, therefore, it is advisable to look to the future and take climate change into account in financing decisions.

In this study, we used the example of US mortgage lending to examine whether more mortgages are originated in counties most vulnerable to future heat waves, relative to their land area, economic importance and population. Our conclusion is that there are slightly more mortgages in these areas compared to their land share, and this is mainly due to larger economic and population presence. Lenders deny slightly more loan applications in these areas, providing further evidence that it is not a higher lending appetite that is behind the higher lending volumes in heat-prone areas. Similar analyses for other countries or climate change dimensions can enrich our knowledge on the relationship between mortgage lending and climate change.

Central banks are also increasingly recognising that climate change can have a fundamental impact on the goals set out in the central bank mandate. Quantifying the risk is a necessary first step, which can be supported by data collection and stress testing. As part of its green programme, the MNB is also using a long-term climate stress test to examine loan repayment rates under different scenarios. Stress tests can be used to capture the knock-on effects and feedbacks for different scenarios, as for example the incorporation of climate risks into the real estate market may trigger reactions from the local population, the economic and financial sectors as well as local policy makers. It is then appropriate to incorporate the risks into supervisory procedures. Central banks can support the transition to environmental sustainability through their collateral policies and asset purchases. The central bank can opt to use positive incentives, but it can also adopt a punitive approach. In order to promote environmental sustainability, it is beneficial if different public authorities take coordinated action around commonly agreed goals. In areas where existing housing will not be or will be less sustainable from an environmental point of view, central bank measures could support the use of appropriate architectural solutions or even reduce lending. Our example of mortgage lending in the US and central bank goals to promote environmental sustainability show that climate targets can have a major impact on the (regional) economy and society. It is therefore also important to address the legitimacy of the measures.

Hungary is among the warming countries as well: the number of hot days in the summer is projected to increase until 2100, and maximum temperatures are also expected to rise. For example, the average temperature in August will be 1.5–8°C higher under different scenarios.[7] Although climate scientists suggest that there will be regional differences in the increase in the frequency of heat waves within the country, Hungary's smaller size means that these will not be as significant as in the US. Issues related to the spatial distribution of lending in preparation for climate change are thus likely to be less of a focus than in the US. However, because of the interactions between the microclimate and the buildings, this does not mean that it is unnecessary to consider the advantages and disadvantages of a spatially differentiated approach. The phenomenon of urban heat islands, for example, is well documented in the literature and can be mitigated by certain construction techniques. And the properties of the financed buildings can be influenced by the central bank, as the MNB does this with the green loan.

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[7] The interval represents the median values of the five scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5).

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