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Do banks manage their flood risk exposures? Evidence from the Danish credit register

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Abstract

Today, 0.9 per cent of Danish housing bank loans are exposed to the direct effects of coastal flood risk. 1.5-1.9 per cent are exposed to the second-round effects of coastal flood risk.

The share of current housing bank loans that would be exposed to flood risk in year 2100 is even higher. Up to 1.9 per cent of housing bank loans could be directly exposed and up to 6 per cent could be indirectly exposed.

There is little evidence that banks manage their flood risk exposures. Houses that are exposed to coastal flood risk are not less likely to have a housing bank loan than otherwise similar houses. They also do not have lower loan-to-value ratios. Finally, exposed loans do not have higher interest rates.

Some regional banks are highly exposed to flood risk. The lack of flood risk management in these banks could worsen the adverse local economic impact of floods. Banks should incorporate flood risk and geographical concentrations in their risk management for real estate lending.

In Denmark with its low altitude and a long coastline, coastal flood risk affects many houses. Rising sea levels due to climate change will lead to both more extreme and more frequent floods. For many households, their house is their most important asset.[1] An increase in flood risk can have severe economic consequences for them.

As houses in Denmark are typically highly leveraged, flood risk can spill over into the market for housing bank loans. New houses often have loan-to-value ratios of up to 95 per cent.[2] A loss in house values because of a flood is therefore likely to affect the housing bank loan market, if homeowners default on their housing bank loan. In that way, a severe flood can lead to balance sheet losses for lenders and cause financial disruption.

The purpose of this memo is twofold: First, it provides novel descriptive evidence on the importance of flood risk for the Danish housing bank loan market and Danish banks. Second, it investigates whether Danish banks incorporate flood risk into their lending decisions.

To analyse the importance of flood risk for the Danish housing bank loan market, we combine granular data on the flood risk exposure of each property in Denmark with data on all collateralised loans from the Danish credit register and data on house characteristics from the Danish housing and building register. This yields a rich dataset with highly detailed information on the flood-risk exposure and collateral quality of housing bank loans in Denmark. The latter is crucial for our objective to understand whether banks incorporate flood risk into lending decisions.

[1] For an overview of the importance of housing wealth for Danish households, see Browning, Gørtz & Leth-Petersen (2013).

[2] The Danish mortgage market has a unique structure, where up to 80 percent of the value of a house can be collateralised with a regulated first-lien mortgage (realkreditlån). An additional 15 percent of the value of the house can be collateralised with a second-lien mortgage, on which loan terms are more variable (banklån).

How this economic memo furthers our understanding of flood risk Box 1

Danmarks Nationalbank investigated the potential scope flood risk for the first time in 2019 (1). That first analysis used data from Tingbogen. An analysis of Danmarks Nationalbank in 2021 provided an overview of the flood risk exposure of Danish banks (2). The second analysis used the Danish credit register. We supplement these analyses in multiple ways.

First, we analyse data on all banks, while the previous analyses only considered large banks. Our analysis therefore also includes small, regional banks. These have, by definition, geographically concentrated portfolios. The previous analysis hypothesised that such geographically concentrated banks are more exposed to flood risk, but did not have the data to show this. We show that this is indeed the case.

Second, we focus on housing bank loans, while the previous analysis considered all real estate. The previous analysis included mortgage loans (realkreditlån). As mortgage loans have priority over housing bank loans, they are arguably less at risk. The previous analysis also included loans collateralised with non-residential real estate. Different types of real estate differ among other things in terms of their resaleability or in terms of how easy they can be valued. It is therefore difficult to compare loans collateralised with residential and non-residential real estate. One of the goals of this analysis is to investigate whether flood risk is incorporated into loan terms. Comparability of loans is therefore important.

Third, we analyse flood risk exposures of urban and rural regions separately. The previous analysis highlighted that some banks have high exposures concentrated in few municipalities. This is problematic for those banks. But it may not be problematic for the municipalities, if they are served by many different banks. This is true for urban regions, where banking competition is high. Rural regions are instead often characterised by low bank competition and large market shares of regional banks. Concentrated exposures of regional banks could be problematic for such rural regions.

1. Danmarks Nationalbank (2019), Climate change can have a spillover effect on financial stability. Danmarks Nationalbank Analysis No. 26, December 2019.
2. Danmarks Nationalbank (2021), Flood risk can potentially affect a large share of credit institutions' exposure. Danmarks Nationalbank Analysis, No. 13, June 2021.

In our analysis, we focus on second-lien housing bank loans (banklån), as they are much more likely to be affected by eventual losses, given their subordinate lien status. Moreover, loan terms on first-lien mortgage loans (realkredit) are much more standardised and do incorporate individual borrower risk to a lesser extent.[3] Moreover, we focus on housing bank loans that are collateralised with single-family houses, which make up a large fraction of the Danish real estate market and typically have more comparable financing terms than other segments of the real estate market.

We find that up to 0.9 per cent of housing bank loans are exposed to flood risk today. By year 2100, this fraction will increase to 1.5 per cent under a baseline scenario for climate change and to 1.9 per cent under a pessimistic scenario.

A large flood could bring about a local macro-financial spiral with second-round effects. For instance, a flood might cause local house prices and demand to fall, thereby harming the balance sheet of local banks. Due to such local second-round effects, a housing bank loan can be indirectly exposed to flood risk if it lies in a municipality with many exposed houses, even though it is not directly exposed to flood risk. We find that the share of indirectly exposed housing bank loans is much higher than the share of directly exposed housing bank loans – up to 1.9 per cent today. By year 2100, the share of indirectly exposed housing bank loans will increase to 6 per cent of all Danish houses under the pessimistic climate scenario.

While average exposures of banks are low, some regional banks are highly exposed to flood risk. These regional banks are important lenders in rural municipalities. As bank lending relationships are typically sticky, local lending is likely to fall if a regional bank experiences financial distress. This can amplify the negative consequences of floods in such municipalities.

3 Mortgage loans do incorporate risk in terms of loan types with higher administrative fees for variable rate loans and deferred amortisation loans.

A dataset linking flood risk to housing collateral

Box 2

To measure the exposure of the housing bank loan portfolio of banks to flood risk, we combine data on flood risk with data from the Danish credit register.

Flood risk exposure of properties
We obtain detailed information on flood risk from Technical University of Denmark (DTU). For each property in Denmark, we obtain the average water level associated with a return period of 20, 50 and 100 years. For example, the average water level associated with a return period of 20 years is expected to occur at least once every 20 years. This data is based on historical water level distributions and an elevation model of Denmark.

For the projected flood risk increases due to sea level rise, the projected mean sea level rise is added to the historical water level distributions. We obtain projections under two different scenarios, defined by the International Panel on Climate Change: the RCP 4.5 scenario, which is widely considered as a baseline scenario, and the RCP 8.5 scenario, which is widely considered as a risk scenario. For each of these scenarios, we obtain average sea level rise projections for the periods 2041-2070 and 2071-2100.

Linking properties to housing bank loans
We obtain data from the Danish credit register on all loans in Denmark that are collateralised with some property in the fourth quarter of 2020. We focus on loans that are collateralised with single-family houses, as that is a particularly broad and homogenous class of properties. 63 per cent of all loans that are collateralised with real estate are collateralised with single-family homes. Of these 63 per cent, 19 percent are housing bank loans.

For each loan, we obtain a rich set of loan characteristics. In addition, we obtain borrower characteristics, lender characteristics and collateral characteristics. We merge this data with the flood risk data using the information about the collateral of the loan.

Data on collateral quality
We enrich the dataset with information about the quality of houses, e.g. the size, age, distance to sea and elevation above sea level of a house. We obtain this data from a variety of sources, including the Danish address register and the Danish housing and building register. This data is novel, and including it is crucial for our analysis, as this allows us to compare loans with collateral of similar quality that differs in flood risk.

The increases in exposures by the year 2100 should not be read to imply anything about the current loan portfolios of banks. As the average housing bank loan has a maturity of around 15 years, the current loan portfolios of banks will have matured by then. Instead, the future exposures should be interpreted as those exposures that would arise if banks do not take flood risk into account. Whether they do so is an open, empirical question.

We therefore next investigate whether banks incorporate flood risk into their credit risk management. To do so, it is crucial that we compare exposed loans to similar, unexposed loans. We define loans as similar, if they are originated by the same bank in the same year, and are collateralised with houses in the same municipality, of similar size, with a similar distance to the sea, and with a similar value.

We consider three adjustment margins: First, banks can decide not to accept exposed houses as collateral (extensive margin). Second, banks can limit the amounts that are collateralised (intensive margin). Third, banks can charge a higher interest rate on loans with exposed houses (interest rate margin). While banks could in principle adjust other loan terms, we consider these to be the most important margins of adjustment.

Flood risk is on average not incorporated into loan terms: Loans that are exposed to flood risk have similar interest rates and loan-to-value ratios (LTVs) as otherwise similar loans that are not exposed to flood risk. Houses that are exposed to flood risk are also not less likely to have a bank loan.

Our results suggest that the high exposures of some regional banks in rural areas could bring some institutes into financial difficulties. Local banks matter for local lending, at least in the short run. Financial difficulties of local banks could aggravate the negative local economic consequences of a flood. Banks should therefore incorporate flood risks and geographical concentrations in their risk management for real estate lending.

Climate change will double the fraction of housing bank loans affected by flood risk

Table 1

Housing bank loans with direct flood risk exposure

Scenario	Time\return period	20 years	50 years	100 years
	2021	0.68	0.81	0.88
Baseline scenario (RCP 4.5)	2041-2070	0.95	1.09	1.21
	2071-2100	1.18	1.37	1.47
	2021	0.68	0.81	0.88
Pessimistic scenario (RCP 8.5)	2041-2070	1.06	1.21	1.36
	2071-2100	1.59	1.79	1.94

Housing bank loans with direct or indirect flood risk exposure

Scenario	Time\return period	20 years	50 years	100 years
	2021	1.53	1.81	1.88
Baseline scenario (RCP 4.5)	2041-2070	2.16	2.28	2.37
	2071-2100	2.35	4.64	4.70
	2021	1.53	1.81	1.88
Pessimistic scenario (RCP 8.5)	2041-2070	2.25	2.37	3.66
	2071-2100	4.79	5.42	5.98

Note: This table shows the share of housing bank loans that are directly or indirectly exposed to flood risk. A housing bank loan is directly exposed to flood risk, if the house that serves as collateral for the housing bank loan is at risk of being flooded. A housing bank loan is indirectly exposed to flood risk, if the house that serves as collateral lies in a municipality, where at least 10 per cent of houses are at risk of being flooded. Sample period 2020Q4.
Source: DTU, credit register, and own calculations.

Flooding can affect banks' loan portfolios through multiple channels

A coastal flood can affect the housing bank loan portfolio of banks through multiple channels:

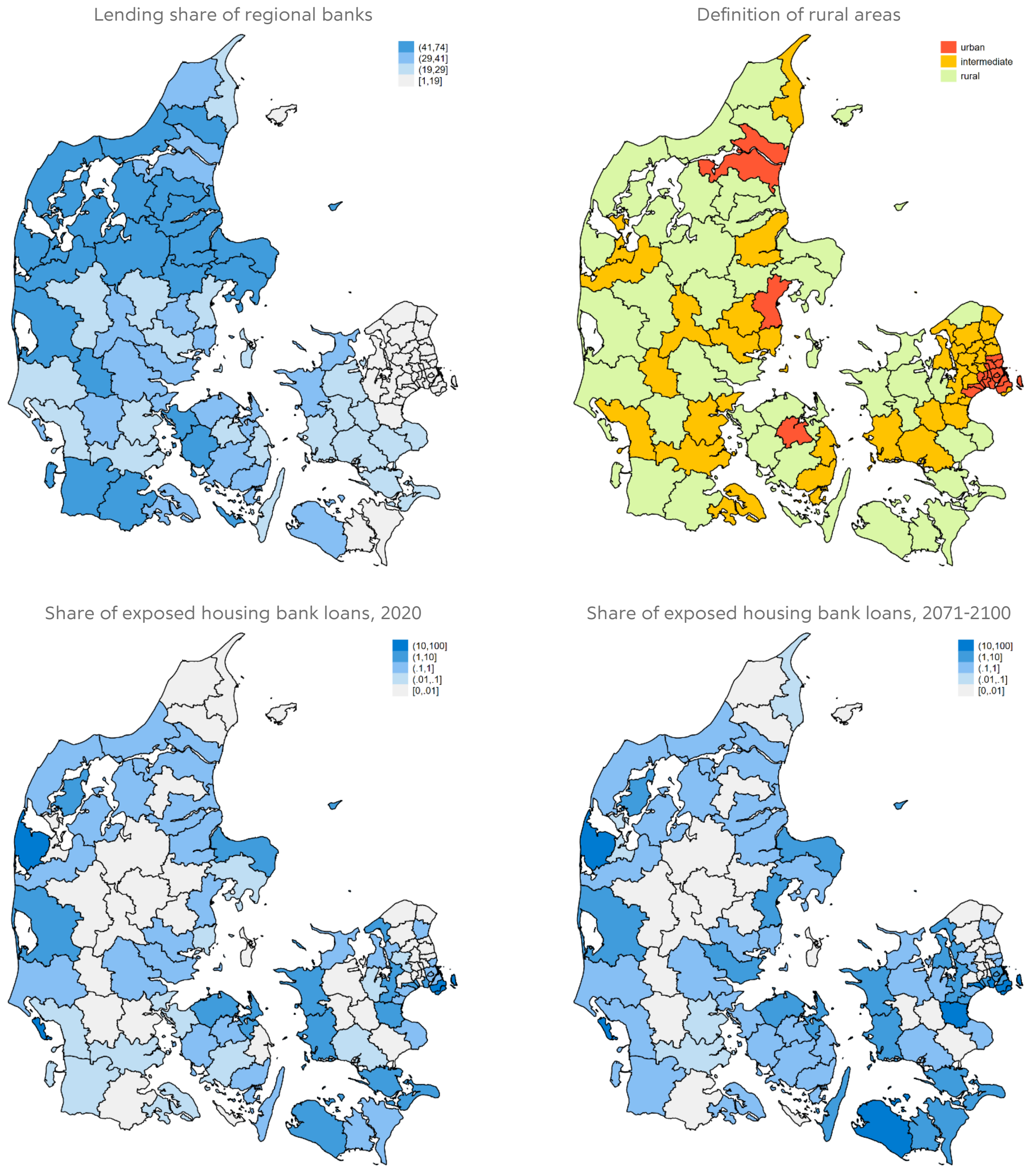
- Direct effect stemming from defaults on loans collateralised with flooded houses.
- Indirect effect stemming from a fall in house prices of exposed houses.
- Indirect, second-round fall in local demand that adversely affects local asset values and activity.

Direct exposure through flood damage
A flood can affect the loan portfolio of a bank directly through households becoming unable or unwilling to repay the loans on their flooded homes. While there exists a government-sponsored flood insurance scheme in Denmark, this insurance scheme only provides partial coverage, and only with a delay.[4] A household whose house is flooded will therefore face financial losses. If the household is unable to repay its loan for an extended period of time, the bank must write it down. Second-lien housing bank loans are more risky in that regard than first-lien mortgage loans.

Indirect exposure through risk premiums
A flood can affect the loan portfolio of a bank indirectly through higher flood risk premiums on

[4] Flood insurance is regulated in Stormflodsloven. See here for an overview of the Danish flood insurance coverage: https://www.naturskaderaadet.dk/media/nczhop2d/d%C3%A6kningsvejledning-stormflod-oversv%C3%B8mmelse-og-t%C3%B8rke.pdf

Regional banks are important lenders in rural areas Chart 1



Note: The top-left panel shows the lending share of regional banks for housing bank loans. Darker shades of blue indicate areas where regional banks have a higher lending share. National banks are defined as banks with an average weighted distance of the housing bank loan portfolio of the bank to the headquarter of the bank of more than 80 kilometres. Regional banks are banks that are not classified as national banks. The top-right panel shows the degree of urbanisation of a municipality, as defined by EUROSTAT. The bottom left panel shows the fraction of exposed housing bank loans in 2020. The bottom right panel shows the fraction of exposed housing bank loans in 2071-2100 under the RCP 4.5 scenario. Sample period 2020Q4.

Source: Credit register, EUROSTAT and own calculations.

exposed houses in flood-prone areas, leading to falls in house prices. Earlier work by Danmarks Nationalbank[5] has shown that a flood leads to a reduction of prices of houses that are exposed to flood risk even in areas that are not directly hit by the flood. This is because flood risk becomes more salient after a flood, which leads prospective house buyers to demand a higher flood risk premium.

Indirect exposure through local second-round effects
In regions with large flood risk exposures, a flood can affect the prices of non-exposed houses through local second-round effects. Because of the negative effects of the flood from direct flooding damage and an indirect fall in house prices, local demand for non-tradable good falls, reducing the growth of the local economy. This channel through which house price movements affect the real economy is well documented in, e.g., Mian, Rao and Sufi (2013).

Flood risk exposure of the housing bank loan portfolio is high for some regional banks

The direct exposure of banks to coastal flood risk is small, but it will increase because of climate change. The indirect exposure of banks because of second-round effects is substantially larger, and will also increase more dramatically because of climate change.

Albeit regional banks are on average less exposed to flood risk than national banks, some regional banks have significant exposures to flood risk, both direct and indirect. This might amplify the negative regional impact of a flood through local financial second-round effects.

Overall direct exposure of the housing bank loan portfolio of the banking sector is low, but will increase
Less than one per cent of the housing bank loans in our sample are currently exposed to flood risk. Exposure is measured using different return periods for floods: for example, floods that occurs at least once with a return period of 20 years are expected to occur on average once over a 20-year horizon.

0.68 per cent of housing bank loans are exposed to floods with a return period of 20 years; 0.81 per cent of housing bank loans are exposed to floods with a return period of 50 years; and 0.88 per cent of housing bank loans are exposed to floods with a return period of 100 years.

Depending on different scenarios for climate change, the share of housing bank loans exposed to flood risk will increase up to twofold by the end of the century. Under the RCP 4.5 scenario, 1.5 per cent of housing bank loans will be exposed to floods with a return period of 100 years in 2071-2100. Under the RCP 8.5 scenario, 1.9 per cent of housing bank loans will be exposed to such floods in 2071-2100.

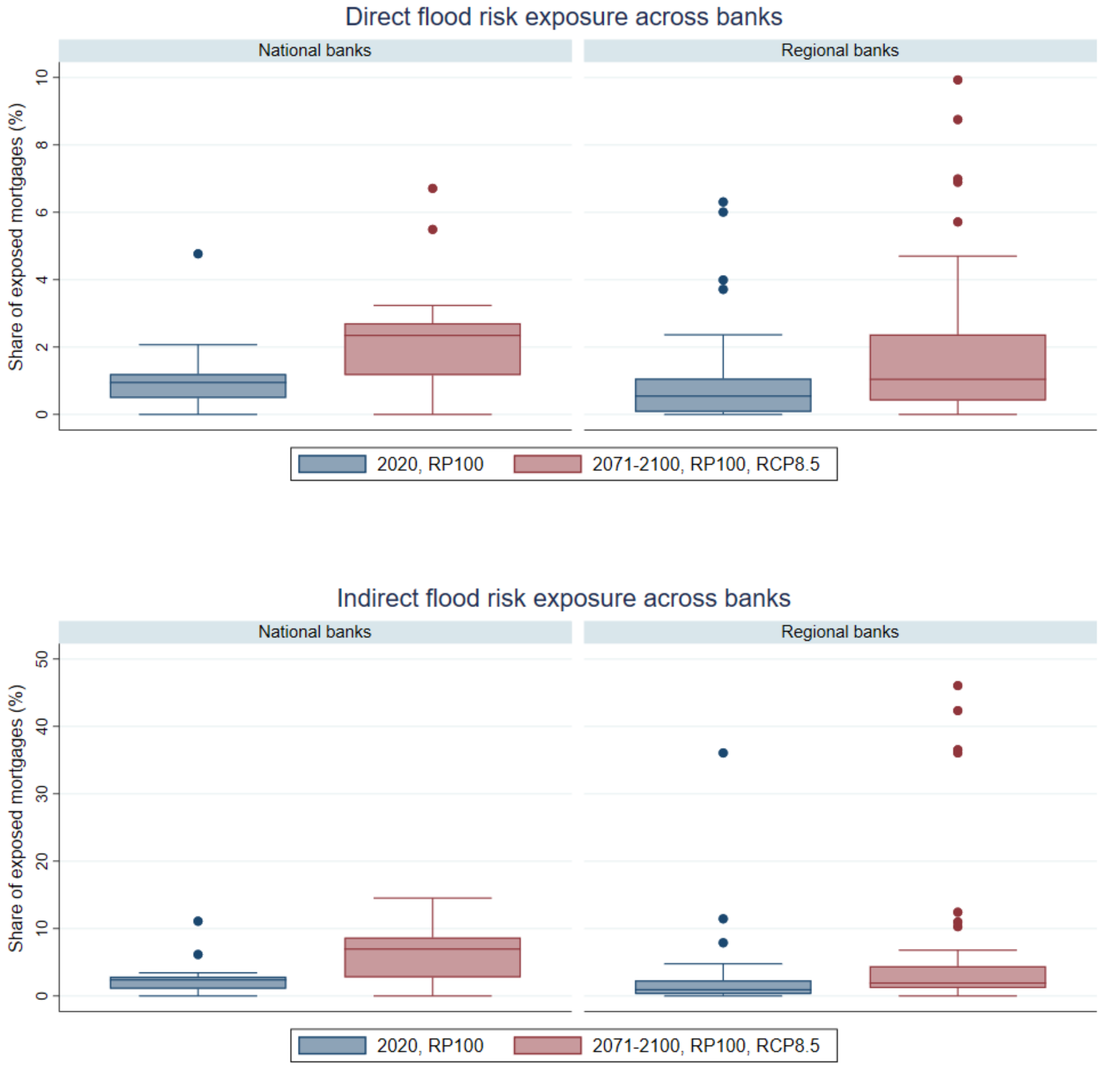
These numbers are not directly comparable to the previous analysis from Danmarks Nationalbank, as that analysis computed exposures in amounts of DKK. Moreover, the previous analysis included exposures of banks because of non-residential real estate. Finally, as the previous analysis focused on the tail risks to the financial sector, it focused on a worst-case scenario for climate change. In contrast, this economic memo focuses on more salient mean scenarios.

Overall second-round exposure of the housing bank loan portfolio is higher than the direct exposure, and it will increase by more over time
Second-round exposures matter in municipalities where a substantial fraction of houses is exposed to flood risk. We define a housing bank loan as exposed to flood risk through second round effects, when at least 10 per cent of the properties in the municipality of the collateralised house are directly exposed to flood risk.

[5] See Danmarks Nationalbank (2021b) , Flood risk discounts in the Danish housing market. *Danmarks Nationalbank Analysis*, No. 13, June 2021.

Regional banks are on average less exposed to flood risk than national banks, but some regional banks are highly exposed

Chart 2



Note: This chart displays box plots for the flood risk exposure of banks. The lower bound of the box is the 25th percentile, the upper bound the 75th percentile of the distribution. The line in the box is the median. The outer lines denote the adjacent values. The dots denote outliers. National banks are defined as banks with an average weighted distance of the housing bank loan portfolio of the bank to the headquarter of the bank of more than 80 kilometres. Regional banks are those banks that are not classified as national banks. A housing bank loan is directly exposed to flood risk, if the house that serves as collateral for the housing bank loan is at risk of being flooded. A housing bank loan is indirectly exposed to flood risk, if the house that serves as collateral is in a municipality, in which at least 10 per cent of houses are at risk of being flooded. Sample period 2020Q4.

Source: DTU, the credit register, and own calculations.

Second round exposures are substantially larger than direct exposures: 1.5 per cent of housing bank loans are either directly or indirectly exposed to flood risk

at a 20-year horizon today, compared to only 0.68 per cent being directly exposed. Second-round exposures increase more strongly than direct exposures: under the RCP 8.5 scenario, up to 6.0 per cent of housing bank loans could be exposed to flood risk.

Exposed housing bank loans are overall similar to other housing bank loans Table 2

	Not exposed, urban	Exposed, urban	Not exposed, rural	Exposed, rural
Loan characteristics:				
Effective interest rate (% p.a.)	5.4	4.8	6.1	6.4
Maturity at origination (years)	14.1	15.9	12.7	11.6
Age of the loan (years)	4.1	3.8	4.3	4.4
Priority	2.2	2.3	2.1	2.1
Principal ('000 DKK)	276.7	377.1	208.2	202.9
Outstanding amount ('000 DKK)	201.5	295.5	147.0	139.0
Collateral characteristics:				
House value ('000 DKK)	2690.1	3941.9	1701.1	1325.0
Loan-to-value ratio	77.8	71.6	83.4	83.7
Distance to sea (km)	6.7	1.9	10.2	0.9
Elevation (m)	28.5	0.1	33.5	0.0
Size (deciles)	5.5	5.0	5.8	5.7
Age (deciles)	5.2	4.9	5.0	5.3
Bank characteristics:				
Large bank share (%)	85.4	89.9	78.1	80.0
Regional bank share (%)	31.0	19.0	44.9	65.0
Observations	146168	1012	129346	1326

Note: This table displays summary statistics for bank housing bank loans. Exposures are calculated using a return period of 100 years. Future exposures assume the RCP 4.5 scenario. Urban municipalities are defined as those in group 1 or group 2, according to the definition of urban areas by EUROSTAT (https://ec.europa.eu/eurostat/web/degree-of-urbanisation/background). Large banks are defined as banks in group 1 or group 2 of the Danish FSA, as of 2020. National banks are defined as banks with an average weighted distance of the housing bank loan portfolio of the bank to the headquarter of the bank of more than 80 kilometres. Regional banks are those banks that are not classified as national banks. Sample period 2020Q4.
Source: DTU, credit register, and own calculations.

Exposure of the housing bank loan portfolio of some regional banks is high

While the overall exposure of Danish banks to flood risk is limited, some banks have large exposures. In particular, the exposure to flood risk differs between national and regional banks. Regional banks that are located in coastal areas can be highly exposed to flood risk.

We employ two definitions of regional banks. According to our first definition, a bank is regional if the average value-weighted distance of the housing bank loan portfolio of the bank to its headquarter is less than 80 kilometres.[6] To compute this measure, we calculate the distance for each housing bank loan between the municipality of the underlying collateral and the municipality of the headquarter of the bank. Of the 65 banks in our sample, 40 are classified as regional banks. They account for around 19 per cent of housing bank loans in the full sample.

According to our second definition, a bank is regional if the Herfindahl index of its lending shares in the top 8 municipalities is more than 0.05. Chart 3 shows that banks can be sorted well into national banks and regional banks according to these two criteria.[7]

Regional banks are important for housing bank loans, especially in rural areas. Chart 1 shows the fraction of lending of regional banks in each municipality (left panel). In many rural municipalities (the green areas in the right panel), regional banks account for between 41 to 74 per cent of all housing bank loans. We define rural areas according to the degree of urbanisation (DEGURBA) by EUROSTAT, although other measures yield a similar picture.

When measured by their direct flood risk exposure, regional banks are on average less exposed to flood risk than national banks. There is, however, a lot of variance. Some regional banks are highly exposed to flood risk, with exposures of 4-6 per cent. Chart 2 shows the distribution of flood risk for national and regional banks using box plots. The points denote statistical outliers. In the top panel, it shows the direct flood risk exposure of banks. The regional banks that are highly exposed to flood risk are visible as the long right tail of the distribution and the statistical outliers.

Flood risk exposure will increase along the intensive and the extensive margin. Due to climate change, there will be more highly exposed regional banks, as shown by an increase in the 75th percentile line. Banks that are already exposed will be more exposed, as shown by an upward move in the outliers.

Measuring the second-round exposure of banks to flood risk yields a similar picture. Exposures become very high, with some regional banks having more than 40 per cent of their housing bank loan portfolio exposed to second-round flood risk.

High exposure of regional banks is problematic for local economic stability

Significant exposures of local banks can amplify the effects of a flood on local economies through a negative macro-financial spiral. If a flood leads to a reduction in house prices and local demand and thereby harms the balance sheet of local banks, it can lead to a disruption in local lending. As bank lending relationships are typically sticky, this can put further downward pressure on local demand and house prices, setting off a negative spiral. Limiting regional exposures is therefore important not just for local banks, but also for local economies.

[6] We construct the distance $d_{m,b}$ of a housing bank loan *m* from the headquarter of bank *b* as the distance between the mid-points of the municipalities of the collateralised house and the headquarter of the bank. The outstanding amount of a housing bank loan is given by $x_{m,b}$, the total amount of housing bank loan lending is given by x_b. Thus, the value weighted distance of the housing bank loan portfolio is given by

$$d_b = \sum_m \frac{x_{m,b}}{x_b} d_{m,b}.$$

[7] The Herfindahl index measures the geographic concentration of the portfolio of a bank by the sum of the squared portfolio shares of each municipality in the total housing bank loan portfolio of the bank for the top 8 municipalities. The higher the Herfindahl index, the more regionally concentrated the portfolio of a bank.

Extensive margin: exposed houses are not less likely to have a bank loan compared to similar, unexposed houses.

Table 3

	(1)	(2)	(3)	(4)
Flood exposure	-0.0580***	0.00896	-0.0763***	0.00912
	(0.0148)	(0.00880)	(0.0145)	(0.0133)
Flood exposure=1 # municipality dummy=1			0.0426**	-0.000423
			(0.0189)	(0.0159)
M x V x S x D FE	No	Yes	No	Yes
Observations	780846	647509	780846	647509
Adjusted R^2	0.000	0.017	0.000	0.017

- Standard errors in parentheses
- * p<0.1, ** p<0.05, *** p<0.01

Note: The dependent variable in this regression is a dummy that takes the value of 1 if a house has a bank loan. Flood exposure is a dummy variable that takes the value of 1 if the property that is used as collateral for the loan is exposed to floods with a return period of 100 years today. K x V x S x D indicates interacted municipality, house value decile, house size decile and distance to the sea bin dummies. Sample period 2020Q4.
Source: DTU, credit register, and own calculations.

Banks do not seem to manage their flood risk exposure

After investigating the exposures of banks to flood risk, we now want to better understand whether banks manage their flood risk exposures. We consider three margins of risk management. As the most important margins, banks can limit their flood risk exposure by

- Not lending to households with exposed houses (extensive margin).
- Offering lower loan-to-value ratios to households with exposed houses (intensive margin).
- Charging higher interest rates to households with exposed houses (interest rate margin).

Few differences between exposed and non-exposed housing bank loans

As a first step, we investigate whether exposed housing bank loans look different from other housing bank loans. Table 2 reports summary statistics. We sort loans into four groups: loans in the first group are in urban areas and are not exposed to flood risk, loans in the second group are in rural areas and are exposed to flood risk. Loans in the third and fourth group are in rural areas, and are not or are exposed to flood risk, respectively. The dataset consists of around 275,000 housing bank loans from 65 banks.

Loans that are exposed to flood risk have similar interest rates, ages, priorities and maturities as loans that are not exposed to flood risk. Exposed loans are somewhat larger, both measured in terms of their principal and in terms of their outstanding amount.

Collateralised houses that are exposed to flood risk have higher values and lower loan-to-value ratios, compared to houses that are not exposed to flood risk. They are less likely to lie in urban municipalities. They are much closer to the sea and have a much lower elevation above sea level, compared to non-exposed houses.

Exposed and non-exposed housing bank loans are similarly held by large banks.[8] Exposed loans are also more likely to be on the balance sheets of regional banks, where regional banks are defined as banks with an average distance between the housing bank

8 The definition of small and large banks follows the Danish Financial Supervisory Authority's classification. Banks in groups 1 and 2 and a large foreign bank are categorised as large banks.

Intensive margin: flood risk is on average not incorporated into loan terms Table 4

	Interest rate			LTV ratio		
	(1)	(2)	(3)	(4)	(5)	(6)
Flood exposure	0.00550	0.0975	-0.146	-0.0108	-0.0148	0.0182**
	(0.165)	(0.102)	(0.107)	(0.0164)	(0.0143)	(0.00862)
Loan controls	Yes	Yes	Yes	Yes	Yes	Yes
M x T x V x S x D FE	No	No	Yes	No	No	Yes
Bank x Time FE	No	Yes	Yes	No	Yes	Yes
Observations	277852	277697	182394	277852	277697	182394
Adjusted R^2	0.347	0.470	0.528	0.211	0.281	0.414

- Standard errors in parentheses
- * p<0.1, ** p<0.05, *** p<0.01

Note: Flood exposure is a dummy variable that takes the value of 1 if the property that is used as collateral for the loan is exposed to floods with a return period of 100 years today. Loan controls include dummies for the maturity of the loan (at origination), the priority number of the loan, the type of loan, the amortisation schedule of the loan, the rent fixation period and whether the loan has a fixed interest rate. For the LTV regressions, loan controls additionally include dummies for the deciles of the interest rate, for the interest rate regressions dummies for the deciles of the LTV. Bank x Time FE indicates interacted bank and time dummies. M x T x V x S x D FE indicates interacted municipality, time, house value decile, house size decile and distance to the sea bin dummies. Sample period: 2020Q4.

Source: DTU, credit register and own calculations.

loans and the headquarter of the bank of less than 80 kilometres.

Loans in rural areas are disproportionately made by regional banks. This is in line with the previous evidence that regional banks are important lenders in rural areas.

No evidence of flood risk management along the extensive margin

As a first margin to manage their flood risk exposure, banks can decide not to lend to households that are exposed to flood risk (extensive margin). In that way, banks can completely avoid becoming exposed to flood risk.

To estimate the effect of flood risk on the likelihood that an exposed house has a bank loan, we estimate the following regression model at the house level:[9]

$$1(Bank\ Loan)_{\mathrm{h}} = \alpha + \beta_{\mathrm{flood}}\mathrm{flood\ exposure}_{\mathrm{h}} + \gamma_{\mathrm{m(h)}} \times \gamma_{\mathrm{v(h)}} \times \gamma_{\mathrm{s(h)}} \times \gamma_{\mathrm{d(h)}} + \varepsilon_{\mathrm{h}}.$$

The dependent variable takes a value of 1 if house *h* has a bank loan in the fourth quarter of 2020, and 0 otherwise. As the likelihood of having a bank loan can vary across municipalities, we include interacted municipality, house value, house size and distance to sea dummies. In that way, we ensure that we compare houses that are in the same municipality, have the same value, the same size and the same distance to the sea, but differ in their exposure to flood risk.[10]

Exposed houses are not less likely to have a bank loan compared to similar, unexposed houses, as table 3 shows. While exposed houses are unconditionally 5.8 per cent less likely to have a housing bank loan than unexposed houses (column 1), there is no difference in the likelihood of having a housing bank loan when comparing only similar houses (column 2).

It could be that flood risk is considered differently in booming, urban areas than in declining, rural areas. For example, banks might be more willing to lend to

9 Because of the interacted fixed effects in our regression, we are limited to estimating a linear probability model.

10 We cluster standard errors at the municipality level.

exposed houses in urban areas, knowing these houses are comparatively easy to re-sell. However, we find that there are no differences between urban and rural areas. In columns 3 and 4 of table 3, we include an interaction between the flood exposure dummy and a rural municipality dummy. Unconditionally, exposed houses in urban areas are 7.6 per cent less likely to have a bank loan, while exposed houses in rural areas are 3.4 per cent (=7.63-4.26) less likely to have a housing bank loan (column 3). These differences vanish once we compare similar houses (column 4).

No evidence of flood risk management along the intensive margin

As a second margin to manage their flood risk exposure, banks can limit the LTVs of houses that are exposed to flood risk (intensive margin). In that way, banks can require a higher down payment of households that own exposed houses. This limits the exposure of banks to flood risk.

There is international evidence that banks in some countries limit LTVs of exposed houses. For example, Sastry (2021) finds that exposure to flood risk lowers LTV ratios in Florida by around 0.85 per cent.

To estimate the effect of flood risk on loan-to-value ratios, we estimate the following regression model at the loan level:

$$\mathrm{ltv}_{h(l)t} = \alpha + \beta_{flood}\mathrm{flood\ exposure}_{h(l)} + \Theta X_l + \gamma_{b(l)} \times \gamma_t + \gamma_{m(l)} \times \gamma_{v(l)} \times \gamma_{s(l)} \times \gamma_{d(l)} \times \gamma_t + \varepsilon_{lt}.$$

The independent variable is the LTV of house *h* used as collateral for loan *l* issued at time *t*. The LTV is the one observed in the quarter for which we obtain data (2020Q4), not the one at origination. This is a relevant measure, as it measures the current exposure of the bank to the flood risk of the house. The explanatory variable of interest is the flood risk exposure of house *h* that serves as collateral for the loan. If banks limit their exposure to flood risk by giving lower loan-to-value ratios to houses that are exposed to flood risk, we would expect β_{flood} to be negative.

Flood exposure could be correlated with other loan characteristics. We therefore include a range of loan characteristics X_l as control variables.[11] To control for time-varying credit supply, we include interacted dummies for the lender bank *b* and the origination period *t*. To control for credit demand, we include a rich interacted set of dummies that proxy for the quality of the collateral, namely its value *v*, its municipality *m*, its size *s*, and its distance to the sea *d*. As credit demand can be time-varying, we interact this set of dummies further with a dummy for the origination period.[12]

We find that the point estimate of the coefficient of flood risk on LTV ratios is not different from zero in the two specifications without control dummies (columns 4-5 of table 4). When comparing similar houses, exposed houses have 1.8 percentage point *higher* LTV ratios (column 6 of table 4). Given an average LTV of 80 per cent, this implies an around 2 per cent higher LTV. The bottom panels of Tables 7 and 8 show that this effect is robust to different definitions of return periods and different time horizons. If anything, the coefficient becomes more positive if different flood risk definitions are used.

No evidence of flood risk management along the interest rate margin

As a third margin to manage their flood risk exposure, banks can charge higher risk premiums for housing bank loans on houses that are exposed to flood risk (interest rate margin). In that way, banks do not avoid exposure to flood risk, but they seek a compensation from the households for the risk of becoming exposed to flood risk.

[11] These include dummies for the original maturity of the loan, dummies for the priority of the loan, dummies for the amortisation schedule of the loan, a dummy for whether the loan has an initial amortisation-free period, dummies for the interest fixation period of the loan, dummies for the renegotiation status of the loan and dummies for the write-down status of the loan. We also include dummies for deciles of the interest rate of the loan.

[12] As error terms might be correlated across banks and municipalities, we doubly cluster them at those levels.

LTV ratios of exposed housing bank loans are higher, especially in rural areas

Table 5

Dependent variable: interest rate	(1)	(2)	(3)	(4)
Flood exposure	-0.163	-0.321*	-0.192*	-0.115
	(0.138)	(0.161)	(0.105)	(0.158)
Flood exposure=1 # municipality dummy=1	0.0445	0.321	0.158	-0.0722
	(0.215)	(0.219)	(0.350)	(0.199)
Loan controls	Yes	Yes	Yes	Yes
M x T x V x S x D FE	Yes	Yes	Yes	Yes
Bank x Time FE	Yes	Yes	Yes	Yes
Observations	182394	182394	182394	182394
Adjusted R^2	0.528	0.528	0.528	0.528
F-test (p-value)	0.485	0.999	0.915	0.153

Dependent variable: LTV ratio	(1)	(2)	(3)	(4)
Flood exposure	0.0133	0.0151*	0.0153*	0.0108
	(0.00851)	(0.00870)	(0.00899)	(0.00934)
Flood exposure=1 # municipality dummy=1	0.0126	0.00558	0.00962	0.0173
	(0.0161)	(0.0114)	(0.0158)	(0.0153)
Loan controls	Yes	Yes	Yes	Yes
M x T x V x S x D FE	Yes	Yes	Yes	Yes
Bank x Time FE	Yes	Yes	Yes	Yes
Observations	182394	182394	182394	182394
Adjusted R^2	0.414	0.414	0.414	0.414
F-test (p-value)	0.0797	0.0695	0.0878	0.0329

- Standard errors in parentheses
- * p<0.1, ** p<0.05, *** p<0.01

Note: In model 1, the municipality dummy is 1 if the municipality is classified as a rural area according to Eurostat. In model 2, the municipality dummy is 1 if the municipality has a population density of 300 or less, which is the classification of rural areas according to the world bank. In model 3, the municipality dummy is 1 if the Herfindahl of the top 8 banks in the municipality is more than 0.33 (the average across municipalities). In model 4, the municipality dummy is 1 if historical flooding damages per person are more than 100 DKK. Flood exposure is a dummy variable that takes the value of 1 if the property that is used as collateral for the loan is exposed to floods with a return period of 100 years today. Loan controls include dummies for the maturity of the loan (at origination), the priority number of the loan, the type of loan, the amortization schedule of the loan, the rent fixation period and whether the loan has a fixed interest rate. For the LTV regressions, loan controls additionally include dummies for the deciles of the interest rate, for the interest rate regressions dummies for the deciles of the LTV. Bank x Time FE indicates interacted bank and time dummies. M x T x V x S x D FE indicates interacted municipality, time, house value decile, house size decile and distance to the sea bin dummies. Sample period 2020Q4.
Source: DTU, credit register, Danish FSA, Danmarks Statistik, EUROSTAT and own calculations.

There is evidence that banks in other countries use the interest margin to manage their flood risk exposure. For example, Nguyen, Ongena, Qi and Sila (2022) find that houses in neighbourhoods that are exposed to flood risk in the US face higher interest rates.

To estimate the effect of flood risk on interest rates, we estimate a similar model as for the LTV:

$$r_{lt} = \alpha + \beta_{flood}\text{flood exposure}_{h(l)} + \Theta X_l + \gamma_{b(l)} \times \gamma_t + \gamma_{m(l)} \times \gamma_{v(l)} \times \gamma_{s(l)} \times \gamma_{d(l)} \times \gamma_t + \varepsilon_{lt}.$$

The independent variable is the interest rate *r* of loan *l* with origination period *t*. We regress this interest rate on the flood exposure of house *h* that is used as

collateral for loan *l*, as well as a set of control variables. Relative to the LTV regression, we include dummies for the deciles for the LTV as an additional

Small and regional banks require lower down payments for housing bank loans exposed to flood risk, though differences are small

Table 6

	Dependent variable: interest rate			
	(1)	(2)	(3)	(4)
Flood exposure	-0.0958	-0.168	-0.203	-0.121
	(0.112)	(0.145)	(0.146)	(0.122)
Flood exposure=1 # bank dummy=1	-0.302	0.0641	0.153	-0.147
	(0.286)	(0.237)	(0.214)	(0.230)
Loan controls	Yes	Yes	Yes	Yes
M x T x V x S x D FE	Yes	Yes	Yes	Yes
Bank x Time FE	Yes	Yes	Yes	Yes
Observations	180795	182394	182394	182394
Adjusted R^2	0.527	0.528	0.528	0.528
F-test (p-value)	0.156	0.556	0.746	0.186
	Dependent variable: LTV ratio			
	(1)	(2)	(3)	(4)
Flood exposure	0.0118	0.0102	0.0164*	0.0160*
	(0.00930)	(0.0100)	(0.00953)	(0.00871)
Flood exposure=1 # bank dummy=1	0.0302	0.0225	0.00468	0.0133
	(0.0268)	(0.0183)	(0.0138)	(0.0249)
Loan controls	Yes	Yes	Yes	Yes
M x T x V x S x D FE	Yes	Yes	Yes	Yes
Bank x Time FE	Yes	Yes	Yes	Yes
Observations	180795	182394	182394	182394
Adjusted R^2	0.415	0.414	0.414	0.414
F-test (p-value)	0.0818	0.0215	0.0961	0.224

- Standard errors in parentheses
- * p<0.1, ** p<0.05, *** p<0.01

Note: In model 1, the bank dummy is 1 if the bank is a small bank, as defined by the Danish FSA, and 0 otherwise. In model 2, the bank dummy is 1 if the lender bank has a Herfindahl index across municipalities of 0.05 or more. In model 3, the bank dummy is 1 if the distance of the bank to the portfolio is less than 80 kilometres. In model 4, the bank dummy is 1 if the bank has its headquarter in a municipality with historical flooding damage of more than 100 DKK per person. Flood exposure is a dummy variable that takes the value of 1 if the property that is used as collateral for the loan is exposed to floods with a return period of 100 years today. Loan controls include dummies for the maturity of the loan (at origination), the priority number of the loan, the type of loan, the amortisation schedule of the loan, the rent fixation period and whether the loan has a fixed interest rate. For the LTV regressions, loan controls additionally include dummies for the deciles of the interest rate, for the interest rate regressions dummies for the deciles of the LTV. Bank x Time FE indicates interacted bank and time dummies. M x T x V x S x D FE indicates interacted municipality, time, house value decile, house size decile and distance to the sea bin dummies. Sample period 2020Q4.

Source: DTU, credit register, Danish FSA, Danmarks Statistik and own calculations.

control variable. If banks ask for a risk premium for flood risk, we would expect that the coefficient β_{flood} is positive.

We find that the point estimate of the coefficient of flood risk on interest rates is never significantly different from zero (columns 1-3 of table 4).

This result is robust to enriching the estimated model with interacted fixed effects: there is no specification under which the effect of flood risk on interest rates becomes significantly different from zero.

Neither varying the return period (top panel of table 7) nor varying the time horizon until exposure (top panel of table 8) changes the fact that we do not find a significant result.

Exposed housing bank loans by small banks have higher LTVs than exposed housing bank loans by large banks
While banks on average do not price flood risk, there could be important heterogeneity that would alleviate our concern about flood risk not being priced. For example, it could be that banks where loans exposed to flood risk make up a larger share of the loan portfolio price flood risk differently than other banks. To investigate whether this is the case, we interact the flood risk coefficient in the regressions for the LTV and the interest rate with a bank dummy that takes the value of 1 if the lender bank of a housing bank loan is a small bank or a regional bank.

We do not find evidence that regional banks are more concerned about flood risk than national banks (table 5). We use four different measures of regional banks.

In column 1, we compare whether small banks, which are defined as those in Group 3 of the Danish FSA in 2020, impose different LTVs on exposed houses than national banks. If anything, small banks allow for 3.0 percentage points higher LTVs for exposed houses than large banks, though the coefficient is not statistically different from zero. Small banks give LTVs to exposed houses that are 4.2 percentage points (=1.18+3.02) higher than those of similar, unexposed houses. This coefficient is statistically significant from zero at the 10 per cent confidence level according to an F-test. Small banks also charge somewhat lower interest rates to exposed houses, though that effect is again not significantly different from zero.

In column 2, the bank dummy is one if a bank is regional according to its Herfindahl index. It also appears that regional banks allow for higher LTVs, though the statistical significance is weak.

In column 3, the bank dummy is one if a bank is regional according to its portfolio distance from the headquarter. We do not find differences in LTVs or interest rates.

It might also be that historical experience matters. For example, banks that have already experienced flooding losses might be more cautious in pricing flood risk. In column 4, the bank dummy is one if a bank has its headquarter in a region which historically has had high flood damage. However, we do not find that banks in areas with a historically high level of flood damage give lower LTVs to exposed houses.

Exposed housing bank loans in rural areas have higher LTVs than otherwise similar unexposed houses
It might be that while flood risk is not incorporated into loan terms in urban areas, it could be in rural areas. To investigate this further, we interact the flood risk coefficient in the regressions for the LTV and the interest rate with a municipality dummy that takes the value of 1 if the collateral of the housing bank loan lies in a rural municipality and 0 otherwise.

We do not find evidence that flood risk is incorporated more in rural areas (table 6). On the contrary, exposed houses in rural areas have higher LTVs. We employ four different definitions of rural areas.

The first definition is the degree of urbanisation from EUROSTAT (column 1). LTVs of exposed houses in rural areas are 1.26 percentage points higher than LTVs of exposed houses in rural areas, though the difference is not statistically significant. LTVs of exposed houses in rural areas are 2.59 percentage points (1.33+1.26) higher than LTVs of unexposed houses, which is statistically significant according to an F-test. We do not find any effect for interest rates.

Using other definitions of rural municipalities, like the population density of a municipality (column 2) or the degree of bank competition in a municipality as measured by the Herfindahl index of the top 8 banks (column 3), yields a similar picture. LTVs of exposed houses in rural areas are significantly higher than LTVs of unexposed houses. In urban areas, this is not the case.

Finally, we investigate whether LTVs are lower in areas with higher historical flood risk exposure (column 4). Again, we find the opposite. In areas with higher historical flood risk exposure, LTVs are higher.

Higher LTVs of exposed housing bank loans are likely driven by credit demand factors

There could be two reasons for the unintuitive result that exposed houses have higher LTVs than similar, unexposed houses. These are unobserved borrower heterogeneity in terms of wealth and higher investment needs for exposed houses.

As the credit register does not contain information about the wealth of borrowers, we cannot condition on it. In general, borrowers with lower wealth have higher LTV ratios, as they can make a smaller down payment. Such borrowers might also self-select into houses that are exposed to flood risk, as such houses are priced at a discount relative to similar, unexposed houses.[13] As a consequence, we would expect to see that exposed houses have higher LTV ratios.

Moreover, it might be the case that houses that are exposed to flood risk require investments to protect them against flood damage. Banks might be willing to fund these investments, as they protect the value of the collateral of banks. Again, as a consequence, we would expect to see that exposed houses have higher LTV ratios.

Lack of incorporation of flood risk into loan terms is problematic for local economic stability

The results suggest that flood risk is not incorporated into loan terms. Regional banks do not incorporate flood risk more than national banks, and flood risk is not incorporated more in rural regions than in urban regions.

Yet, flood risk exposures of banks are significant, especially when accounting for indirect spillover effects of a flood. Some regional banks are already highly exposed to flood risk, and exposures are going to increase because of climate change. These high exposures, together with an apparent lack of flood risk management by these regional banks, could lead to a negative financial spiral in the wake of a flood. This could become problematic for local economic stability.

One might argue that banks should not elicit each idiosyncratic risk if monitoring is costly. But flood risk is also easy to observe – the information used to measure flood risk in this memo is easily available. Moreover, internationally, there is evidence that banks in other countries do price flood risk (e.g. Sastry (2021), Nguyen et al. (2022).

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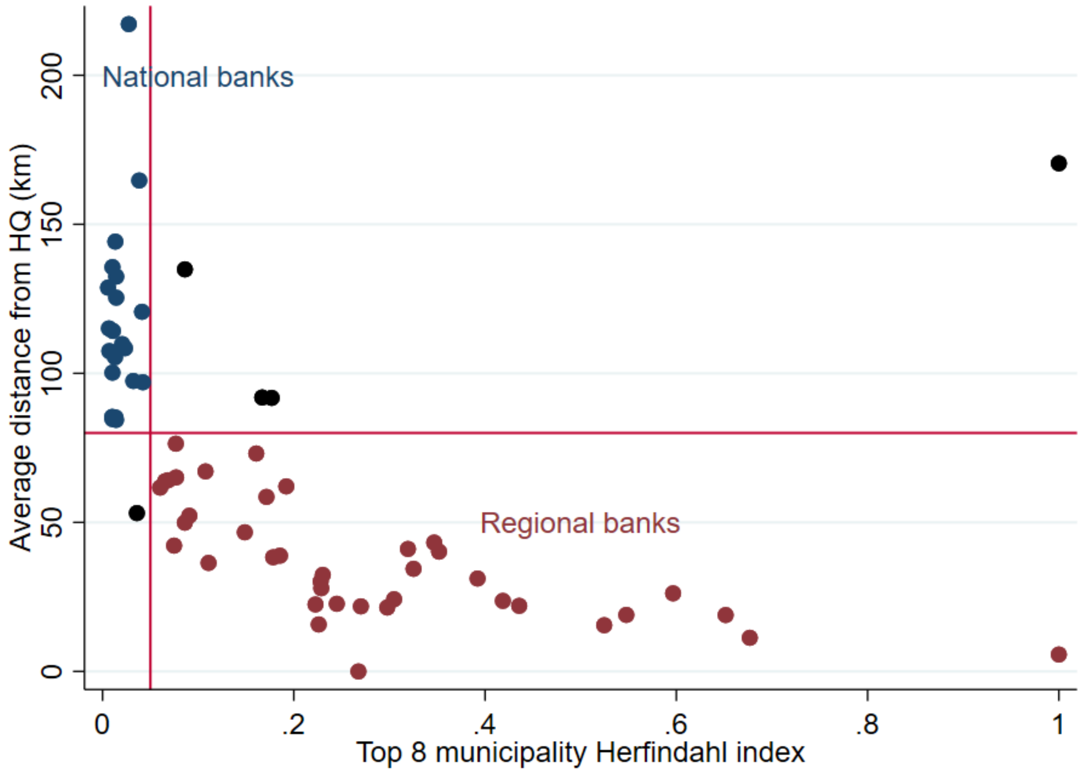
Danish banks can be classified as regional and national banks along two dimensions

Chart 3



Note: This chart shows a scatter plot of the Herfindahl index of the housing bank loans lending of Danish banks across municipalities against the average distance of loans from the headquarter of the bank. Sample period 2020Q4.
Source: Credit register and own calculations.

Robustness: varying the return period does not change the results

Table 7

	Dependent variable: interest rate			
	(1)	(2)	(3)	(4)
>20 year	-0.142			-0.143
	(0.119)			(0.116)
>50 year		-0.0825		
		(0.101)		
>100 year			-0.146	
			(0.107)	
Only 50 year				0.148
				(0.212)
Only 100 year				-0.598
				(0.453)
Loan controls	Yes	Yes	Yes	Yes
M x T x V x S x D FE	Yes	Yes	Yes	Yes
Bank x Time FE	Yes	Yes	Yes	Yes
Observations	182394	182394	182394	182394
Adjusted R^2	0.528	0.528	0.528	0.528

	Dependent variable: LTV ratio			
	(1)	(2)	(3)	(4)
>20 year	0.0166**			0.0176**
	(0.00801)			(0.00816)
>50 year		0.0150**		
		(0.00704)		
>100 year			0.0182**	
			(0.00862)	
Only 50 year				0.00683
				(0.0212)
Only 100 year				0.0395
				(0.0280)
Loan controls	Yes	Yes	Yes	Yes
M x T x V x S x D FE	Yes	Yes	Yes	Yes
Bank x Time FE	Yes	Yes	Yes	Yes
Observations	182394	182394	182394	182394
Adjusted R^2	0.414	0.414	0.414	0.414

- Standard errors in parentheses
- * p<0.1, ** p<0.05, *** p<0.01

Note: Flood exposure is a dummy variable that takes the value of 1 if the property that is used as collateral for the loan is exposed to floods with a return period of 100 years today. Loan controls include dummies for the maturity of the loan (at origination), the priority number of the loan, the type of loan, the amortisation schedule of the loan, the rent fixation period and whether the loan has a fixed interest rate. For the LTV regressions, loan controls additionally include dummies for the deciles of the interest rate, for the interest rate regressions dummies for the deciles of the LTV. Bank x Time FE indicates interacted bank and time dummies. M x T x V x S x D FE indicates interacted municipality, time, house value decile, house size decile and distance to the sea bin dummies. Sample period: 2020Q4.

Source: DTU, credit register and own calculations.

Robustness: varying the time horizon does not change the results

Table 8

Dependent variable: interest rate

	(1)	(2)	(3)	(4)
	(1)	(2)	(3)	(4)
2020 or earlier	-0.146			-0.149
	(0.107)			(0.110)
2041-2070 or earlier		-0.100		
		(0.0981)		
2071-2100 or earlier			-0.0773	
			(0.0820)	
Only 2041-2070				-0.0122
				(0.150)
Only 2071-2100				-0.0289
				(0.122)
loan controls	Yes	Yes	Yes	Yes
K x T x V x S x D FE	Yes	Yes	Yes	Yes
Bank x Time FE	Yes	Yes	Yes	Yes
Observations	182394	182394	182394	182394
Observations	186950	182394	182394	182394
Adjusted R^2	0.525	0.528	0.528	0.528

Dependent variable: LTV ratio

	(1)	(2)	(3)	(4)
2020 or earlier	0.0182**			0.0219**
	(0.00862)			(0.00910)
2041-2070 or earlier		0.0232**		
		(0.0116)		
2071-2100 or earlier			0.0212**	
			(0.00942)	
Only 2041-2070				0.0297
				(0.0242)
Only 2071-2100				0.0151
				(0.0153)
Loan controls	Yes	Yes	Yes	Yes
M x T x V x S x D FE	Yes	Yes	Yes	Yes
Bank x Time FE	Yes	Yes	Yes	Yes
Observations	182394	182394	182394	182394
Adjusted R^2	0.414	0.414	0.414	0.414

- Standard errors in parentheses
- * p<0.1, ** p<0.05, *** p<0.01

Note: Flood exposure is a dummy variable that takes the value of 1 if the property that is used as collateral for the loan is exposed to floods with a return period of 100 years today. Loan controls include dummies for the maturity of the loan (at origination), the priority number of the loan, the type of loan, the amortisation schedule of the loan, the rent fixation period and whether the loan has a fixed interest rate. For the LTV regressions, loan controls additionally include dummies for the deciles of the interest rate, for the interest rate regressions dummies for the deciles of the LTV. Bank x Time FE indicates interacted bank and time dummies. M x T x V x S x D FE indicates interacted municipality, time, house value decile, house size decile and distance to the sea bin dummies. Sample period: 2020Q4.

Source: DTU, credit register and own calculations.

Data cleaning procedure for the credit register data

Box 3

The data on credit comes from the Danish credit register. The credit register has been organised into various tables. The basis of our analysis is a table called *STAT_Ejendomstabel*, which links all collateralised loans and mortgages to their underlying collateral. We clean this data as described below.

We drop loans with any of the following characteristics:

- a missing priority number
- a missing issuance date
- a remaining maturity of more than 40 or less than zero years
- a time outstanding of more than 40 years
- a collateral with a negative LTV ratio, or an LTV ratio of more than 10.

We keep loans with all of the following characteristics:

- The collateral is residential real estate.
- The collateral is a property in Denmark.
- The collateral is owner-occupied real estate.
- The collateral is a single-family home.
- The loan is denominated in DKK.
- The loan is without renegotiated terms.
- The debtor is a household.

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