WORKING PAPER

DANMARKS NATIONALBANK

3 APRIL 2020 — NO. 154

Modest pass-through of monetary policy to retail rates but no reversal

Jakob Feveile Adolfsen
jfa@nationalbanken.dk
DANMARKS NATIONALBANK

Morten Spange
msp@nationalbanken.dk
DANMARKS NATIONALBANK

WORKING PAPER — DANMARKS NATIONALBANK
3 APRIL 2020 — NO. 154

Modest pass-through of monetary policy to retail rates but no reversal

Abstract
In this paper, we search for evidence of a reversal rate in monetary policy based on a sample of Danish banks. Our findings do not point towards a reversal in the pass-through of changes to the monetary policy rate. While the immediate pass-through to bank lending rates has been lower following the introduction of negative policy rates, the direction has not changed. Moreover, we do not find support for the hypothesis that in a negative rate environment banks with a higher deposit share respond less to cuts in the policy interest rate or experience lower lending growth than other banks. We find that the slowdown in pass-through around the introduction of negative policy rates follows an initial slowdown in the aftermath of the financial crisis. We argue that this may to some extent reflect that banks adjusted their required compensation for risk.

Resume
I dette papir søger vi efter evidens for en pengepolitisk reverseringsrente baseret på en stikprøve af danske banker. Vores resultater peger ikke i retning af en reversering af gennemslaget fra ændringer i de pengepolitiske renter. Mens det øjeblikkelige gennemslag til bankernes udlånsrenter har været lavere efter introduktionen af negative renter, så er retningen uændret. Vi finder desuden ikke støtte til hypotesen om, at banker med en høj indlånsandel reagerer mindre på reduktioner i de pengepolitiske renter eller oplever lavere udlånsvækst end andre banker i en situation med negative renter. Vi finder, at reduktionen i gennemslaget omkring det tidspunkt, hvor de negative renter blev introduceret, kommer efter en tidligere reduktion, som fandt sted i kølvandet på den finansielle krise. Vi argumenterer for, at det i et vist omfang afspejler, at bankerne justerede deres krævede kompensation for risiko.

Key words
Negative interest rates; Interest rate pass-through; Monetary policy; Effective lower bound; Bank lending; Credit risk; Financial crisis.

JEL classification
E52; E58; G21.

Acknowledgements
The authors wish to thank Jens Skovsted Halsnæs, Simon Juul Hviid, Martin Nygaard Jørgensen, Signe Krogstrup, Rasmus Kofoed Mandsberg and other colleagues from Danmarks Nationalbank for comments and discussions of the paper.

The authors alone are responsible for any remaining errors.

Modest pass-through of monetary policy to retail rates but no reversal*

Jakob Feveile Adolfsen† Morten Spange ‡
Danmarks Nationalbank *Danmarks Nationalbank*

Abstract

In this paper, we search for evidence of a reversal rate in monetary policy based on a sample of Danish banks. Our findings do not point towards a reversal in the pass-through of changes to the monetary policy rate. While the immediate pass-through to bank lending rates has been lower following the introduction of negative policy rates, the direction has not changed. Moreover, we do not find support for the hypothesis that in a negative rate environment banks with a higher deposit share respond less to cuts in the policy interest rate or experience lower lending growth than other banks. We find that the slowdown in pass-through around the introduction of negative policy rates follows an initial slowdown in the aftermath of the financial crisis. We argue that this may to some extent reflect that banks adjusted their required compensation for risk.

`KEYWORDS`: Negative interest rates; Interest rate pass-through; Monetary policy; Effective lower bound; Bank lending; Credit risk; Financial crisis.
`JEL CLASSIFICATION`: E52; E58; G21.

1 Introduction

In Denmark, the key monetary policy rate, the interest rate on certificates of deposits, became negative in July 2012. Since then it has remained in negative territory with the exception of a few months in 2014. Moreover, interest rates are also negative in the euro area, Switzerland and Japan. In December 2019, the Swedish Riksbank raised its key policy rates to zero, putting an end to nearly five years of negative rates.

*The viewpoints and conclusions stated are the responsibility of the individual contributors, and do not necessarily reflect the views of Danmarks Nationalbank. The authors alone are responsible for any remaining errors. The authors wish to thank Jens Skovsted Halsnæs, Simon Juul Hviid, Martin Nygaard Jørgensen, Signe Krogstrup, Rasmus Kofoed Mandsberg and other colleagues from Danmarks Nationalbank for comments and discussions of the paper.

†Danmarks Nationalbank, Havnegade 5, 1093 København K, email: jfa@nationalbanken.dk.
‡Danmarks Nationalbank, Havnegade 5, 1093 København K, email: msp@nationalbanken.dk.

The low interest rate environment that we are experiencing across the advanced economies reflects a secular decline in equilibrium real interest rates combined with stubbornly weak inflation (Brand *et al.*, 2018). Persistently low inflation in countries with negative interest rates has led to concern that the monetary policy transmission mechanism changes course when policy rates are negative. Based on a New Keynesian model, Brunnermeier and Koby (2019) show that a so-called reversal rate may exist at which the intended effect of monetary policy stimulus is reversed and becomes contractionary. When the policy rate is equal to the reversal rate, further rate cuts will lead to an increase in lending rates and less credit creation by banks. Eggertsson *et al.* (2019) set up a model in which the usual monetary policy transmission mechanism breaks down when policy rates turn negative. They back the predictions of their model with evidence from the response of Swedish banks to negative policy rates in Sweden.

In this paper, we assess the transmission of negative policy rates through the Danish banking sector. While Danmarks Nationalbank sets interest rates with the sole objective of maintaining a fixed exchange rate between the Danish krone and the euro, it is nonetheless an interesting case to study in order to assess the broader implications of negative policy rates.[1] Our main focus is on the pass-through from monetary policy rates to bank retail lending rates. The hypothesis that negative interest rates may be contractionary reflects the pressure that negative interest rates exert on bank profitability. This is because interest rates on a share of bank liabilities appear sticky at zero. Specifically, whereas average deposit rates for Danish firms have been negative for a number of years, negative deposit rates for households are a much more recent phenomenon and only apply to a small share of total household deposits.

The reluctance to impose negative rates on household deposits implies that the earnings of banks with a high ratio of household deposits to total liabilities are likely to be affected more than the earnings of banks with fewer deposits from households. Over time, this accumulates into differences in net worth and thereby in the lending capacity of banks. Hence, the identifying assumption in this paper is that banks with a high ratio of household deposits to total liabilities are more affected by the cut in policy rates into

[1]Despite the fixed exchange rate regime, low Danish policy rates ultimately reflect the same global factors as elsewhere (Adolfsen and Pedersen, 2019). This is because the exchange rate peg implies that in the absence of foreign exchange market pressures, Danish monetary policy rates closely track those of the ECB. In recent years, international capital flows have implied that Danish policy rates have been up to 55 basis points below those of the ECB. The initial cut into negative territory in 2012 was a response to capital inflows during the sovereign debt crisis in a number of euro area countries, while the key rate was cut to -0.75 as strong capital inflows emerged following the decision of the Swiss National Bank to suspend the floor under the Swiss franc against the euro.

negative territory than banks with a lower share of household deposits.[2] We therefore split the sample into banks with high and low deposit shares, and compare their responses to changes in the policy rate since the introduction of negative rates in 2012.

Our key finding is that we see no evidence of a reversal in the transmission of monetary policy through the banking sector in the period of negative policy rates. While pass-through to lending rates is slower than before the introduction of negative interest rates, it remains positive. Moreover, there are no indications that the pass-through of negative rates to bank lending rates depends on the deposit shares of the individual banks. Also, we find no evidence to suggest that banks relying heavily on deposit funding see restricted credit growth relative to banks that rely less on funding from deposits. As the ratio of household deposits to total liabilities is a measure of the extent to which the lending capacity of a bank could theoretically be affected by negative policy rates, we conclude that there are no indications that negative rates have reversed the transmission of monetary policy to the real economy in Denmark.

The absence of a reversal rate in our study may be linked to the profitability of Danish banks. In the model of Brunnermeier and Koby (2019), a rate cut increases the value of banks' existing assets, while their net interest income and thereby their profitability are reduced. Assuming that banks are unwilling to set negative deposit rates, the latter effect becomes much more pronounced as policy rates become negative, reducing the banks' net worth. To grant loans, banks are required to hold capital. As banks' net worth is reduced, this means that at some point they are forced to cut back on lending. However, the earnings of Danish banks have remained healthy throughout the period of negative policy rates. This reflects the fact that the decline in net interest income has in part been compensated by higher income from fees and contribution charges from mortgages, while write-downs have also been low, cf. Danmarks Nationalbank (2019).[3] As a result, scarcity of capital has not been restricting their ability to meet the demand for credit.[4]

Our key finding that the pass-through of monetary policy has not been reversed is in line with the findings of a number of studies based on other European countries. A study by the Riksbank finds that while the bank lending channel might have been slightly muted for households, mildly negative interest rates have successfully contributed to a more expansionary monetary policy in Sweden.[5] A number of studies have analysed how

[2]The empirical approach largely follows Eggertsson *et al.* (2019).

[3]Covering the period until 2016, Madaschi and Nuevo (2017) find that the profitability of Danish and Swedish banks improved in the years following the introduction of negative policy rates.

[4]Instead, modest credit growth can reflect an increased desire to save. This is a global phenomenon which has reduced the equilibrium real interest rate that balances aggregate savings and aggregate investments, cf. Holston *et al.* (2017).

[5]See Erikson and Vestin (2019).

negative policy rates have been transmitted through the banking sector in the euro area or selected euro area countries. Indeed, the majority of studies find that they have been effective. The findings of Altavilla *et al.* (2019) (euro area), Bottero *et al.* (2019) (Italy), Eisenschmidt and Smets (2018) (Germany) and Demiralp *et al.* (2019) (euro area) all suggest that negative policy rates have been effective in providing monetary accommodation. The accommodative effects of negative policy rates have also been emphasised in official ECB communication, see e.g. Lane (2019). Based on a sample of euro area banks, Tan (2019) also finds positive effects of negative policy rates on bank lending. However, his findings suggest that the positive effect dissipates as negative rates persist.

In contrast, but in line with Eggertsson *et al.* (2019), Heider *et al.* (2018) find that the introduction of negative policy rates has led to less lending by euro area banks with greater reliance on deposit funding. This lends empirical support to the reversal rate hypothesis.

Pass-through to bank lending rates varies over time and across banks for a number of reasons. We show that the slowdown in the pass-through to lending rates that was linked to the introduction of negative policy rates was preceded by a slowdown around the time of the financial crisis in 2008. The slowdown following the financial crisis is not uniform across banks. In particular, we find that banks that experienced relatively higher lending growth in the years immediately prior to the crisis were reluctant to cut lending rates in step with the cuts in the policy rate. Taking lending growth in the pre-crisis years as an indicator of the quality of banks' loan portfolios, this suggests that banks with more risky loans have been reluctant to cut lending rates in response to cuts in policy rates.[6] We argue that this may reflect a change in the required compensation for risk.

2 The pass-through of negative policy rates

Since its latest peak in August 2011 until the end of January 2020, Danmarks Nationalbank's key policy rate, the interest rate on certificates of deposits, was reduced by 195 basis points, from 1.2 per cent to a historical low of -0.75 per cent, thereby venturing well

[6] Other studies have pointed towards bank-specific risk exposure as being a main determinant of variation in banks' responses to the financial crisis (Ivashina and Scharfstein, 2010; Cornett *et al.*, 2011; Jensen and Johannesen, 2017).

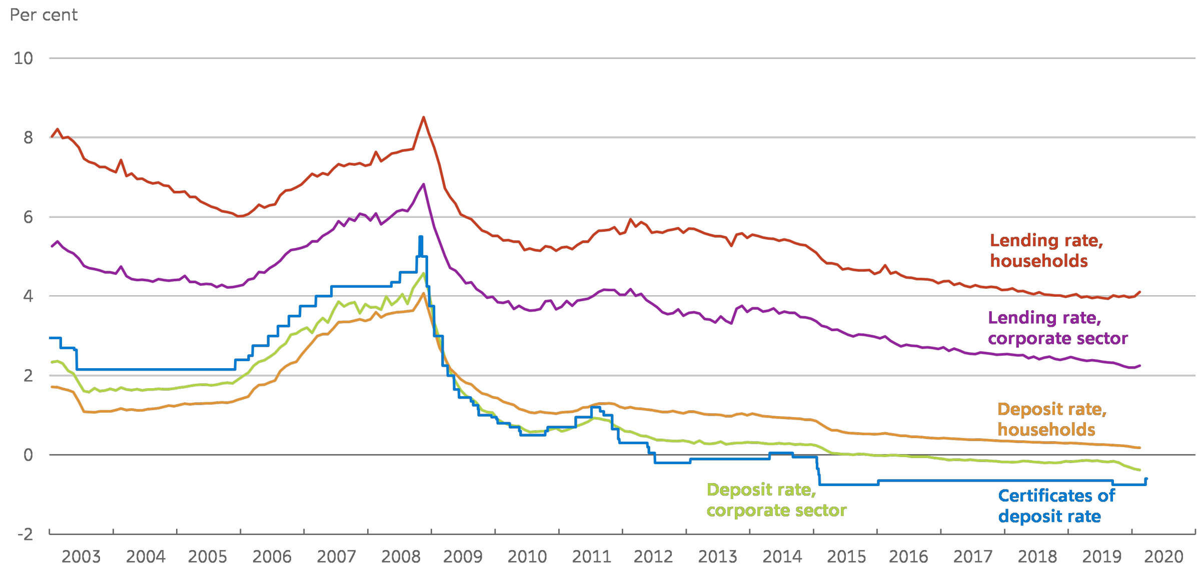
into negative territory, cf. figure 1.[7] The decline in policy rates reflects two factors. First, as Denmark maintains an exchange rate peg against the euro, changes to the ECB's policy rate are typically mirrored one-to-one by Danmarks Nationalbank. Secondly, strong capital inflows in 2012 and especially in early 2015 prompted Danmarks Nationalbank to cut policy rates unilaterally to prevent the currency from appreciating. As a consequence, Danish policy rates are currently below those of the ECB, and they have been negative since July 2012 with the exception of a few months in 2014. During this period, the policy rate has been changed a number of times.

Banks' average lending rates to households and corporations have declined by 166 and 191 basis points, respectively, between August 2011 and the end of January 2020. This is almost equivalent to the concurrent decline in the policy rate. However, compared with previous episodes of declining policy rates, the pass-through to lending rates has been unusually slow. Moreover, over the same period banks have reduced their interest rate margins measured as the difference between lending and deposit rates, as banks' average deposit rates to households and firms have declined by 127 and 111 basis points, respectively. The reduction in margins may in part reflect that the Danish economy has been recovering from the financial crisis, as credit margins are typically found to be counter-cyclical.[8] But the compression in margins also reflects that banks have been hesitant to introduce negative interest rates on deposits – in particular on deposits from households.

[7] Reserves at Danmark Nationalbank are held either in the form of current account deposits or in the form of certificates of deposits. While current account deposits have been exempt from negative interest rates, a cap on banks' aggregate current account holdings implies that the interest rate on certificates of deposits is the marginal policy rate. Hence, in this paper the policy rate refers to the rate on certificates of deposits. However, the findings in the paper are robust to using a weighted average of the interest rates on current account deposits and certificates of deposits, respectively, as a measure of the policy rate, see appendix D.1. Moreover, the findings are also robust to substituting the monetary policy rate with the short-term money market rate, which is the relevant interest rate for marginal funding in the money market, see appendix D.2.

[8] See e.g. Aliaga-Díaz and Olivero (2010) for evidence from a study based on US banks.

Figure 1: *Bank rates are gradually declining*

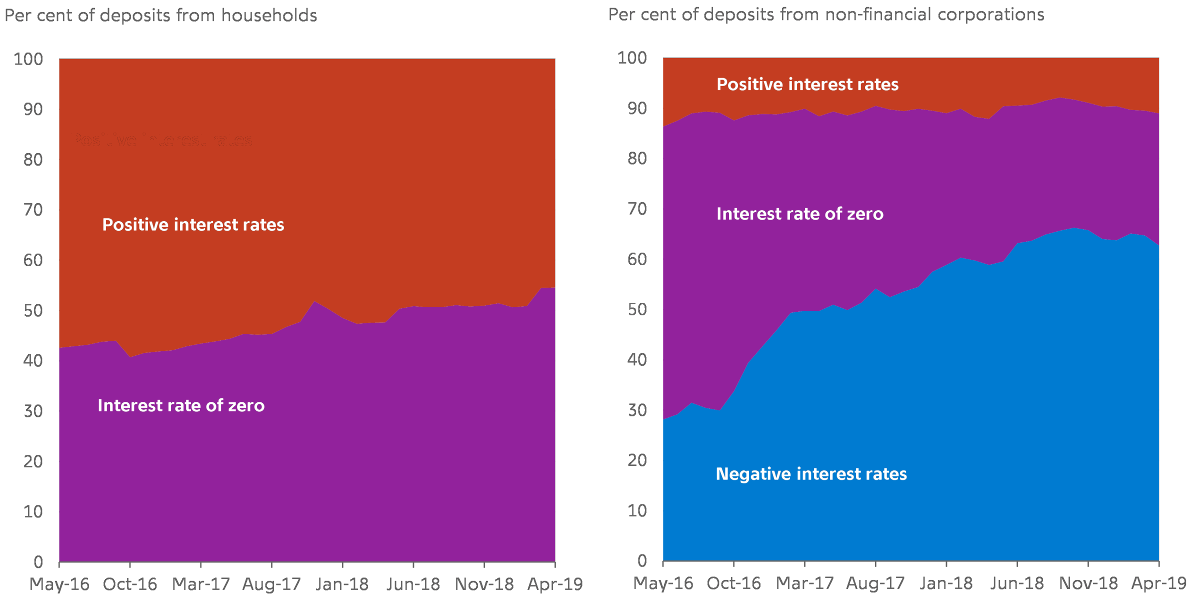


Source: Danmarks Nationalbank.

Figure 2 illustrates the shares of deposits from households and non-financial corporations that are remunerated with a positive rate, a zero rate and a negative rate, respectively. For firms the share of deposits with a negative deposit rate had risen to approximately two-thirds by April 2019. However, while the share of household deposits receiving a zero interest rate had risen to more than half by April 2019, no households received a negative deposit rate.[9] This suggests that pass-through to household deposit rates has been impaired. Hence, a key factor behind the reversal rate – the impaired pass-through to household deposit rates – seems to be present in the Danish data. However, while the pass-through to lending rates appears to have slowed, the aggregate data does not indicate that a reversal rate has been reached.

[9]The relatively high share of deposits with a positive deposit rate reflects lending-related deposits, time deposits etc. The vast majority of ordinary demand deposits carry an interest rate of zero. In August 2019, Jyske Bank became the first Danish bank to announce that it would impose negative rates on household deposits above a certain threshold with effect from December that same year.

Figure 2: *Household deposit rates have been sticky at zero*



Source: Danmarks Nationalbank.

To formally test for reversals in the response of banks to changes in monetary policy rates in negative territory, we follow Eggertsson *et al.* (2019) and estimate the equation below. Throughout the paper, we use a dataset with monthly data for 23 large and medium-sized Danish banks in the period, January 2003 to January 2020. Data is based on official reporting of MFI statistics from the banks to Danmarks Nationalbank and enriched with data on monetary policy rates from Danmarks Nationalbank as well as some accounting data from the banks.[10]

$$\Delta i^b_{i,t} = \alpha + \sum_{k=0}^{2} \beta_k \Delta i^{CB}_{t-k} + \sum_{k=0}^{2} \gamma_k \Delta i^{CB}_{t-k} \times I^{neg}_t + \theta I^{neg}_t + \delta_i + \varepsilon_{i,t} \tag{1}$$

$i^b_{i,t}$ is the lending rate of bank i (to households, corporates or a weighted average of the two), i^{CB}_t is the certificates of deposit rate of Danmarks Nationalbank. We include 2 lags of i^{CB}_t , as most of the total interest rate pass-through to bank rates in Denmark has typically taken place within the first 3 months of the change in the policy rate (Drejer *et al.*, 2011).[11] I^{neg}_t is a dummy, which takes the value 1 following the introduction of negative interest rates in July 2012. δ_i controls for bank-fixed effects.

The findings confirm that the pass-through of monetary policy rates to bank lending rates has weakened since the introduction of negative policy rates as $\sum_{k=0}^{2} \hat{\gamma}_k < 0$, cf.

[10]See appendix A for further details on the dataset.

[11]The findings in this paper are robust to including only 1 lag, see appendix D.3. Findings are also robust to not including lags. Findings for 0 lags are available on request.

table 1. However, there are no signs of a reversal in the sign of monetary policy pass-through as $\sum_{k=0}^{2}\hat{\beta}_k + \sum_{k=0}^{2}\hat{\gamma}_k > 0$. Moreover, there are indications that the pass-through of monetary policy has remained positive as $\sum_{k=0}^{2}\hat{\beta}_k + \sum_{k=0}^{2}\hat{\gamma}_k$ is significantly different from 0, albeit to a smaller extent than before the introduction of negative policy rates.[12]

[12]We still do not see any reversal in interest rate pass-through when restricting attention to interest rate cuts, see appendix D.4.

Table 1: *Reduced pass-through to lending rates but no reversal*

	i_t^b: Households and corporates (weighted average)	i_t^b: Households	i_t^b: Corporates
Δi_t^{CB}	0.44^{***}	0.50^{***}	0.37^{***}
	(0.05)	(0.02)	(0.09)
Δi_{t-1}^{CB}	0.19^{***}	0.20^{***}	0.19^{**}
	(0.04)	(0.01)	(0.09)
Δi_{t-2}^{CB}	0.04	0.03	0.06
	(0.05)	(0.02)	(0.09)
$\Delta i_t^{CB} \times I_t^{neg}$	-0.17^{***}	-0.11	-0.26^{***}
	(0.05)	(0.07)	(0.03)
$\Delta i_{t-1}^{CB} \times I_t^{neg}$	-0.11^{**}	-0.12^{***}	-0.14
	(0.05)	(0.04)	(0.12)
$\Delta i_{t-2}^{CB} \times I_t^{neg}$	-0.07^{*}	-0.12^{***}	-0.02
	(0.03)	(0.02)	(0.07)
I_t^{neg}	-0.02^{***}	-0.01	-0.02^{***}
	(0.004)	(0.01)	(0.004)
Constant	-0.003	-0.01^{***}	-0.001
	(0.002)	(0.002)	(0.003)
N	3,523	3,525	3,525
No. of banks	23	23	23

Pass-through and marginal effect:

Pass-through before: $\sum_{k=0}^{2} \hat{\beta}_k$	0.68^{***}	0.73^{***}	0.62^{***}
	(0.04)	(0.01)	(0.09)
Pass-through after: $\sum_{k=0}^{2} \hat{\beta}_k + \sum_{k=0}^{2} \hat{\gamma}_k$	0.32^{***}	0.38^{***}	0.20^{***}
	(0.03)	(0.06)	(0.05)
Marginal effect of negative rates: $\sum_{k=0}^{2} \hat{\gamma}_k$	-0.36^{***}	-0.35^{***}	-0.43^{***}
	(0.05)	(0.05)	(0.07)

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

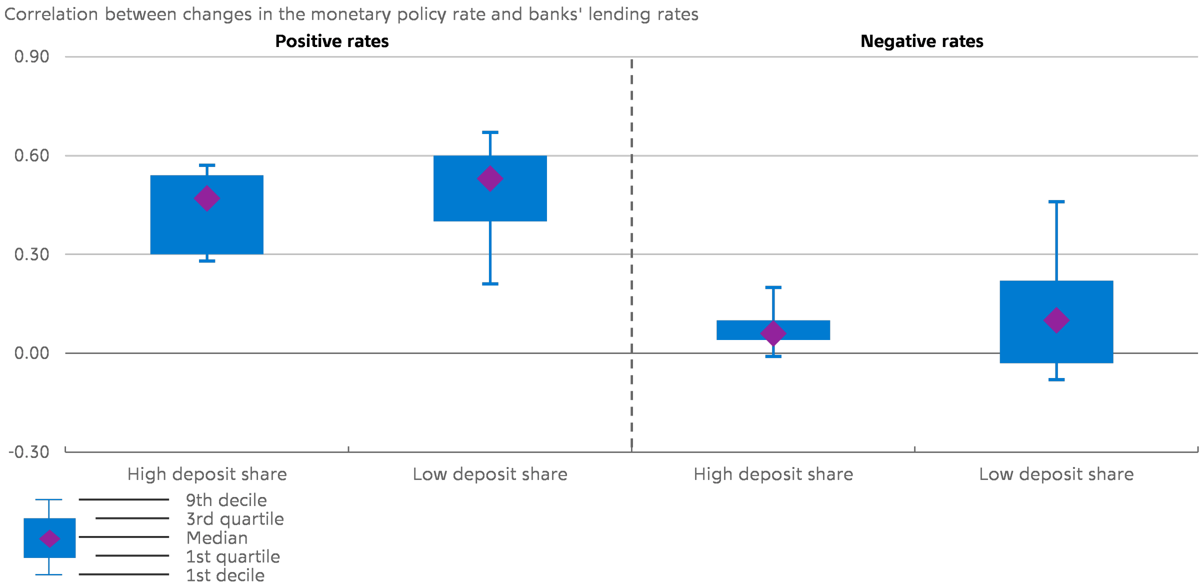
Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (1) weighted by bank size, as we are interested in the aggregate pass-through of monetary policy (i.e. the average size of the balance sheet during the period), and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded. See appendix A for details on data.

2.1 Pass-through and deposit funding

While average lending rates have continued to decline following the introduction of negative policy rates, this may mask important heterogeneity across banks. As banks have been reluctant to impose negative rates on deposits, banks with a high ratio of deposits to total liabilities would be expected to be affected the most by negative policy rates. In fact, Eggertsson *et al.* (2019) find evidence that banks that rely more on deposit funding are likely to increase retail rates when facing a further cut in the policy rate. It is these banks that are behind their findings of an overall reversal in monetary policy pass-through in Sweden.

As the nominal rigidity in deposit rates has been present on household deposits in Danish banks, we divide the banks in our sample into two groups based on whether their household deposit share is below or above the median. The household deposit share is calculated as total deposits from households in Danish kroner divided by total liabilities. We find that within-month correlations between bank rates and the monetary policy rate for Danish banks indicate that the slowdown in the pass-through of policy rate changes since July 2012 is unaffected by the extent to which banks rely on deposits as a source of funding, cf. figure 3.

Figure 3: *Similar slowdown in correlation with bank rates across different bank types*



Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The figure shows the distribution of within-month correlations between Danmarks Nationalbank's interest rate on certificates of deposits and the banks' lending rates to households and non-financial corporations (weighted by the amount of loans to households and non-financial corporations) in banks with a household deposit share above and below the median before and after the introduction of negative interest rates in July 2012. Entities with a banking licence that cannot be classified as traditional banks are excluded. See appendix A for details on data.
Source: Danmarks Nationalbank and own calculations.

To further investigate the reversal rate hypothesis, we run a regression similar to (1) but with an additional interaction with a dummy indicating whether banks had a high or low share of household deposits on their balance sheets in August 2011, $\mathbf{1}_{Highdeposit,i}$, cf. below.[13] August 2011 is chosen, as it marks the peak in the monetary policy rate just before it went below zero. Hence, we assume that it is exogenous to banks' response to negative rates as well as anticipation effects from the policy rate approaching zero. We find that although a high deposit share appears to be associated with a somewhat weaker degree of pass-through of policy rates to lending rates, the difference between high- and low-deposit banks is statistically insignificant, cf. table 2. This is the case at both positive and negative policy rates. Moreover, there is no reversal in the aggregate pass-through

[13] In order to investigate the differences between banks of different sizes, we do not weight the regression with bank size. High or low deposit shares are determined by the median share of household deposits in Danish kroner on the banks' balance sheets in August 2011. As 5 of the banks in our sample did not report interest rates to Danmarks Nationalbank in 2011, our sample is reduced from 23 to 18 banks. See summary statistics on household deposit shares in August 2011 for the two groups of banks in appendix A.

of monetary policy to retail rates following the introduction of negative policy rates, even for the the group of banks with a high reliance on deposit funding. These banks are most heavily exposed to the downward rigidity in household deposit rates. Hence, we do not find any evidence of a reversal in monetary policy pass-through through the banks that could be expected to reverse their responses to further cuts in the policy rate *a priori*. These findings are unchanged when including year-fixed effects that capture common trends in interest rates, see appendix D.7.

$$\begin{aligned}\Delta i^{b}_{i,t} = \alpha + \sum_{k=0}^{2}\beta_k \Delta i^{CB}_{t-k} + \sum_{k=0}^{2}\gamma_k \Delta i^{CB}_{t-k} \times I^{neg}_t \times \mathbf{1}_{Highdeposit,i} + \sum_{k=0}^{2}\psi_{1,k}\Delta i^{CB}_{t-k} \times I^{neg}_t \\ + \sum_{k=0}^{2}\psi_{2,k}\Delta i^{CB}_{t-k} \times \mathbf{1}_{Highdeposit,i} + \psi_3 I^{neg}_t \times \mathbf{1}_{Highdeposit,i} + \theta I^{neg}_t + \delta_i + \varepsilon_{i,t}\end{aligned} \quad (2)$$

Table 2: *Regression shows no effect of reliance on deposit funding*

Pass-through and marginal effects	
Pass-through of high deposit before: $\sum_{k=0}^{2}\hat{\beta}_k + \sum_{k=0}^{2}\hat{\psi}_{2,k}$	0.64^{***}
	(0.02)
Pass-through of low deposit before: $\sum_{k=0}^{2}\hat{\beta}_k$	0.69^{***}
	(0.03)
Pass-through of high deposit after: $\sum_{k=0}^{2}\hat{\beta}_k + \sum_{k=0}^{2}\hat{\gamma}_k + \sum_{k=0}^{2}\hat{\psi}_{1,k} + \sum_{k=0}^{2}\hat{\psi}_{2,k}$	0.11^{*}
	(0.06)
Pass-through of low deposit after: $\sum_{k=0}^{2}\hat{\beta}_k + \sum_{k=0}^{2}\hat{\psi}_{1,k}$	0.19^{***}
	(0.05)
Marginal effect of high deposit before: $\sum_{k=0}^{2}\hat{\psi}_{2,k}$	-0.05
	(0.04)
Marginal effect of high deposit after: $\sum_{k=0}^{2}\hat{\gamma}_k + \sum_{k=0}^{2}\hat{\psi}_{2,k}$	-0.09
	(0.08)
Diff-in-diff estimate	-0.04
	(0.09)
N	3,176
No. of banks	18

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.10$

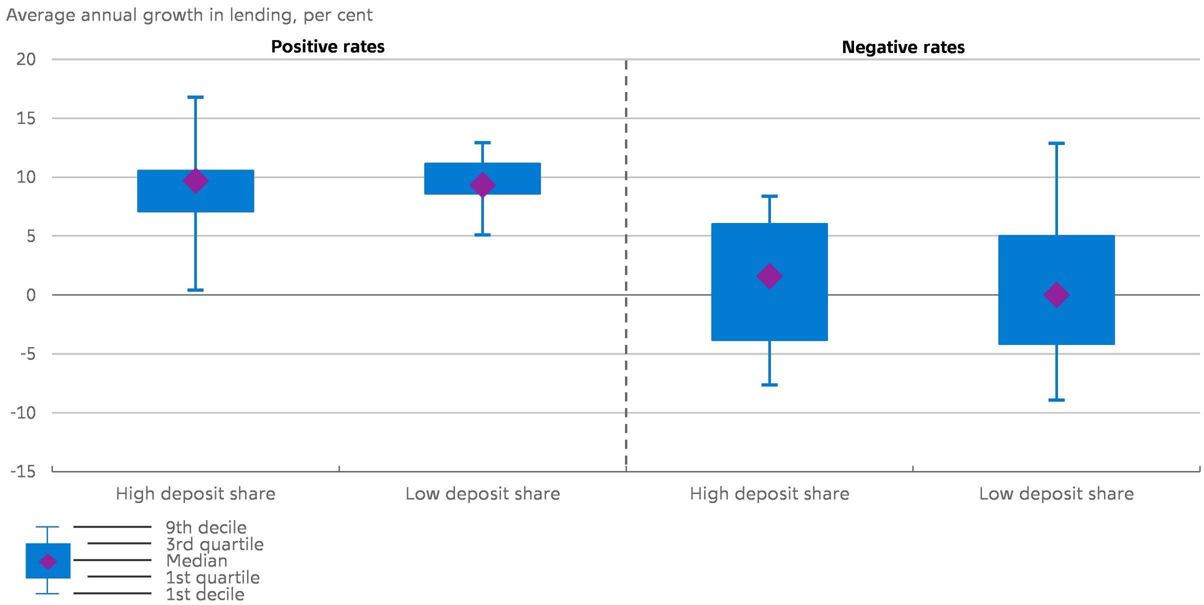
Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. Pass-through and marginal effects are calculated on an estimation of equation (2) not weighted by bank size, as we are interested in investigating differences across banks, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded. See appendix A for details on data.

The findings in the paper are based on a relatively small sample of approximately 20 banks. Moreover, while the time period of negative policy rates spans more than 7 years, the number of policy rate changes over that period is limited to nine of which three were in the course of less than one month in January-February 2015. The relatively small sample limits the statistical significance of the findings, as the precision of the estimates is reduced by the modest sample size. In particular, we cannot rule out that the inability to detect differences between banks with high and low deposit shares reflects the small sample size. However, as discussed in the introduction, the findings are consistent with studies conducted on larger datasets for euro area banks. Moreover, as explained in the next section, we find further evidence against the reversal rate hypothesis in a larger dataset that only includes lending volumes.

2.2 Lending volumes and deposit funding

When evaluating the transmission of monetary policy through the banking sector, it is also of interest to investigate the effect of negative policy rates on lending volumes. Eggertsson *et al.* (2019) find that for the period of negative policy rates, Swedish banks with a high deposit share have experienced weaker credit growth than Swedish banks with a lower deposit share. This is consistent with findings for the euro area, cf. Heider *et al.* (2018). We assess whether in the Danish data there is a link between a bank's deposit share and its lending growth following the introduction of negative interest rates. To that end, we use the same division of banks as in the previous section based on whether a bank's deposit share was above or below the median in August 2011. Figure 4 shows that both groups of banks experienced slower lending growth in the latter period, but it does not suggest a clear link between credit growth and deposit share across banks.

Figure 4: *Similar slowdown in bank lending across different bank types*



Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The figure shows the average annual growth in lending to households and non-financial corporations in banks with a household deposit share above and below the median before and after the introduction of negative interest rates in July 2012. Entities with a banking licence that cannot be classified as traditional banks are excluded. See appendix A for details on data.
Source: Danmarks Nationalbank and own calculations.

To formally test whether banks with high household deposit shares have experienced lower lending growth at negative policy rates, we conduct two regressions similar to Eggertsson *et al.* (2019) on Danish data as specified in the equations below.

$$\Delta \log (lending_{i,t}) = \alpha + \beta I_t^{neg} \times Depositshare_i + \theta I_t^{neg} + \delta_i + m_{i,t} + \delta_t + \varepsilon_{i,t} \quad (3)$$

$$\Delta \log (lending_{i,t}) = \alpha + \beta I_t^{neg} \times \mathbf{1}_{Highdeposit,i} + \theta I_t^{neg} + \delta_i + m_{i,t} + \delta_t + \varepsilon_{i,t} \quad (4)$$

$lending_{i,t}$ is bank i's lending to households and corporates, I_t^{neg} is a dummy which takes the value 1 following the introduction of negative interest rates in July 2012, $Depositshare_i$ is the share of household deposits on the balance sheet in August 2011, $\mathbf{1}_{Highdeposit,i}$ indicates whether the bank has a deposit share above the median in August 2011, δ_i captures bank-fixed effects, $m_{i,t}$ captures bank mergers[14] and δ_t is a year dummy that captures common bank shocks and the overall credit development in the Danish economy. If banks with a high share of household deposits experienced lower credit growth, we should see that $\hat{\beta} < 0$. However, this is not the case, cf. table 3.[15]

Table 3: *Regression shows reduced transmission, but no reversal of transmission*

	1-month change in lending	3-month change in lending	6-month change in lending	12-month change in lending
$I_t^{neg} \times Depositshare_i$	0.009	0.03**	0.07**	0.12**
	(0.005)	(0.01)	(0.02)	(0.05)
$I_t^{neg} \times \mathbf{1}_{Highdeposit,i}$	−0.001	−0.001	−0.001	−0.006
	(0.003)	(0.009)	(0.02)	(0.04)
N	3,216	3,182	3,131	3,026
No. of banks	18	18	18	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (3) and (4) not weighted by bank size as we are interested in investigating differences across banks, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded. See appendix A for details on data.

Moreover, as small banks also report loan and deposit volumes on an annual basis, we were able to verify robustness of our findings on lending growth when expanding the sample size by the number of banks, see appendix D.6. It indicates that the missing evidence of the key mechanisms driving the reversal rate hypothesis is not only due to the small sample size.

[14]When assessing changes in banks' balance sheets it is important to control for bank mergers, as large changes in the balance sheets of the banks involved appear around a number of the mergers.

[15]Findings are robust to limiting the estimation sample to start in January 2010 as in Eggertsson *et al.* (2019), see appendix D.5.

3 Identification of factors determining interest rate pass-through

3.1 When did pass-through slow down?

In the previous section, we found evidence of a slowdown in pass-through taking place in July 2012. However, it is clear from figure 1 in section 2 that banks already slowed their response to reductions in the monetary policy rate starting at the outbreak of the financial crisis in late 2008. To see how pass-through has evolved since the financial crisis, we test separately how interest rate pass-through was affected by the financial crisis and the introduction of negative policy rates. Specifically, we perform a regression with indicators for the periods before November 2008, between November 2008 and June 2012, and from July 2012, cf. the equation below. November 2008 is chosen as the first cut-off, as it represents the peak in the monetary policy rate before the declines in interest rates during the crisis.[16]

$$\Delta i_{i,t}^{b} = \alpha + \sum_{k=0}^{2} \beta_k \Delta i_{t-k}^{CB} + \sum_{k=0}^{2} \sum_{j \in (pre,crisis,neg)} \gamma_{k,j} \Delta i_{t-k}^{CB} \times I_{j,t} + \sum_{j \in (pre,crisis,neg)} \theta_j I_{j,t} + \delta_i + \varepsilon_{i,t},$$

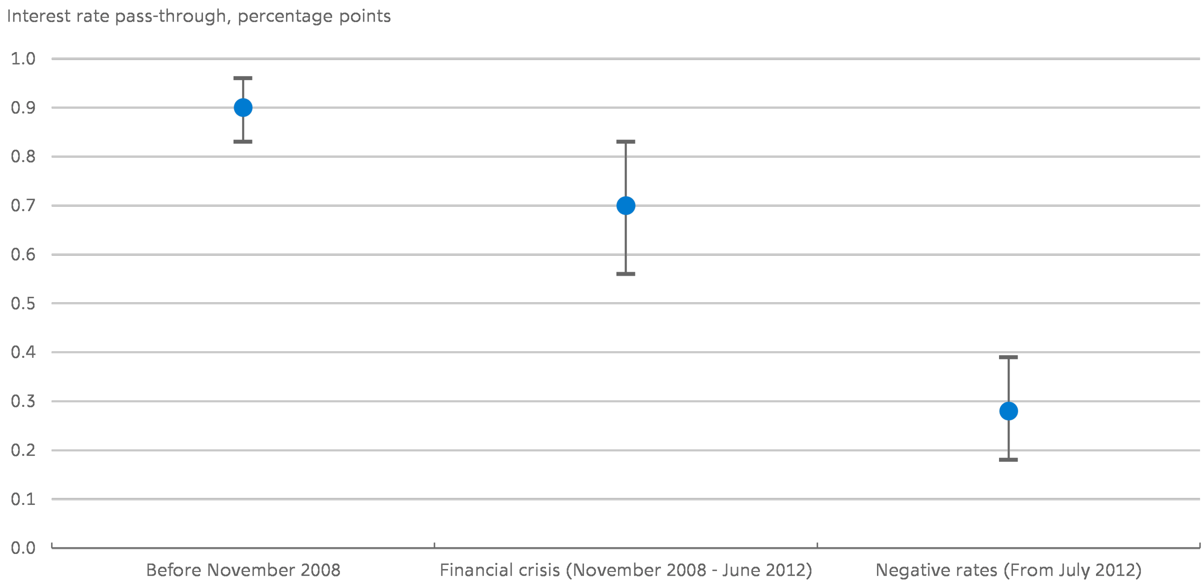
$$I_{pre,t} = \begin{cases} 1 & \text{if} \quad t < \text{November 2008} \\ 0 & \text{if} \quad t \geq \text{November 2008} \end{cases}$$

$$I_{crisis,t} = \begin{cases} 1 & \text{if} \quad t \in \{\text{November 2008}, \ldots, \text{June 2012}\} \\ 0 & \text{if} \quad t \notin \{\text{November 2008}, \ldots, \text{June 2012}\} \end{cases}$$

$$I_{neg,t} = \begin{cases} 1 & \text{if} \quad t \geq \text{July 2012} \\ 0 & \text{if} \quad t < \text{July 2012} \end{cases} \tag{5}$$

[16] Danmarks Nationalbank's policy rate in Denmark began to decline one month later than the ECB's policy rate in 2008 due to depreciation pressure on the exchange rate of the Danish krone.

Figure 5: *A slowdown in the pass-through of monetary policy took place before negative rates*



Note: Interest rate pass-through within 3 months and 95 per cent uncertainty bands in different time periods estimated in equation (5).

First, we observe a slowdown in pass-through between November 2008 and June 2012 relative to the period before, cf. figure 5. This slow-down is statistically significant and its magnitude is 20 percentage points, cf. table 4. It may in part reflect the fact that the outbreak of the financial crisis marked a sharp turn of the business cycle. Based on a study of US banks, Aliaga-Díaz and Olivero (2010) document that margins in credit markets are countercyclical. Second, we also observe a further slowdown in pass-through of an additional 42 percentage points with the introduction of negative interest rates relative to the period between November 2008 and June 2012. This slowdown is also statistically significant.

Table 4: *Marginal effects of the three time periods are significant*

	pre vs. *crisis*	*pre* vs. *neg*	*crisis* vs. *neg*
Marginal effects	-0.20^{**}	-0.61^{***}	-0.41^{***}
for changes in j	(0.09)	(0.07)	(0.09)
N	3,523		
No. of banks	23		

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. Marginal effects are calculated from an estimation of equation (5) weighted by bank size, as we are interested in the aggregate pass-through of monetary policy (i.e. the average size of the balance sheet during the period), and it includes bank-fixed effects. The significance of the marginal effects is based on joined F-tests of linear combinations of the parameters. Standard errors from the calculations of linear combinations are shown in parentheses. Entities with a banking licence that cannot be classified as traditional banks are excluded. See appendix A for details on data.

3.2 Bank-specific risk exposure and the slowdown in pass-through

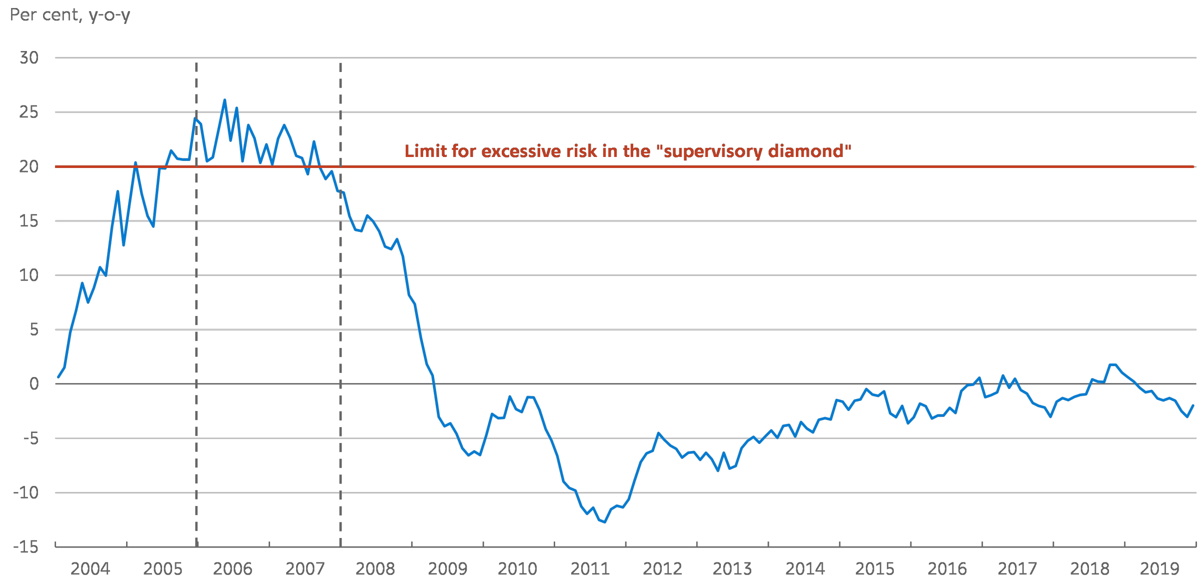
In this section we examine the implications of bank-specific risk for interest rate pass-through. A number of studies have pointed to bank-specific risk exposure as being an important determinant of variation in banks' lending behaviour in the aftermath of the financial crisis (Ivashina and Scharfstein, 2010; Cornett *et al.*, 2011; Jensen and Johannesen, 2017). Specifically, Jensen and Johannesen (2017) use the loan to deposit ratio as a proxy for risk exposure and show that Danish banks with a high loan to deposit ratio before the financial crisis reduced credit growth and raised interest rates to households between 2008-11 relative to banks with a lower loan to deposit ratio.

We use aggregate growth in credit to households and non-financial corporations between ultimo 2005-07 as an instrument for the riskiness of lending portfolios after 2009.[17] This reflects that the years immediately prior to the financial crisis were characterised by excessive risk-taking in the financial sector according to the supervisory diamond of the Danish Financial Supervisory Authority (FSA), cf. figure 6. It has been shown that credit growth before the crisis was a good predictor of distress in the banking sector during the crisis (Rangvid, 2013). Moreover, credit growth through 2006 and 2007 is correlated with the share of loans with credit quality ratings outside of the best category through the

[17] We use credit growth in all currencies to capture excessive risk-taking overall. The finding in this section is robust to restricting credit growth to credit denominated in Danish kroner, see appendix D.8.

crisis as well as with changes in loan impairment charges, cf. figure 7.[18]

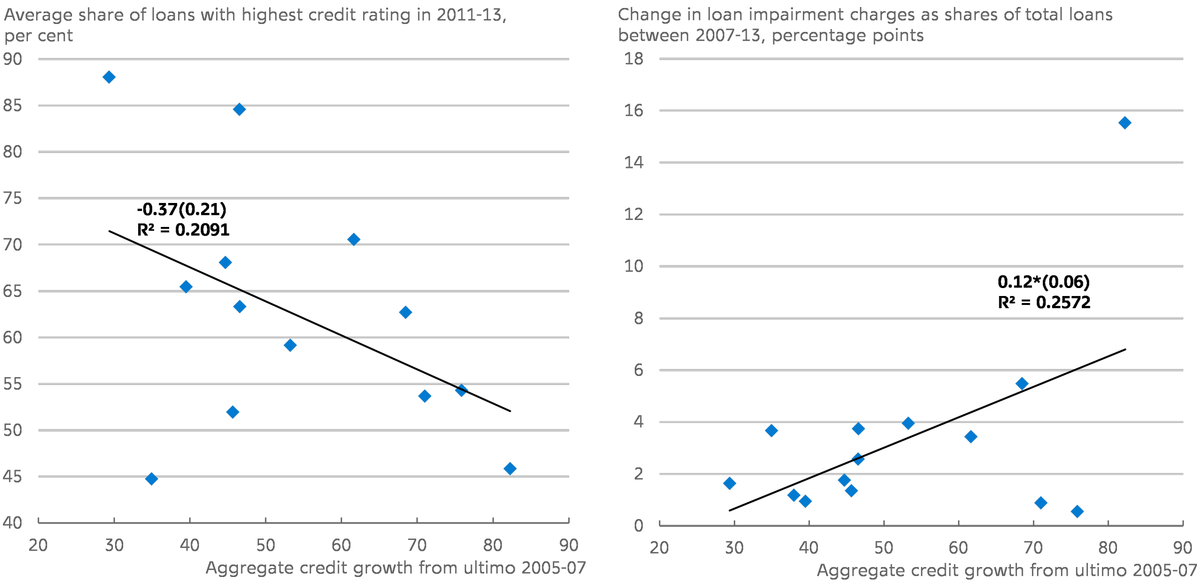
Figure 6: *Bank credit growth peaks between 2006 and 2007*



Note: Annual change in bank credit to households and non-financial corporations. The dotted lines mark the period in which we use credit growth as an instrument for development of risk in the loan port folio during the following crisis. The supervisory diamond was established in 2008 and hence did not restrict credit growth in years prior to that.
Source: Danmarks Nationalbank and the Danish FSA.

[18]Credit quality is measured as credit ratings reported by the banks to the Danish FSA. These are only available from 2011. We look not only at the worst credit rating category, as we seek to understand price setting of the entire loan portfolio. When including 2014 and/or 2015, when the share of loans with the highest credit rating were at its lowest, see figure A.1, the correlation is statistically significant at a 5 per cent level. However, to ensure consistency with the period shown for changes in loan impairment charges, we only include data until 2013 for credit ratings. 2013 is chosen as the peak of loan impairment charges during the European debt crisis and before the beginning of the recovery in the Danish economy. By choosing 2013 and not the peak of the financial crisis in 2009, we are more likely to capture anticipated losses on outstanding loans incorporated in banks' risk assessments, and hence price setting, in light of the experiences in the financial crisis.

Figure 7: *High credit growth before the crisis correlates with lower quality of the loan portfolio through the crisis*

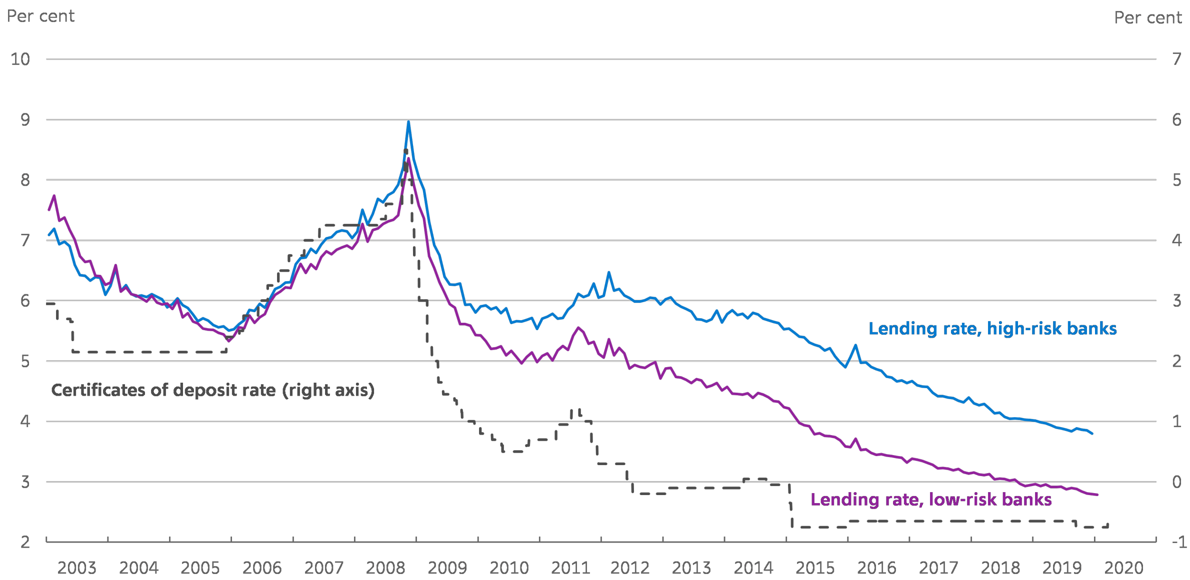


Note: Credit growth is calculated on credit to households and non-financial corporations. Banks with missing observations for credit to households and non-financial corporations in 2005-07, credit ratings in 2011-13 or loan impairment charges in 2007-13 are left out from the figure. Credit ratings are not reported to the Danish FSA by Nordea and Handelsbanken, as they are head-quartered in other countries.
Source: Danmarks Nationalbank and the Danish FSA.

Therefore, we divide the sample into two groups according to whether their total lending growth in the years 2006-07 was above or below the median. We denote the two groups as high-risk banks and low-risk banks, respectively.[19] Lending rates charged by the two groups were almost identical until the end of 2008, cf. figure 8. However, following the financial crisis, banks with a high risk exposure kept lending rates unchanged or even increased them between 2009-14, while banks with a low risk exposure to a larger extent followed the downward trend in the monetary policy rate.

[19]See summary statistics on lending growth before the crisis for the two groups of banks in appendix A.

Figure 8: *Banks with a risky lending portfolio raised lending rates in response to the crisis*



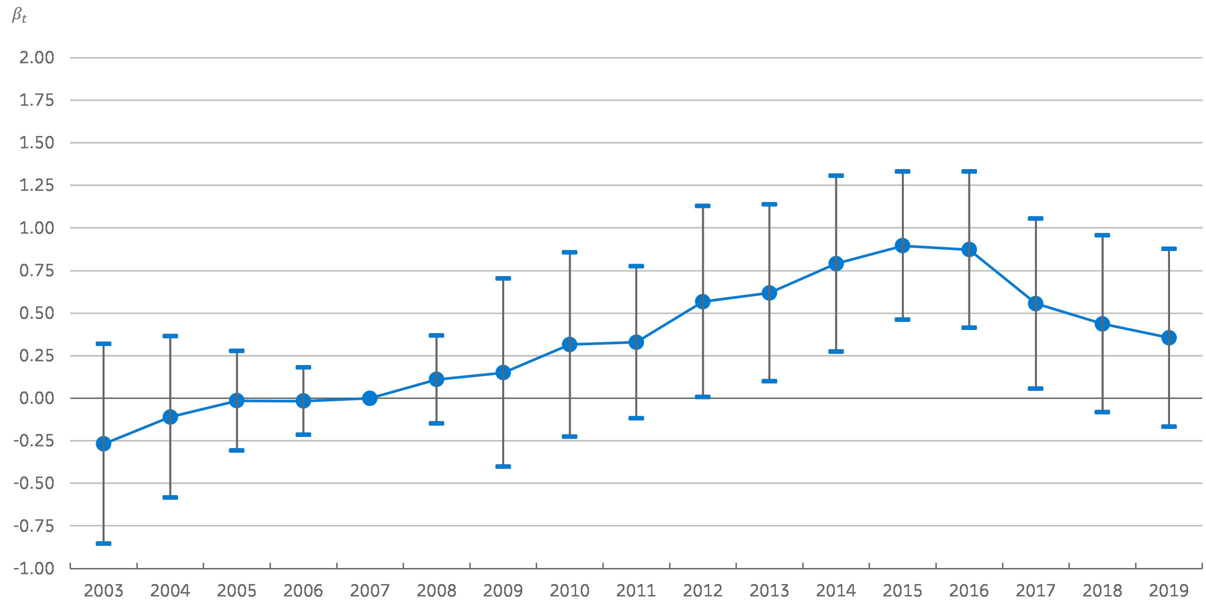
Note: An average of effective lending rates to households and non-financial corporations for banks with a high and low risk exposure. High and low risk exposure is defined as above and below the median growth in lending in 2006 and 2007, i.e. just before the financial crisis.
Source: Danmarks Nationalbank and own calculations.

In order to test whether the lending rates of the two types of banks differ significantly we regress the banks' lending rates on an indicator variable for the banks' risk, $\mathbf{1}_{Highrisk,i}$, which equals 1 for high-risk banks and 0 for low-risk banks approximated by high and low lending growth through 2006-07, interacted with year dummies, δ_t, where $t \in \{2004, \ldots, 2020\}$, i.e.

$$i^b_{i,t} = \alpha + \sum_{t \in T} \beta_t \mathbf{1}_{Highrisk,i} \times \delta_t + \delta_i + \delta_t + \varepsilon_{i,t} \tag{6}$$

The spread between the lending rates of the two types of banks began to increase from 2010 and became significant at a 5 per cent level from 2012. It was widening until 2015 and stayed statistically significant for a number of years despite a recovery of the economy, cf. figure 9. The fact that the spread is still visible illustrates the persistence of the effects from the crisis.

Figure 9: *Risky banks began to catch up around 2015*



Note: Estimates with 95 per cent uncertainty bands from estimating equation (6). Estimates are controlled for bank-fixed effects. High and low risk exposure is defined as above and below the median growth in lending in 2006 and 2007, i.e. just before the financial crisis.

Moreover, in the equation below, we run a diff-in-diff regression for interest rate pass-through where $\mathbf{1}_{Highrisk,i}$ is interacted with a dummy indicating the period from 2010 when the difference in interest rates began to widen as shown in figure 9. The estimates confirm that interest rate pass-through has been lower for high-risk banks after the financial crisis, cf. table 5. In fact, we cannot rule out that pass-through for the risky banks has been zero. Moreover, there was no significant difference between the two groups in terms of pass-through before 2010. These findings are unchanged when including year-fixed effects that capture common trends in credit risk and interest rates, see appendix D.7. Our findings suggest that the slowdown in pass-through measured since the crisis may in part reflect an increase in the credit risk premium for banks with low quality in their lending portfolios.

$$\begin{aligned}\Delta i^b_{i,t} = \alpha + \sum_{k=0}^{2} \beta_k \Delta i^{CB}_{t-k} + \sum_{k=0}^{2} \gamma_k \Delta i^{CB}_{t-k} \times I_{t,t\geq Jan2010} \times \mathbf{1}_{Highrisk,i} + \sum_{k=0}^{2} \psi_{1,k} \Delta i^{CB}_{t-k} \times I_{t,t\geq Jan2010} \\ + \sum_{k=0}^{2} \psi_{2,k} \Delta i^{CB}_{t-k} \times \mathbf{1}_{Highrisk,i} + \psi_3 I_{t,t\geq Jan2010} \times \mathbf{1}_{Highrisk,i} + \theta I_{t,t\geq Jan2010} + \delta_i + \varepsilon_{i,t}\end{aligned} \tag{7}$$

Table 5: Regression shows lower pass-through to risk-exposed banks

Pass-through and marginal effects	
Pass-through of high risk before 2010: $\sum_{k=0}^{2} \hat{\beta}_k + \sum_{k=0}^{2} \hat{\psi}_{2,k}$	0.75^{***}
	(0.02)
Pass-through of low risk before 2010: $\sum_{k=0}^{2} \hat{\beta}_k$	0.71^{***}
	(0.03)
Pass-through of high risk after 2010: $\sum_{k=0}^{2} \hat{\beta}_k + \sum_{k=0}^{2} \hat{\gamma}_k + \sum_{k=0}^{2} \hat{\psi}_{1,k} + \sum_{k=0}^{2} \hat{\psi}_{2,k}$	0.001
	(0.06)
Pass-through of low risk after 2010: $\sum_{k=0}^{2} \hat{\beta}_k + \sum_{k=0}^{2} \hat{\psi}_{1,k}$	0.36^{***}
	(0.03)
Marginal effect of high risk after 2010: $\sum_{k=0}^{2} \hat{\gamma}_k + \sum_{k=0}^{2} \hat{\psi}_{2,k}$	-0.36^{***}
	(0.07)
Diff-in-diff estimate	-0.40^{***}
	(0.08)
N	3,126
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (7) not weighted by bank size, as we are interested in investigating differences across banks. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded. See appendix A for details on data.

4 Discussion

The reversal rate argument hinges on the assumption that cuts in policy rates put pressure on banks' net worth, thereby inducing them to increase lending rates and scale back on lending. However, the earnings of Danish banks have been strong since the introduction of negative rates. While net interest income has declined, this has partly been offset by other sources of income. The integration of banks and mortgage banks has allowed banks as a whole to at least in part make up for the loss in interest income by increasing administration margins imposed on mortgages, cf. Danmarks Nationalbank (2019). Moreover, fee income has increased, impairment charges on loans and guarantees have been very low since 2015 and banks have experienced capital gains. Healthy earnings from sources other than net interest income reduce the likelihood of hitting the reversal rate. The finding that bank profitability has been holding up well in spite of negative policy rates is not unique to Denmark. Based on a panel of more than 5,000 banks from 27 European and Asian countries, Lopez *et al.* (2019) conclude that negative rates have had benign implications for bank profitability.

According to Brunnermeier and Koby (2019), the reversal rate creeps up over time as the initial impact of the revaluation of banks' assets fades out, while net interest income stays low. However, the impact of negative policy rates on bank earnings, and hence the level of the reversal rate, will depend on how deposit rates respond. In August 2019, Jyske Bank became the first Danish bank to announce that it would impose negative rates on household deposits above a certain threshold with effect from December that same year. Since then a number of other banks have followed suit. A relaxation of the zero lower bound on deposit rates would reduce the negative impact of negative policy rates on banks' interest income, thereby reducing the likelihood of hitting the reversal rate.

The way banks respond to negative policy rates is likely to reflect local financial market conditions. Denmark is characterised by having a large mortgage credit sector which does not take deposits. As the key component of lending rates in the mortgage credit sector is determined in financial markets, they have been gradually declining in line with other market rates. This may in itself have induced banks to reduce lending rates to stay competitive. The banks' response may also depend on how negative policy rates are implemented. Some central banks have introduced a tiered system in which part of the banks' reserves in the central bank is exempt from negative rates. In future research it would be interesting to study the implications of tiering and how banks respond to changes in the exemption threshold.

The findings in the second part of this paper suggest that the initial slowdown in monetary policy transmission following the financial crisis might at least in part reflect a re-assessment of the riskiness of banks' lending portfolios and an increase in the required compensation for risk. The change in pass-through after 2008 may also mask a change in the composition of bank lending. Following the financial crisis, households as well as firms have substituted bank lending for mortgage lending. Mortgage banks only extend credit against collateral in buildings. This would suggest that some of the highest quality credit has transferred from deposit banks to mortgage banks, ceteris paribus reducing the average quality of outstanding bank credit and leading to higher lending rates.

If the observed reduction in pass-through from policy rates to lending rates following the financial crisis reflects a re-assessment of the riskiness of loan portfolios or an increase in the required compensation for risk, it may be temporary. Once risk premia have adjusted to post-crisis levels, pass-through of new policy rate changes might have been back to its post-crisis level in the absence of new events such as the introduction of negative policy rates. Interactions between risk-related factors and the degree of pass-through to lending rates could be assessed by taking into account developments in the spread between lending rates and the risk-free rate. However, changes in this spread may also reflect other factors, such as the degree of competition in the banking sector.

5 Conclusion

The introduction of negative policy rates in a number of countries has sparked a debate about their implications for the economy. In particular, the notion of a so-called reversal rate has attracted attention. The reversal rate is a theoretical concept at which the pass-through of monetary policy reverses course, and further cuts in the policy rate lead to higher bank lending rates and lower credit growth. This paper searches for evidence of a reversal rate based on a sample of Danish banks.

The key Danish monetary policy rate has been negative since July 2012 with the exception of a few months in 2014. During this period, banks have been hesitant to lower interest rates on household deposits into negative territory, and pass-through to lending rates has slowed significantly. However, we find no evidence of a reversal rate at which Danish banks have increased lending rates or reduced lending in response to cuts in the policy rate. This is the case even for banks with a relatively high share of household deposits. We also show that the slowdown in transmission associated with the introduction of negative policy rates was preceded by a slowdown around the time of the financial crisis. The slowdown was particularly pronounced for banks which experienced rapid lending growth immediately prior to the crisis, suggesting that it is linked to an increase in the required compensation for risk.

Literature

ADOLFSEN, J. F. and PEDERSEN, J. (2019). The natural real interest rate in Denmark has declined. Danmarks Nationalbank Analysis, No. 13.

ALIAGA-DÍAZ, R. and OLIVERO, M. P. (2010). Is there a financial Accelerator in US banking? Evidence from the cyclicality of banks' price-cost margins. *Economics Letters*, **108** (2), 167–171.

ALTAVILLA, C., BURLON, L., GIANNETTI, M. and HOLTON, S. (2019). Is there a zero lower bound? The effects of negative policy rates on banks and firms. ECB Working Paper Series, No. 2289.

BOTTERO, M., MINOIU, C., PEYDRO, J.-L., POLO, A., PRESBITERO, A. F. and SETTE, E. (2019). Negative Monetary Policy Rates and Portfolio Rebalancing: Evidence from Credit Register Data. IMF Working Paper, 19/44.

BRAND, C., BIELECKI, M. and PENAVLER, A. (2018). The natural rate of interest: estimates, drivers, and challenges to monetary policy,. ECB Occasional Paper Series, No. 217.

BRUNNERMEIER, M. K. and KOBY, Y. (2019). The Reversal Interest Rate. unpublished manuscript, Princeton University.

CORNETT, M. M., MCNUTT, J. J., STRAHAN, P. E. and TEHRANIAN, H. (2011). Liquidity risk management and credit supply in the financial crisis. *Journal of Financial Economics*, **101** (2), 297–312.

DANMARKS NATIONALBANK (2019). Lower excess capital adequacy for the banks. Danmarks Nationalbank Analysis (Financial Stability), No. 25.

DEMIRALP, S., EISENSCHMIDT, J. and VLASSOPOULOS, T. (2019). Negative interest rates, excess liquidity and retail deposits: banks' reaction to unconventional monetary policy in the euro area. ECB Working Paper Series, No. 2283.

DREJER, P. A., KOCH, M. C., RASMUSSEN, M. H., SPANGE, M. and SØRENSEN, S. V. (2011). The effects of monetary policy in Denmark. Danmarks Nationalbank, Monetary Review, Part 2, p. 1-66.

EGGERTSSON, G. B., JUELSRUD, R. E., SUMMERS, L. H. and WOLD, E. G. (2019). Negative nominal interest rates and the bank lending channel. Norges Bank Working Paper 2019-4.

Eisenschmidt, J. and Smets, F. (2018). Negative interest rates: Lessond from the euro area. In Álvaro Aguirre, M. Brunnermeier and D. Saravia (eds.), *Monetary policy and Financial stability: Transmission mechanisms and policy implications*, *Central Banking, Analysis, and Economic Policies Book Series*, vol. 26, *2*, Central Bank of Chile, pp. 13–42.

Erikson, H. and Vestin, D. (2019). Pass-through at Mildly Negative Policy Rates: The Swedish Case. Sveriges Riksbank, Staff memo.

Heider, F., Saidi, F. and Schepens, G. (2018). Life below zero: Bank lending under negative policy rates. ECB Working Paper Series, No. 2173.

Holston, K., Laubach, T. and Williams, J. C. (2017). Measuring the Natural Rate of Interest: International Trends and Determinants. *Journal of International Economics*, **108**, 59–75, supplement 1.

Ivashina, V. and Scharfstein, D. (2010). Bank Lending During the Financial Crisis of 2008. *Journal of Financial Economics*, **97** (3), 319–38.

Jensen, T. L. and Johannesen, N. (2017). The Consumption Effects of the 2007-2008 Financial Crisis: Evidence from Households in Denmark. *American Economic Review*, **107** (11), 3386–3414.

Lane, P. R. (2019). Monetary Policy and Below-Target Inflation. speech at the Bank of Finland conference on monetary Policy and future of EMU.

Lopez, J. A., Rose, A. K. and Spiegel, M. M. (2019). Why Have Negative Nominal Interest Rates Had Such a Small Effect on Bank Performance? Cross Country Evidence. unpublished manuscript.

Madaschi, C. and Nuevo, I. P. (2017). The profitability of banks in a context of negative monetary policy rates: the cases of Sweden and Denmark. ECB Occasional Paper Series, No. 195.

Rangvid, J. (2013). The financial crisis in Denmark - causes, consequences and lessons. Ministry of Industry, Business and Financial Affairs, report.

Tan, G. (2019). Beyond the zero lower bound: negative policy rates and bank lending. De Nederlandsche Bank Working Paper No. 649.

Appendix

A Data

The dataset comprises individual banks with a banking licence in Denmark and covers January 2003 to January 2020. It is unbalanced, as some banks have not reported figures in all months for various reasons, e.g. default or mergers with other banks. Interest rates, lending and deposit volumes as well as liabilities are based on monthly MFI reporting of the banks. We restrict loans and deposits to loans and deposits in Danish kroner, as these are relevant for measuring the pass-through of interest rates set by Danmarks Nationalbank. The household sector is sector 1400 and the sector of non-financial corporations is sector 1100 in the MFI statistics.

MFI data has been enriched by monthly data for outstanding reserves held with Danmarks Nationalbank in the form of certificates of deposit, current account balances and weekly loans as well as by Danmarks Nationalbank's official policy rates. Moreover, annual numbers from the banks' income statements have been merged with the dataset. Lastly, dummies for bank mergers have been added based on the list of FinansDanmark.[20]

We have improved data quality in the following steps:

- Interest rates outside the range of $[-2; 20]$ have been replaced by missing values.
- Negative deposit and lending volumes have been replaced by missing values.
- Banks that do not or only to a very limited extent offer traditional banking services in terms of deposit accounts and lending have been excluded. This includes leasing banks that are a part of a business group with its main business in another business area, e.g. Scania Finans, and banks that primarily rely on investment banking as their business model, e.g. Saxo Bank.
- Banks with limited traditional banking business in Denmark have been excluded, e.g. BNP Paribas Denmark. The remaining foreign-based banks are the Danish affiliates of Nordea and Handelsbanken.
- We exclude observations for Sparekassen Sjælland-Fyn in November and December 2015 and Handelsbanken before October 2003 as they are extreme outliers for different reasons. Amagerbanken is excluded after 2007, as it encountered severe

[20]See https://finansdanmark.dk/toerre-tal/fusioner/. Some mergers appear later in the data than the official date of the merger due to inconsistencies between the official dates and statistical reporting. Therefore, we have adjusted the dummy variables for mergers to match the statistical dates. A full list of merger dates is available on request.

difficulties and was eventually taken over by Finansiel Stabilitet (i.e. a shareholder bank owned by the Danish state) in the financial crisis.

After cleaning of data, the sample contains 23 banks, cf. table A.1.

Table A.1: *Banks in the sample*

Register Code	Bank
400	Lån & Spar Bank
522	Sparekassen Sjælland-Fyn
880	Handelsbanken
2222	Nordea Bank
3000	Danske Bank
5201	Amagerbanken
5301	Arbejdernes Landsbank
5470	Forstædernes Bank
5999	Danske Andelskassers Bank
6503	Bank Nordik
7440	Nørresundby Bank
7670	Ringkjøbing Landbobank
7681	Alm. Brand Bank
7730	Vestjysk Bank
7858	Jyske Bank
8079	Sydbank
8117	Nykredit Bank
9070	Sparekassen Vendsyssel
9217	Jutlander Bank
9335	Sparekassen Kronjylland
9380	Spar Nord Bank
9686	Den Jyske Sparekasse
12000	Sammenslutningen af Danske Andelskasser

Summary statistics on household deposit shares in August 2011 and total lending growth through 2006 and 2007, which are used to define the dummies in section 2.1 and 3.2 respectively, are shown in table A.2 and A.3

Table A.2: *Household deposit shares in August 2011*

	Mean	Std. Dev.	No. of banks	Minimum	Median	Maximum
Banks with low deposit shares	25.63	9.53	9	12.02	29.38	37.10
Banks with high deposit shares	51.25	9.67	9	37.72	53.55	68.68
Total	38.44	16.14	18	12.02	37.41	68.68

Table A.3: *Total lending growth through 2006 and 2007*

	Mean	Std. Dev.	No. of banks	Minimum	Median	Maximum
Banks with low pre-crisis lending growth	37.40	7.02	9	24.29	37.96	45.68
Banks with high pre-crisis lending growth	65.41	14.20	9	46.58	68.48	83.00
Total	51.41	18.05	18	24.29	46.13	83.00

B Estimation output

Table A.4: *Estimation of equation (2)*

	Estimate
Δi_t^{CB}	0.45^{***}
	(0.04)
Δi_{t-1}^{CB}	0.18^{***}
	(0.04)
Δi_{t-2}^{CB}	0.07
	(0.05)
$\Delta i_t^{CB} \times I_t^{neg} \times \mathbf{1}_{Highdeposit,i}$	0.04
	(0.14)
$\Delta i_{t-1}^{CB} \times I_t^{neg} \times \mathbf{1}_{Highdeposit,i}$	-0.13
	(0.21)
$\Delta i_{t-2}^{CB} \times I_t^{neg} \times \mathbf{1}_{Highdeposit,i}$	0.05
	(0.15)
$\Delta i_t^{CB} \times I_t^{neg}$	-0.36^{***}
	(0.11)
$\Delta i_{t-1}^{CB} \times I_t^{neg}$	0.01
	(0.15)
$\Delta i_{t-2}^{CB} \times I_t^{neg}$	-0.14
	(0.10)
$\Delta i_t^{CB} \times \mathbf{1}_{Highdeposit,i}$	0.04
	(0.08)
$\Delta i_{t-1}^{CB} \times \mathbf{1}_{Highdeposit,i}$	0.03
	(0.09)
$\Delta i_{t-2}^{CB} \times \mathbf{1}_{Highdeposit,i}$	-0.12^{*}
	(0.06)
$I_t^{neg} \times \mathbf{1}_{Highdeposit,i}$	-0.01^{**}
	(0.006)
I_t^{neg}	-0.03^{***}
	(0.003)
Constant	0.01^{***}
	(0.001)
N	3,176
No. of banks	18

$^{***}\ p < 0.01$; $^{**}\ p < 0.05$; $^{*}\ p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (2) not weighted by bank size, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.5: *Estimation of equation (3)*

	1-month change in lending	3-month change in lending	6-month change in lending	12-month change in lending
I_t^{neg}	0.004	0.003	-0.01	-0.06^{**}
	(0.005)	(0.01)	(0.01)	(0.02)
$I_t^{neg} \times Depositshare_i$	0.009	0.03^{**}	0.07^{**}	0.12^{**}
	(0.005)	(0.01)	(0.02)	(0.05)
Constant	0.01^{*}	0.02	0.04	0.12^{***}
	(0.005)	(0.02)	(0.03)	(0.04)
N	3,216	3,182	3,131	3,026
No. of banks	18	18	18	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (3) not weighted by bank size, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.6: *Estimation of equation (4)*

	1-month change in lending	3-month change in lending	6-month change in lending	12-month change in lending
I_t^{neg}	0.01	0.02	0.01	-0.01
	(0.01)	(0.02)	(0.02)	(0.02)
$I_t^{neg} \times \mathbf{1}_{Highdeposit,i}$	-0.001	-0.001	-0.001	-0.006
	(0.003)	(0.009)	(0.02)	(0.04)
Constant	0.01^{*}	0.02	0.04	0.13^{**}
	(0.005)	(0.02)	(0.03)	(0.04)
N	3,216	3,182	3,131	3,026
No. of banks	18	18	18	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (4) not weighted by bank size, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.7: *Estimation of equation (5)*

	Estimate
Δi_t^{CB}	0.51^{***}
	(0.05)
Δi_{t-1}^{CB}	0.21^{***}
	(0.04)
Δi_{t-2}^{CB}	0.18^{**}
	(0.08)
$\Delta i_t^{CB} \times I_{crisis,t}$	-0.07
	(0.07)
$\Delta i_{t-1}^{CB} \times I_{crisis,t}$	0.03
	(0.06)
$\Delta i_{t-2}^{CB} \times I_{crisis,t}$	-0.16^{***}
	(0.05)
$\Delta i_t^{CB} \times I_{neg,t}$	-0.27^{***}
	(0.07)
$\Delta i_{t-1}^{CB} \times I_{neg,t}$	-0.15^{***}
	(0.05)
$\Delta i_{t-2}^{CB} \times I_{neg,t}$	-0.20^{***}
	(0.06)
$I_{crisis,t}$	0.04^{***}
	(0.01)
$I_{neg,t}$	0.003
	(0.004)
Constant	-0.02^{***}
	(0.002)
N	3,523
No. of banks	23

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (5) weighted by bank size, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.8: *Estimation of equation (6)*

	Estimate
$2003 \times \mathbf{1}_{Highrisk,i}$	-0.27
	(0.28)
$2004 \times \mathbf{1}_{Highrisk,i}$	-0.11
	(0.22)
$2005 \times \mathbf{1}_{Highrisk,i}$	-0.01
	(0.14)
$2006 \times \mathbf{1}_{Highrisk,i}$	-0.02
	(0.09)
$2008 \times \mathbf{1}_{Highrisk,i}$	0.11
	(0.12)
$2009 \times \mathbf{1}_{Highrisk,i}$	0.15
	(0.26)
$2010 \times \mathbf{1}_{Highrisk,i}$	0.32
	(0.26)
$2011 \times \mathbf{1}_{Highrisk,i}$	0.33
	(0.21)
$2012 \times \mathbf{1}_{Highrisk,i}$	0.57^{**}
	(0.27)
$2013 \times \mathbf{1}_{Highrisk,i}$	0.62^{**}
	(0.25)
$2014 \times \mathbf{1}_{Highrisk,i}$	0.79^{***}
	(0.24)
$2015 \times \mathbf{1}_{Highrisk,i}$	0.90^{***}
	(0.21)
$2016 \times \mathbf{1}_{Highrisk,i}$	0.87^{***}
	(0.22)
$2017 \times \mathbf{1}_{Highrisk,i}$	0.56^{**}
	(0.24)
$2018 \times \mathbf{1}_{Highrisk,i}$	0.44^{*}
	(0.25)
$2019 \times \mathbf{1}_{Highrisk,i}$	0.36
	(0.25)
$2020 \times \mathbf{1}_{Highrisk,i}$	0.51^{*}
	(0.25)
N	3,184
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (6) not weighted by bank size, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.9: *Estimation of equation (7)*

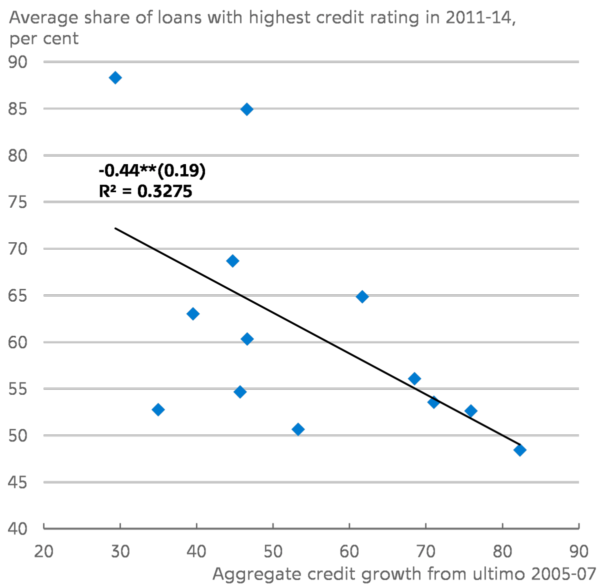
	Estimate
Δi_t^{CB}	0.45***
	(0.06)
Δi_{t-1}^{CB}	0.17***
	(0.04)
Δi_{t-2}^{CB}	0.10
	(0.06)
$\Delta i_t^{CB} \times I_{t,t\geq Jan2010} \times \mathbf{1}_{Highrisk,i}$	−0.50***
	(0.12)
$\Delta i_{t-1}^{CB} \times I_{t,t\geq Jan2010} \times \mathbf{1}_{Highrisk,i}$	0.20
	(0.19)
$\Delta i_{t-2}^{CB} \times I_{t,t\geq Jan2010} \times \mathbf{1}_{Highrisk,i}$	−0.10
	(0.12)
$\Delta i_t^{CB} \times I_{t,t\geq Jan2010}$	−0.05
	(0.06)
$\Delta i_{t-1}^{CB} \times I_{t,t\geq Jan2010}$	−0.18
	(0.10)
$\Delta i_{t-2}^{CB} \times I_{t,t\geq Jan2010}$	−0.12
	(0.07)
$\Delta i_t^{CB} \times \mathbf{1}_{Highrisk,i}$	0.08
	(0.07)
$\Delta i_{t-1}^{CB} \times \mathbf{1}_{Highrisk,i}$	0.04
	(0.08)
$\Delta i_{t-2}^{CB} \times \mathbf{1}_{Highrisk,i}$	−0.08
	(0.08)
$I_{t,t\geq Jan2010} \times \mathbf{1}_{Highrisk,i}$	−0.01
	(0.01)
$I_{t,t\geq Jan2010}$	−0.01*
	(0.01)
Constant	0.0002
	(0.002)
N	3,126
No. of banks	18

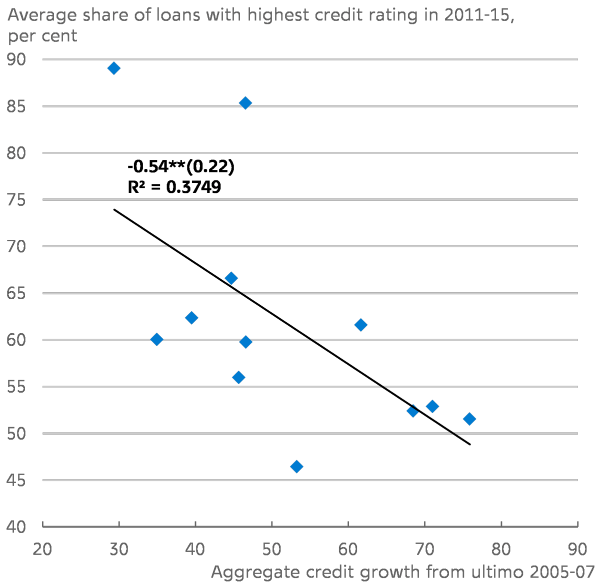
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (7) not weighted by bank size, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded.

C Correlations between lending growth before the crisis and credit quality

Figure A.1: *Correlation between credit growth before the crisis and credit quality when including 2014 (left) and 2015 (right)*





Note: Credit growth is calculated on credit to households and non-financial corporations. Credit ratings are not reported to the Danish FSA by Nordea and Handelsbanken, as they are head-quartered in other countries.
Source: Danmarks Nationalbank and the Danish FSA.

D Robustness

D.1 Using a weighted monetary policy rate based on bank-specific reserves in Danmarks Nationalbank

Table A.10: *Pass-through from estimation of equation (1)*

	i_t^b: Households and corporates (weighted average)	i_t^b: Households	i_t^b: Corporates
Pass-through before: $\sum_{k=0}^{2} \hat{\beta}_k$	0.67***	0.73***	0.61***
	(0.04)	(0.02)	(0.09)
Pass-through after: $\sum_{k=0}^{2} \hat{\beta}_k + \sum_{k=0}^{2} \hat{\gamma}_k$	0.26***	0.26***	0.18*
	(0.04)	(0.07)	(0.09)
N	3,073	3,073	3,073
No. of banks	21	21	21

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to August 2018, as we only have data on bank-specific reserves until August 2018, and it covers large and medium-sized banks in Denmark. The regression is an estimation of equation (1), but with a bank-specific monetary policy rate based on the banks' shares of reserves in current account deposits and certificates of deposits, which are subject to different interest rates. The estimation is weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.11: *Marginal effects of a high deposit share, estimation of equation (2)*

Marginal effects	
Before: $\sum_{k=0}^{2}\hat{\psi}_{2,k}$	-0.03
	(0.04)
After: $\sum_{k=0}^{2}\hat{\gamma}_k + \sum_{k=0}^{2}\hat{\psi}_{2,k}$	-0.08
	(0.20)
Diff-in-diff estimate	-0.05
	(0.19)
N	2,815
No. of banks	17

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to August 2018, as we only have data on bank-specific reserves until August 2018, and it covers large and medium-sized banks in Denmark. The regression is an estimation of equation (2), but with a bank-specific monetary policy rate based on the banks' shares of reserves in current account deposits and certificates of deposits, which are subject to different interest rates. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.12: *Marginal effects of the three time periods, estimation of equation (5)*

	pre vs. *crisis*	*pre* vs. *neg*	*crisis* vs. *neg*
Marginal effects	-0.21^{**}	-0.62^{***}	-0.41^{***}
for changes in j	(0.09)	(0.07)	(0.05)
N	3,073		
No. of banks	21		

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to August 2018, as we only have data on bank-specific reserves until August 2018, and it covers large and medium-sized banks in Denmark. The regression is an estimation of equation (5), but with a bank-specific monetary policy rate based on the banks' shares of reserves in current account deposits and certificates of deposits, which are subject to different interest rates. The estimation is weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.13: *Marginal effects of high risk exposure, estimation of equation (7)*

Marginal effects	
Marginal effect of high risk after 2010: $\sum_{k=0}^{2} \hat{\gamma}_k + \sum_{k=0}^{2} \hat{\psi}_{2,k}$	-0.29^{***}
	(0.10)
Diff-in-diff estimate	-0.34^{***}
	(0.10)
N	2,787
No. of banks	17

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to August 2018, as we only have data on bank-specific reserves until August 2018, and it covers large and medium-sized banks in Denmark. The regression is an estimation of equation (7), but with a bank-specific monetary policy rate based on the banks' shares of reserves in current account deposits and certificates of deposits, which are subject to different interest rates. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

D.2 Using the short-term money market rate

Table A.14: *Pass-through from estimation of equation (1)*

	i_t^b: Households and corporates (weighted average)	i_t^b: Households	i_t^b: Corporates
Before: $\sum_{k=0}^{2}\hat{\beta}_k$	0.59***	0.64***	0.54***
	(0.03)	(0.01)	(0.08)
After: $\sum_{k=0}^{2}\hat{\beta}_k + \sum_{k=0}^{2}\hat{\gamma}_k$	0.31***	0.34***	0.20***
	(0.05)	(0.06)	(0.06)
N	3,508	3,510	3,510
No. of banks	23	23	23

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (1), but with the 1-month money market rate replacing the monetary policy rate. The estimation is weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.15: *Marginal effects of a high deposit share, estimation of equation (2)*

Marginal effects	
Before: $\sum_{k=0}^{2} \hat{\psi}_{2,k}$	-0.02
	(0.43)
After: $\sum_{k=0}^{2} \hat{\gamma}_k + \sum_{k=0}^{2} \hat{\psi}_{2,k}$	-0.17
	(0.10)
Diff-in-diff estimate	-0.14
	(0.11)
N	3,163
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (2), but with the 1-month money market rate replacing the monetary policy rate. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.16: *Marginal effects of the three time periods, estimation of equation (5)*

	pre vs. *crisis*	*pre* vs. *neg*	*crisis* vs. *neg*
Marginal effects	-0.25^{*}	-0.52^{***}	-0.27^{**}
for changes in j	(0.12)	(0.08)	(0.11)
N	3,508		
No. of banks	23		

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (5), but with the 1-month money market rate replacing the monetary policy rate. The estimation is weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.17: *Marginal effects of high risk exposure, estimation of equation (7)*

Marginal effects	
Marginal effect of high risk after 2010: $\sum_{k=0}^{2}\hat{\gamma}_k + \sum_{k=0}^{2}\hat{\psi}_{2,k}$	-0.29^{***}
	(0.09)
Diff-in-diff estimate	-0.37^{***}
	(0.10)
N	3,111
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (7), but with the 1-month money market rate replacing the monetary policy rate. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

D.3 Using only 1 lag

Table A.18: *Pass-through from estimation of equation (1)*

	i_t^b: Households and corporates (weighted average)	i_t^b: Households	i_t^b: Corporates
Before: $\sum_{k=0}^{1}\hat{\beta}_k$	0.66^{***}	0.72^{***}	0.60^{***}
	(0.06)	(0.02)	(0.13)
After: $\sum_{k=0}^{1}\hat{\beta}_k + \sum_{k=0}^{1}\hat{\gamma}_k$	0.34^{***}	0.44^{***}	0.17^{**}
	(0.03)	(0.05)	(0.06)
N	3,547	3,549	3,549
No. of banks	23	23	23

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (1), but with 1 lag of the monetary policy rate. The estimation is weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.19: *Marginal effects of a high deposit share, estimation of equation (2)*

Marginal effects	
Before: $\sum_{k=0}^{1} \hat{\psi}_{2,k}$	-0.004
	(0.04)
After: $\sum_{k=0}^{1} \hat{\gamma}_k + \sum_{k=0}^{1} \hat{\psi}_{2,k}$	-0.04
	(0.08)
Diff-in-diff estimate	-0.04
	(0.08)
N	3,195
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (2), but with 1 lag of the monetary policy rate. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.20: *Marginal effects of the three time periods, estimation of equation (5)*

	pre vs. *crisis*	*pre* vs. *neg*	*crisis* vs. *neg*
Marginal effects	-0.11	-0.50^{***}	-0.39^{***}
for changes in j	(0.07)	(0.08)	(0.09)
N	3,547		
No. of banks	23		

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (5), but with 1 lag of the monetary policy rate. The estimation is weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.21: *Marginal effects of high risk exposure, estimation of equation (7)*

Marginal effects	
Marginal effect of high risk after 2010: $\sum_{k=0}^{1}\hat{\gamma}_k + \sum_{k=0}^{1}\hat{\psi}_{2,k}$	-0.25^{***}
	(0.06)
Diff-in-diff estimate	-0.32^{***}
	(0.07)
N	3,145
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (7), but with 0 and 1 lag of the monetary policy rate. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

D.4 Restricting attention to cuts in the policy rate

Table A.22: *Pass-through of negative changes in the monetary policy rate from estimation of equation (1)*

Pass-through at negative rates:	
With 2 lags	0.03
	(0.06)
With 1 lag	0.34^{***}
	(0.04)
N	3,547
No. of banks	23

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (1), but with an interaction for cuts in the monetary policy rate. The estimation is weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

D.5 Restricting estimation period to begin in January 2010

Table A.23: *Impact of a high deposit share on lending growth at negative rates from estimation of equation (3) and (4)*

	1-month change in lending	3-month change in lending	6-month change in lending	12-month change in lending
$I_t^{neg} \times Depositshare_i$	0.01	0.02	0.03	0.03
	(0.01)	(0.02)	(0.03)	(0.07)
$I_t^{neg} \times \mathbf{1}_{Highdeposit,i}$	−0.001	−0.01	−0.02	−0.05
	(0.003)	(0.007)	(0.01)	(0.03)
N	1,957	1,955	1,952	1,946
No. of banks	18	18	18	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2010 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (3) and (4) not weighted by bank size, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded.

D.6 Large sample, including small banks

Table A.24: *Impact of a high deposit share on lending growth at negative rates from estimation of equation (3) and (4)*

	12-month change in lending
$I_t^{neg} \times Depositshare_i$	0.06
	(0.06)
$I_t^{neg} \times \mathbf{1}_{Highdeposit,i}$	0.05*
	(0.03)
N	530
No. of banks	40

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from 2003 to 2018 and covers all banks in Denmark. The regression is an estimation of equation (3) and (4), but on a larger dataset with annual observations. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors reported in parentheses are clustered on banks. Entities with a banking licence that cannot be classified as traditional banks are excluded in line with the same principles as for the smaller dataset. This leaves 40 banks in total.

D.7 Inclusion of year dummies

Table A.25: *Marginal effects of a high deposit share, estimation of equation (2)*

Marginal effects	
Before: $\sum_{k=0}^{2} \hat{\psi}_{2,k}$	-0.06
	(0.04)
After: $\sum_{k=0}^{2} \hat{\gamma}_k + \sum_{k=0}^{1} \hat{\psi}_{2,k}$	-0.09
	(0.08)
Diff-in-diff estimate	-0.03
	(0.09)
N	3,176
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (2), but with year-fixed effects. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

Table A.26: *Marginal effects of high risk exposure, estimation of equation (7)*

Marginal effects	
Marginal effect of high risk after 2010: $\sum_{k=0}^{2} \hat{\gamma}_k + \sum_{k=0}^{2} \hat{\psi}_{2,k}$	-0.35^{***}
	(0.06)
Diff-in-diff estimate	-0.38^{***}
	(0.08)
N	3,126
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (7), but with year-fixed effects. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

D.8 Using only pre-crisis lending in DKK as an indicator of high risk

Table A.27: *Marginal effects of high risk exposure, estimation of equation (7)*

Marginal effects	
Marginal effect of high risk after 2010: $\sum_{k=0}^{1} \hat{\gamma}_k + \sum_{k=0}^{1} \hat{\psi}_{2,k}$	-0.29^{***}
	(0.09)
Diff-in-diff estimate	-0.35^{***}
	(0.10)
N	3,126
No. of banks	18

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Note: Data is from January 2003 to January 2020 and covers large and medium-sized banks in Denmark. The regression is an estimation of equation (7), but with lending growth only in DKK denominated credit through 2006 and 2007. The estimation is not weighted by bank size, and it includes bank-fixed effects. Standard errors from the estimation are clustered on banks. The significance of the linear combinations of parameters is determined through joined F-tests. Entities with a banking licence that cannot be classified as traditional banks are excluded.

PUBLICATIONS

NEWS

News offers a quick and accessible insight into an Analysis, an Economic Memo, a Working Paper or a Report from Danmarks Nationalbank. News is published continuously.

ANALYSIS

Analysis from Danmarks Nationalbank focuses on economic and financial matter. Some of the analyses are published with a regular frequency e.g. *Outlook for the Danish economy and Financial stability*. Other analyses are published continuously.

REPORT

Report comprises recurring reports and reviews of the functioning of Danmarks Nationalbank. For instance Report includes the *Annual report* and the annual publication *Danish government borrowing and debt.*

ECONOMIC MEMO

Economic Memo is a cross between Analysis and Working Paper and it often shows the ongoing study of the authors. The publication series is primarily targeted at professionals and is solely available in English. Economic Memo is published continuously.

WORKING PAPER

Working Paper presents research projects by economists in Danmarks Nationalbank and their associates. The series is primarily targeted at professionals and people with an interest for academia. Working Paper is published continuously.

DANMARKS NATIONALBANK
HAVNEGADE 5
DK-1093 COPENHAGEN K
WWW.NATIONALBANKEN.DK

DANMARKS NATIONALBANK