FEDERAL RESERVE BANK OF SAN FRANCISCO

WORKING PAPER SERIES

The Transmission of Negative Nominal Interest Rates in Finland

Simon Kwan
Federal Reserve Bank of San Francisco

Mauricio Ulate
Federal Reserve Bank of San Francisco

Ville Voutilainen
Bank of Finland

April 2023

Working Paper 2023-11

https://www.frbsf.org/economic-research/publications/working-papers/2023/11/

Suggested citation:

Kwan, Simon, Mauricio Ulate, Ville Voutilainen. 2023 "The Transmission of Negative Nominal Interest Rates in Finland," Federal Reserve Bank of San Francisco Working Paper 2023-11. https://doi.org/10.24148/wp2023-11

The Transmission of Negative Nominal Interest Rates in Finland*

Simon Kwan Mauricio Ulate Ville Voutilainen

April 2023

Despite the implementation of negative nominal interest rates by several advanced economies in the last decade and the many papers that have been written about this novel policy tool, there is still much we do not know about the effectiveness of this instrument. The pass-through of negative policy rates to loan rates is one of the main points of contention. In this paper, we analyze the pass-through of the ECB's changes in the deposit facility rate to mortgage rates in Finland between 2005 and 2020. We use monthly data and three different empirical methodologies: correlational event studies, high-frequency identification, and exposure-measure regressions. We provide robust evidence that there continues to be pass-through of a cut in the policy rate to mortgage rates even when the policy rate is in negative territory, but that this pass-through is smaller than when the policy rate is in positive territory. The evidence in this paper contrasts with some previous studies and provides moments that can be useful to discipline theoretical negative-rates models.

*Simon Kwan and Mauricio Ulate: Federal Reserve Bank of San Francisco, Ville Voutilainen: Bank of Finland. We thank Cynthia Balloch and Botao Wu for useful comments and suggestions. Any opinions and conclusions expressed herein are those of the authors and do not necessarily represent the views of the Bank of Finland, the Federal Reserve Bank of San Francisco, the Eurosystem, or the Federal Reserve System.

1 Introduction

Ever since the Great Financial Crisis of 2008-2009, monetary-policy makers in many advanced economies have lowered their main policy interest rate to the vicinity of zero percent in order to stimulate economic activity. To confront a perceived zero lower bound on the monetary policy rate, central banks expanded their tool set to experiment with unconventional approaches, including negative nominal interest rates, quantitative easing, and forward guidance. Among these unconventional tools, negative policy rates hold a special significance because, if they worked effectively, then the other unconventional policies might not even be necessary under most circumstances.

Despite their implementation in Europe and Japan, questions remain regarding the effectiveness of negative nominal interest rates and their transmission to the financial system and the real economy. While there appears to be some consensus on the transmission of negative rates to bond rates and deposit rates, their transmission to lending interest rates is much less clear.[1] As discussed in Balloch, Koby, and Ulate (2022), while a slight majority of papers in the negative-rates literature has found that cuts in the policy rate in negative territory still pass through to different types of loan rates, significant disagreement remains.[2] Eggertsson et al. (2019), for instance, argues that cuts in the policy rate in negative territory do not pass through to mortgage rates in Sweden.

In this paper, we contribute to the literature assessing the effectiveness of unconventional monetary policy tools by studying how the pass-through of the policy rate to mortgage rates in Finland changes once the policy rate turns negative. Using three empirical methodologies: correlational event studies, high-frequency identification, and exposure-measure regressions, we provide robust evidence that there continues to be pass-through of a cut in the policy rate to mortgage rates even in the territory where the policy rate is negative (henceforth referred to as "negative territory"). However, we also find that the pass-through in negative territory is smaller than the one in positive territory.

[1]The transmission to bond rates has been found to be roughly one-for-one while the transmission to deposit rates has found to be very limited or nonexistent, see Balloch et al. (2022).

[2]Other useful reviews of the negative-rates literature include Brandao-Marques et al. (2021), Heider et al. (2021), Tenreyro (2021), and Ulate (2021a).

Focusing on only one euro-zone country, Finland, has some empirical advantages. First, the bank loans we study in this paper, mortgages, are more homogeneous to Finnish households than they would be to the whole euro zone, so that the mortgage rates that we study are more directly comparable over time and across banks. Second, all Finnish banks are supervised and regulated by the same authority so that loan pricing is expected to be more uniform. Third, we can exploit the granular data collected by the Finnish banking regulator under uniform reporting requirements. Finally, being a small country among the nineteen economies in the euro zone, Finland's GDP is just about 2 percent of the euro zone's GDP. Thus, the monetary policy of the European Central Bank (ECB) is unlikely to respond directly to Finnish economic developments alone, mitigating concerns related to the endogenity of the policy rate.

Moreover, Finland can also serve as a point of comparison for other countries where the transmission of negative rates to mortgages has been previously studied, such as Sweden. Finland is adjacent to Sweden by land and separated from it by the Baltic Sea. The two countries are similar in many respects, including their banking market structure and banking products. An important difference is that Finland is in the euro area while Sweden has its own currency and sets its own monetary policy.

Identifying the causal effects of cuts in the policy rate on loan rates in negative territory is not an easy task. Balloch, Koby, and Ulate (2022) enumerates the different identification schemes that have been used to answer this question: high-frequency identification, exposure-measure regressions, and cross-country regressions. In this paper, we first use correlational regressions to illustrate how the pass-through of the policy interest rate to mortgage rates might have changed once the policy rate became negative. We further delve into high-frequency and exposure-measure regressions in order to provide better-identified evidence on the causal effects of negative nominal interest rates. In what follows, we describe these methodologies in greater detail, together with our results when using each of them.

As a first pass, we measure correlations between changes in the policy rate and changes in mortgage rates, and assess how these correlations vary between positive and negative territory. Since our interest here is primarily on correlation and not on causation, no special identification strategy is needed. The results of these regressions indicate that, in positive territory, a large fraction of the change in the ECB's policy rate was transmitted to Finnish banks' mortgage rates, up to almost 86 percent over four months. When the policy rate was negative, this total pass-through over four months was reduced to around 53 percent, but it remained statistically and economically significant, indicating that monetary policy may still be effective in negative territory.

To identify the causal effects of monetary policy, our second strategy uses high-frequency data to extract unexpected monetary policy shocks from changes in yields at different maturities implied by market data around small windows that bracket monetary policy announcements. We then measure the impact of these high-frequency monetary policy shocks on monthly mortgage rates both before and after the implementation of negative rates. We find that a surprise monetary-policy easing (tightening) leads to a statistically significant decrease (increase) in the mortgage rate, both before and during the negative policy rate period. This transmission is mediated mostly via the policy rate's target factor, while the path factor seems to play a small role.[3] The transmission of monetary policy shocks to mortgage rates is found to be larger in positive territory than in negative territory, but the difference is not statistically significant.

Our third identification strategy leverages an "exposure measure" to negative nominal interest rates. It is important to emphasize that this strategy cannot identify the aggregate effects of negative rates; instead it identifies the effects on banks that are more exposed to the negative-rate environment relative to the effects on banks that are less exposed. The identification assumption is that other unobservable factors do not affect the outcomes of interest in the cross section of banks in a manner that is correlated with banks' exposures to the policy rate. The exposure measure we use is the deposit-to-asset ratio (DAR).[4] We find that when the policy rate is non-negative, banks with a higher DAR do not exhibit any differences in the pass-through of monetary policy to mortgage rates compared to banks with a lower DAR. However, when the policy rate is negative,

[3] This evidence is consistent with the notion that we are capturing mainly the effects of negative nominal interest rates as opposed to the effects of quantitative easing or forward guidance.

[4] This is the exposure measure most commonly used in the literature. Banks with higher DARs are assumed to be more exposed to negative rates, because they obtain a higher share of their funding from deposits whose interest rate is (for the most part) subject to a zero lower bound.

banks relying more on deposit funding pass through a smaller fraction of monetary policy changes to mortgage rates than banks relying on alternative sources of funding.

Overall, our first two methodologies present evidence that the ECB's policy rate was transmitted to Finnish mortgage rates even when the policy rate fell below zero, validating the ECB's negative interest rate policy as an effective policy tool. However, they also point to the fact that monetary policy loses some of its effectiveness in negative territory. Our third empirical methodology provides evidence that this efficiency loss can be traced to the zero lower bound on deposit interest rates. To the extent that commercial banks cannot transmit the fall in the policy rate to their depositors, banks' profitability may decline. Ceteris paribus, lower profitability puts pressure on banks' equity, which in turn reduces their ability to pass through cuts in the policy rate to their lending rates. This is a combination of the deposit margin channel of bank profitability and the risk bearing (or balance sheet channel) of bank lending discussed in Balloch et al. (2022).

By now, the empirical literature that discusses the effectiveness of low and negative nominal interest rates has become vast and diverse. As mentioned above, besides simple correlations, these papers have used high-frequency identification, exposure-measure regressions, or cross-country regressions. The papers using high-frequency identification, like Ampudia and van den Heuvel (2019), Bats et al. (2020), or Wang (2019), have typically found detrimental effects on bank stock prices from negative rate implementation. Importantly, Bräuning and Wu (2017) show that this can still be consistent with a decrease in lending rates like the one we find in this paper.

Papers that use exposure-measure regressions, like Heider et al. (2019), Bottero et al. (2019), Bittner et al. (2020), Basten and Mariathasan (2018), Hong and Kandrac (2018), or Amzallag et al. (2019) typically use the DAR as an exposure measure and find that the profitability of more-exposed banks declines relative to less-exposed banks after a cut in the policy rate in negative territory. The results regarding bank lending are less clear-cut in these exposure-measure papers, presumably due to offsetting channels that may be active. If more-exposed banks suffer a greater fall in profitability due to negative rates, this can prevent them from decreasing their lending rate as much as less-exposed banks through the risk-bearing or balance-sheet channels, but it might also lead them to decrease their lending rate more via the reaching-for-yield channel.[5] More-exposed banks could also experience a smaller decrease in their funding rate, preventing them from lowering their lending rates as much as less-exposed banks (independently of the impact on profitability). Our results hint at the possibility that the reaching-for-yield channel might be dominated by other channels, leading to more-exposed banks passing through a smaller fraction of cuts in the policy rate to mortgage rates in negative territory.

Yet another strategy used in the negative-rates literature is cross-country identification, where many countries with different monetary policy stances are studied. These papers usually include time fixed effects (and bank fixed effects) in their regressions and try to recover the aggregate effects of negative rates. The identifying assumption is that the outcome of interest (lending rates, deposit rates, bank return on equity, etc.) would have behaved similarly across different countries in the absence of differences in the policy rate. Since this paper focuses on Finland, we will not make use of this identification scheme. However, our results complement well with those from the largest negative-rates cross-country papers like Lopez et al. (2020) or Ulate (2021b), which find a positive but diminished pass-through to loan rates in negative territory.

Relative to the previous literature, our contribution is to use several distinct empirical methodologies that complement each other and paint a coherent picture of the transmission of negative policy rates to mortgage rates in Finland. This combination of techniques can help us pinpoint the underlying mechanisms that drive the impacts of negative rates, for example highlighting the importance of the deposit margin channel and downplaying that of the reaching-for-yield channel for cross-sectional results.

While our paper does not directly contain any theoretical results, it is related to the theoretical literature that studies the usefulness of low or negative policy rates. Ulate (2021b) proposes two opposing channels through which negative rates impact the economy. On the one hand, negative rates lower the opportunity cost of lending for banks with excess reserves, which stimulates the economy. On the other hand, when the de-

[5] As detailed in Balloch et al. (2022), the risk-bearing channel refers to the idea that regulatory constraints or risk aversion can limit lending after a fall in bank profitability. Similarly, models with balance sheet constraints imply that low profitability may limit banks' ability to obtain funding, for example due to moral hazard. By contrast, reaching for yield highlights the notion that decreasing profitability could increase incentives for bank risk-taking, perhaps leading them to lend more or to take on riskier borrowers.

posit margin gets compressed by negative rates, banks may end up with less equity and a reduced lending capacity. In a quantitative implementation, the author finds that between 60% and 90% of the efficiency of monetary policy is preserved in negative territory. Brunnermeier and Koby (2018) studies the "reversal rate" (the level of the interest rate where decreasing the policy rate further becomes contractionary for lending) in a model where banks have monopoly power and can accrue capital gains from cuts in the policy rate. In a calibrated model, the reversal rate for the euro area is estimated to be around -1%, indicating that moderately negative rates are still stimulative.[6] Eggertsson et al. (2019) proposes a monetary DSGE model with banks where negative rates do not have stimulative effects, inspired by their Swedish evidence that mortgages rates do not decline with the policy rate in negative territory.

As summarized by Balloch et al. (2022), with the notable exception of Eggertsson et al. (2019), the majority of the theoretical negative-rates papers find that a temporary excursion into negative territory to combat a recession can be effective, with some caveats. The first caveat is that the effectiveness of a cut in the policy rate in negative territory is generally found to be less than the effectiveness of a cut in positive territory. The second caveat is that the effectiveness of negative rates can wane or even reverse as rates become more negative or more time is spent in negative territory. Our results in this paper are consistent with all of these findings.

The rest of the paper is organized as follow: Section 2 briefly describes the Finnish economy and banking system as well as the data used. In Section 3, we examine the extent to which changes in the policy rate were transmitted to newly-originated mortgage rates in Finland before and during the negative rate period using correlational event studies. To identify the causal effects of monetary policy, Section 4 employs a high-frequency identification strategy to examine policy transmission. To further explore the effects of negative rates on the transmission across differentially exposed banks, Section 5 exploits banks' cross-sectional differences in funding sources. Finally, Section 6 concludes.

[6] Additionally, de Groot and Haas (2020) studies the signaling channel, a mechanism through which negative rates can stimulate the economy even if current deposit rates are stuck at zero; Onofri et al. (2021) emphasizes that the effects of negative rates might be more stimulative if households save in bonds or if banks have access to wholesale funding; Balloch and Koby (2019) study the long run impacts of persistently low interest rates using evidence from Japan.

2 Background about Finland and Summary Statistics

Finland is a small, open economy which has been part of the European Union since 1995 and of the euro area since its establishment in 1999. In 2019, Finnish GDP was 242 billion euros (269 billion USD), which was about 2 percent of the euro area's GDP. The banking sector in Finland is dominated by a handful of large banking organizations. Monetary conditions in Finland are set by the monetary policy of the ECB. The ECB's main policy instrument is the Deposit Facility Rate (DFR), which is the interest rate banks receive for their deposits held at the ECB. In June 2014, the ECB lowered the DFR to negative territory. Figure 1 shows the DFR, along with the euro area over-night interest rate (EONIA), the 6 month Euribor, as well as 2- and 10-year Finnish government bond yields. Historically, short-term euro area rates, as well as government bond yields, have followed the DFR somewhat closely. During the Negative Interest Rate Policy (NIRP) period, when the DFR was negative, short-term rates converged with the DFR, whereas the 2-year government yield turned even more negative than the DFR.

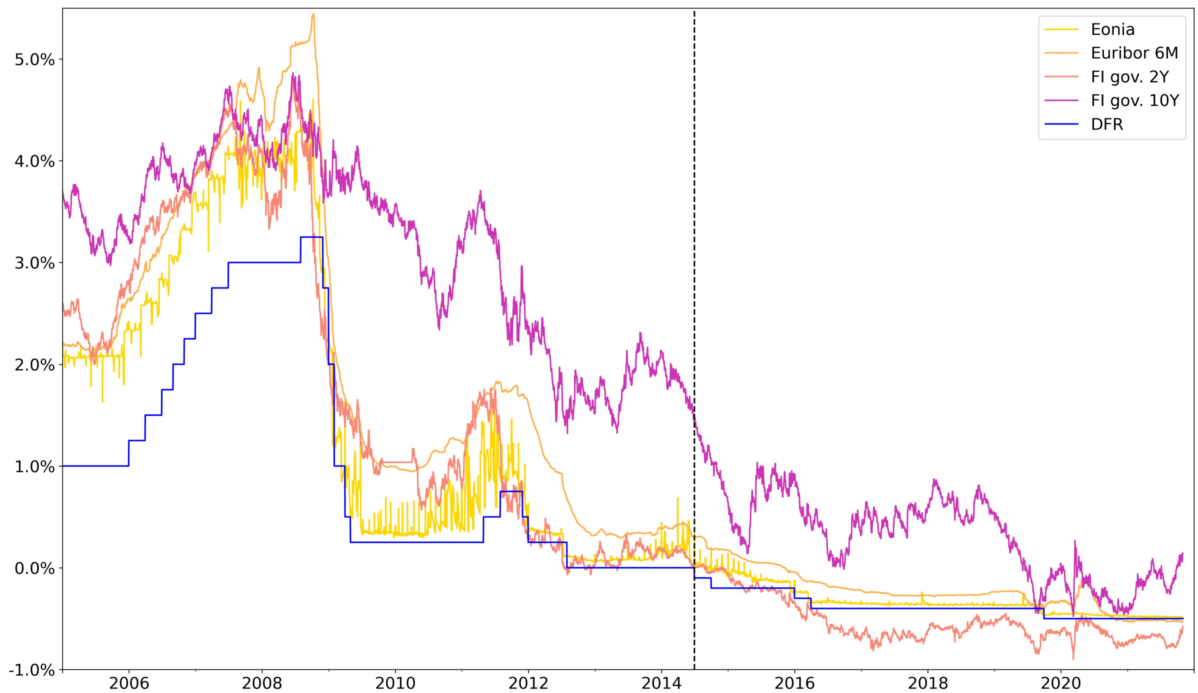
For our analyzes, we employ a panel dataset with information on the balance sheets of Finnish credit institutions from January 2005 to October 2020 at the bank-group level. The dataset contains amounts and interest rates on new mortgage loans to Finnish residents originated by 10 bank groups.[7] Together, the 10 bank groups in the sample account for 95 percent of all new mortgage origination in Finland near the end of 2020. We also collect data on each sample bank-group's balance sheet ratios such as the deposits-to-assets ratio.[8] Our main data source is the "Balance Sheet Items and Interest Rate Statistics of Finnish Monetary Financial Institutions" dataset.[9] We complement our main data source with bank-group level balance-sheet information from S&P's Market Intelligence

[7]"New mortgage loans" refers to euro-denominated newly-issued mortgage loan contracts (in contrast to new draw-downs). Bank-group specific interest rates on new mortgages are the volume-weighted average of contractually agreed total interest rates. See Appendix A for more details.

[8]"Deposit-to-asset ratio" refers to the ratio of customer deposits (i.e., excluding deposits by banks) to total assets. See Appendix A for more details.

[9]The Bank of Finland, among other national central banks in the Eurosystem, collects statistical data on credit institutions. The data are collected as part of Monetary Financial Institution data collection, see the Bank of Finland's website for more information. Data for the analysis are sourced internally at the Bank of Finland.

Figure 1: Deposit facility rate and market rates



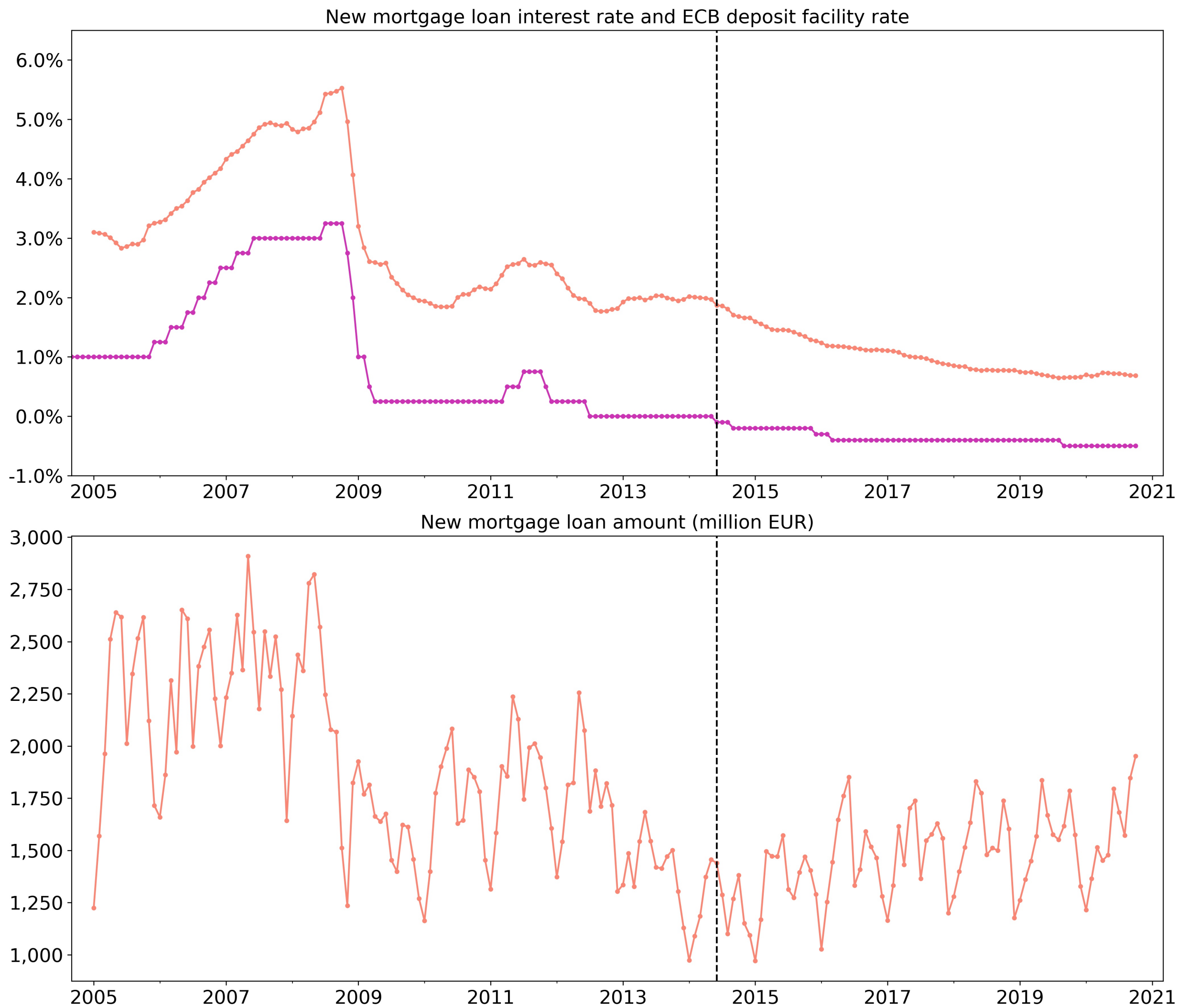
Notes: The figure displays the ECB's deposit facility rate along with the Euro over-night rate (Eonia), the 6-month Euribor rate, as well as the 2- and 10-year Finnish government bond yields. The vertical black dashed line denotes the start of NIRP. The frequency is daily between 2005-01-01 and 2021-12-31. Source: Bloomberg and authors' calculations.

database.

Figure 2 displays new mortgage loan amounts in the bottom panel with the corresponding average interest rate (aggregated over bank groups) in the top panel. The DFR is also included in the top panel of the figure for comparison. We can see that interest rates on new mortgage loans have fallen in tandem with the DFR. The amount of new mortgage loans plummeted during the 2008-09 Great Financial Crisis, and has not yet returned to the pre-crisis level. During the negative interest rate period, new mortgage originations have been trending up.

Table 1 shows descriptive statistics for new mortgage interest rates (MR) and quantities (MA), the deposit facility rate (DFR), as well as the deposit-to-asset ratio (DAR). The average interest rate on new mortgages in our sample is 215 basis points with a standard deviation of 129 basis points. On average, monthly changes in mortgage rates have been negative, with the largest monthly decline (-118 basis points) observed during the

Figure 2: Interest rates and amounts of new mortgage loans



Notes: The frequency of the data is monthly. "New mortgage loans" refers to newly-originated mortgage loan contracts. The top panel displays the volume-weighted average mortgage rate over the sample banks (orange line) as well as the ECB's deposit facility rate (purple line). The bottom panel displays the total amount of new mortgages over the sample banks. The black vertical dashed line denotes the start of NIRP in June 2014. Source: Bank of Finland and authors' calculations.

Great Financial Crisis. The largest two-month decline is -235 basis points. The amount of monthly new mortgages varies quite extensively over bank groups and periods, with the largest (95th percentile) monthly originations being over 700 million euros and the smallest (5th percentile) being just about 6 million euros. There is also a lot of variation in the deposit-to-asset ratio across bank groups, from a low of 25% to a high of 83%.

Table 1: Descriptive statistics for monthly panel data

	Mean	SD	Obs.	Min.	5p	25p	50p	75p	95p	Max.
MR	215	129	1,808	-	63	106	196	271	490	-
$\Delta MR_{t-1,t}$	-1	15	1,798	-118	-20	-5	-1	4	16	88
$\Delta MR_{t-1,t+1}$	-3	25	1,780	-235	-29	-8	-2	6	25	84
MA	178	230	1,808	-	6	28	68	242	710	-
DFR	48	111	190	-50	-50	-40	0	100	300	325
$\Delta DFR_{t-1,t}$	-1	13	189	-100	-10	0	0	0	25	25
DAR	49%	24%	10	25%	26%	30%	42%	67%	82%	83%

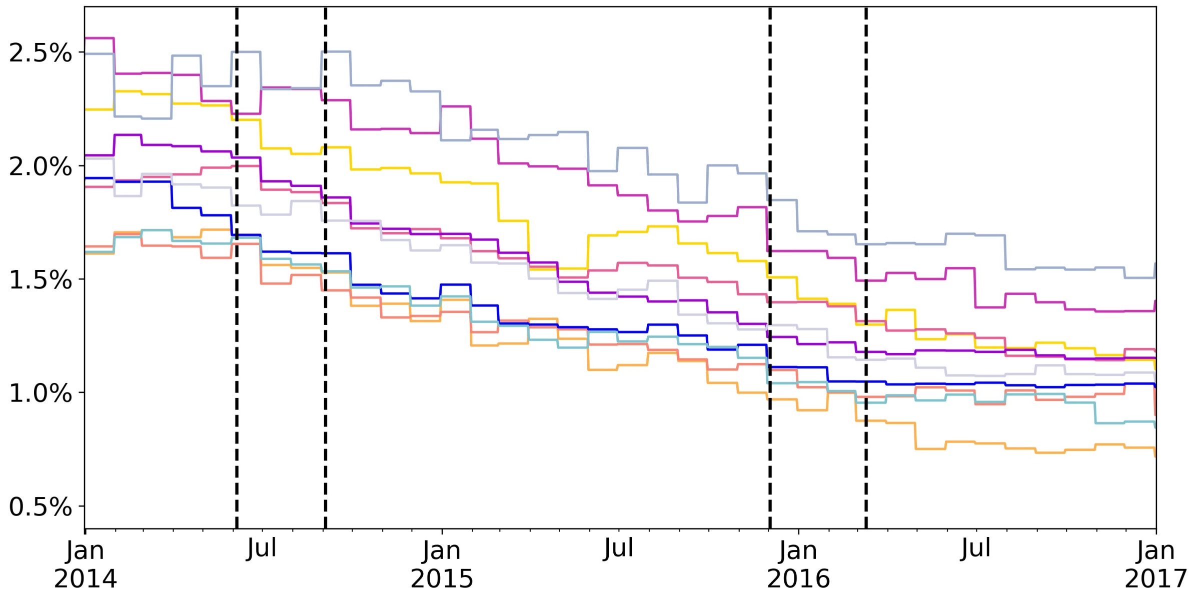
Notes: This table presents descriptive statistics for the monthly panel data. The sample spans from January 2005 to October 2020. The variables are the new mortgage loans interest rate in levels (MR, in basis points) as well as one-month and two-month changes, the amount of new mortgage loans (MA, in million EUR), the level and the one-month change in the deposit facility rate (DFR, in basis points), as well as bank-group specific deposit-to-asset ratios (DAR). The left panel displays the mean, standard deviation, and he number of observations for each variable. The right panel displays the minimum and maximum values as well as selected percentiles for the variable's distribution. The statistics for mortgage loans are calculated over time and bank groups, whereas the statistics for the DFR are calculated over time. For the deposit-to-asset ratio we first calculate the time-series averages for each bank group over the year 2013 and the statistics are then calculated from these averages. There are 10 bank groups in the sample. The minimum and maximum values of new mortgage amounts and interest rate levels are omitted for confidentiality. Source: S&P Market Intelligence, Bank of Finland, and authors' calculations.

Figure 3 shows the average interest rate on new mortgages between 2014 and 2016 separately for each of the 10 bank groups in our sample. The bank-level mortgage rate tends to fall around cuts in the DFR, especially for the first, second, and third cuts in negative territory. In the following section, we take a more systematic look at this relationship by regressing bank-group mortgage rates on bank fixed effects and changes in the policy rate both before and after the negative-rates period.

3 Correlations

To investigate the extent to which changes in the policy rate pass onto the rates on newly originated mortgages, including the possibility of lags in transmission, we specify

Figure 3: Interest rate on new mortgage loans by bank group



Notes: The figure displays the average interest rate on new mortgage loans by bank group between 2014 and 2016. The series are at daily frequency (up-sampled from monthly observations using forward fill). The vertical dashed lines denote the dates of cuts in the ECB's deposit facility rate (a 10 basis points cut in all four cases). Source: Bank of Finland and authors' calculations.

the following panel regression with bank fixed effects:

$$\Delta y_{b,t} = \alpha_b + \sum_{k=0}^{K} \beta_k \Delta i_{t-k} + Post_t \cdot \sum_{k=0}^{K} \mu_k \Delta i_{t-k} + \varepsilon_{b,t}, \tag{1}$$

where b is a given bank, t is the time period, Δ is the difference operator, $y_{b,t}$ is the interest rate on new mortgages charged by bank b at time t, α_b is a bank fixed effect, i_t is the DFR in period t, $Post_t$ is a dummy variable equal to one if t is after 2014M6 (the first implementation of negative rates by the ECB), $\varepsilon_{b,t}$ is an error term for bank b at time t, and K indicates the maximum number of lags in transmission being considered in the regression.

The second term in equation (1) measures how much of the change in the policy rate was transmitted to the mortgage rate on average across bank groups, both contemporaneously and with lags, during the period when the policy rate was non-negative. If banks changed their mortgage rates by exactly the same amount as the change in the policy rate instantly and permanently, the contemporaneous coefficient, β_0, would be equal to one and all lagged coefficients would be equal to zero. When some of the transmission takes place with a lag, the coefficient β_0 is less than one, and the lagged coefficient β_k measures how much of the mortgage rate change in month t is a result of the change in the policy rate in month $t-k$. Summing the coefficients β_0 to β_k measures the total transmission of the policy rate to the mortgage rate over $k+1$ months.

The third term in equation (1) measures the additional transmission of the policy rate to mortgage rates when the policy rate was negative, on average across bank groups. If there was no change in the transmission of the policy rate to the mortgage rate when the policy rate became negative, all the μ coefficients would be zero. The sum of the μ coefficients measures the total change in transmission during the negative-rates period, and the sum of the β coefficients and the μ coefficients measures the total transmission during the negative-rates period.

The estimates from the regression in equation (1) with $K = 3$ are shown in Table 2.[10] The top panel provides estimates of the β coefficients measuring the transmission of the policy rate to mortgage rates when the policy rate is greater than zero. These estimates provide evidence that the change in the policy rate by the ECB was transmitted to Finnish banks' mortgage rates, both contemporaneously and with lags. At 69 percent, the contemporaneous transmission of the policy rate to the mortgage rate is significantly positive and economically large. Although the bulk of the transmission of the policy rate to the mortgage rate took place contemporaneously, the significant coefficients on the lags point to some of the transmission occurring with a delay. The last column of the top panel in Table 2 shows the sum of β's, which measures the total transmission of the policy rate to the mortgage rate over four months, estimated to be 86 percent. The result suggests a large fraction of the change in the ECB's policy rate was eventually transmitted to Finnish banks' mortgage rates while the policy rate was positive.

The middle panel of Table 2 displays the additional transmission during the negative-rates period from June 2014 to October 2020. During this period, the contemporaneous

[10] Adding more lags or fitting the regression using weighted (instead of ordinary) least squares provides very similar results. For the weighted regression results, see Table 5 in the Appendix.

Table 2: Results from correlational analysis

Change in the mortgage rate (pp)				
β_0	β_1	β_2	β_3	$\sum_{k=0}^{3} \beta_k$
0.689^{***}	0.237^{***}	0.055	-0.122^{***}	0.859^{***}
(0.052)	(0.050)	(0.030)	(0.033)	(0.034)
μ_0	μ_1	μ_2	μ_3	$\sum_{k=0}^{3} \mu_k$
-0.358^{***}	-0.170^{**}	0.079	0.125	-0.324^{***}
(0.090)	(0.064)	(0.057)	(0.074)	(0.052)
$\beta_0 + \mu_0$	$\beta_1 + \mu_1$	$\beta_2 + \mu_2$	$\beta_3 + \mu_3$	$\sum_{k=0}^{3} \beta_k + \mu_k$
0.332^{***}	0.067	0.133^{***}	0.003	0.535^{***}
(0.102)	(0.061)	(0.037)	(0.073)	(0.056)
Number of observations			1774	
Adjusted R^2			0.43	
Bank-group fixed effects			Yes	

Notes: This table presents selected coefficients and standard errors (in brackets) estimated from the regression in equation (1) with $K = 3$ and the dependent variable being the one-month difference in the rate on new mortgage loans in percentage points. The change in the policy rate is also measured in percentage points. Standard errors are clustered at the bank-group level. Asterisks denote statistical significance: *=10%, **=5%, ***=1%.

transmission is found to be significantly smaller, as evidenced by the significantly negative μ_0. The last column in the middle panel displays the sum of the μ's, which is significantly negative at -32 percent. This suggests that the effectiveness of monetary policy decreased when the policy rate was below zero.

Overall, the estimates in Table 2 indicate that the total pass-through from the policy rate to the mortgage rate was reduced by 38 percent during the negative-rates period. Despite this sizable reduction, the net pass-through from the policy rate to mortgage rates was still 53 percent when the policy rate was below zero (last column of the bottom panel). This provides suggestive evidence that monetary policy remained operational through the interest rate channel during the negative-rates period. In order to better identify the causal effects of monetary policy, in the next section we employ a high-frequency identification strategy to examine the policy transmission of negative nominal interest rates.

4 High Frequency Identification

As mentioned in the introduction, using high-frequency data allows the econometrician to identify monetary surprises from short windows surrounding monetary policy announcements. The idea is to take the difference between several measures of yields before the monetary policy announcement happens and those same measures after the announcement has occurred. If the window around the monetary policy announcement is small enough, the change in asset prices is likely driven solely by the new information embedded in the announcement. This method arguably provides a "clean" measure of unexpected monetary policy shocks, to the extent that the expected component of the monetary policy announcement has already been incorporated into the pre-announcement asset prices in an efficient market.

To operationalize this identification scheme in our particular context, we need data on asset prices around monetary policy announcements. We follow Altavilla et al. (2019), utilizing their Euro Area Monetary Policy event study Database (EA-MPD).[11] This dataset contains, among other things, what the authors call the changes in the "Monetary Event Window". These are changes between the median quote of a given asset price in the ten-minute window before the ECB's press release of its monetary policy decision (from 13:25 CET to 13:35 CET) and the median quote for that same asset price in the ten-minute window after the ECB's press conference that accompanies its monetary policy decision (from 15:40 CET to 15:50 CET).

The derivation of our monetary policy surprises follows a procedure similar to the one described in Gurkaynak, Sack, and Swanson (2005) in the case of the United States. First, we select seven bond yields from EA-MD data (the same ones as in Altavilla et al., 2019) that describe the euro area's yield curve from 1 month to 10 years. Next, we extract the first two principal components of the (normalized) bond yield series. We rotate the resulting components such that the first component, S_1, captures the "target" factor (corresponding to surprise change in the short-term policy rate) and the second component,

[11] The data version used in this paper is from January 30th 2022. The most up-to-date dataset is available at https://www.ecb.europa.eu/pub/pdf/annex/Dataset_EA-MPD.xlsx

S_2, captures the "path" factor (corresponding to expected future changes in policy rates which are independent from changes in the current policy rate).

The rotated factors do not naturally have an interpretable direction or scale. We re-scale the factors such that S_1 moves the first asset price (the one month Overnight Index Swap, OIS, yield) by exactly 1 unit. This way we can interpret a shock to the target factor (S_1) as if it were a one percent shock to the short-term rate. Further, the re-scaling is such that it forces S_1 and S_2 to have the same effect on the one-year yield (12 month OIS yield). This allows us to interpret S_2 as a longer run (path) factor that moves the one-year yield as much (and in the same direction) as S_1. Finally, to use the shocks in regressions, we aggregate the shock series to monthly frequency by summing the shocks from all the monetary policy decisions taking place during the same month. We plot the resulting monetary policy surprise series in Figure 4 of Appendix B.[12]

After identifying the monetary policy shocks, a vector of S_t, using high frequency data, we test the causal effects of monetary policy on mortgage rates by running the following regression:

$$y_{t+1} - y_{t-1} = \alpha + \mu Post_t + \beta_1 S_{1,t} + \beta_2 S_{2,t} + \gamma_1 S_{1,t} Post_t + \gamma_2 S_{2,t} Post_t + \varepsilon_t, \qquad (2)$$

where y_t is the interest rate on new mortgages aggregated across banks at time t, $S_{i,t}$ is the i-th identified monetary policy shock at time t (S_1 being the target shock and S_2 the path shock), and $Post_t$ is the dummy indicating whether t is in the negative interest rate period. The results from the regression in equation (2) are shown in Table 3.[13]

We gather several important lessons from the results in Table 3. First, a surprise tightening in monetary policy, as measured by an increase in the target factor S_1, leads to a statistically significant increase in the mortgage rate, both before and during the negative-rates period. Second, the difference between the pre-NIRP and the NIRP co-

[12] We exclude from the sample the monetary policy decision dates on November 6th 2008 and December 4th 2008. These dates, occurring during the height of the Great Financial Crisis, have a particularly large difference between the asset price changes in the monetary event window and the changes in the daily window, indicating that financial market participants may have required a longer interval to fully "process" the information contained in the actions of the ECB.

[13] In equation 2, we use a two-month change in the mortgage rate as the left-hand side variable. The results would be similar if we used a one-month change.

Table 3: Results from high-frequency analysis

	Change in the mortgage rate (bps)
S1	
S1 pre-NIRP	6.57**
	(2.68)
S1 NIRP	3.16***
	(0.86)
S1 diff	−3.41
	(2.83)
S2	
S2 pre-NIRP	1.01
	(1.73)
S2 NIRP	0.87
	(0.81)
S2 diff	−0.14
	(1.91)
ST	
ST pre-NIRP	7.57**
	(3.09)
ST NIRP	4.03***
	(1.22)
ST diff	−3.54
	(3.32)
Number of observations	185
Adjusted R^2	0.06

Notes: This table presents the coefficients and standard errors (in brackets) estimated from the regression in equation (2) with the dependent variable being the two-month difference (from $t-1$ to $t+1$) in the mortgage rate in basis points. The two independent variables are the monetary policy shocks derived using the extraction method described in the main text. Estimates are given for each shock (S_1 and S_2) as well as their sum (S_T). Standard errors are HAC robust with a maximum of one lag. Asterisks denote statistical significance: *=10%, **=5%, ***=1%.

efficients for S_1 is negative but not significant, meaning that perhaps the transmission of target shocks to mortgages rates weakened during the negative-rates period, but that this cannot be asserted at the standard levels of statistical significance. Third, for the path factor, S_2, the pre-NIRP and the NIRP coefficients are similar, in both cases not statistically significant. This indicates that the effects of shocks to the path factor do not seem to be an important part in the transmission of the ECB's monetary policy to Finnish mortgages rates. The significance of S_1 combined with the insignificance of S_2 suggests that we are capturing mostly the effect of negative rates (which would be reflected in the target factor) as opposed to the effect of quantitative easing or forward guidance (which are likely to be reflected in the path factor).

The reduction in effectiveness (even if not statistically significant) that we find between the positive policy rate period and the negative policy rate period using our high-frequency identification strategy is of around 50% (for either S_1 or the combination of S_1 and S_2). This magnitude is similar to the decrease in effectiveness of around 40% that we found in Section 3. It is also comparable to the 30% decrease in effectiveness found in Ulate (2021b).[14] Overall, the results suggest that monetary policy surprises have kept passing through to mortgage rates in the negative-rates period but that pass-through has likely diminished.[15]

5 Exposure Measure Regressions

Finally, our third empirical method uses banks' exposure to negative interest rates to identify the effects of negative rates on more-exposed banks vis-a-vis less-exposed banks. This type of identification is somewhat common in the literature (see, for example, Heider et al., 2019; Bittner et al., 2020) and requires taking a stance on what constitutes being "more exposed" to negative rates. Here, we use the deposit-to-asset ratio as the measure of exposure, which is the most commonly used exposure measure as described in Balloch et al. (2022).

Banks with higher deposit-to-asset ratios are assumed to be more exposed to negative rates, because they obtain a higher share of their funding from deposits, for which the interest rate is likely to be floored at zero percent. When the policy rate is in positive territory, and the rates on different sources of funding co-move strongly, the degree of exposure to deposit funding is not expected to affect the pass-through. By contrast, when

[14] Albeit the decrease in effectiveness in Ulate (2021b) is for welfare and not just for loan rate pass-through. Given that there are other channels through which negative rates can stimulate the economy that do not rely on the banking sector, it is natural for the welfare results to show a lower fall in effectiveness compared to the loan pass-through results.

[15] We have also employed an alternative method to extract the monetary policy shocks, following Bräuning and Wu (2017) who identify monetary policy shocks from asset price changes on days bracketing the monetary policy announcements. Those results are well in line with the baseline results shown here and are available upon request.

the policy rate is in negative territory, the rates on non-deposit funding respond more strongly to changes in the policy rate (see figure 1) than deposit rates. Consequently, banks relying more on deposit funding (indicated by a higher DAR), ceteris paribus, are expected to pass through less of the change in the policy rate to mortgage rates.

To test whether banks with more exposure to deposit funding pass through less of the changes in the policy rate to their mortgage rates in negative territory, we run the following regression:

$$\Delta y_{b,t} = \alpha_b + \delta_t + \beta \cdot DAR_b \cdot \Delta i_t + \mu \cdot Post_t \cdot DAR_b \cdot \Delta i_t + \varepsilon_{b,t}, \tag{3}$$

where $\Delta y_{b,t}$ is the change in the rate on new mortgage loans issued by bank b between time $t-1$ and t, α_b denotes a set of bank fixed effects, δ_t denotes a set of time fixed effects, and DAR_b is the average deposit-to-asset ratio of bank b in 2013. $Post_t$ continues to be the dummy for the negative-rate period as in equations (1) and (2).

In equation (3), the coefficient β measures how much more-exposed banks cut their mortgage rates after a cut in the policy rate compared to less-exposed banks when the policy rate is in positive territory. The sum of the coefficients $(\beta + \mu)$ measures this same relative difference when the policy rate is in negative territory. Therefore, the coefficient μ measures how much more the transmission of more-exposed banks is hindered in negative territory compared to positive territory. As explained above, we expect μ to be negative.

The results of estimating equation (3) by OLS are presented in table 4. As expected, the coefficient β is not significantly different from zero, indicating that when the policy rate is positive, banks with a higher DAR do not exhibit a different pass-through of monetary policy to mortgage rates compared to banks with a lower DAR. By contrast, μ is negative and significant at the 10% level, indicating that banks with a higher DAR pass through a smaller fraction of monetary policy changes to mortgage rates when the policy rate is negative compared to banks with a lower DAR.

As noted earlier, the mechanism can be as follows. Banks with a higher DAR rely more heavily on deposits for their funding. In negative territory, the deposit rate essen-

Table 4: Results from exposure-measure analysis

	Change in the mortgage rate (bps)
β	-0.197
	(0.131)
μ	-1.084^{*}
	(0.533)
Number of observations	219
Adjusted R^2	0.87
Bank group fixed effects	Yes
Period fixed effects	Yes

Notes: This table presents selected coefficients and standard errors (in brackets) estimated from regression equation (3) with the dependent variable being the one-month difference in the mortgage rate in basis points. The change in the policy rate is also measured in basis points and the deposit-to-asset ratio is measured as a number between 0 and 1. Standard errors are clustered at the bank group level. Asterisks denote statistical significance: *=10%, **=5%, ***=1%.

tially stops co-moving with the policy rate, while interest rates on other sources of funding continue to co-move with the policy rate. Therefore, banks with a higher DAR face a smaller reduction in their funding costs compared to banks with a lower DAR when the ECB cuts the DFR in negative territory. As a consequence, banks with a higher DAR pass through less of the reduction in the policy rate to the mortgage rate, ceteris paribus.[16]

To gauge the economic significance of the exposure to deposits, we multiply the estimated coefficient μ by the difference in DAR between the 25th and the 75th percentile of the deposit-to-asset ratio in our sample. The result indicates that a bank at the 75th percentile of the DAR distribution transmits roughly 40% less of the fall in the DFR to mortgage rates than a bank at the 25th percentile of the DAR distribution during the negative-rates period. This difference is relevant and economically significant. It is also in line with the magnitude of the reduction in transmission during the negative-rates period that we found in the correlational regressions and high-frequency identification, indicating that the deposit margin channel can be an important contributor to the decrease in the aggregate transmission.

[16] If banks do not have monopoly power, then a smaller reduction in their funding rate implies that they cannot reduce their lending rates (including the mortgage rate) as much. If banks have monopoly power, still a smaller reduction in their funding rate means that their deposit spread gets reduced by more, decreasing their profitability and eventually their equity and their ability to decrease their lending rates.

Note that these exposure-measure regressions do not identify the aggregate response of mortgage rates to changes in the policy rate in negative territory (these aggregate effects would be absorbed by the time fixed effects in the regression). They merely identify the response of more-exposed banks relative to the response of less-exposed banks. From these regressions alone, we would not be able to tell whether aggregate mortgage rates increased or decreased with the advent of negative rates. However, given our results in the correlational analysis and the high-frequency identification, it is safe to interpret that mortgage rates indeed fall with the policy rate even in negative territory, but that this occurs less for more-exposed banks.

6 Conclusion

The transmission mechanisms and effectiveness of unconventional monetary policy tools in general, and of negative policy interest rates in particular, have received a lot of attention from economists and policy makers. This paper contributes to this growing literature by studying the transmission of the ECB's policy rate to Finnish mortgage rates before and during the negative policy rate period. We find evidence that the ECB's policy rate was transmitted to Finnish mortgage rates even when the policy rate fell below zero, supporting the ECB's negative interest rate policy as an effective policy tool.

We employ three empirical strategies to study the monetary policy pass-through in Finland. First, results of the correlational analysis show that, in positive territory, a large fraction of the change in the ECB's policy rate was transmitted to Finnish banks' mortgage rates both contemporaneously and with lags, up to 86 percent over four months. When the policy rate was negative, the total pass-through was reduced significantly. Nevertheless, the total pass-through from the policy rate to the mortgage rate was estimated to be 53 percent during the negative interest rate period, suggesting that the interest rate channel of monetary policy remained operational.

Our second empirical strategy pins down the causal effects of monetary policy more clearly. In this strategy, we first identify monetary policy shocks over a short window around monetary policy announcements, providing estimates of the monetary policy shock's target factor and the future policy rate path factor. These monetary policy shocks are then used to explain the changes in the mortgage rate. Our results show that a surprise easing (tightening) in monetary policy leads to a statistically significant decrease (increase) in the mortgage rate, both before and during the negative policy rate period. While the monetary policy shock's target factor is found to be significant, the future rate path factor is not, suggesting that we are capturing the effects of negative nominal interest rates and not those of quantitative easing or forward guidance. Additionally, the transmission in the negative-rates period is smaller than that in the positive policy rate period (although this difference is not statistically significant). This evidence further confirms the effectiveness of negative policy rates via the interest rate channel.

In our third empirical strategy, we exploit differences in Finnish banks' reliance on deposits as a funding source to identify the differential effects of negative policy rates among more- versus less-exposed banks. To the extent that bank deposit rates are likely constrained by the zero lower bound while market-based funding rates are not, banks relying more on deposit funding are expected to have a smaller pass-through to mortgage rates during the negative policy rate period. Our results show that when the policy rate was non-negative, banks with a higher DAR did not exhibit any differences in the pass-through of monetary policy to mortgage rates compared to banks with a lower DAR. However, when the policy rate was negative, banks relying more on deposit funding passed through a smaller fraction of monetary policy changes to mortgage rates than banks with a lower DAR.

Taken together, the results in this paper show that the effectiveness of monetary policy during the negative policy rate period was likely diminished, but did not disappear. They lend credence to the usage of negative nominal interest rate policies by central banks. Although the negative rate policy lasted for years, the policy rate did not become very negative during our sampling period. While the limits of negative interest rate policies are beyond the scope of this paper, these are interesting questions for future research that have important policy implications.

References

ALTAVILLA, C., L. BRUGNOLINI, R. S. GÜRKAYNAK, R. MOTTO, AND G. RAGUSA (2019): "Measuring euro area monetary policy," *Journal of Monetary Economics*, 108, 162–179.

AMPUDIA, M. AND S. J. VAN DEN HEUVEL (2019): "Monetary Policy and Bank Equity Values in a Time of Low and Negative Interest Rates," Finance and Economics Discussion Series 2019-064, Board of Governors of the Federal Reserve System (U.S.).

AMZALLAG, A., A. CALZA, D. GEORGARAKOS, AND J. SOUSA (2019): "Monetary policy transmission to mortgages in a negative interest rate environment," Working Paper Series 2243, European Central Bank.

BALLOCH, C. AND Y. KOBY (2019): "Low Rates and Bank Loan Supply: Theory and Evidence from Japan," Mimeo.

BALLOCH, C., Y. KOBY, AND M. ULATE (2022): "Making Sense of Negative Nominal Interest Rates," Working Paper Series 2022-12, Federal Reserve Bank of San Francisco.

BASTEN, C. AND M. MARIATHASAN (2018): "How Banks Respond to Negative Interest Rates: Evidence from the Swiss Exemption Threshold," CESifo Working Paper Series 6901, CESifo Group Munich.

BATS, J., M. GIULIODORI, AND A. HOUBEN (2020): "Monetary policy effects in times of negative interest rates: What do bank stock prices tell us?" DNB Working Papers 694, Netherlands Central Bank, Research Department.

BITTNER, C., D. BONFIM, F. HEIDER, F. SAIDI, G. SCHEPENS, AND C. SOARES (2020): "Why so negative? The effect of monetary policy on bank credit supply across the euro area," Tech. rep., mimeo.

BOTTERO, M., C. MINOIU, J.-L. PEYDRO, A. POLO, A. F. PRESBITERO, AND E. SETTE (2019): "Expansionary Yet Different: Credit Supply and Real Effects of Negative Interest Rate Policy," Working Papers 1090, Barcelona Graduate School of Economics.

Brandao-Marques, L., M. Casiraghi, G. Gelos, G. Kamber, and R. Meeks (2021): "Negative Interest Rates: Taking Stock of the Experience So Far," IMF Departmental Papers 2021/003, International Monetary Fund, accessed at: https://www.imf.org/en/Publications/Departmental-Papers-Policy-Papers/Issues/2021/03/01/Negative-Interest-Rates-Taking-Stock-of-the-Experience-So-Far-50115.

Brunnermeier, M. K. and Y. Koby (2018): "The Reversal Interest Rate," NBER Working Papers 25406, National Bureau of Economic Research, Inc.

Bräuning, F. and B. Wu (2017): "ECB Monetary Policy Transmission During Normal and Negative Interest Rate Periods," Tech. rep., mimeo.

de Groot, O. and A. Haas (2020): "The Signalling Channel of Negative Interest Rates," Cepr discussion papers, C.E.P.R. Discussion Papers.

Eggertsson, G. B., R. E. Juelsrud, L. H. Summers, and E. G. Wold (2019): "Negative Nominal Interest Rates and the Bank Lending Channel," NBER Working Papers 25416, National Bureau of Economic Research, Inc.

Gurkaynak, R., B. Sack, and E. Swanson (2005): "Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements," *International Journal of Central Banking*, 1.

Heider, F., F. Saidi, and G. Schepens (2019): "Life below Zero: Bank Lending under Negative Policy Rates," *The Review of Financial Studies*, 32, 3728–3761.

——— (2021): "Banks and Negative Interest Rates," *Annual Review of Financial Economics*, 13, 201–218.

Hong, G. H. and J. Kandrac (2018): "Pushed Past the Limit? How Japanese Banks Reacted to Negative Interest Rates," Tech. rep., IMF Working Paper No. 18/131. International Monetary Fund.

Lopez, J. A., A. K. Rose, and M. M. Spiegel (2020): "Why have negative nominal interest rates had such a small effect on bank performance? Cross country evidence," *European Economic Review*, 124.

ONOFRI, M., G. PEERSMAN, AND F. R. SMETS (2021): "The Effectiveness Of A Negative Interest Rate Policy," Working Papers of Faculty of Economics and Business Administration, Ghent University, Belgium 21/1015, Ghent University, Faculty of Economics and Business Administration.

TENREYRO, S. (2021): "Let's talk about negative rates," Speech given by Silvana Tenreyro, External Member of the Monetary Policy Committee of the Bank of England, at a UWE Bristol webinar on 11 January 2021. Accessed at: https://personal.lse.ac.uk/tenreyro/negatives.pdf.

ULATE, M. (2021a): "Alternative Models of Interest Rate Pass-Through in Normal and Negative Territory," *International Journal of Central Banking*, 17, 3–34.

——— (2021b): "Going Negative at the Zero Lower Bound: The Effects of Negative Nominal Interest Rates," *American Economic Review*, 111, 1–40.

WANG, O. (2019): "Banks, Low Interest Rates, and Monetary Policy Transmission," Tech. rep., mimeo.

Appendices for Online Publication

Appendix A describes our data in greater detail while Appendix B describes the construction of our monetary policy shocks using with high-frequency data.

A Further Details about the Data

A.1 Interest Rates and Amounts of New Mortgages

The series on amounts and interest rates of new mortgages come from our main data sources: the Balance Sheet Items and Interest Rate Statistics of Finnish Monetary Financial Institutions (MFIs). These statistical datasets are collected by the Bank of Finland via the RATI survey. The data is sourced internally at the bank of Finland and cannot be distributed for confidentiality reasons. Series for mortgages are extracted using the following specification:

- Creditors are MFIs that belong to the 12 biggest bank groups in Finland. Ten of the groups have been granting mortgages and we select these groups into our sample.
- Debtor country: Finland.
- Debtor sector: Households and non-profits serving households.
- Instrument: Loans excluding repos and credit card debt.
- Purpose: Mortgage.
- Transaction: True new contracts.
- Measures: Amount flows and contractual interest rates.

A.2 Deposit-to-asset Ratios

Our main data sources provide data only for Finnish functions of the bank groups. Some groups are international banks with the bulk of their activities outside of Finland. Our aim for the deposit-to-asset ratio has been to construct series that reflect the situation at the consolidated bank-group level. The reasoning behind this is that funds are assumed to be fungible within a given bank group.

We derive the deposit-to-asset ratios as follows. For the international bank groups we use a dataset provided by S&P Market Intelligence. We extract data separately for the numerator (deposits from customers, mnemonic *SNL_TOTAL_DEPOSITS*) and for the denominator (all assets owned by the company, mnemonic *SNL_TOTAL_ASSETS*) and then divide them to obtain the deposit-to-asset ratio. For bank groups operating primarily in Finland, we use our main data source. In this case, the numerator is deposits excluding deposits from MFIs (in an attempt to better match the deposits definition used for international groups) and the denominator is total assets.[17]

A.3 Deposit Facility Rate and Monetary Policy Dates

The ECB's monetary policy decision dates were extracted from the ECB's web page. The series for the deposit facility rate was sourced from the Bank of Finland's internal database but are also available from the ECB's web page.[18]

A.4 Additional Results

Table 5 presents results similar to Table 2 but using weighted least-squares regressions instead of ordinary least-squares regressions.

B High-Frequency Monetary Policy Surprises

In this section, we provide further information on the extraction method of monetary policy surprises. This is a combination of the approaches used by Gurkaynak, Sack, and Swanson (2005) (here GSS for short) and Altavilla, Brugnolini, Gürkaynak, Motto, and Ragusa (2019) (here ABGMR for short). The former extract two policy shocks ("target" and "path" shocks) for the federal funds rate from US asset yield changes around Federal Reserve monetary policy decision dates. The latter investigate monetary policy surprises of the ECB – from yield changes of the approximated euro area yield curve – and, in

[17] Here both numerator and denominator include intra-group items. This is due to the fact that we cannot disentangle the intra-group items for the entire sample length.

[18] Decision dates: www.ecb.europa.eu/press/govcdec/mopo/html/index.en.html. Key interest rates: www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html.

Table 5: Results from correlation analysis, weighted regressions

Change in the mortgage rate (pp)				
β_0	β_1	β_2	β_3	$\sum_{k=0}^{3} \beta_k$
0.622***	0.335***	0.039*	−0.114***	0.882***
(0.026)	(0.022)	(0.021)	(0.010)	(0.015)
μ_0	μ_1	μ_2	μ_3	$\sum_{k=0}^{3} \mu_k$
−0.228***	−0.300***	0.086*	0.150*	−0.291***
(0.047)	(0.052)	(0.044)	(0.071)	(0.042)
$\beta_0 + \mu_0$	$\beta_1 + \mu_1$	$\beta_2 + \mu_2$	$\beta_3 + \mu_3$	$\sum_{k=0}^{3} \beta_k + \mu_k$
0.394***	0.035	0.125***	0.037	0.591***
(0.037)	(0.035)	(0.026)	(0.068)	(0.045)
Number of observations			1774	
Adjusted R^2			0.61	
Bank group fixed effects			Yes	

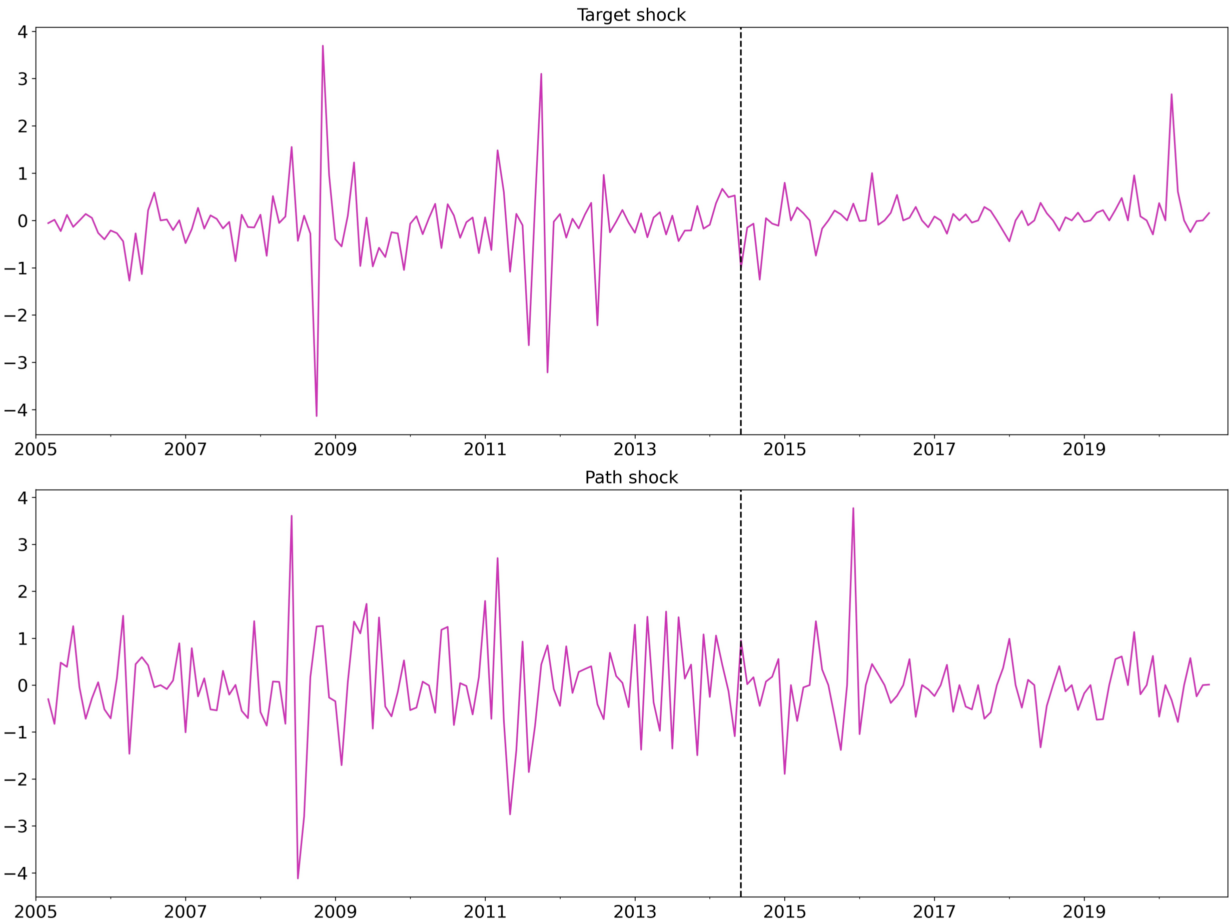
Notes: This table presents selected coefficients and standard errors (in brackets) estimated from the regression in equation (1) with K=3 and the dependent variable being the one-month difference (from $t-1$ to t) in the rate on new mortgage loans in percentage points. The change in the policy rate is also measured in percentage points. The regression uses weighted least-squares such that bank group observations within each period receive a weight according to their relative new-loans volume, whereas periods are weighted equally. Standard errors are clustered at the bank group level. Asterisks denote statistical significance: *=10%, **=5%, ***=1%.

addition to the two shocks in GSS, also identify a third shock, namely surprises about the future of quantitative easing (QE) programs. In our approach, we extract two shocks (target and path) for the ECB monetary policy decisions as in GSS but using the ABGMR dataset for the euro area.

We begin by selecting into matrix $\hat{X}$ (indexed at each monetary policy decision date) changes in seven asset yields (same series as in ABGMR, describing the euro area yield curve from 1 month to 10 years) in a tight window around the ECB's monetary policy decision events. The asset yield series include indexed swaps of Eonia with 1-, 3-, 6- and 12-month maturities (OIS1M, OIS3M, OIS6M, OIS12M) as well as German government bond yields for 2-, 5-, and 10-year maturities (DE2Y, DE5Y, DE10Y). The series are taken directly from the EA-MPD Excel file from the sheet "*Monetary Event Window*".[19] First,

[19]The series are taken from Excel "as is", that is, we do not perform similar adjustment for the first two columns as GSS (p. 89-90) to clean for the overlap in the expected path of the policy rate.

Figure 4: Derived monetary policy shocks



Notes: This figure displays the target and path shocks using our extraction method akin to Gurkaynak, Sack, and Swanson (2005) and Altavilla, Brugnolini, Gürkaynak, Motto, and Ragusa (2019). The shocks are derived for each monetary policy decision date and grouped to monthly frequency by summing shocks within each month. The vertical dashed line denotes the start of NIRP in June 2014. Source: EA-MPD, Bloomberg, and authors' calculations.

we obtain a normalized matrix X by applying a z-score transformation on each of the columns $\hat{X}_j$ in $\hat{X}$. Next, we extract the first two principal components of X, yielding a matrix $\hat{F}$ of orthogonal column vectors $\hat{F}_j$, $j = 1, 2$. Lastly, we normalize each of the columns in $\hat{F}$ to have unit variance, resulting in factor matrix F and associated loading matrix $\aleph$.

Shocks $\hat{S}$ are obtained when we rotate F with a suitable matrix U. In particular, the shocks are given by

$$\hat{S} = F\,U, \tag{4}$$

where the rotation matrix U is identified by four restrictions as described in GSS page 91. Specifically, if we write U as:

$$U = \begin{bmatrix} \alpha_1 & \beta_1 \\ \alpha_2 & \beta_2 \end{bmatrix}, \tag{5}$$

then the four restrictions can be described as:

$$1 = \alpha_1^2 + \alpha_2^2 \tag{6}$$

$$1 = \beta_1^2 + \beta_2^2 \tag{7}$$

$$0 = \alpha_1\beta_1 + \alpha_2\beta_2 \tag{8}$$

$$0 = \beta_1\aleph_{11} + \beta_2\aleph_{21}, \tag{9}$$

where $\aleph_{ij}$ is the element in the i-th row and j-th column of $\aleph$. With this rotation, we can define a new matrix of loadings $L = U'\aleph$. Finally, $\hat{S}$ can be re-scaled to obtain the final shock matrix S as follows: S_1 moves the one month rate change (column X_1, that is, OIS1M) one-for-one, and S_1 and S_2 have the same effect on the one year rate change (column X_4, that is, OIS1Y). This can be accomplished by defining:

$$S = \hat{S} \cdot M, \tag{10}$$

where:

$$M = \begin{bmatrix} L_{11} & 0 \\ 0 & L_{11}\frac{L_{24}}{L_{14}} \end{bmatrix}, \tag{11}$$

and L_{ij} is the element in the i-th row and j-th column of the loading matrix L.