

The Transmission of Negative Nominal Interest Rates in Finland*

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Despite the implementation of negative nominal interest rates by several advanced economies in the last decade, there is still much we do not know about the effectiveness of this instrument. 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: 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.

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1 Introduction

Ever since the Great Financial Crisis of 2008-2009, monetary-policy makers in many advanced economies have frequently brought 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 loan 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. \(2023\)](#), 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 distinct empirical methodologies: 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.

¹The 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. \(2022\)](#).

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

Focusing on a single loan product, mortgages, for a single euro-zone country, Finland, has some empirical advantages. First, 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 mortgage 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 about the endogeneity 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 (c.f., [Eggertsson et al., 2023](#)). Finland is adjacent to Sweden by land and separated from it by the Baltic Sea. The two economies 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 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 event studies 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 identify the causal effects of negative nominal interest rates. In what follows, we describe these methodologies in detail, together with our results when using each of them.

To begin, we study the relationship between changes in the policy rate and changes in mortgage rates, denoted the "mortgage-rate beta", and assess how this relationship varies between positive and negative territory. The results of these event-study 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 was still effective at influencing mortgage rates 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 When the policy rate is non-negative, we find that 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, banks relying more on deposit funding pass through a smaller fraction of monetary policy

³This 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.

⁴This 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.

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, providing some validation to 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 rates. To the extent that commercial banks cannot transmit the fall in the policy rate in negative territory 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, in addition to event studies, 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 \(2022\)](#), [Bats et al. \(2023\)](#), or [Wang \(2022\)](#), have typically found detrimental effects on bank stock prices from negative rate implementation. Importantly, [Bräuning and Wu \(2017\)](#) shows that this can 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. \(2022\)](#), [Bittner et al. \(2022\)](#), [Basten and Mariathan \(2023\)](#), [Hong and Kandrac \(2022\)](#), 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 indicate that the reaching-for-yield channel is likely to 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 do not make use of this identification scheme. However, our results complement well with those from the negative-rates cross-country papers with the largest samples, like [Lopez et al. \(2020\)](#) or [Ulate \(2021b\)](#), which find a positive but diminished pass-through to loan rates in negative territory.

Relative to existing literature, our contribution is to simultaneously 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.

Although this is an empirical paper, our findings are directly 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 deposit margin gets

⁵As 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.

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. [Abadi et al. \(2023\)](#) 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. \(2023\)](#) 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. \(2023\)](#), the majority of the theoretical negative-rates papers with quantitative implementations 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 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.

⁶Additionally, [de Groot and Haas \(2023\)](#) studies the signaling channel, another mechanism through which negative rates can stimulate the economy even if current deposit rates are stuck at zero; [Onofri et al. \(2023\)](#) 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 \(2023\)](#) 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 analysis, we employ a monthly 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 as of December 2020. We also collect data on each sample bank-group's balance sheet ratios such as the deposit-to-asset ratio.⁸ Our main data source is the "Balance Sheet Items and Interest Rate Statistics of Finnish Monetary Financial Institutions" dataset.⁹ We complement this with bank-group level balance-sheet information from S&P's Market Intelligence database.

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.

⁹The 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

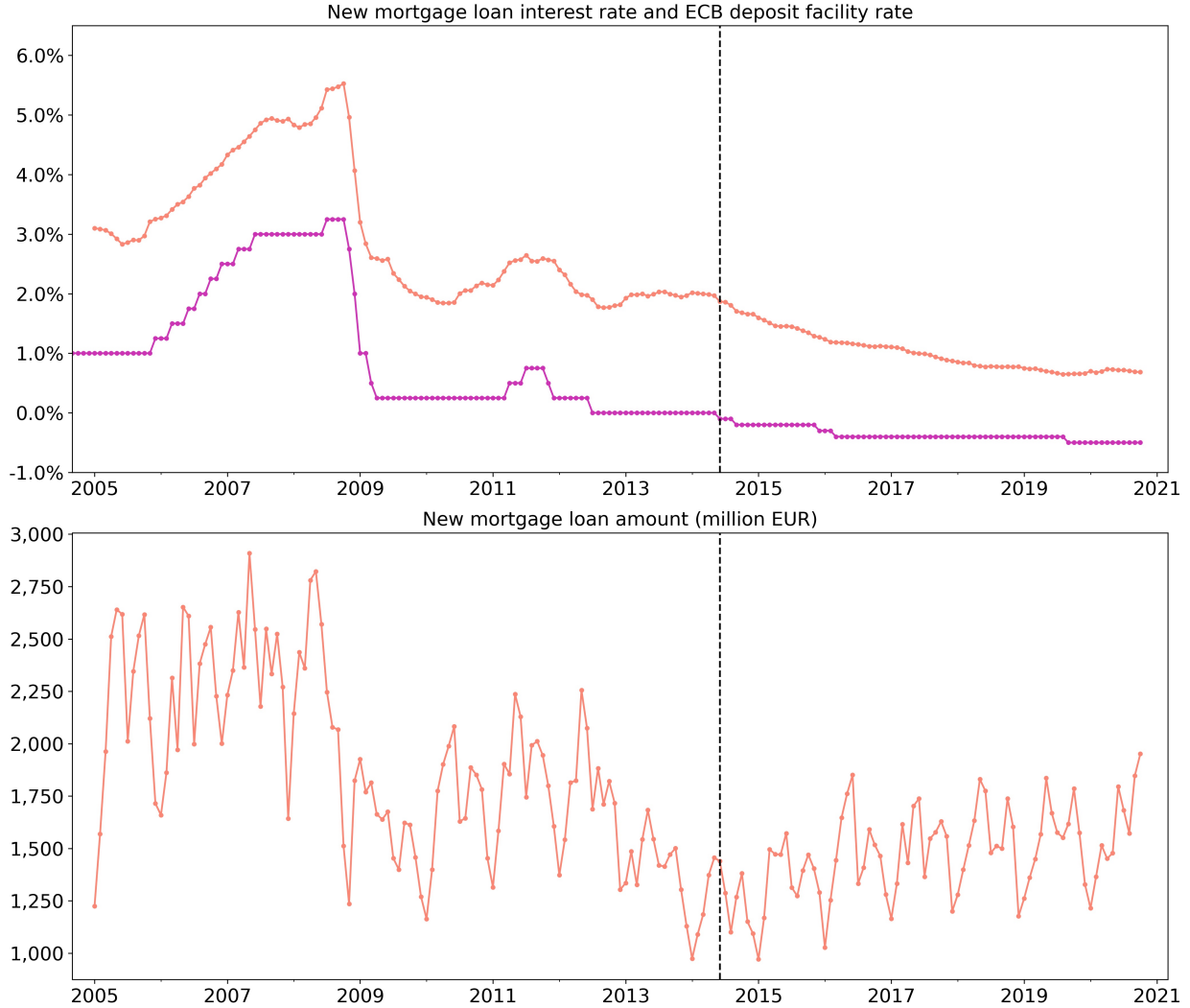


Notes: The figure displays the ECB’s deposit facility rate along with the Euro over-night rate (Eonia), the 6-month Euribor rate, as well as the 2- and 10-year Finnish government bond yields. The vertical black dashed line denotes the start of NIRP. The frequency is daily between 2005-01-01 and 2021-12-31.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

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 bottom panel shows that the amount of new mortgage loans plummeted following 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.

In terms of the composition of bank loans, the share of mortgages as a percent of total outstanding bank loans in Finland at the end of 2022 was roughly 42% (about 103 billion euros), which is in line with the average in the Euro Area. Finnish banks typically hold mortgage loans on their balance sheets (that is, little securitization takes place). Furthermore, banks may acquire market-based funding by issuing bonds collateralized by pools of mortgage loans, or so-called covered bonds. Covered bonds, which have high credit

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.

ratings, have been a source of relatively inexpensive funding for Finnish banks. Yet, deposits from the public are still the single-most important funding source (Putkuri, 2020). The fact that Finnish banks mostly keep mortgages on their balance sheets makes our setting different from that in the United States, where many banks use the “originate-to-distribute” model so they do not keep mortgages on their balance sheet. Moreover, banks

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 the 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.

in other European countries, particularly the Nordic countries (including Sweden) have business models that are much closer to the Finnish one than to the U.S. one.

In terms of the rate-fixing structure of mortgages in Finland, the vast majority of them have a semi-variable rate with a fixing period of one year or less.¹⁰ It is worth noting that the share of mortgages with a rate-fixing term of one year or less is greater in Finland (which has a sample average of 97% between 2010 and 2020) than in other countries where the pass-through to mortgage rates has been studied (73% in Sweden and 53% in Italy). This could explain some of the differences in the results that we obtain compared to papers like [Eggertsson et al. \(2023, studying Sweden\)](#) or [Amzallag et al. \(2019, studying Italy\)](#), both of which find a lower pass-through of negative rates to mortgages rates

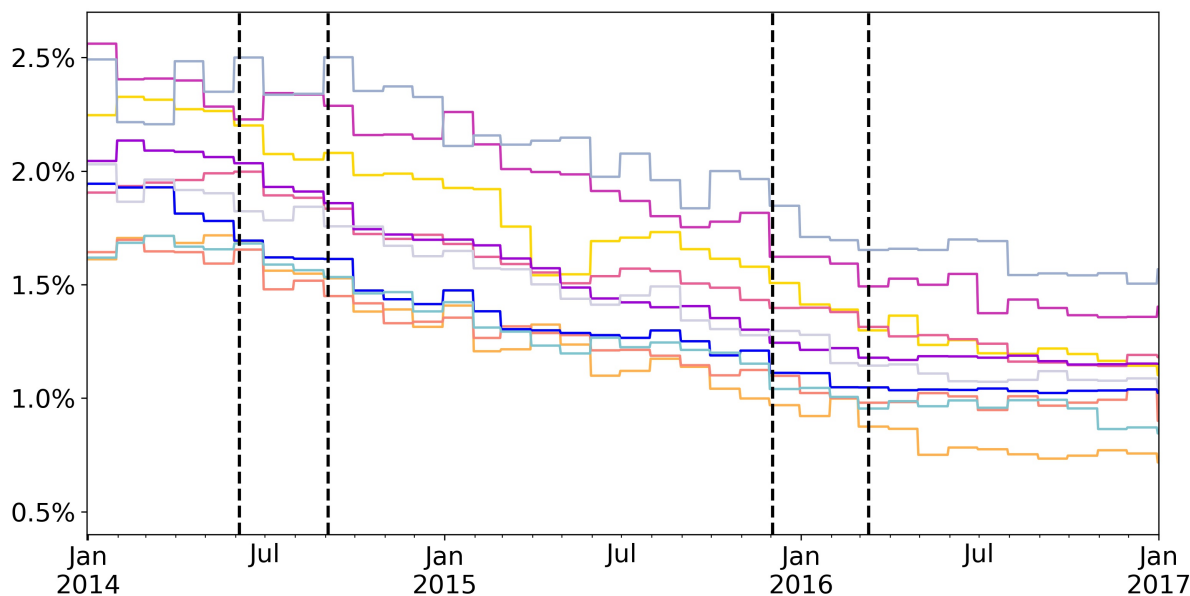
¹⁰As an example, take a mortgage with one-year fixing that starts on January 1st, 2024, and has a rate of the one-year Euribor plus 1%. For all of 2024, this mortgage would have an interest rate of what the one-year Euribor was on January 1st of 2024 plus 1%. Then, for all of 2025, the rate would be whatever the one-year Euribor will be in January 2025 plus 1%, and so on. The reference rate, in this case one-year Euribor, resets yearly. That is why the mortgage rate is denoted as a semi-variable rate with a fixing period of one year.

than we do. Given that a higher share of variable-rate mortgages is expected to increase the pass-through of the policy rate to mortgages rates, as documented in [Amzallag et al. \(2019\)](#), these differences in findings are in line with expectations.

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 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%.

Figure 3 shows the average interest rate on new mortgages, between 2014 and 2016,

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.

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 Mortgage-Rate Betas

In this section, we investigate the extent to which changes in the policy rate pass onto the rates on newly originated mortgages. We will denote this pass-through of the policy rate to the mortgage rate as the “mortgage-rate beta”. This concept is similar to the deposit-rate beta in [Drechsler et al. \(2017\)](#) and [Drechsler et al. \(2021\)](#), but for a product on the asset side of the bank balance sheet (mortgages) instead of one on the liability side.

To assess the mortgage-rate beta, including the possibility of lags in transmission and differences between normal and negative territory, we specify the following panel regression with bank fixed effects:

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

In equation (1), 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 policy rate (DFR) in period t , $Post_t$ is a dummy variable equal to one if t is on or after June 2014 (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 $t - k$. The sum $\sum_{k=0}^K \beta_k$ measures the total transmission of the policy rate to the mortgage rate over $K + 1$ months (the cumulative mortgage-rate beta in positive territory).

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 ($\sum_{k=0}^K \mu_k$) measures the total change in transmission during the negative-rates period, and the sum of all the β and μ coefficients ($\sum_{k=0}^K \beta_k + \sum_{k=0}^K \mu_k$) measures the total transmission during the negative-rates period (the cumulative mortgage-rate beta in negative territory).

The estimates from the regression in equation (1) with $K = 3$ are shown in Table 2.¹¹ 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 roughly 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-

¹¹Adding 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*** (0.052)	0.237*** (0.050)	0.055 (0.030)	-0.122*** (0.033)	0.859*** (0.034)
μ_0	μ_1	μ_2	μ_3	$\sum_{k=0}^3 \mu_k$
-0.358*** (0.090)	-0.170** (0.064)	0.079 (0.057)	0.125 (0.074)	-0.324*** (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*** (0.102)	0.067 (0.061)	0.133*** (0.037)	0.003 (0.073)	0.535*** (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. The sample period is January 2005 to October 2020. Standard errors are clustered at the bank-group level. Asterisks denote statistical significance: *=10%, **=5%, ***=1%.

rates period from June 2014 to October 2020. During this period, the contemporaneous 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 (from 0.859 to 0.535) 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 evidence suggests that monetary policy remained operational through the interest rate channel during the negative-rates period. To identify the causal effects of monetary policy more precisely, in the next section we employ a high-frequency identification strategy to examine the policy transmission of negative nominal

interest rates.

While the results in Table 2 use the DFR as a measure of the ECB’s policy rate, the actual policy rate that matters the most for the operations between commercial banks and the ECB has varied over time. In particular, the effective policy rate before the Great Financial Crisis was mostly the rate on marginal refinancing operations (MRO), while during the crisis, this relevant policy rate became the DFR. In order to capture the fact that the relevant policy rate switched from the MRO to the DFR over the second half of 2008, we compute a concatenated policy rate that smoothly transitions between the MRO and the DFR during the second half of 2008.¹² Appendix Table 6 presents the results of the regression in equation (1) but using this concatenated policy rate instead of just the DFR. The main takeaways are the same as in Table 2, but the reduction in effectiveness during the negative rates period gets reduced roughly by half (strengthening the result that rate cuts continue to be effective in negative territory).

4 High Frequency Identification

As mentioned in the introduction, using high-frequency data allows the econometrician to identify monetary surprises from short event-windows surrounding monetary policy announcements. The idea is to take the difference between several measures of yields before the monetary policy announcement and those same measures after the announcement has occurred. If the window around the monetary policy announcement is short 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

¹²Specifically, the concatenated policy rate is given as follows: up to July of 2008 it is just the MRO, in August of 2008 it is 80% MRO + 20% DFR, in September it is 60% MRO + 40% DFR, in October it is 40% MRO + 60% DFR, in November it is 20% MRO + 80% DFR, and from December of 2008 onwards it is just DFR.

on asset prices around monetary policy announcements. We follow [Altavilla et al. \(2019\)](#), utilizing their Euro Area Monetary Policy event study Database (EA-MPD).¹³ 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^T , captures the “target” factor (corresponding to the surprise change in the short-term policy rate) and the second component, S^P , 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^T 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^T) as if it were a one percent shock to the short-term rate. Further, the re-scaling is such that it forces S^T and S^P to have the same effect on the one-year yield (12 month OIS yield). This allows us to interpret S^P as a longer run (path) factor that moves the one-year yield as much (and in the same direction) as S^T . 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.¹⁴ We plot the resulting

¹³The 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

¹⁴We 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 “pro-

monetary policy surprise series in Figure 4 of Appendix B.

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

$$y_{t+1} - y_{t-1} = \alpha + \gamma Post_t + \beta^T S_t^T + \beta^P S_t^P + \mu^T S_t^T Post_t + \mu^P S_t^P Post_t + \varepsilon_t, \quad (2)$$

where y_t is the interest rate on new mortgages aggregated across banks at time t , S_t^i is the i identified monetary policy shock at time t (S^T being the target shock and S^P 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 the top panel of Table 3.¹⁵ The bottom panel of Table 3 presents similar results but when there is a single extracted shock instead of two orthogonal ones.

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^T , 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 coefficients for S^T 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^P , 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 mortgage rates. The significance of S^T combined with the insignificance of S^P suggests that, during the unconventional monetary policy period, 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).¹⁶

cess" the information contained in the actions of the ECB due to the huge uncertainty of the period.

¹⁵In 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.

¹⁶The fact that an overwhelming majority of mortgages in Finland are effectively variable-rate is likely a contributing element in explaining why the target factor matters more than the path factor. However, it is not enough to explain the significance of the target factor. For example, even if 100% of mortgages were variable rate, if banks get all their funding from deposits that are subject to the deposit zero lower bound,

Table 3: Results from high-frequency analysis

	Change in the mortgage rate (bps)
Target Shock (S^T)	
S^T pre-NIRP (β^T)	6.57** (2.68)
S^T NIRP ($\beta^T + \mu^T$)	3.16*** (0.86)
S^T difference (μ^T)	-3.41 (2.83)
Path Shock (S^P)	
S^P pre-NIRP (β^P)	1.01 (1.73)
S^P NIRP ($\beta^P + \mu^P$)	0.87 (0.81)
S^P difference (μ^P)	-0.14 (1.91)
Number of observations	185
Adjusted R^2	0.06
Single Shock	
pre-NIRP (β)	6.09** (2.99)
NIRP ($\beta + \mu$)	2.80* (1.67)
difference (μ)	-3.29 (3.43)
Number of observations	185
Adjusted R^2	0.05

Notes: The top part of the 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. The bottom part of the table presents the results of a regression similar to that in equation (2) but where there is a single extracted shock that is the first principal component of the asset prices described in the text, normalized to move the short rate one-for-one. Standard errors are HAC robust with a maximum of one lag. Asterisks denote statistical significance: *=10%, **=5%, ***=1%.

The reduction in effectiveness (even if not statistically significant) that we find be-
when the DFR becomes more negative, their funding rate would not react and they would be unable to decrease their mortgage rates, so the target factor would have no effect on the rate (neither would the path factor).

tween the positive policy rate period and the negative policy rate period using our high-frequency identification strategy is of around 50% (for either S^T or the single shock in the bottom panel of table 3). 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).¹⁷ 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.^{18,19}

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., 2022) and requires taking a stance on what constitutes being "more exposed" to negative rates. Here, as the measure of exposure, we use the deposit-to-asset ratio 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 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,

¹⁷The 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 seems reasonable for the welfare results to show a lower fall in effectiveness compared to the loan pass-through results.

¹⁸We 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.

¹⁹Appendix Section B presents the results of estimating equation (2) but including one lag of the shocks, the main conclusions are unchanged.

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:

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

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 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 β coefficient is not significantly different from zero, indicating that when the policy rate is positive, banks with a higher DAR do not exhibit a differential 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.²⁰

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 essentially 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

²⁰Appendix Table 7 gives the results of the regression in equation (3) but using the concatenated policy rate described at the end of Section 3. The main takeaways are unaffected by this change.

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%.

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*.²¹

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 (37%). The result indicates that a bank at the 75th percentile of the DAR distribution transmits roughly 40 percent 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 Sections 3 and 4, indicating that the deposit margin channel can be an important contributor to the decrease in the aggregate transmission.

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

²¹If 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.

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 event studies 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 nominal 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, event studies 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 precisely. 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.

Our third empirical strategy exploits 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 (the lowest DFR was -0.5%). 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.

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Appendices for Online Publication

Appendix A describes our data in greater detail while Appendix C describes the construction of our monetary policy shocks using 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. The 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.

The above choices define “normal” mortgages used to finance purchase or renovation of a home. Importantly, our sample does not include “enterprise” or “business” mortgages.

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.²²

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 is also available from the ECB's web page.²³

B Additional Results

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

Table 6 presents results similar to Table 2 but using as independent variable the first difference of a version of the policy rate that is a combination of the rate on marginal refinancing operations (MRO) and the deposit facility rate (DFR). The combination is as follows: up to July of 2008 it is just the MRO, in August of 2008 it is 80% MRO + 20% DFR, in September it is 60% MRO + 40% DFR, in October it is 40% MRO + 60% DFR, in November it is 20% MRO + 80% DFR, and from December of 2008 onwards it is just DFR.

²²Here 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.

²³Decision 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*** (0.026)	0.335*** (0.022)	0.039* (0.021)	-0.114*** (0.010)	0.882*** (0.015)
μ_0	μ_1	μ_2	μ_3	$\sum_{k=0}^3 \mu_k$
-0.228*** (0.047)	-0.300*** (0.052)	0.086* (0.044)	0.150* (0.071)	-0.291*** (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*** (0.037)	0.035 (0.035)	0.125*** (0.026)	0.037 (0.068)	0.591*** (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%.

This weighting scheme is standing in for the fact that during the second half of 2008, as the Great Financial Crisis was unfolding, the main policy rate of the ECB transitioned from being the MRO to being the DFR as the European banking system was flooded with liquidity and most banks started holding excess reserves at the ECB. When most banks have excess reserves, the relevant rate in a corridor system becomes the rate on reserves, which in the Euro Area is precisely the DFR. Table 7 presents results similar to those in Table 4 but using this concatenated policy rate.

Table 8 presents results similar to Table 3 but including one lag of the shocks.

C 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

Table 6: Results from correlational analysis using concatenated policy rate

Change in the mortgage rate (pp)				
β_0	β_1	β_2	β_3	$\sum_{k=0}^3 \beta_k$
0.542*** (0.049)	0.225*** (0.051)	0.114*** (0.032)	-0.042 (0.040)	0.839*** (0.024)
μ_0	μ_1	μ_2	μ_3	$\sum_{k=0}^3 \mu_k$
-0.178* (0.085)	-0.114 (0.064)	0.064 (0.059)	0.077 (0.077)	-0.151** (0.055)
$\beta_0 + \mu_0$	$\beta_1 + \mu_1$	$\beta_2 + \mu_2$	$\beta_3 + \mu_3$	$\sum_{k=0}^3 \beta_k + \mu_k$
0.364*** (0.101)	0.111 (0.063)	0.178*** (0.040)	0.035 (0.073)	0.688*** (0.064)
Number of observations			1774	
Adjusted R^2			0.417	
Bank-group fixed effects			Yes	

Notes: This table presents selected coefficients and standard errors (in brackets) estimated from the regression in equation (1) with $K = 3$. The dependent variable is the one-month difference in the rate on new mortgage loans in percentage points and the independent variable is the first difference of a concatenated version of the policy rate that is a combination of the rate on marginal refinancing operations (MRO) and the deposit facility rate (DFR). The combination is as follows: up to July of 2008 it is just the MRO, in August of 2008 it is 80% MRO + 20% DFR, in September it is 60% MRO + 40% DFR, in October it is 40% MRO + 60% DFR, in November it is 20% MRO + 80% DFR, and from December of 2008 onwards it is just DFR. The change in the policy rate is measured in percentage points. The sample period is January 2005 to October 2020. Standard errors are clustered at the bank-group level. Asterisks denote statistical significance: *=10%, **=5%, ***=1%.

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 U.S. 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 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.²⁴

²⁴Extracting three shocks instead of two would make very little difference for our results.

Table 7: Results from exposure-measure analysis using concatenated policy rate

	Change in the mortgage rate (bps)
β	-0.185 (0.102)
μ	-1.049* (0.521)
Number of observations	244
Adjusted R^2	0.839
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 independent variable is the first difference of a concatenated version of the policy rate that is a combination of the rate on marginal refinancing operations (MRO) and the deposit facility rate (DFR). The combination is as follows: up to July of 2008 it is just the MRO, in August of 2008 it is 80% MRO + 20% DFR, in September it is 60% MRO + 40% DFR, in October it is 40% MRO + 60% DFR, in November it is 20% MRO + 80% DFR, and from December of 2008 onwards it is just DFR. The change in the policy rate is 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%.

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".²⁵ First, 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

²⁵The 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.

Table 8: Results from high-frequency analysis, one lag

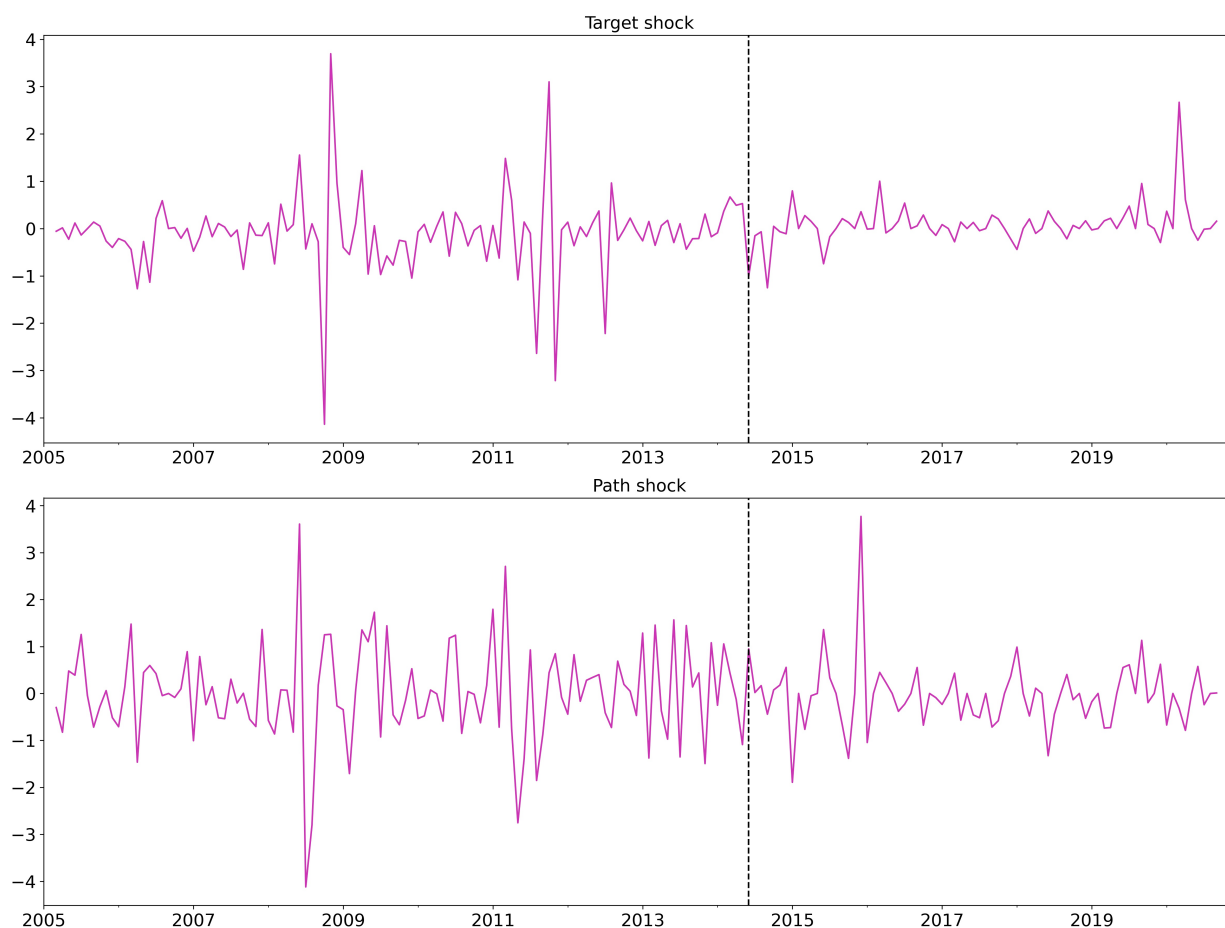
	Change in the mortgage rate (bps)	
	Contem.	1st Lag
Target Shock (S^T)		
S^T pre-NIRP (β^T)	7.08*** (2.39)	3.03 (3.09)
S^T NIRP ($\beta^T + \mu^T$)	3.02*** (0.89)	1.60** (0.62)
S^T difference (μ^T)	-4.07 (2.57)	-1.42 (3.15)
Path Shock (S^P)		
S^P pre-NIRP (β^P)	1.24 (1.81)	1.04 (1.71)
S^P NIRP ($\beta^P + \mu^P$)	0.98 (0.84)	0.51 (0.77)
S^P difference (μ^P)	-0.26 (2.00)	-0.53 (1.87)
<hr/>		
Number of observations	185	
Adjusted R^2	0.06	
<hr/>		
Single Shock		
pre-NIRP (β)	6.79** (3.04)	3.41 (2.37)
NIRP ($\beta + \mu$)	3.15* (1.65)	1.77 (1.40)
difference (μ)	-3.64 (3.46)	-1.64 (2.76)
<hr/>		
Number of observations	185	
Adjusted R^2	0.05	
<hr/>		

Notes: The top part of the table presents the coefficients and standard errors (in brackets) estimated from the regression in equation (2) but including one lag of each of the two shocks. The bottom part of the table presents the results of a similar regression where there is a single extracted shock that is the first principal component of the asset prices described in the text, normalized to move the short rate one-for-one. Standard errors are HAC robust with a maximum of one lag. Asterisks denote statistical significance: *=10%, **=5%, ***=1%.

shocks are given by

$$\hat{S} = F U, \quad (4)$$

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, Gurkaynak, Motto, and Rugga (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 and authors' calculations.

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

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

then the four restrictions can be described as:

$$1 = \alpha_1^2 + \alpha_2^2 \quad (6)$$

$$1 = \beta_1^2 + \beta_2^2 \quad (7)$$

$$0 = \alpha_1\beta_1 + \alpha_2\beta_2 \quad (8)$$

$$0 = \beta_1\aleph_{11} + \beta_2\aleph_{21}, \quad (9)$$

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^T moves the one month rate change (column X_1 , that is, OIS1M) one-for-one, and S^T and S^P have the same effect on the one year rate change (column X_4 , that is, OIS1Y). This can be accomplished by defining:

$$S = \hat{S} \cdot M, \quad (10)$$

where:

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

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