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Emil Bandoni, Friederike Fourné,
Barbara Jarmulska

Mortgage loan rates and the defaults of variable rate mortgages

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Abstract

Using a granular database of variable rate euro area loans and analysing their defaults between 2014 and 2019, we show that the effect of interest rate changes on mortgage defaults is highly non-linear. First, we find that the risk associated with higher contemporaneous interest rates is concentrated among borrowers who got the loan at ultra-low interest rates, their default probability being 2.6 times higher than our sample average. Second, we show that the effect of interest rate changes on the default probability is asymmetric: interest rate cuts have rather small effects, whereas increases significantly raise default probabilities. Finally, we show that the magnitude of the effect of an interest rate increase depends on the history of net interest rate changes, with a consecutive interest rate increase having a 3 times stronger impact on the default probability than an increase following an interest rate decrease.

Keywords: Monetary Policy, Financial Stability, Mortgages. **JEL:** E52, G21, G51

Non-technical summary

Housing crises are more frequent than commonly thought: since the late 19^{th} century, advanced economies have faced an average of four housing market turmoils per decade (Dotsis *et al.*, 2023). Housing finance has been shown to play an important role in the Global Financial Crisis (Mian and Sufi, 2009, 2011). A sudden increase in mortgage repayment obligations could cause households to be unable to service their debt, and an increase in mortgage defaults could damage the entire economy (Aron and Muellbauer, 2016; Campbell and Cocco, 2015). A sudden increase in debt service burdens is of particular concern for borrowers with variable rate loans. While mortgage defaults have been on a downward trend in the euro area since the Global Financial Crisis, the ultra-low interest rate environment that started around 2014 contributed to the build-up of stocks of mortgage loans subject to interest rate increases during the 2022-2024 monetary policy tightening cycle.

We extend the existing literature on mortgage defaults by exploring substantial non-linearities in the reaction of household mortgage default probabilities to interest rate changes. We provide evidence of particularly vulnerable groups of borrowers among those who received their mortgages at particularly low interest rates. We base our analysis on loan-level data for four euro area countries with a relatively high share of floating rate loans in their stock of mortgages. Our research focuses on loans originated since 1996, and analyses mortgage defaults in the years 2014-2019. To the best of our knowledge, we are the first to document the following non-linearities in the reaction of mortgage default probability to loan interest rate changes.

First, building on our baseline finding that higher interest rates correlate with a higher probability of default, we show that the effect on mortgage probability of default of contemporaneous interest rates differs by origination interest rates: the mortgage default risk associated with higher contemporaneous interest rates is concentrated among borrowers who got the loan at ultra-low interest rates.

Second, we show that the effect of interest rate changes on default probability is asymmetric and differs across the interest rate distribution at mortgage origination. Although statistically significant, interest rate decreases have a rather small effect. In contrast, increases in interest rates have more severe effects on default probabilities.

Finally, we show that the magnitude of the effect of an interest rate increase depends on the history of net interest rate changes. The results suggest that the effect of an interest rate increase is greater for loans that have already experienced a net interest rate increase compared to loans where the interest rate increase is lower than the previous net decrease.

1. Introduction

Housing crises are more frequent than commonly thought: since the late 19^{th} century, advanced economies have faced an average of four housing market turmoils per decade (Dotsis *et al.*, 2023). Housing finance has been shown to play an important role in the Global Financial Crisis (Mian and Sufi, 2009, 2011). A sudden increase in mortgage repayment obligations could cause households to be unable to service their debt, and an increase in mortgage defaults could damage the entire economy (Aron and Muellbauer, 2016; Campbell and Cocco, 2015). A sudden increase in debt service burdens is of particular concern for borrowers with variable rate loans. While mortgage defaults have been on a downward trend in the euro area since the Global Financial Crisis, the ultra-low interest rate environment that started around 2014 contributed to the build-up of stocks of mortgage loans subject to interest rate increases during the 2022-2024 monetary policy tightening cycle.

We extend the existing literature on mortgage defaults by exploring substantial non-linearities in the reaction of household mortgage default probabilities to interest rate changes. We provide evidence of particularly vulnerable groups of borrowers among those who received their mortgages at particularly low interest rates. We base our analysis on loan-level data for four euro area countries with a relatively high share of floating rate loans in their stock of mortgages. Our research focuses on loans originated since 1996, and analyses mortgage defaults in the years 2014-2019. To the best of our knowledge, we are the first to document the following non-linearities in the reaction of mortgage default probability to loan interest rate changes.

First, building on our baseline finding that higher interest rates correlate with a higher probability of default, we show that the effect on mortgage probability of default of contemporaneous interest rates differs by origination interest rates: the mortgage default risk associated with higher contemporaneous interest rates is concentrated among borrowers who got the loan at ultra-low interest rates. When the contemporaneous interest rate is relatively high, the predicted default probability of loans extended with ultra-low interest rates is 2.6 times higher than the average default rate in our sample.

Second, we show that the effect of interest rate changes on default probability is asymmetric and differs across the interest rate distribution at mortgage origination. Although statistically significant, interest rate decreases have a rather small effect. Conversely, increases in interest rates have more severe effects on default probabilities, in particular relatively larger interest rate increases that affected loans extended at low origination interest rates. The default probability of mortgages extended at ultra-low interest rates which experienced interest rate increases greater than 70 basis points is 9 times higher than the default probability of loans that were extended at ultra-low interest rates and did not experience a change to their interest rate.

Finally, we show that the magnitude of the effect of an interest rate increase depends on the history of net interest rate changes. The results suggest that the effect of an increase in the interest rate is three times greater for those loans that already experienced a net interest rate increase, compared to loans where the interest rate increase is lower than the previous net decrease.

Taken together, these findings suggest that borrowers whose mortgages originated in an environment of very low interest rates could be a group particularly vulnerable to a default when interest rates start to increase. We believe that the mechanism behind it is the following. In times of lower interest rates, borrowers can obtain relatively higher mortgage loans. At the same time, if a loan is originated at ultra-low interest rates, even a relatively small increase of interest rates in absolute terms implies a large increase in relative terms. As both higher indebtedness and lower origination interest rates increase the sensitivity of loan-service-to-income ratios to interest rates, taken together, these factors can lead to substantial increases in monthly payments for some borrowers. This mechanism should be seen against the background of a tendency of market participants to be excessively optimistic in good times, and of borrowers to likely underestimate the likelihood and extent of possible increases of interest rates throughout the life of the mortgage. Our results are relevant from a financial stability and macroprudential policy perspective because they identify potential risks to the banking sector stemming from a certain subset of mortgage markets, and they support activating borrower-based measures limiting the debt-service-to-income ratios, including stress testing interest rates at origination in the periods when interest rates are particularly low.

The remainder of this paper is structured as follows. Section (2) provides an overview of the existing literature. Sections (3) and (4) provide more information on the data and the methodology. Section (5) contains the results. Section (6) discusses the interpretation of the results, and Section (7) concludes.

2. Literature review

There exists a large body of literature that focuses on identifying, examining, and quantifying triggers and determinants of mortgage defaults (see, e.g. the extensive literature reviews in Quercia and Stegman, 1992; Jones and Sirmans, 2015).

A major branch of the literature looks at the conditions under which mortgage defaults become more likely. These studies agree on the joint importance of house price declines (leading to a negative equity status) and borrowers' reduction in loan repayment capacity (driven by income shocks or increases in required loan repayments), commonly called the *double trigger hypothesis*, in providing key default incentives to households (Campbell and Cocco, 2015; Gerardi *et al.*, 2015; Elul *et al.*, 2010; Bajari *et al.*, 2008; Foote *et al.*, 2008). Linn and Lyons (2019) add a country's institutional quality as a third trigger. The enforcement of laws and regulations provides households with additional incentives to default (or not). Guiso *et al.* (2013) suggest that also idiosyncratic factors might be relevant triggers, including, among others, the individual assessment of the importance of fairness and morality in a society, or the contentedness of the household with the economic environment and the banking system. With regard to determinants of defaults, mortgage balances, maturity, interest rates, and individual borrower characteristics (e.g. income and occupation) are among the most popular metrics studied in the literature (see for example Alfaro and Gallardo, 2012; Gerlach-Kristen and Lyons, 2018; Gaudencio *et al.*, 2019).

Another branch of the literature focuses on the link between lending standards and default probabilities (Dell'Ariccia *et al.*, 2012; Hallissey *et al.*, 2014; Gaudencio *et al.*, 2019). The role of loan-to-value (LTV) ratios has been extensively analysed in the literature (see e.g., Jones and Sirmans, 2015; Galan and Lamas, 2023, and the literature cited therein), probably to a large extent due to its popularity among policymakers worldwide (van Hoenselaar *et al.*, 2021). Both initial and current LTV ratios are often found to be positively correlated with default probabilities. Elul *et al.* (2010) estimate a dynamic logit model and show that the current LTV ratio is positively and monotonically related to the default risk. However, once households take out an additional loan, the higher the LTV ratio of the first loan, the higher the default risk of the second loan. Deng (1997) and May and Tudela (2005) show that the relationship between LTV and the probability of default is far from linear, with the risk of default especially pronounced for loans within riskier LTV buckets. Galan and Lamas (2023) show for Spain that looking at conventional LTV figures might distort the risk assessment of loans due to "inflated appraisals."

Although LTV caps tend to be the most popular type of borrower-based measures, income-based measures are also relevant. The effect of debt-to-income (DTI) or debt-service-to-income (DSTI) [1] ratios has also been extensively studied. Regarding the strand of the literature that analyses LTVs jointly with income-based lending standards, Kelly and O'Toole (2018) identify a non-linear relationship between origination LTV and DSTI from a non-linear spline model. Overall, for the UK, their results suggest that defaults increase in LTV while they decrease in DSTI at origination. It has also been found that a reduction in mortgage payments driven by interest rate cuts is correlated with a decrease in overall mortgage

[1] Alternatively, loan-to-income (LTI) or loan-service-to-income (LSTI).

defaults (Di Maggio *et al.*, 2017), which is particularly true for borrowers with adjustable-rate mortgage loans and high LTVs.

Several papers in the literature seem close in spirit to our analysis in terms of focus on non-linearities in the response of the default probability to changes in interest rates or debt-service-to-income ratios. Fuster and Willen (2017) use a dataset of subprime loans to show that a decrease in the interest rate that leads to a reduction in mortgage payment is related to a reduction in default risk. Their results suggest that interest rate cuts significantly reduce default risks. The effect is neither linear in the interest rate nor in combination with lending standards, such as the LTV ratio. Nier *et al.* (2019) find that DSTI values seem to matter most once a certain threshold is exceeded. In addition, Dirma and Karmelavičius (2025) use Lithuanian data to show that the strength of the effect of changes in the DSTI ratio is concave across the DSTI distribution.

Methodologically, the literature typically resorts to probability frameworks such as logit and probit models to analyse default probabilities. Machine learning tools might be used in an effort to exploit more rigorously the - potentially highly non-linear - relations in loan-level data sets (see, e.g, Barbaglia *et al.*, 2021, and literature cited therein). Survival models, in particular Cox proportional hazard models, are also applied. These approaches allow analysing the possible default determinants and the importance of loan, borrower, regulatory or macroeconomic factors, using databases where the final maturity of many loans has not yet been reached.

3. Data

We use loan-level data on securitised mortgages from the European DataWarehouse (EDW),[2] focusing on variable rate loans in four countries (Spain, Ireland, Italy, and Portugal). We complement the loan-level dataset with macroeconomic variables on unemployment and aggregate real disposable income from Eurostat. Data reporting to the EDW began in 2014, but the origination year of reported loans dates back to the 1990s. After a thorough data cleaning process, our data set contains more than 9 million observations in quarterly frequency. We analyse mortgage loan defaults in years 2014-2019 of loans originated since 1996. Section (A.1) provides additional details on the data preparation process.

Our data comes with the caveat related to its representativeness, as securitised loans which

[2]EDW was introduced by the European Central Bank in 2011 as part of its Asset-Backed Securities (ABS) loan-level data (LLD) initiative and it started collecting data in 2014. The LLD initiative establishes specific information requirements for ABSs and for non-marketable debt instruments backed by eligible credit claims accepted as collateral in Eurosystem credit operations. In particular, we use loan-level data of loans belonging to a Residential Mortgage Backed Security (RMBS).

we can observe constitute only a fraction of loans extended in the countries we analyse. Selection bias may arise, but the literature on the credit quality of securitised loans is inconclusive. On the one hand, securitised loans may be of lower quality than loans that remain on banks' balance sheets (see Keys *et al.* (2010)). On the other hand, a selection bias might also operate in the opposite direction, as other studies (Albertazzi *et al.* (2015) and Bonner *et al.* (2016)) find that the main motivation for euro area banks to issue asset-backed securities is funding rather than risk mitigation, and in this case banks may have an incentive to securitise high quality loans given the investors' scrutiny. Despite these concerns, the EDW database provides a unique opportunity to study loan-level default behaviour, as such data are generally scarce, especially from a cross-country perspective.

3.1. Descriptive statistics

We restrict the set of descriptive statistics to the default rate, which is the dependent variable, and the explanatory variables of interest to our work, namely loan-level interest rate variables. In addition, Table (A1) in the Appendix provides summary statistics for all variables used in the analysis, including a set of loan, borrower and property characteristics deemed to be important for modeling default risk.[3]

On average, the data provide about 1.6 million individual observations per year, with an average mortgage volume of more than 30 billion euro per year (Figure (1)). Country contributions to these volumes differ, with Spain and Portugal accounting for the biggest and smallest shares, respectively. In line with the time lag usually observed between the origination of a loan and its first inclusion in a securitisation pool, the total volume slightly decreases over time. Our dataset ends before the Covid-19 pandemic started, with the most recent defaults in our data occurring in the first quarter of 2020. During the pandemic, regulatory adjustments (e.g., loan moratoria) or policy interventions (e.g., job protection schemes) may have affected loan performance and thus may have changed the relation between loan-level variables, in particular interest rates, and loan defaults. Excluding the COVID-19 pandemic implies that explanatory variables end in 2019, as the default status refers to the period of 12 months ahead. Our default dependent variable is a dummy taking the value of 1 if a loan is either defaulted, in foreclosure, or 90 days in arrears. The average default rate stands at 0.9% across time and countries, and, despite some heterogeneity across countries, default rates are generally low and follow a downward trend (Figure (2)).

Mortgage interest rates are generally low in our sample and decline on average throughout the 2014-2019 observation period (Figure (3a)), which is consistent with the fact that financing conditions eased in the period covered. The interest rate observed in our sample

[3]For more details on EDW data, including borrower and loan characteristics, see Gaudencio *et al.* (2019).

Figure 1: Volumes of mortgage loans

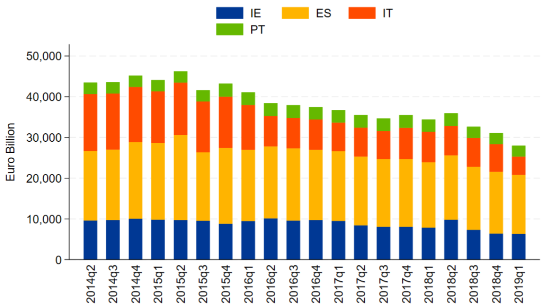
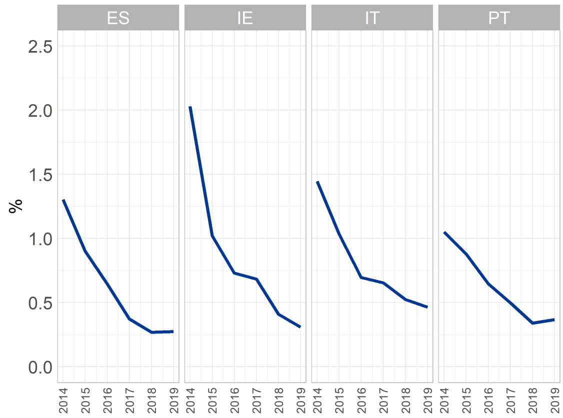


Figure 2: Mortgage default rates across countries

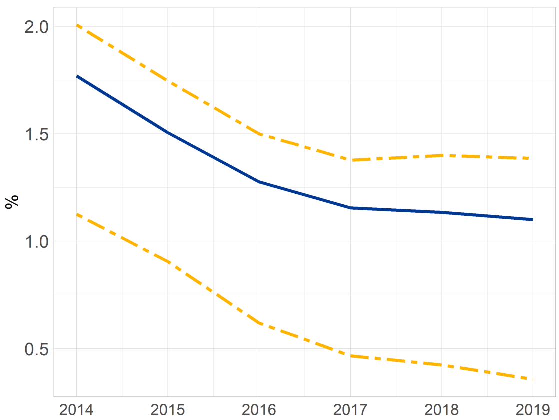


Notes: Left figure: Evolution of volume of mortgage loans across time and countries. Right figure: One year ahead default rates over time. *Sources:* EDW and authors' calculations.

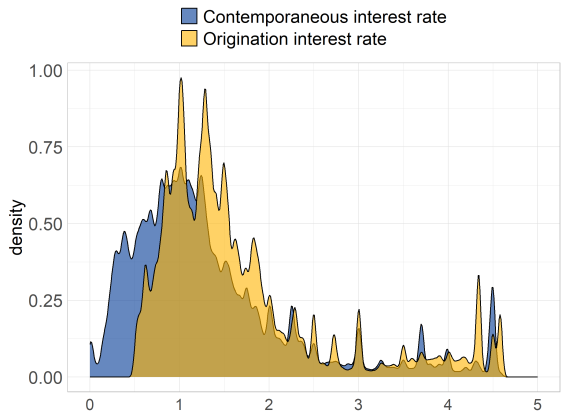
has decreased with respect to the one at origination for the majority of the loans (Figure (3b)). However, we also observe loans for which the interest rates increased with respect to origination, although their frequency is much lower than that where an interest rate increase has been recorded (also see Figure (A1) in the Appendix).

Figure 3: Evolution of loan-level interest rates

(a) Contemporaneous interest rate over time (median, IQR)



(b) Density of contemporaneous and origination interest rate



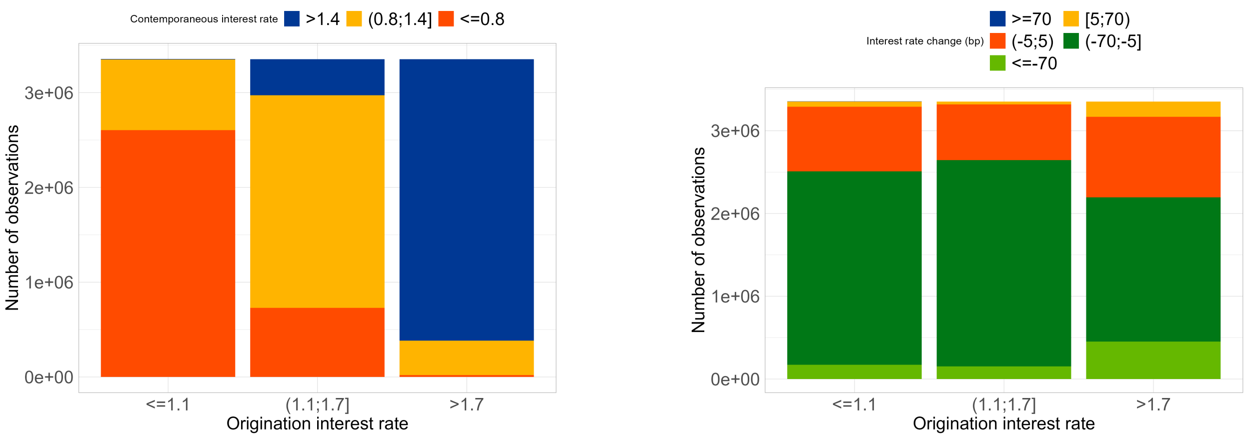
Notes: Left figure: Evolution of contemporaneous interest rate over time, showing median and inter-quartile range across countries. Right figure: Pooled distribution of origination and contemporaneous interest rate across countries. *Sources:* EDW and authors' calculations.

To enhance the interpretability of the results we show in Section 5, we construct discrete variables based on mortgage interest rates or their changes. First, we split loans into three equally sized buckets for both their contemporaneous and origination interest rate distribution (computed across all countries). Due to the overall low interest rate levels, the thresholds differentiating across the terciles are quite close. However, for the sake of simplicity, we will refer to the top tercile as *high interest rate*. Second, we construct another discrete variable that groups loans according to their interest rate changes (with respect to origination). This variable has five symmetric categories around a reference category allowing for changes of +/- 5 basis points, with changes (in basis points) classified as ≤ -70, $(-70, -5]$, $(-5, 5)$, $[5, 70)$, ≥ 70. Appendix (B2) provides details on the distribution of loans across buckets.

Figure (4) provides insights into the joint distributions of these categorical interest rate variables. A large share of loans extended at low interest rates continue being characterised by low contemporaneous interest rates (Figure (4a)). Similarly, loans with initially high interest rates tend to fall into buckets with higher contemporaneous interest rates. Interest rate decreases occur more frequently than increases, with the most pronounced decreases particularly concentrated among loans with high initial interest rates (Figure (4b)). Regarding the magnitude of the interest rate changes, category of five to 70 basis points decrease is the most common (Figure (5b)). As the fraction of loans with interest rate increases is low and hardly visible in Figure (4a), Figure (5a) focuses on those loans only, highlighting that we indeed observe interest rate increases across the entire distribution of origination interest rates. Although it is true that observations are not equally distributed across the joint distribution of origination interest rates and buckets of interest rate changes, Table (B4) in the Appendix shows that all combinations hold a satisfactorily high number of observations to run an empirical analysis and draw meaningful conclusions (always at least 1000 observations).

Figure 4: Joint distributions of loan-level interest rates - the entire sample

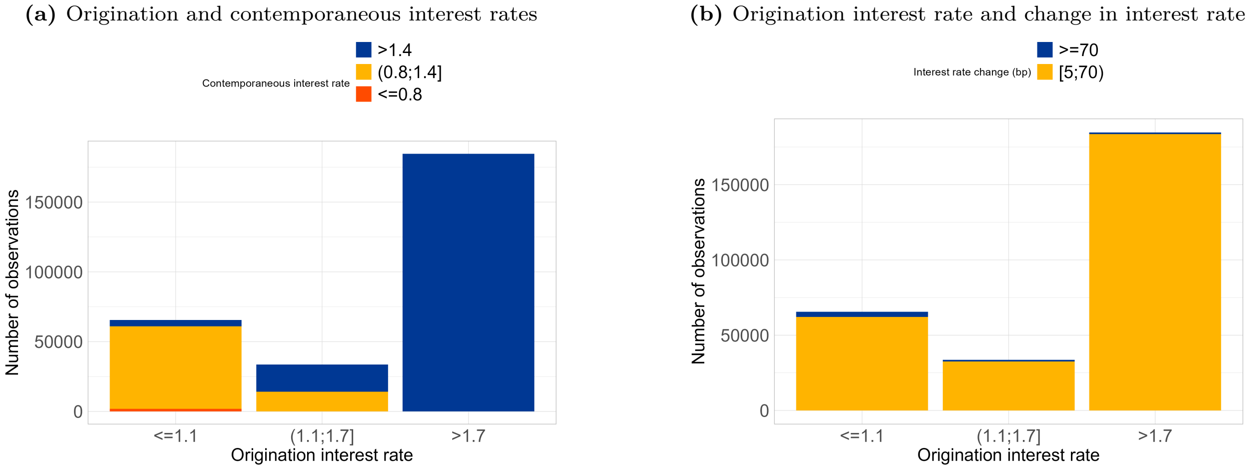
(a) Origination and contemporaneous interest rates **(b)** Origination interest rate and change in interest rate



Notes: Figures show the joint distribution of contemporaneous and origination interest rates (left figure) and interest rate changes (in basis points) and origination interest rates (right figure). All thresholds for the origination and contemporaneous interest rate for grouping them into buckets correspond to cross sectional terciles. *Sources:* EDW and authors' calculations.

We also check the joint distributions of origination interest rates or interest rates changes

Figure 5: Joint distributions of loan-level interest rates - loans which experienced interest rate increases



Notes: Figures show the joint distribution of contemporaneous and origination interest rates (left figure) and interest rate changes (in basis points) and origination interest rates (right figure), focusing on the subset of loans that experienced an interest rate increase. All thresholds for the origination and contemporaneous interest rate for grouping them into buckets correspond to cross sectional terciles. *Sources:* EDW and authors' calculations.

against various loan characteristics (origination LTVs, LTIs and LSTIs, borrower income, employment status of the borrower, maturity, country, year of origination, reporting year and principal repayment type). Looking at charts A2 and A3 in the Appendix we conclude that it does not seem that there exists a systematic relationship between loan characteristics and interest rate origination level, or later changes, that could be concerning for our analysis.

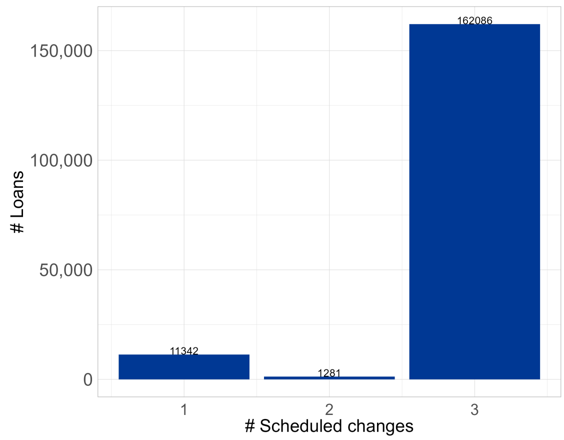
3.2. Mortgage interest rate components and endogeneity concerns

As our analysis focuses on interest rate changes and their effect on mortgage defaults, it is important to consider all components of mortgage interest rates to rule out possible endogeneity concerns. A variable interest rate consists of two parts: the underlying benchmark rate and the loan-specific margin. In this section, we show that the margins determined at loan origination tend to remain broadly constant throughout the life of the loan. This implies that changes in mortgage rates in our sample are primarily driven by fluctuations in the underlying benchmark rates (such as EURIBOR) rather than adjustments to the loan-specific margin. This is crucial for our analysis, as margin adjustments could reflect the bank's risk assessment for a given loan. Hence, by showing that interest rate changes that we capture are not driven by changes to loan-specific margins, we address a potential endogeneity concern, where the endogeneity could stem from changes in the riskiness of a borrower affecting simultaneously borrowers' interest margins and borrowers' probability of default. In contrast, from a single loan's perspective, monetary policy decisions about changes to the policy rate are exogenous.

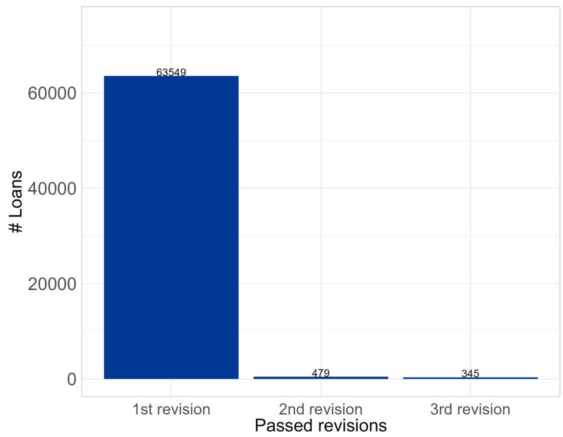
About 21% of all individual mortgages covered in our dataset report up to three scheduled

Figure 6: Revisions to the interest rate margin - numbers of scheduled and experienced revisions

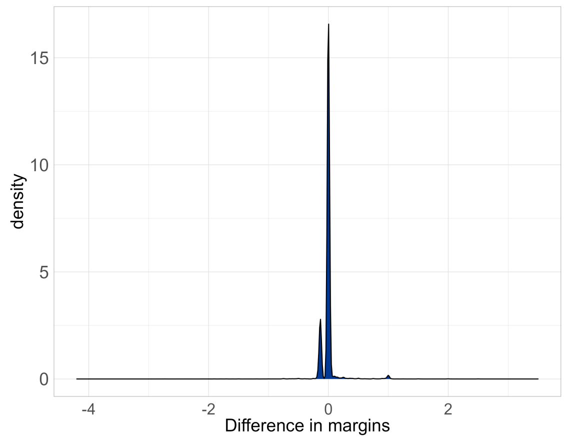
(a) Number of all scheduled margin revisions



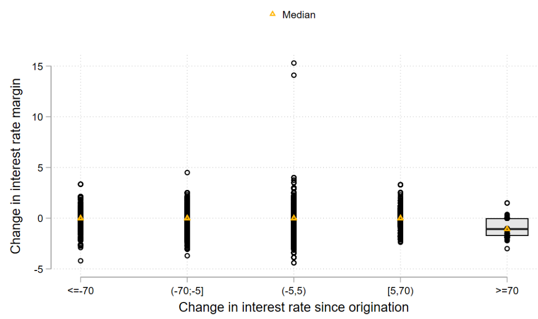
(b) Number of experienced margin revisions



(c) Distribution of margin revisions



(d) Margin revisions by interest rate changes



Notes: Figure (a): All scheduled revisions, including those beyond our sample period. Figure (b) focuses on loans that actually experienced these revisions. Figure (c) and (d) provide insights into the changes in interest rate margins and their distribution across buckets of interest rate changes. *Source:* EDW and authors' calculations.

margin revisions, with the majority reporting three revisions (Figure (6a)). These numbers also include revisions scheduled beyond our sample period. Restricting the subsample of interest to those that have already undergone at least one adjustment, the share decreases to 7.6%. While this in itself is already a reassuringly low share of loans, we still analyse loans with margin revisions in more detail. Among these loans, a large majority passed their first revision date, while only a few experienced more than one margin adjustment (Figure (6b)). Figure (6c) shows the distribution of changes in the interest rate margin for those loans that passed their revision dates. The largest mass is concentrated around zero, implying that a majority of loans that had a scheduled revision did not, in fact, experience changes in the interest rate margin. However, if margin changes did occur, they tended to reduce the margin charged on top of the benchmark interest rate. Furthermore, Figure (6d) breaks down the adjustment in margins by buckets of interest rate changes. We do not find any evidence that interest rate changes since origination may be systematically driven by adjustments to the interest rate margin. In general, we interpret it as implying that the interest rate changes that we observe in our sample are exogenous with respect to the probability of default.

4. Methodology

We run a pooled conditional logistic model at the quarterly frequency to quantify the sensitivity of mortgage defaults to interest rates. In this context, default is defined as the probability of a loan to default within the next four quarters given today's macroeconomic, loan, and borrower characteristics. Equation (1) shows the most parsimonious specification that serves as our baseline:

$$log \frac{P(DF_{i,c,t+4} = 1|\Psi_i)}{P(DF_{i,c,t+4} = 0|\Psi_i)} = \alpha + \lambda i_{i,c,t} + \theta \mathbf{Z_{i,c,t}} + \gamma \mathbf{Y_{i,c}} + \beta \mathbf{X_{c,t}} + \omega_{\mathbf{c}} + \rho_{\mathbf{o}} + \epsilon_{i,c,t}, \tag{1}$$

where the subscripts i, c, t refer to loan i originated in country c and observed in quarter t. $DF_{i,t+4}$ is a dummy indicating one year ahead default following our criteria established above. P is the probability of one year ahead mortgage default conditional on loan, country and borrower characteristics. $i_{i,c,t}$ denotes the interest rate, which is crucial for our analysis. We estimate Equation (1) using various versions of the interest rate variable, namely origination and contemporaneous loan-level interest rates and differences between them, included as continuous variables or turned into buckets (as explained in Section 3.1). λ captures the corresponding coefficient.

We add a set of explanatory variables to our specification. α is a constant across all observations. $Y_{i,c}$ holds borrower and loan-level characteristics at origination with associated coefficients collected in γ. This includes information on occupation and income (where the latter is constructed as the percentage deviation of the borrower's income from the median income across all mortgagors in country c at the time of origination of the loan), as well as information on LTV and LTI at origination and the repayment schedule. $Z_{i,c,t}$ collects information on the remaining loan term and the age of the borrower that is updated each quarter. θ is the respective coefficient matrix. $X_{c,t}$ comprises country level data on (quarterly) real disposable income growth and the unemployment rate to capture the overall macroeconomic environment. We include a set of country dummies ω_c controlling for time-invariant country characteristics with similar effects on all loans originated in one country, and year of origination fixed effects ρ_o accounting for potential differences across time. $\epsilon_{i,c,t}$ is the error term. We assume that the underlying latent choice between repayment and default follows a logistic distribution. We cluster standard errors at the loan level to address concerns of heteroskedasticity stemming from the likely persistence of loan-level characteristics.

Two groups within the set of explanatory variables deserve some more discussion. First, as opposed to the majority the literature, we include LTV at origination instead of contemporaneous LTV ratios to address a potential source of endogeneity arising from the simultaneous impact of interest rates on LTVs and default probabilities. By doing so, we effectively shut down the mechanism underlying the double trigger hypothesis, regularly referred to in the literature. Yet, we note that within the euro area, mortgagors have little incentive for strategic defaults, since all mortgages are recourse loans. Second, there exists literature on mortgage defaults that focuses on excessive risk-taking by banks when interest rates are low. Evidence of loose lending standards in the context of low policy rates is shown by Maddaloni and Peydró (2011), while Maddaloni and Peydró (2013) suggest that there was a degree of excessive risk taking in mortgage lending before the Global Financial Crisis, when long-term rates were very low. Furthermore, some results on search for yield and excessive risk taking by high-deposit banks have been documented focusing on the negative monetary policy rates era (Heider *et al.*, 2019; Bubeck *et al.*, 2020). In order to address the concern that banks' risk-taking behaviour in low-rate environments might bias our results, we control for a number of loan-level (LTV and LTI) and borrower-level (income, employment status) characteristics at origination that should account for riskier borrowers being characterised by higher default probabilities.

5. Interest rates, their changes and mortgage loans defaults

We now turn to the main focus of our paper, namely analysing the non-linear impact of interest rates on mortgage defaults. Table (1) holds the odds ratios for different interest rate measures from estimating Equation (1): interest rate at origination or contemporaneous, and the change between contemporaneous and origination interest rates as continuous variables. As is common in the literature, each regression focuses on a single measure of interest rate.

An increase in the interest rate at the time of origination by one percentage point is associated with a 1.42 times higher likelihood of a mortgage default (column 2 of Table (1)). A similar increase in the contemporaneous interest rate has a slightly stronger effect of 1.46 (column 1). Column 3 focuses on interest rate changes directly and shows that an increase in the interest rate change by one basis point since origination is associated with an odds ratio of 1.001. Note that a one-basis-point change represents only a hundredth of a percent, which poses a challenge to compare absolute numbers across the results.

In addition to focusing on the relationship between interest rates and mortgage defaults, we also verify that the results for the remaining variables align with those found in the literature. Table (C5) shows the full extension of the results shown in Table 1. In line with intuition and expectations, benign economic conditions, i.e. lower unemployment rates or stronger real disposable income growth, are associated with lower default probabilities. At the borrower level, higher income, more secure employment (e.g., civil servant as opposed to self-employed), or younger borrowers correlate with lower default probabilities. In turn, borrowers with longer loan maturities, higher loan-to-income or loan-to-value ratios are more likely to default. Furthermore, coefficient estimates on all variables are stable irrespective of the interest rate variable, i.e. whether contemporaneous, origination, or changes in the interest rate are considered, showing their robustness.

Table 1: Impact of continuous interest rate variables on one year ahead mortgage default

	One year ahead default		
	(1)	(2)	(3)
Contemporaneous interest rate	1.460***		
	(0.012)		
Origination interest rate		1.416***	
		(0.011)	
Change in interest rate			1.001***
			(0.000)
Controls	X	X	X
Country FE	X	X	X
Year origination FE	X	X	X
Pseudo R-sqr	0.056	0.055	0.048
N	9,531,845	9,531,845	9,531,845
AUROC	0.719	0.717	0.703

Signif. Codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Notes: Table reports odds ratios, with clustered standard errors at the loan level in parentheses. Dependent variable is one year ahead default. Apart from the continuous interest rate variables, the following controls are included in all regressions: country-level unemployment rate and real disposable income growth, and loan-level controls including: combined income at origination (deviation from the time- and country-specific median), remaining loan maturity, age of the borrower, LTV and LTI at origination, an occupational status dummy, and a loan repayment type dummy. All regressions include a constant. Results including all control variables can be found in Table C5 in the Annex.

5.1. Vulnerabilities from non-linear interest rate effects

This section takes the findings from Table (1) as a starting point and expands on them to more fully explore the relationship between mortgage defaults and their sensitivity to interest rate changes over time. In this section, to explore the non-linearity with regard to origination interest rate, we estimate Equation (2), which contains interest rate variables split into buckets (contemporaneous interest rates or interest rate changes since origination, $Bi_{i,c,t}$) and buckets of interest rates at origination ($Boi_{i,c}$). We split the continuous interest rates variables into buckets to ease the interpretation of our results. The top panels of Figures (7) to (8) present the results based on the coefficients λ_k of Equation (2), and in addition and for comparison also λ of Equation (1):

$$\begin{aligned} log\frac{P(DF_{i,c,t+4}=1|\Psi_i)}{P(DF_{i,c,t+4}=0|\Psi_i)} &= \alpha + \sum_{k=1}^{3(5)} \lambda_k Bi_{i,c,t,k} + \sum_{y=1}^{3} \psi_y Boi_{i,c,y} \\ &+ \theta \mathbf{Z_{i,c,t}} + \gamma \mathbf{Y_{i,c}} + \beta \mathbf{X_{c,t}} + \omega_\mathbf{c} + \rho_\mathbf{o} + \epsilon_{i,c,t}, \end{aligned} \tag{2}$$

where k indicates either one of the three terciles of the contemporaneous interest rate distribution or one of the five buckets of interest rate changes and y indicates whether a loan falls into the first, second or third tercile of the origination interest rate distribution. The marginal effects shown in the lower panels of Figures (7) to (8) are based on Equation (3) and also take into account the interaction between the interest rate variables, given by κ_{k^*,y^*}:

$$\begin{aligned} log\frac{P(DF_{i,c,t+4}=1|\Psi_i)}{P(DF_{i,c,t+4}=0|\Psi_i)} &= \alpha + \sum_{k=1}^{3(5)} \lambda_k Bi_{i,c,t,k} + \sum_{y=1}^{3} \psi_y Boi_{i,c,y} + \sum_{k^*=1}^{3(5)} \sum_{y^*=1}^{3} \kappa_{k^*,y^*} Bi_{i,c,t,k^*} * Boi_{i,c,y^*} \\ &+ \theta \mathbf{Z_{i,c,t}} + \gamma \mathbf{Y_{i,c}} + \beta \mathbf{X_{c,t}} + \omega_\mathbf{c} + \rho_\mathbf{o} + \epsilon_{i,c,t}. \end{aligned} \tag{3}$$

Result 1: The increased risk of mortgage default associated with higher interest rates is concentrated among borrowers who received the loan at very low interest rates. We exploit the granularity of the loan-level data to examine in a first step whether the effect of the contemporaneous interest rate is of equal size across the interest rate distribution. We therefore estimate Equation (2) including the categorical variable described in Section 3.1, which classifies loans into the three terciles of the contemporaneous interest rate distribution. Since we believe that the effect might depend on the initial interest rate level, we include as an additional control variable the categorical variable of the origination interest rate. Figure (7a) shows the marginal effects from this regression (light grey bars). As a reference, we include the marginal effect from including the (continuous) measure of the contemporaneous interest rate from Table (1) column (1) (dark grey bar).

The average marginal effect of the continuous contemporaneous interest rate variable suggests that an increase in the contemporaneous interest rate by one percentage point is associated with an increase in the probability of default by 0.3 percentage points. Although not directly comparable to the continuous counterpart, the inclusion of the categorical variable reveals important non-linearities that are not captured by the average effect. Importantly, a relatively high contemporaneous interest rate is associated with a default probability higher by about 0.46 basis points compared to loans in the first tercile of the distribution, which is 1.5 higher than what the average marginal effect would suggest. In turn, the effect from falling into the second tercile of the contemporaneous interest rate distribution relative to being in lowest one is less than half of the average effect based on the continuous variable.

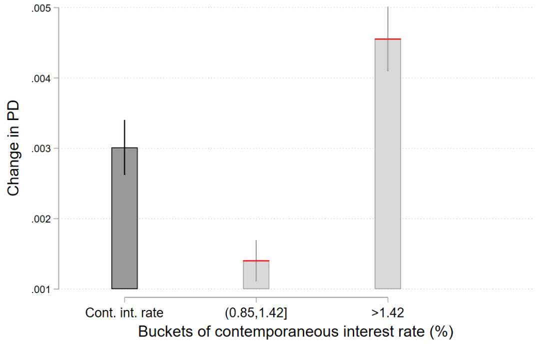
We expect the origination interest rate level to affect the strength of the effect of the contemporaneous interest rate. By estimating Equation (3) including also the interaction between the categorical interest rate measure of contemporaneous and origination interest rates, we provide more detailed results on the impact of the contemporaneous interest rate on mortgage defaults (Figure (7b)). For each tercile of the contemporaneous interest rate distribution, the coloured bars represent the three terciles of the interest rate distribution at the time of loan origination. The height of these bars depicts the marginal effect of belonging to the 2^{nd} or 3^{rd} tercile of the contemporaneous interest rate distribution relative to the 1^{st} tercile of the latter. To facilitate comparisons across our results, the red lines replicate the average effects for each tercile from Figure (7a). In addition, to provide some intuition on the results, Figure (7c) displays the predicted default probabilities for these groups. The red line represents the empirical default probability of 0.9% in our data.

Our results shown in Figure (7b) indicate that the marginal effect of the higher contemporaneous interest rate is economically negligible for loans in the top terciles of the origination interest rate distribution. Instead, we find that the risk associated with higher interest rates is concentrated among borrowers who got the loan at low interest rates. This holds true across the entire contemporaneous interest rate distribution. Loans that were extended at very low levels ($\leq$ 1.14%) but contemporaneously have relatively high interest rates (contemporaneous interest rate $>$ 1.42%) are associated with a 2.2 percentage points increase in default probability relative to loans with an interest rate in the first tercile of the contemporaneous interest rate distribution (i.e., those with an interest rate $\leq$ 0.85%). This effect is around 4.8 times greater than the average effect for loans in the top tercile of the contemporaneous interest rate distribution (as indicated by the red line).

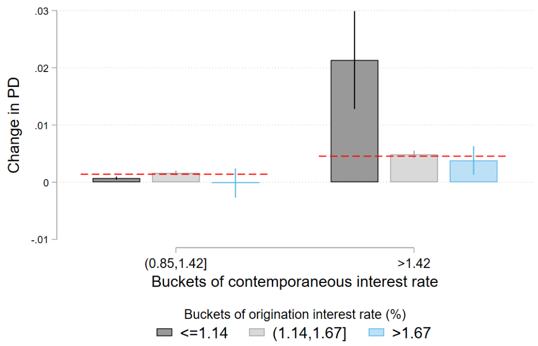
Figure (7c), which displays the predicted default probabilities, shows that the default patterns remain stable in the bottom half of the contemporaneous interest rate distribution. Predicted default probabilities increase abruptly for low origination interest rate loans when contemporaneous interest rates are relatively high. As predicted probabilities, in contrast to marginal effects, do not depend on the chosen base category, Figure (7c) addresses a potential concern that may arise when looking at Figure (7b), namely if the differences we find are driven by increases of interest rates in focus category, or decreases in reference category. Figure (7c) shows that the results are indeed driven by the interest rate increases, as we argue.

Figure 7: Sensitivity of defaults to interest rates

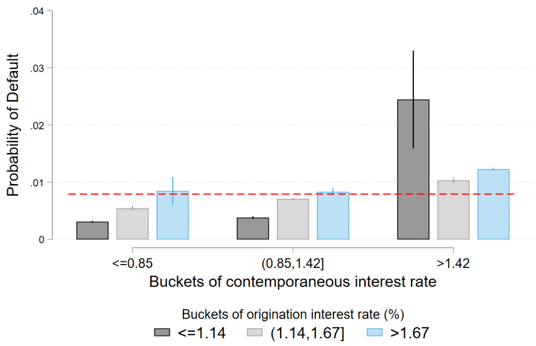
(a) Marginal effects of the contemporaneous interest rate



(b) Marginal effects of the contemporaneous interest rate by origination interest rates



(c) Predicted default probabilities by contemporaneous and origination interest rates



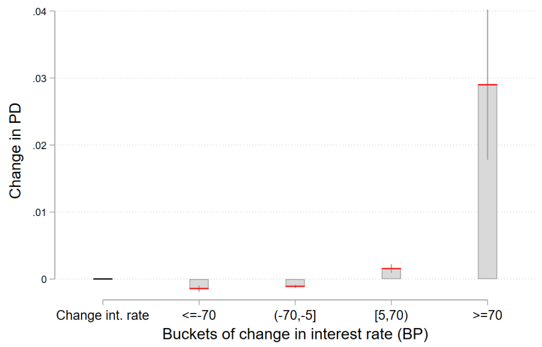
Notes: Figures show the marginal effects of the contemporaneous interest rate for various specifications. Spikes show 95% confidence bands. Figure (a): For reference, left (dark grey) bar shows the marginal effect from running the regression including the continuous measure of the contemporaneous interest rate. Light grey bars show the effects of the categorical measure of the contemporaneous interest rate variable. Model includes both the categorical variable for the contemporaneous and the origination interest rate but not their interaction. These effects are relative to a benchmark group, i.e., loans that fall into the lower third of the interest rate distribution. Figure (b): Model specification includes the interaction between the categorical variable for the contemporaneous and origination interest rate. Red lines replicate effects from Figure (a). Bars show the marginal effect of the contemporaneous interest rate with colours representing buckets of origination interest rate. These effects are again relative to a benchmark group, i.e. loans falling into the first quartile of the interest rate distribution. Figure (c): Predicted default probabilities from our model in Figure (b). Red line denotes average default probability of 0.9% in our data.

Result 2: The effect of interest rate changes is asymmetric: interest rate increases have stronger effects on the probability of default than interest rate decreases of similar size. After analysing differences between loans with "high" and "low" interest rates, we focus on interest rate changes (since origination).

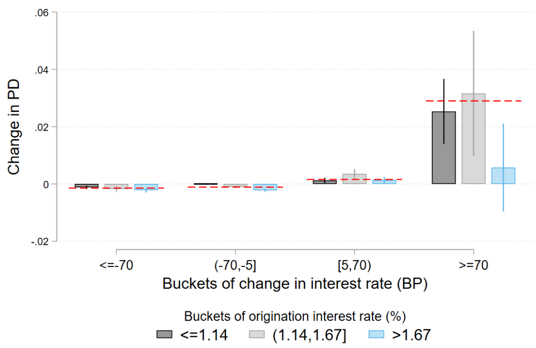
Figure (8a) illustrates the asymmetric marginal effects of interest rate decreases and increases of similar magnitude. This regression specification includes as separate regressors the categorical variable on buckets of interest rate changes and buckets of origination interest rates (Equation (2)). All marginal effects are in comparison to loans where the contemporaneous interest rate is around the level of the initial interest rate, i.e. the change of interest rates falls within a range of -5 to +5 basis points. Although statistically significant, interest rate decreases have quite small effects. In contrast, increases in interest rates have more severe effects on default probabilities. Although limited increases of up to 70 basis points are associated with an increase in the probability of default by 0.2 percentage points (relative to loans with contemporaneous interest rates at the level of origination), an increase by more than 70 basis points is associated with an increase in the default probability by 2.9 percentage points.

Figure 8: Sensitivity of defaults to interest rate changes since origination

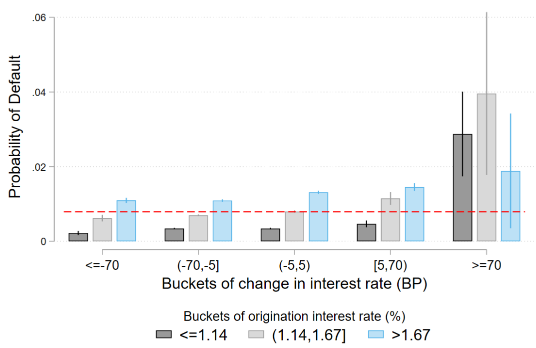
(a) Marginal effects of interest rate changes since origination



(b) Marginal effects of interest rate changes since origination by origination interest rates



(c) Predicted default probabilities by interest rate changes since origination and origination interest rates



Notes: Figures show the marginal effects of interest rate changes for various specifications. Spikes show 95% confidence bands. Figure (a): For reference, left (dark grey) bar shows the marginal effect from running the regression including the continuous measure of interest rate changes. Light grey bars show the effects of the categorical measure of interest rate changes, grouping into various buckets of changes. Model includes both the categorical variable of interest rate changes and the origination interest rate but not their interaction. These effects are relative to a benchmark group, i.e., loans with an interest rate level similar to the one at origination. Figure (b): Model specification includes the interaction between the categorical measure of interest rate changes and origination interest rates. Red lines replicate effects from Figure (a). Bars show the marginal effect of interest rate changes with colours representing buckets of origination interest rates. These effects are again relative to a benchmark group, i.e. loans with an interest rate level similar to the one at origination. Figure (c): Predicted default probabilities from our model in Figure (b). Red line denotes average default probability of 0.9% in our data.

Figure (8b) shows the marginal effects of interest rate changes along the interest rate at origination distribution, including additionally the interaction between the (categorical) variable of interest rate changes and the (categorical) variable on the interest rate level at the time of origination (Equation (3)). All results are calculated against the pool of loans in which interest rates have hardly changed since origination. Interest rate decreases, if at all, benefit loans with initially high interest rates. However, the associated marginal effects are small and at most amount to a decrease in the default probability by -0.2 percentage points (relative to loans that did not experience a change in their interest rate since origination). Interest rate increases, in turn, have sizable effects that are most pronounced for low origination interest rate loans. An increase in the interest rate since origination by more than 70 basis points is associated with an increase in default probability by 2.5 percentage points (relative to loans that did not experience a change in their interest rate since origination). This effect is 20 times greater than the effect of a moderate increase ranging between five to 70 basis points. The marginal effects of interest rate increases on borrowers with already high interest rates at the time of origination are statistically insignificant.

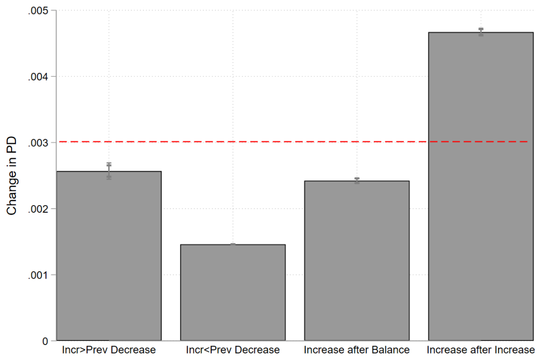
We complement these results with Figure (8c) which displays the predicted default probabilities. This chart confirms the finding of Figure (8b), namely that loans with low origination interest rates that experience an increase in interest rates by at least 70 basis points have the highest default probability from our sample.

Result 3: The magnitude of the effect of an interest rate increase depends on the history of net interest rate changes. We complement our set of results by adopting a more dynamic approach and investigating whether the effect of an increase in the interest rate is influenced by the loan's interest rate history. To do so, we add to our regression specification both the origination and contemporaneous interest rate level as continuous variables. We focus our analysis on loans that experience an increase in their interest rate from one quarter to the next. To assess the importance of the loan's previous interest rate trajectory, we differentiate between four distinct scenarios: i) The increase in the interest rate is greater than the net decrease in the interest rate since origination at the time of the interest rate increase (i.e. the interest rate after the increase is higher than the origination interest rate); ii) The interest rate increase is smaller than the net decrease in the interest rate since origination at the time of the interest rate increase (i.e. the interest rate after the increase is still lower than the rate at origination); iii) The increase in the interest rate is equal to the net decrease in the interest rate since origination at the time of the interest rate increase (i.e. the interest rate level after the increase equals the origination level) and iv) At the time of the increase, the interest rate is already higher than at origination (i.e. the interest rate keeps increasing and exceeds the initial interest rate level already at the point where the increase happens). To this end, we estimate the following Equation:

$$log\frac{P(DF_{i,ct+4}=1|\Psi_i)}{P(DF_{i,c,t+4}=0|\Psi_i)} = \alpha + \sum_{k=1}^{4}\lambda_k i_{i,c,t} * Bihist_{i,c,t,k} + \psi i_{O,i,c} + \theta\mathbf{Z_{i,c,t}} + \gamma\mathbf{Y_{i,c}} + \beta\mathbf{X_{c,t}} + \omega_{\mathbf{c}} + \rho_{\mathbf{o}} + \epsilon_{i,c,t}, \quad (4)$$

where $i_{i,c,t,k}$ and $i_{O,i,c}$ are the contemporaneous and origination interest rates as continuous variables, and $Bihist_{i,c,t}$ is an indicator variable differentiating between four distinct scenarios, k, of loan-specific history of interest rate changes. Figure (9) shows the average marginal effects of interest rate increases for all four scenarios. Again, the red line shows the average effect in all scenarios.

Figure 9: Marginal effects of increase in contemporaneous interest rate by past trajectory



Notes: Figure shows the marginal effect of an increase in the interest for four distinct cases, shown on the horizontal axis. Spikes show 5% confidence bands. Model includes the continuous interest rate variables but not their interactions. All results focus on the subset of loans that experience an interest rate increase during any quarter and fall into one of the four scenarios. Red line denotes the average marginal effect of an increase in the interest rate across the four scenarios.

The results are in line with intuition, indicating that an increase in the interest rate has a three times greater effect on loans that already experienced net interest rate increase compared to loans where the interest rate increase is less than the previous net decrease at the time of the interest rate increase.

5.2. Robustness checks

Our analysis focuses on a group of countries that have historically been characterised by a majority of floating rate loans. However, these countries also have a pool of fixed rate mortgages (at approximately 7% of all floating rate loans). A natural concern that may arise is whether borrowers self-select into one of these two interest rate regimes. On the one hand, in periods of low interest rates, riskier borrowers may opt for variable rate loans in order to secure (temporarily) lower borrowing costs. On the other hand, individual characteristics such as financial literacy or expectation formation may influence borrowers' choice of one of the two interest rate regimes (Albertazzi *et al.*, 2024). We account for this possible bias by performing a Heckman-style analysis (Heckman, 1979) based on a probit formulation of our original regression equation in line with Van de Ven and Van Praag (1981) or Bennett and Berinsky (2005), where we model the latent selection into fixed or floating rate loans as a probit model. This approach allows to account for any unobserved characteristics that may affect the decision between variable and fixed rate pricing and, in turn, may also affect the riskiness of the mortgage, i.e. its probability of default. Details can be found in the Appendix section (C.2.1). Although the finance literature commonly uses a logit specification for default models, the literature also shows that the differences between logit and probit discrete choice models are generally very small (Long, 1997; Fahrmeir and Tutz, 2001; Gill, 2001). We first show that our results are robust to the choice between a logit and probit specification (Figure (C4)) and then provide evidence that selection does not seem to affect our results. Table (C7) shows the regression results from the two-stage probit analysis, and Table (C8) displays the results from the formal test of no-selection bias in our data.

One concern may be that our results on the effect of interest rate changes are driven by the choice of thresholds. The small effects we observe on interest rate changes below 70 basis points may, in fact, be driven by those loans experiencing almost no changes in their interest rate. We hence re-run our analysis based on a more granular classification of interest rate changes. The results are available in Section (C.2.3) in the Appendix. The effect of increases in the interest rates on default probabilities is considerably stronger than the effect of interest rate decreases of similar magnitude. This effect is particularly pronounced for low-interest rate loans. The effect of medium-sized interest rate increases on default probabilities is still less than half of the size of the effect of more sizable interest rate increases. Decreases in the interest rate, if at all, benefit high origination interest rate loans. While this supports our main results, we also highlight the caveat that with this more granular variable, unequal distribution of observations across the joint distribution of origination interest rates and interest rate changes may be more concerning than in the baseline we showed in Section 5.1, with only about 800 loans extended at already high interest rates and additionally experiencing substantial interest rate increases.

Another concern may arise from using cross-sectional thresholds to classify loans into the terciles of the respective interest rate distribution. Figure (C11) replicates our main results based on country-specific cut-offs. More details on the country-specific terciles are available in Table (B2). Again, this does not alter our general findings.

The general specification including macroeconomic variables may eventually miss time-invariant country-specific characteristics potentially affecting the estimated effects. As an alternative, we hence re-estimate our baseline equation removing the macro variables and replacing them instead with a set of country and time fixed effects (Table (C9)). Concurrently, this specification also speaks to the question of the exact effect we wish to measure. With time fixed effects, we ensure to compare loans at the same point in time and not potentially during two very different economic environments. Following the specification in our main results, we include as interest rate measure the level of contemporaneous and origination interest rate. Results also hold when adding the variable on interest rate changes or when including the categorical interest rate variables and combinations thereof. Second, we add the interaction between country and time of origination fixed effects as an additional layer to further refine the comparison groups to retrieve effects based on loans originated within the same country, in the same year and observed during the same quarter (C10). Figures (C6) and (C7) recompute the marginal effects similar to our baseline analysis and show that our main results remain unchanged.

With our baseline specification, we may have certain banks driving results if their contractual specificities are very different from others. Hence, we adjust our regressions to include bank fixed effects, such that our results effectively show effects based on a comparison of loans issued by the same bank. The results are shown in the Appendix Table (C11). Figure (C8) shows the corresponding marginal effects, which are similar to our baseline results and support the evidence that low origination interest rate loans are more vulnerable to changes in the interest rate.

With respect to the statistical significance of our results, we may adopt an alternative approach by clustering standard errors at the country and year of origination level. Table (C12) and Figure (C9) show that accounting for alternative clusters of heterogneity across observations does not affect statistical significance. If at all, some effects become statistically more significant.

Our results are also stable with respect to the definition of the LTV variable. Replacing LTV at origination with the contemporaneous LTV ratio to align with the literature does not affect our results.

6. Intuition behind the results and relevance for macroprudential policy

There could be many factors driving the result of a particular sensitivity of mortgage defaults to interest rate increases of loans originated at ultra-low interest rates, possibly related to borrower- or loan-level characteristics or various externalities. Although we do not claim to find the ultimate reason for why they may be more susceptible to vulnerability, we would still like to provide some intuition. We argue that the mechanism is the following: while there are many factors determining the borrower-level size of the mortgage loan (Coletta *et al.*, 2019), debt service ratios have been shown to affect decisions made by households (Cunha *et al.*, 2013). Therefore, in times of lower interest rates, borrowers can obtain relatively higher mortgage loans, as measured by LTIs. At the same time, if a loan is originated at ultra-low interest rates, even a relatively small increase in interest rates in absolute terms implies a large increase in relative terms. As both higher leverage and lower origination interest rates increase the sensitivity of LSTIs to interest rates, taken together, these factors can lead to substantial increases in monthly payments for some borrowers. This mechanism should be seen against the background of a tendency of market participants to be excessively optimistic in good times, and of borrowers to likely underestimate the likelihood and extent of possible increases in interest rates throughout the life of the mortgage. The rest of this section provides more details related to our logic.

First, descriptive charts of our data show that while origination LSTIs of loans originated with relatively higher interest rates are higher than LSTIs of loans originated with lower interest rates (Figure A3 panel i), for LTIs we observe the opposite - i.e., origination LTIs tend to be lower in periods of higher origination interest rates (Figure A3 panel j). If we focus on tails of relatively high-leveraged loans with origination LTIs over 7.5, we note that their share among loans originated at ultra-low interest rates stands at almost 14%, while among loans originated at higher interest rates it is less than 10%. As higher indebtedness implies higher risk and higher vulnerability to changing circumstances, this implies that loans originated at ultra-low interest rates may be on average more risky in terms of their characteristics than loans originated in periods of higher interest rates.

Second, it can be shown that LSTIs of loans with higher origination LTIs and lower origination interest rates react more strongly to interest rate changes than loans with lower origination LTIs and higher interest rates. To this end, we start with observing that the LSTI ratio has an amortisation part and an interest rate part:

$$LSTI_t = \underbrace{\frac{\delta_t D_t}{I_t}}_{\text{Amort. part}} + \underbrace{\frac{i_t D_t}{I_t}}_{\text{Interest part}} = LTI_t(\delta_t + i_t) = LTI_t(\delta_t + (i_0 + x_t)) \tag{5}$$

Where D_i is debt, I_t is income, δ_i is the amortisation rate and i_t is the interest rate at time t, which can also be shown as a sum of interest rate at origination, i_0, and the change of interest rate since origination, x_t. Equation 5 shows that a higher LTI at time t leads to a higher responsiveness of the interest rate part, making LTI a key determinant of LSTI interest rate sensitivity each time the loan resets. δ_t, in turn, decreases with maturity and depends on loan type (e.g., annuity loan or linear amortisation loan). Hence, the value of

LTI_t depends on LTI at origination, LTI_0, on loan maturity and time since origination, and on the loan type. We will now focus on annuity principal repayment type, as they account for the majority of the loans in our sample (Figure A3 panel j). In this type of principal repayment, the payment per period is constant over time and the full principal is repaid at the end of the loan maturity. Hence, the LSTI for an annuity loan can be expressed as follows:

$$LSTI_0 = LTI_0 \frac{i_0}{1-(1+i_0)^{-N}} \tag{6}$$

Equation (6) can be used to derive an expression for how the LSTI ratio would change compared to the LSTI at origination if the interest rate were to increase by x_t percentage points t years after origination:

$$\begin{aligned} \Delta LSTI_t &= LSTI_t - LSTI_0 \\ &= LTI_0 \cdot \frac{1-(1+i_0)^{T-N}}{1-(1+i_0)^{-N}} \cdot \frac{i_T}{1-(1+i_T)^{T-N}} - LTI_0 \frac{i_0}{1-(1+i_0)^{-N}} \end{aligned} \tag{7}$$

From Equation (7) it can be seen that when the interest rate changes, LSTI in turn shifts in a non-linear manner: it depends on LTI at origination, maturity N, remaining life $N - t$ and interest rate at origination i_0. To get an intuition behind the differences in sensitivity of LSTIs to interest rate changes for loans with lower origination interest rates and higher LTIs on one hand, and higher origination interest rates and lower LTIs on another hand, it is useful to consider some stylised examples. Let us consider two annuity loans, with origination LTIs and maturities at average values from our data set for lowest and highest origination interest rates buckets. The first one was originated at 1%, with LTI of 4.9, and maturity of 29 years. The second one of them was originated at 2%, with LTI of 4.4 and maturity of 26 years. Their origination LSTIs would be 19.5% and 21.9%, respectively. If we now assume an increase of interest rates by 100 basis points 5 years after origination for each of these loans, the LSTI of the first loan increases to 22.0%, i.e. by 12.3%, and of the second one to 24.1%, i.e. by 10.4% - hence the interest rate sensitivity of the first loan, the one originated at lower interest rates, is higher than the second one. Although an increase of LSTIs of the order of magnitude discussed above does not seem striking, we chose to show it as it relates to examples that we can observe in our data. However, it is important to flag that an increase of interest rate by 1% is relatively low, considering historical evolution of interest rates. The cost of mortgage borrowing in the euro area increased from a local minimum of 1.3% in September 2021 to a local maximum of 4.0% in November 2023, driven by policy rate hikes of the European Central Bank following a surge in inflation. An increase of loan-level interest rates by 270 basis points would lead to a much more substantial increase of LSTIs of affected loans.

This relatively higher sensitivity of the probability of default of low origination interest rates to interest rate increases could also be viewed through the lens of beliefs about the credit risk of mortgage lending and economic growth, which tend to be overoptimistic during credit booms (Mian *et al.*, 2017; Baron and Xiong, 2017). In addition, the level of financial literacy of mortgage borrowers has been shown to play a role in mortgage choices that households make, since greater financial literacy improves households' ability to correctly evaluate their risk exposure in the choice between floating or fixed interest rate loans (Fornero *et al.*, 2011). In this context it is crucial to flag that Bucks and Pence (2008) find that borrowers with floating rate mortgages appear likely to underestimate or to not know how much their interest rates could change. Taken together, relatively higher leverage, higher LSTI sensitivity to interest rate increases, and excessive optimism related to future interest rate paths of low-origination interest rate mortgage borrowers could be driving our results.

Our results are relevant from a financial stability and macroprudential policy perspective because they identify potential risks to the banking sector stemming from a certain subset of mortgage markets. There is consensus in the literature about the importance of borrower-based measures and in particular LSTI or DSTI[4] caps for mortgage probability of default (see Section (2) on literature review). This consensus is also shared by the practitioners, who very often choose income-based macroprudential measures, LSTI among them, to mitigate housing market risks (see CGFS, 2023). Taken together, our finding that defaults of loans originated at particularly low interest rates have a higher sensitivity to interest rate increases than other loans, and the fact that ultra-low interest rates automatically and by construction lead to lower LSTIs of new borrowers, suggest that stress testing interest rates at origination should be a useful design element of LSTI limits. Such a design element is used in practice by some countries which have LSTI caps activated (e.g., in 2025 these countries included Malta, Portugal, Finland and Canada), but it is rather an exception than a standard practice. Alternatively, LSTI limits could be complemented by DTI limits or in some cases even replaced by them, because, as can be seen in Equation (6), LSTI at origination is determined by DTI, maturity and interest rate at origination.

7. Conclusions

In this paper, we use granular loan-level data to examine how mortgage defaults respond to interest rate changes. We show that the sensitivity of defaults to interest rate changes is highly non-linear and determined by the interest rate at the time of loan origination. Although interest rate decreases do not significantly reduce default probabilities, interest rate

[4]Typically, DSTI caps are chosen as they take into consideration the entire indebtedness of the borrower. However, due to data gaps, in practice LSTI caps may be chosen.

increases may increase default probabilities by almost three percentage points. We provide evidence that this effect is predominantly driven by loans originated at ultra-low interest rates. In addition, the impact of interest rate increases on defaults depends on the loan's interest rate history. Our findings therefore suggest that a potential risk to the mortgage market stems in particular from loans originated in the periods of low interest rates that could become subject to interest rate increases, raising borrowers' debt servicing burden.

Our results are relevant from a financial stability and macroprudential policy perspective because they identify potential risks to the banking sector stemming from a certain subset of mortgage markets. Our results support activating borrower-based measures limiting the debt-service-to-income ratios, including stress testing interest rates at origination in the periods when interest rates are particularly low.

From our analysis several avenues for further research could be derived. First, while our work underlines the importance of granular data in helping us understand how interest rate changes affect mortgage probability of default, our analysis comes with caveats driven by characteristics of our data: i.e., we cover a period in which interest rates were generally low and on average declined over time, and we do not cover a full universe of mortgage loans in countries we analyse as we can only see the loans that got securitised. Therefore, repeating the analysis if and when a more comprehensive dataset becomes available would be beneficial. Second, while our findings allow drawing conclusions relevant for macroprudential policy, our analysis does not directly include borrower-based measures. A complementary analysis could therefore explore the impact on mortgage defaults of debt-service-to-income caps with interest rate stress testing at origination, for example using microsimulation methods.

References

Albertazzi, U., Eramo, G., Gambacorta, L. and Salleo, C. (2015). Asymmetric information in securitization: An empirical assessment. *Journal of Monetary Economics*, **71** (C), 33–49.

—, Fringuellotti, F. and Ongena, S. (2024). Fixed rate versus adjustable rate mortgages: evidence from euro area banks. *European Economic Review*, **161**, 104643.

Alfaro, R. and Gallardo, N. (2012). The determinants of household debt default. *Economic Analysis Review*, **27** (1), 27–54.

Aron, J. and Muellbauer, J. (2016). Modelling and forecasting mortgage delinquency and foreclosure in the uk. *Journal of Urban Economics*, **94** (C), 32–53.

Bajari, P., Chu, C. S. and Park, M. (2008). *An Empirical Model of Subprime Mortgage Default From 2000 to 2007*. NBER Working Papers 14625, National Bureau of Economic Research.

Barbaglia, L., Manzan, S. and Tosetti, E. (2021). Forecasting Loan Default in Europe with Machine Learning*. *Journal of Financial Econometrics*, **21** (2), 569–596.

Baron, M. and Xiong, W. (2017). Credit expansion and neglected crash risk*. *The Quarterly Journal of Economics*, **132** (2), 713–764.

Bennett, S. E. and Berinsky, A. J. (2005). Silent Voices: Public Opinion and Political Participation in America. *Public Opinion Quarterly*, **69** (3), 463–483.

Bonner, C., Streitz, D. and Wedow, M. (2016). On the differential impact of securitization on bank lending during the financial crisis. *SSRN Electronic Journal*.

Bubeck, J., Maddaloni, A. and Peydró, J.-L. (2020). Negative monetary policy rates and systemic banks' risk-taking: Evidence from the euro area securities register. *Journal of Money, Credit and Banking*, **52** (S1), 197–231.

Bucks, B. and Pence, K. (2008). Do borrowers know their mortgage terms? *Journal of Urban Economics*, **64** (2), 218–233.

Campbell, J. and Cocco, J. F. (2015). A model of mortgage default. *Journal of Finance*, **70** (4), 1495–1554.

CGFS (2023). *Macroprudential policies to mitigate housing market risks*. CGFS Papers No 69, BIS.

Coletta, M., De Bonis, R. and Piermattei, S. (2019). Household debt in oecd countries: The role of supply-side and demand-side factors. *Social Indicators Research*, **143**, 1185â1217.

Cunha, M. R., Lambrecht, B. and Pawlina, G. (2013). Determinants of outstanding mortgage loan to value ratios: Evidence from the netherlands. *EFA 2009 Bergen Meetings Paper*.

Dell'Ariccia, G., Igan, D. and Laeven, L. (2012). Credit booms and lending standards: Evidence from the subprime mortgage market. *Journal of Money, Credit and Banking*, **44** (2-3), 367–384.

Deng, Y. (1997). Mortgage termination: An empirical hazard model with a stochastic term structure. *The Journal of Real Estate Finance and Economics*, **14** (3), 309–31.

Di Maggio, M., Kermani, A., Keys, B. J., Piskorski, T., Ramcharan, R., Seru, A. and Yao, V. (2017). Interest rate pass-through: Mortgage rates, household consumption, and voluntary deleveraging. *American Economic Review*, **107** (11), 3550–3588.

Dirma, M. and Karmelavičius, J. (2025). Micro-assessment of macroprudential borrower-based measures. *Journal of Banking Finance*, **176**, 107455.

Dotsis, G., Petris, P. and Psychoyios, D. (2023). Assessing Housing Market Crashes over the Past 150 years. *Journal of Real Estate Finance and Economics, forthcoming.*

Elul, R., Souleles, N. S., Chomsisengphet, S., Glennon, D. and Hunt, R. (2010). What "Triggers" Mortgage Default? *American Economic Review*, **100** (2), 490–94.

Fahrmeir, L. and Tutz, G. (2001). *Multivariate Statistical Modelling based on Generalized Linear Models*. New York: Springer, 2nd edn.

Foote, C., Gerardi, K. and Willen, P. (2008). Negative equity and foreclosure: Theory and evidence. *Journal of Urban Economics*, **64** (2), 234–245.

Fornero, E., Monticone, C. and Trucchi, S. (2011). The effect of financial literacy on mortgage choices. *CeRP Working Papers*, **121**.

Fuster, A. and Willen, P. S. (2017). Payment size, negative equity, and mortgage default. *American Economic Journal: Economic Policy*, **9** (4), 167–91.

Galan, J. E. and Lamas, M. (2023). Beyond the ltv ratio: Lending standards, regulatory arbitrage, and mortgage default. *Journal of Money, Credit and Banking*.

Gaudencio, J., Mazany, A. and Schwarz, C. (2019). The impact of lending standards on default rates of residential real-estate loans. *ECB Occasional Paper*, (220).

Gerardi, K., Herkenhoff, K., Ohanian, L. and Willen, P. (2015). *Can't Pay or Won't Pay? Unemployment, Negative Equity, and Strategic Default*. NBER Working Papers 21630, National Bureau of Economic Research.

Gerlach-Kristen, P. and Lyons, S. (2018). Determinants of mortgage arrears in europe: evidence from household microdata. *International Journal of Housing Policy*, **18** (4), 545–567.

Gill, J. (2001). *Generalized Linear Models: A Unified Approach*.

Guiso, L., Sapienza, P. and Zingales, L. (2013). The determinants of attitudes toward strategic default on mortgages. *Journal of Finance*, **68** (4), 1473–1515.

Hallissey, N., Kelly, R., O'Malley, T. *et al.* (2014). *Macroprudential tools and credit risk of property lending at Irish banks*. Tech. rep., Central Bank of Ireland.

Heckman, J. J. (1979). Sample selection bias as a specification error. *Econometrica*, **47** (1), 153–161.

Heider, F., Saidi, F. and Schepens, G. (2019). Life below zero: Bank lending under negative policy rates. *The Review of Financial Studies*, **32** (10), 3728–3761.

Jones, T. and Sirmans, G. S. (2015). The underlying determinants of residential mortgage default. *Journal of Real Estate Literature*, **23** (2), 169–206.

Kelly, R. and O'Toole, C. (2018). Mortgage default, lending conditions and macroprudential policy: Loan-level evidence from uk buy-to-lets. *Journal of Financial Stability*, **36** (C), 322–335.

Keys, B. J., Mukherjee, T., Seru, A. and Vig, V. (2010). Did securitization lead to lax screening? evidence from subprime loans. *The Quarterly Journal of Economics*, **125** (1), 307–362.

Linn, A. and Lyons, R. (2019). *Three triggers? Negative equity, income shocks and institutions as determinants of mortgage default*. Bank of England working papers 812, Bank of England.

Long, J. (1997). *Regression Models for Categorical and Limited Dependent Variables*. Thousand Oaks, CA: Sage.

Maddaloni, A. and Peydró, J.-L. (2011). Bank risk-taking, securitization, supervision, and low interest rates: Evidence from the euro-area and the us lending standards. *The Review of Financial Studies*, **24** (6), 2121–2165.

— and Peydró, J.-L. (2013). Monetary policy, macroprudential policy and banking stability: evidence from the euro area.

May, O. and Tudela, M. (2005). *When is mortgage indebtedness a financial burden to British households? A dynamic probit approach*. Bank of England working papers 277, Bank of England.

Mian, A. and Sufi, A. (2009). The consequences of mortgage credit expansion: Evidence from the us mortgage default crisis. *The Quarterly Journal of Economics*, **124** (4), 1449–1496.

— and — (2011). House prices, home equity–based borrowing, and the us household leverage crisis. *American Economic Review*, **101** (5), 2132–2156.

—, — and Verner, E. (2017). Household debt and business cycles worldwide*. *The Quarterly Journal of Economics*, **132** (4), 1755–1817.

Nier, E., Popa, R., Shamloo, M. and Voinea, L. (2019). *Debt Service and Default: Calibrating Macroprudential Policy Using Micro Data*. IMF Working Papers 2019/182, International Monetary Fund.

Quercia, R. G. and Stegman, M. A. (1992). Residential mortgage default: A review of the literature. *Journal of Housing Research*, **3** (2), 341–379.

Van de Ven, W. P. and Van Praag, B. M. (1981). The demand for deductibles in private health insurance: A probit model with sample selection. *Journal of Econometrics*, **17** (2), 229–252.

van Hoenselaar, F., Cournède, B., Pace, F. D. and Ziemann, V. (2021). *Mortgage finance across OECD countries*. OECD Economics Department Working Papers 1693, OECD Publishing.

A. Data

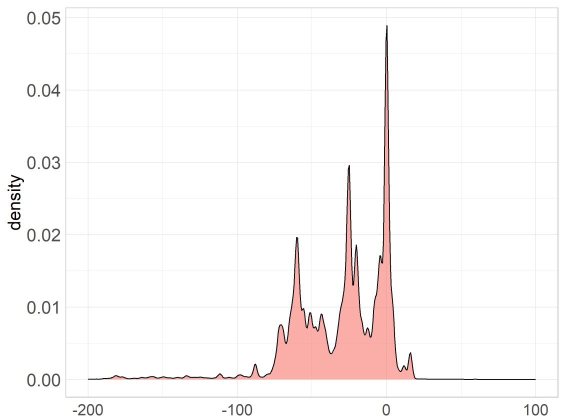
This section provides additional information on data cleaning and contains graphs and tables on the raw data, referred to in the main text.

A.1. Data cleaning

Our analysis is based on loan-level data provided by EDW and focuses on floating rate mortgages in four euro area countries. All statistics, graphs and results are based on a thoroughly cleaned sub-sample of these data to be suitable in answering our research question. First and foremost, all loans under consideration must be classified as variable rate mortgages. Second, we remove loans with implausibly long loan terms (beyond 50 years) and those where the combined income of the borrowers, i.e. income of first and second borrower (if applicable), or the interest rate charged on the loan is either negative or implausibly high. Third, we only keep loans where the borrower is not a legal entity, construction company, or similar. And fourth, we remove borrowers under the age of 18.

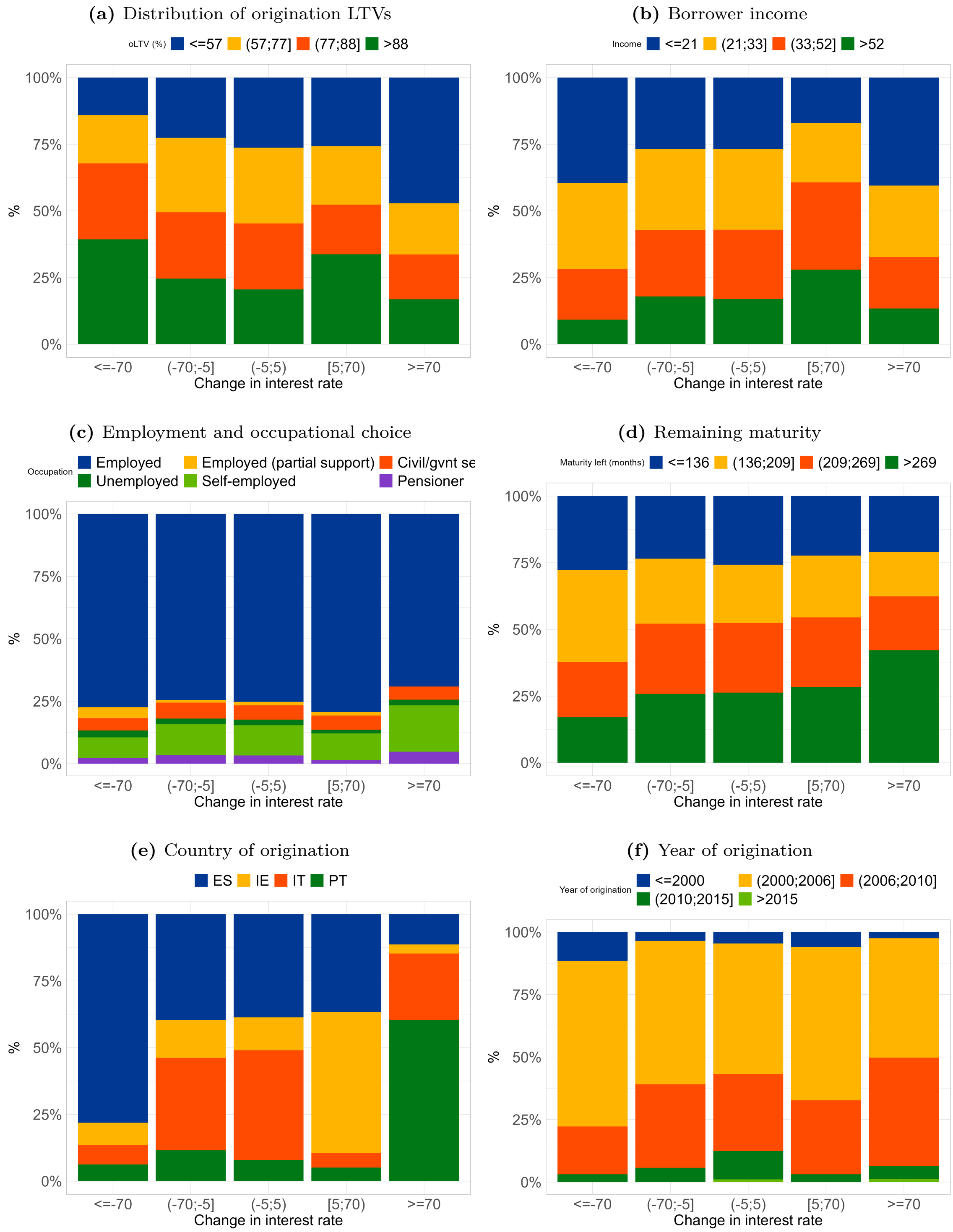
A.2. Graphs and tables

Figure A1: Density of change in interest rates (in basis points)

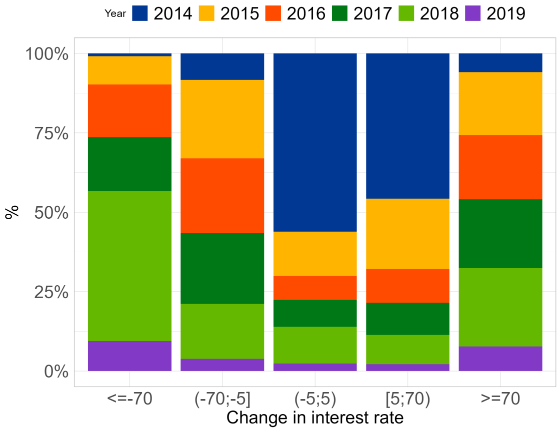


Notes: Pooled distribution of interest rate changes since origination across countries and time. The x-axis is truncated at both sides for better data visualisation. *Sources:* EDW and authors' calculations.

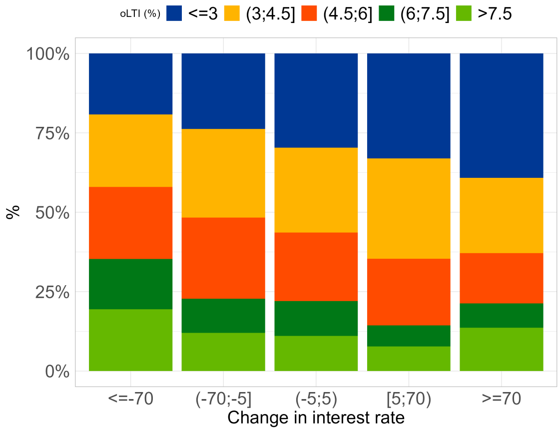
Figure A2: Loan and borrower characteristics by interest rate changes



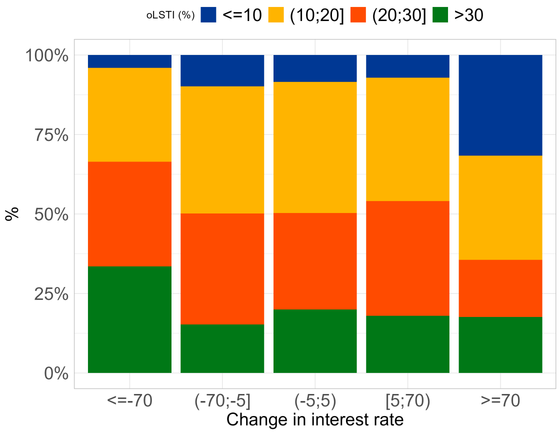
(g) Reporting year



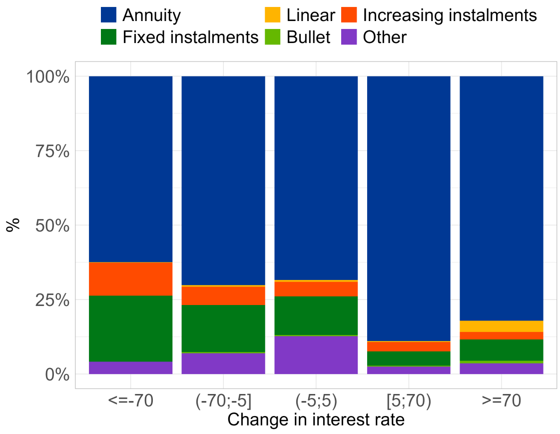
(h) Distribution of origination LTIs



(i) Distribution of origination LSTIs



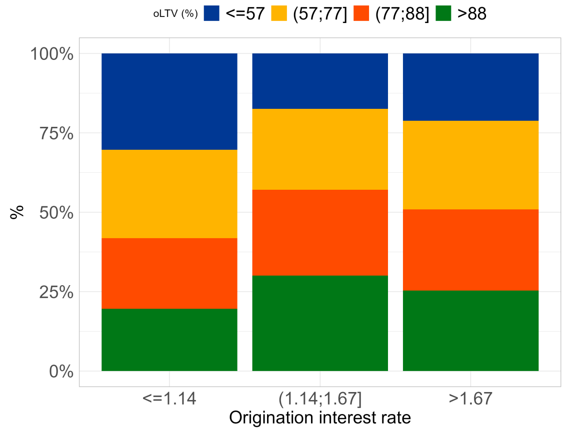
(j) Distribution of principal repayment type



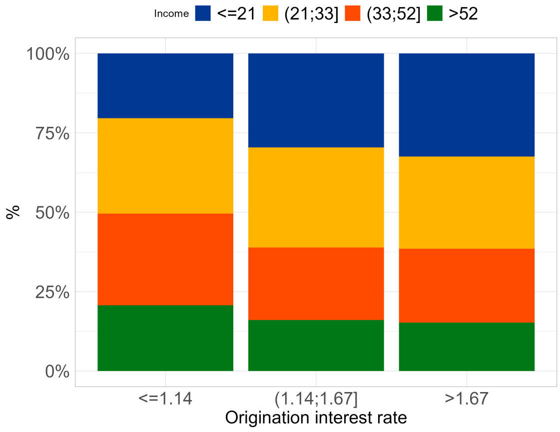
Notes: Figures show the joint distribution of loan/ borrower characteristics and interest rate changes. Interest rate change denoted in basis points. *Sources:* EDW and authors' calculations.

Figure A3: Loan and borrower characteristics by interest rate at origination

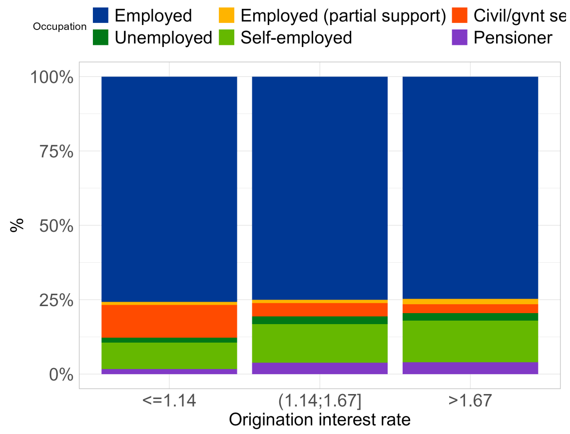
(a) Distribution of origination LTV



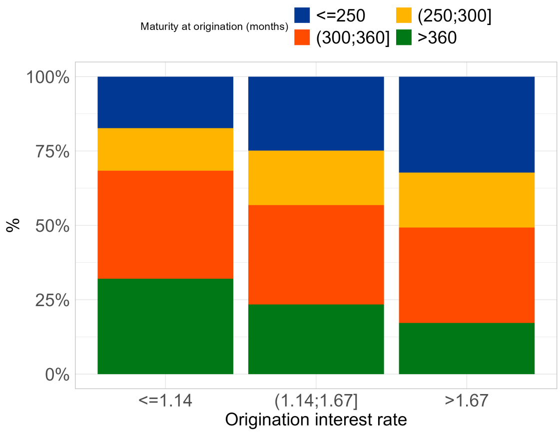
(b) Borrower income



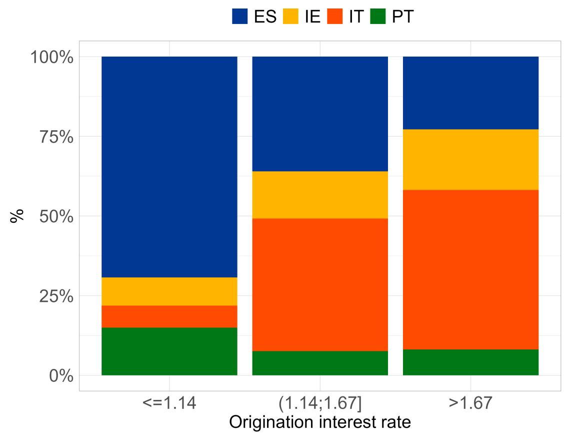
(c) Employment and occupational choice



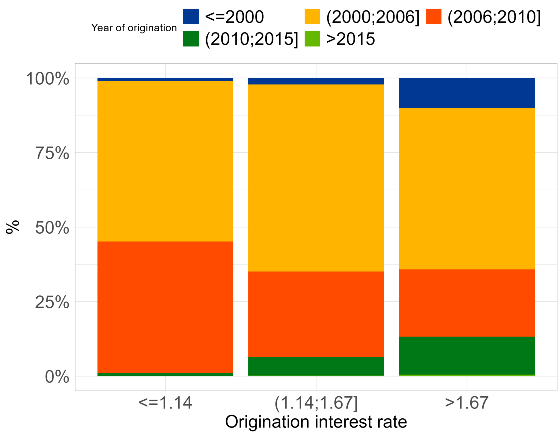
(d) Maturity at origination



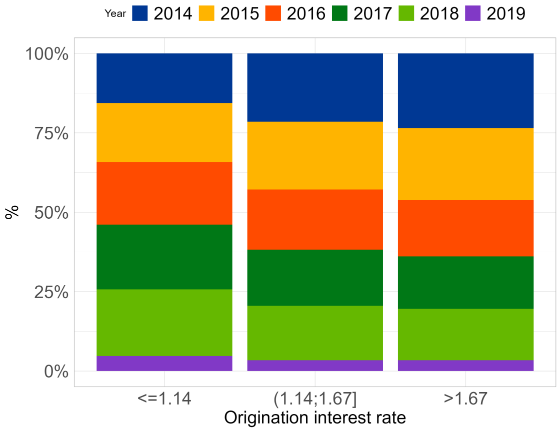
(e) Country of origination



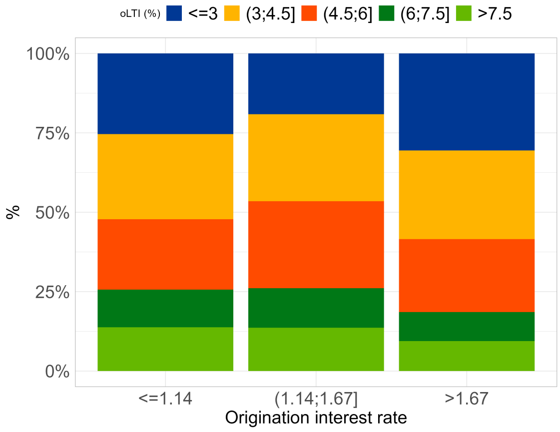
(f) Year of origination



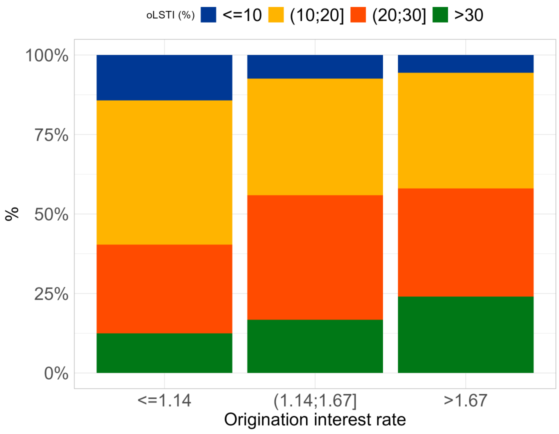
(g) Reporting year



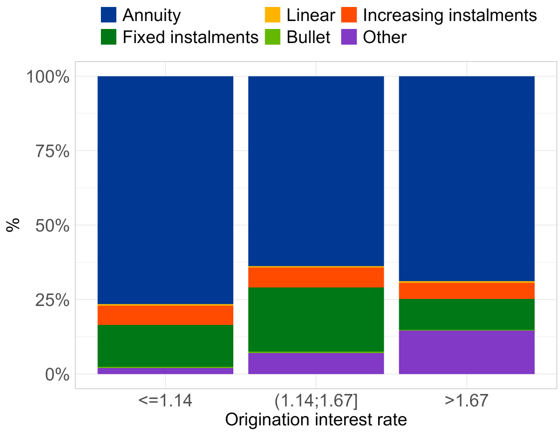
(h) Distribution of origination LTIs



(i) Distribution of origination LSTIs



(j) Distribution of principal repayment type



Notes: Figures show the joint distribution of loan/ borrower characteristics and origination interest rates. Buckets of origination interest rate correspond to cross-country quartiles, denoted in %. *Sources:* EDW and authors' calculations.

Table A1: Summary statistics for variables used in regressions

	Country				
	ES	IE	IT	PT	Total
	4,055,077 (42.5%)	1,371,975 (14.4%)	3,130,712 (32.8%)	974,081 (10.2%)	9,531,845 (100.0%)
Combined income	0.18 (0.65)	0.13 (0.52)	0.30 (0.64)	0.55 (1.01)	0.25 (0.69)
Year origination					
1996	2,850 (0.1%)	1,623 (0.1%)	88 (0.0%)	3,291 (0.3%)	7,852 (0.1%)
1997	16,091 (0.4%)	6,798 (0.5%)	2,550 (0.1%)	8,517 (0.9%)	33,956 (0.4%)
1998	21,230 (0.5%)	13,724 (1.0%)	12,588 (0.4%)	17,916 (1.8%)	65,458 (0.7%)
1999	33,096 (0.8%)	24,536 (1.8%)	35,002 (1.1%)	25,178 (2.6%)	117,812 (1.2%)
2000	58,041 (1.4%)	31,592 (2.3%)	70,497 (2.3%)	28,691 (2.9%)	188,821 (2.0%)
2001	94,253 (2.3%)	35,807 (2.6%)	91,572 (2.9%)	34,924 (3.6%)	256,556 (2.7%)
2002	178,158 (4.4%)	56,979 (4.2%)	161,347 (5.2%)	53,058 (5.4%)	449,542 (4.7%)
2003	278,993 (6.9%)	84,592 (6.2%)	227,711 (7.3%)	70,361 (7.2%)	661,657 (6.9%)
2004	439,093 (10.8%)	154,075 (11.2%)	395,395 (12.6%)	123,259 (12.7%)	1,111,822 (11.7%)
2005	712,211 (17.6%)	216,668 (15.8%)	303,361 (9.7%)	165,905 (17.0%)	1,398,145 (14.7%)
2006	834,902 (20.6%)	287,311 (20.9%)	264,927 (8.5%)	142,617 (14.6%)	1,529,757 (16.0%)
2007	559,002 (13.8%)	261,703 (19.1%)	166,068 (5.3%)	103,032 (10.6%)	1,089,805 (11.4%)
2008	265,492 (6.5%)	123,302 (9.0%)	110,504 (3.5%)	58,143 (6.0%)	557,441 (5.8%)
2009	276,184 (6.8%)	14,337 (1.0%)	226,376 (7.2%)	72,584 (7.5%)	589,481 (6.2%)
2010	225,468 (5.6%)	8,422 (0.6%)	505,047 (16.1%)	50,994 (5.2%)	789,931 (8.3%)
2011	28,661 (0.7%)	6,873 (0.5%)	355,984 (11.4%)	10,149 (1.0%)	401,667 (4.2%)
2012	13,564 (0.3%)	3,214 (0.2%)	61,385 (2.0%)	2,660 (0.3%)	80,823 (0.8%)
2013	6,354 (0.2%)	10,160 (0.7%)	47,512 (1.5%)	1,615 (0.2%)	65,641 (0.7%)
2014	6,797 (0.2%)	18,202 (1.3%)	41,835 (1.3%)	580 (0.1%)	67,414 (0.7%)
2015	4,564 (0.1%)	8,617 (0.6%)	28,918 (0.9%)	383 (0.0%)	42,482 (0.4%)
2016	52 (0.0%)	3,185 (0.2%)	18,038 (0.6%)	136 (0.0%)	21,411 (0.2%)
2017	21 (0.0%)	255 (0.0%)	4,007 (0.1%)	88 (0.0%)	4,371 (0.0%)
Remaining maturity	215.69 (80.90)	212.93 (90.21)	172.67 (89.13)	262.53 (102.86)	205.95 (91.57)
Origination LTV	76.54 (22.55)	76.56 (22.45)	66.51 (17.21)	72.29 (24.30)	72.81 (21.62)
Occupation					
Employed- full loan guaranteed	2,998,510 (73.9%)	1,215,426 (88.6%)	2,184,394 (69.8%)	768,777 (78.9%)	7,167,107 (75.2%)
Employed- partial support	111,013 (2.7%)	0 (0.0%)	11,811 (0.4%)	1,540 (0.2%)	124,364 (1.3%)
Protected life-time employment	455,582 (11.2%)	0 (0.0%)	125,155 (4.0%)	3,449 (0.4%)	584,186 (6.1%)
Unemployed	105,959 (2.6%)	11,752 (0.9%)	50,445 (1.6%)	49,882 (5.1%)	218,038 (2.3%)
Self-employed	299,689 (7.4%)	143,993 (10.5%)	573,240 (18.3%)	116,405 (12.0%)	1,133,327 (11.9%)
Pensioner	84,324 (2.1%)	804 (0.1%)	185,667 (5.9%)	34,028 (3.5%)	304,823 (3.2%)
Repayment instalments					
Annuity	2,399,017 (59.2%)	1,270,827 (92.6%)	2,129,879 (68.0%)	846,441 (86.9%)	6,646,164 (69.7%)
Linear	3,653 (0.1%)	0 (0.0%)	4,506 (0.1%)	42,896 (4.4%)	51,055 (0.5%)
Increasing instalment	453,330 (11.2%)	0 (0.0%)	65,905 (2.1%)	68,806 (7.1%)	588,041 (6.2%)
Fixed instalments w/ struct. protection	0 (0.0%)	0 (0.0%)	67,311 (2.2%)	1,851 (0.2%)	69,162 (0.7%)
Fixed instalments w/o struct. protection	1,157,002 (28.5%)	0 (0.0%)	263,552 (8.4%)	594 (0.1%)	1,421,148 (14.9%)
Bullet	15 (0.0%)	25,295 (1.8%)	284 (0.0%)	5,694 (0.6%)	31,288 (0.3%)
Other	42,060 (1.0%)	75,853 (5.5%)	599,275 (19.1%)	7,799 (0.8%)	724,987 (7.6%)
Age borrower	45.77 (8.65)	44.88 (8.32)	47.56 (10.26)	45.97 (8.76)	46.25 (9.23)
LTI at origination	7.66 (3.13)	5.77 (1.55)	6.43 (2.03)	6.35 (3.26)	6.85 (2.74)
Unemployment rate	19.02 (3.27)	8.04 (2.06)	11.63 (0.75)	10.46 (2.65)	14.14 (5.00)
Real disp income	2.41 (2.14)	4.48 (1.98)	0.81 (0.70)	2.33 (1.90)	2.17 (2.11)
Contemporaneous interest rate	1.01 (0.80)	2.20 (1.45)	1.53 (0.68)	0.97 (0.74)	1.35 (0.98)
Origination interest rate	1.41 (0.91)	2.38 (1.44)	1.81 (0.64)	1.37 (0.67)	1.68 (0.97)

Notes: Table shows summary statistics for the variables used in the analysis. Mean with standard deviation in parentheses for continuous variables and absolute frequencies with relative frequencies in parentheses for categorical variables. Combined income is sum of borrowers' income (if more than one borrower) and measured as deviation from country and year of origination specific median. Remaining maturity (months), LTV and LTI in %, age of borrower in years, country level unemployment, real disposable income growth and interest rates in %. "Structural protection" is abbreviated as "s.p.".

B. Details on additional variables

This section provides further details on the thresholds to group the different interest rate variables according to their three terciles. In addition, this section also provides additional information on the distribution of observations across these terciles and across the categorical variables grouping loans according to their interest rate changes.

Table B2: Thresholds for interest rate variables (%)

	1st tercile	2nd tercile
Origination interest rate		
ES	0.94	1.29
IE	1.35	2.60
IT	1.48	1.87
PT	0.94	1.49
Total	1.14	1.67
Contemporaneous interest rate		
ES	0.57	1.00
IE	1.10	2.40
IT	1.20	1.62
PT	0.53	1.14
Total	0.85	1.42

Notes: Table shows the interest rate thresholds used in this analysis for grouping loans into their respective terciles, both considering country-level thresholds and cross-country distributions.

Table B3: Distribution of loans across buckets of various interest rate variables

	Country				
	ES	**IE**	**IT**	**PT**	**Total**
Terciles of origination interest rate					
1	1,350,376	571,994	1,046,578	325,076	3,294,024
2	1,355,554	341,878	1,041,591	325,467	3,064,490
3	1,349,147	458,103	1,042,543	323,538	3,173,331
Total	4,055,077	1,371,975	3,130,712	974,081	9,531,845
1	33.3%	41.7%	33.4%	33.4%	34.6%
2	33.4%	24.9%	33.3%	33.4%	32.2%
3	33.3%	33.4%	33.3%	33.2%	33.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Terciles of contemporaneous interest rate					
1	1,351,376	461,643	1,071,506	324,895	3,209,420
2	1,351,919	464,002	1,017,436	324,437	3,157,794
3	1,351,782	446,330	1,041,770	324,749	3,164,631
Total	4,055,077	1,371,975	3,130,712	974,081	9,531,845
1	33.3%	33.6%	34.2%	33.4%	33.7%
2	33.3%	33.8%	32.5%	33.3%	33.1%
3	33.3%	32.5%	33.3%	33.3%	33.2%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Ranges of interest rate change					
$<= -70$	606,691	65,335	54,796	48,817	775,639
$(-70, -5]$	2,579,010	877,849	2,201,051	756,631	6,414,541
$(-5, 5)$	785,205	292,998	860,082	152,470	2,090,755
$[5, 70)$	83,546	135,610	13,387	12,823	245,366
$>= 70$	625	183	1,396	3,340	5,544
Total	4,055,077	1,371,975	3,130,712	974,081	9,531,845
$<= -70$	15.0%	4.8%	1.8%	5.0%	8.1%
$(-70, -5]$	63.6%	64.0%	70.3%	77.7%	67.3%
$(-5, 5)$	19.4%	21.4%	27.5%	15.7%	21.9%
$[5, 70)$	2.1%	9.9%	0.4%	1.3%	2.6%
$>=70$	0.0%	0.0%	0.0%	0.3%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Ranges of interest rate change					
$<= -70$	606,691	65,335	54,796	48,817	775,639
$(-70, -35]$	1,394,815	57,296	973,718	559,193	2,985,022
$(-35, -5]$	1,184,195	820,553	1,227,333	197,438	3,429,519
$(-5, 5)$	785,205	292,998	860,082	152,470	2,090,755
$[5, 35)$	81,731	135,361	11,006	9,212	237,310

$[-35, -70)$	1,815	249	2,381	3,611	8,056
$>= 70$	625	183	1,396	3,340	5,544
Total	4,055,077	1,371,975	3,130,712	974,081	9,531,845
$<= -70$	15.0%	4.8%	1.8%	5.0%	8.1%
$(-70, -35]$	34.4%	4.2%	31.1%	57.4%	31.3%
$(-35, -5]$	29.2%	59.8%	39.2%	20.3%	36.0%
$(-5, 5)$	19.4%	21.4%	27.5%	15.7%	21.9%
$[5, 35)$	2.0%	9.9%	0.4%	0.9%	2.5%
$[-35, -70)$	0.0%	0.0%	0.1%	0.4%	0.1%
$>= 70$	0.0%	0.0%	0.0%	0.3%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Notes: Table shows the distribution of various interest rate measures across countries based on cross sectional thresholds when grouping variables into their respective terciles. Within each interest rate measure, upper part shows absolute number of observations, lower part shows %-frequency. Changes in interest rate denoted in basis points.

Table B4: Joint distribution of loans across buckets of various interest rate variables

	Terciles of origination interest rate			
	1	**2**	**3**	**Total**
Terciles of contemporaneous interest rate				
1	2,460,323	695,856	20,202	3,176,381
2	712,612	2,124,186	342,277	3,179,075
3	4,785	356,925	2,814,679	3,176,389
Total	3,177,720	3,176,967	3,177,158	9,531,845
1	77.4%	21.9%	0.6%	33.3%
2	22.4%	66.9%	10.8%	33.4%
3	0.2%	11.2%	88.6%	33.3%
Total	100.0%	100.0%	100.0%	100.0%
Ranges of interest rate change				
<= −70	166,634	156,785	452,220	775,639
(−70, −5]	2,287,532	2,428,636	1,698,373	6,414,541
(−5, 5)	667,407	562,774	860,574	2,090,755
[5, 70)	52,744	27,702	164,920	245,366
>= 70	3,403	1,070	1,071	5,544
Total	3,177,720	3,176,967	3,177,158	9,531,845
<= −70	5.2%	4.9%	14.2%	8.1%
(−70, −5]	72.0%	76.4%	53.5%	67.3%
(−5, 5)	21.0%	17.7%	27.1%	21.9%
[5, 70)	1.7%	0.9%	5.2%	2.6%
>= 70	0.1%	0.0%	0.0%	0.1%
Total	100.0%	100.0%	100.0%	100.0%
Ranges of interest rate change				
<= −70	166,634	156,785	452,220	775,639
(−70, −35]	1,108,691	1,120,248	756,083	2,985,022
(−35, −5]	1,178,841	1,308,388	942,290	3,429,519
(−5, 5)	667,407	562,774	860,574	2,090,755
[5, 35)	49,649	24,808	162,853	237,310
[−35, −70)	3,095	2,894	2,067	8,056
>= 70	3,403	1,070	1,071	5,544
Total	3,177,720	3,176,967	3,177,158	9,531,845
<= −70	5.2%	4.9%	14.2%	8.1%
(−70, −35]	34.9%	35.3%	23.8%	31.3%
(−35, −5]	37.1%	41.2%	29.7%	36.0%
(−5, 5)	21.0%	17.7%	27.1%	21.9%
[5, 35)	1.6%	0.8%	5.1%	2.5%
[−35, −70)	0.1%	0.1%	0.1%	0.1%

>= 70	0.1%	0.0%	0.0%	0.1%
Total	100.0%	100.0%	100.0%	100.0%

Notes: Table shows the joint distribution of origination interest rates versus contemporaneous interest rate and our main definitions of interest rate changes. Terciles of contemporaneous and origination interest rate based on cross sectional thresholds. Within each interest rate measure, upper part shows absolute number of observations, lower part shows %-frequency. Changes in interest rate denoted in basis points.

C. Additional regression results

C.1. Main regression results

Since our main focus is on the interaction between interest rates and mortgage defaults, we only show the results on the remaining variables here. Table (C5) shows the odds ratios for all variables using different measures of the interest rate variable. Results on any control variable are robust to the inclusion of any alternative measures of the interest rate. Next, Table (C6) shows the regression outputs underlying our main results in Figures (7) and (8) on the non-linear impact of interest rates on mortgage defaults. For better readability, we do not show the odds ratios on the control variables again but note that their impact is stable across all specifications.

Table C5: Baseline Regression results: continuous interest rate measures

	One year ahead default		
	(1)	(2)	(3)
Contemporaneous interest rate	1.460***		
	(0.012)		
Origination interest rate		1.416***	
		(0.011)	
Change in interest rate			1.001***
			(0.000)
Unemployment rate	1.159***	1.195***	1.193***
	(0.004)	(0.004)	(0.004)
Real disp income	0.971***	0.969***	0.968***
	(0.002)	(0.002)	(0.002)
Combined income	0.830***	0.828***	0.756***
	(0.013)	(0.013)	(0.012)
Remaining maturity	1.003***	1.003***	1.003***
	(0.000)	(0.000)	(0.000)
Age borrower	1.015***	1.015***	1.015***
	(0.001)	(0.001)	(0.001)
LTI at origination	1.023***	1.022***	1.009***
	(0.003)	(0.003)	(0.003)
LTV at origination	1.009***	1.009***	1.010***
	(0.000)	(0.000)	(0.000)
Occupation			
Employed- full loan guaranteed (ref)	1.000	1.000	1.000
	(.)	(.)	(.)
Employed- partial support	1.579***	1.558***	1.958***
	(0.078)	(0.077)	(0.096)
Protected life-time employment	0.542***	0.546***	0.492***
	(0.026)	(0.026)	(0.024)
Unemployed	1.425***	1.433***	1.466***
	(0.059)	(0.060)	(0.061)
Self-employed	1.864***	1.867***	1.886***
	(0.034)	(0.034)	(0.035)
Pensioner	0.745***	0.748***	0.745***
	(0.037)	(0.037)	(0.037)

Table C5: Baseline Regression results: continuous interest rate measures

	One year ahead default		
	(1)	(2)	(3)
Repayment			
Annuity (ref)	1.000	1.000	1.000
	(.)	(.)	(.)
Linear	3.171***	3.192***	3.114***
	(0.308)	(0.311)	(0.304)
Increasing instalment	1.047	1.046	1.035
	(0.033)	(0.033)	(0.032)
Fixed instalments w/ struct. protection	0.935	0.930	0.971
	(0.087)	(0.086)	(0.090)
Fixed instalments w/o struct. protection	1.567***	1.595***	1.556***
	(0.034)	(0.034)	(0.034)
Bullet	9.841***	9.578***	7.326***
	(0.522)	(0.506)	(0.378)
Other	1.258***	1.287***	1.395***
	(0.033)	(0.034)	(0.035)
Constant	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
Country FE	X	X	X
Year origination FE	X	X	X
Pseudo R-sqr	0.056	0.055	0.048
N	9531845	9531845	9531845
AUROC	0.719	0.717	0.703

Signif. Codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Notes: Table reports odds ratios, with clustered standard errors at the loan level in parentheses.

Table C6: Main Regression results: Non-linear interest rate effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Origination interest rate	0.975	1.459***						
	(0.026)	(0.012)						
Cont. interest rate	1.496***							
	(0.040)							
Change in interest rate		1.004***						
		(0.000)						
Origination interest rate buckets								
<1.14(ref)			1.000	1.000	1.000	1.000	1.000	1.000
			(.)	(.)	(.)	(.)	(.)	(.)
(1.14,1.67]			1.802***	2.174***	2.160***	1.763***	2.363***	2.357***
			(0.049)	(0.054)	(0.054)	(0.076)	(0.088)	(0.088)
>1.67			2.124***	3.497***	3.457***	2.750***	3.918***	3.921***
			(0.076)	(0.091)	(0.090)	(0.423)	(0.147)	(0.147)
Cont. interest rate buckets								
<=0.85 (ref)			1.000			1.000		
			(.)			(.)		
(0.85,1.42]			1.278***			1.231***		
			(0.036)			(0.047)		
>1.42			1.907***			8.157***		
			(0.068)			(1.525)		
Change in interest rate buckets								
<=-70				0.795***			0.609***	
				(0.027)			(0.081)	
$(-70, -35]$				0.789***			0.778***	
				(0.017)			(0.042)	
$(-35, -5]$				0.902***			1.126**	
				(0.015)			(0.045)	
$(-5, 5)$ (ref)				1.000			1.000	
				(.)			(.)	
$[5, 35)$				1.190***			1.257*	
				(0.041)			(0.136)	
$[35, 70)$				1.959***			3.910***	
				(0.327)			(1.109)	
>=70				4.658***			8.482***	
				(0.766)			(1.810)	
Change in interest rate buckets								

Table C6: Main Regression results: Non-linear interest rate effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<=-70					0.827***			0.654**
					(0.028)			(0.086)
(−70, −5]					0.867***			1.006
					(0.013)			(0.039)
(−5, 5) (ref)					1.000			1.000
					(.)			(.)
[5, 70)					1.194***			1.372**
					(0.041)			(0.141)
>=70					4.750***			8.816***
					(0.781)			(1.880)
Interactions								
Origination × cont. interest rate								
<=1.14 × <=0.85						1.000		
						(.)		
<=1.14 × (0.85,1.42]						1.000		
						(.)		
<=1.14 × >1.42						1.000		
						(.)		
(1.14,1.67] × <=0.85						1.000		
						(.)		
(1.14,1.67] × (0.85,1.42]						1.059		
						(0.054)		
(1.14,1.67] × >1.42						0.234***		
						(0.045)		
>1.67 × <=0.85						1.000		
						(.)		
>1.67 × (0.85,1.42]						0.798		
						(0.128)		
>1.67 × >1.42						0.179***		
						(0.043)		
Origination × change in interest rate								
<=1.14 × <=-70							1.000	
							(.)	
<=1.14 × (−70, −35]							1.000	
							(.)	
<=1.14 × (−35, −5]							1.000	

Table C6: Main Regression results: Non-linear interest rate effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
							(.)	
<=1.14 × (−5, 5)							1.000	
							(.)	
<=1.14 × [5, 35)							1.000	
							(.)	
<=1.14 × [35, 70)							1.000	
							(.)	
<=1.14 × >=70							1.000	
							(.)	
(1.14,1.67] × <=-70							1.186	
							(0.178)	
(1.14,1.67] × (−70, −35]							1.084	
							(0.064)	
(1.14,1.67] × (−35, −5]							0.776***	
							(0.036)	
(1.14,1.67] × (−5, 5)							1.000	
							(.)	
(1.14,1.67] × [5, 35)							1.113	
							(0.150)	
(1.14,1.67] × [35, 70)							0.568	
							(0.222)	
(1.14,1.67] × >=70							0.604	
							(0.222)	
>1.67 × <=-70							1.327*	
							(0.180)	
>1.67 × (−70, −35]							0.965	
							(0.057)	
>1.67 × (−35, −5]							0.770***	
							(0.035)	
>1.67 × (−5, 5)							1.000	
							(.)	
>1.67 × [5, 35)							0.898	
							(0.104)	
>1.67 × [35, 70)							0.288**	
							(0.121)	
>1.67 × >=70							0.169***	

Table C6: Main Regression results: Non-linear interest rate effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
							(0.081)	
Origination × change in interest rate								
<=1.14 × <=-70								1.000
								(.)
<=1.14 × (−70, −5]								1.000
								(.)
<=1.14 × (−5, 5)								1.000
								(.)
<=1.14 × [5, 70)								1.000
								(.)
<=1.14 × >=70								1.000
								(.)
(1.14,1.67] × <=-70								1.189
								(0.178)
(1.14,1.67] × (−70, −5]								
1.828***								
(0.094)								
(1.14,1.67] × (−5, 5)								1.000
								(.)
(1.14,1.67] × [5, 70)								1.058
								(0.136)
(1.14,1.67] × >=70								0.595
								(0.219)
>1.67 × <=-70								1.272
								(0.172)
>1.67 × (−70, −5]								0.823***
								(0.035)
>1.67 × (−5, 5)								1.000
								(.)
>1.67 × [5, 70)								0.809
								(0.089)
>1.67 × >=70								0.165***
								(0.079)
Controls	X	X	X	X	X	X	X	X

Table C6: Main Regression results: Non-linear interest rate effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Country FE	X	X	X	X	X	X	X	X
Year origination FE	X	X	X	X	X	X	X	X
Pseudo R-sqr	0.056	0.056	0.061	0.061	0.061	0.061	0.061	0.061
N	9531845	9531845	9531845	9531845	9531845	9531845	9531845	9531845
AUROC	0.719	0.719	0.728	0.727	0.727	0.728	0.728	0.727

Signif. Codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Notes: Table reports odds ratios, with clustered standard errors at the loan level in parentheses. Dependent variable is one year ahead default. Apart from the respective interest rates variables, the following control variables are included in the regressions: country-level unemployment rate and real disposable income growth, and loan-level combined income at loan origination (deviation from time and country-specific median), remaining loan maturity, age of the borrower, LTV and LTI at origination, a dummy capturing the occupational status, and a dummy capturing the loan repayment type. All regressions include a constant.

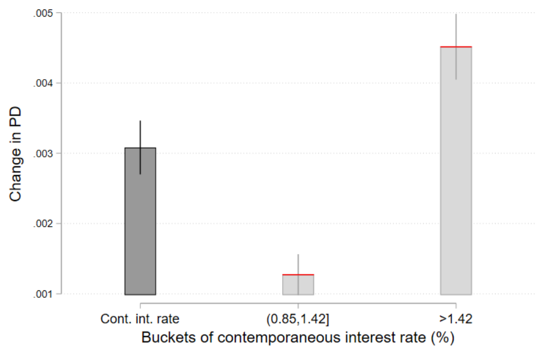
C.2. Robustness checks

C.2.1. Self-selection into floating rate loans

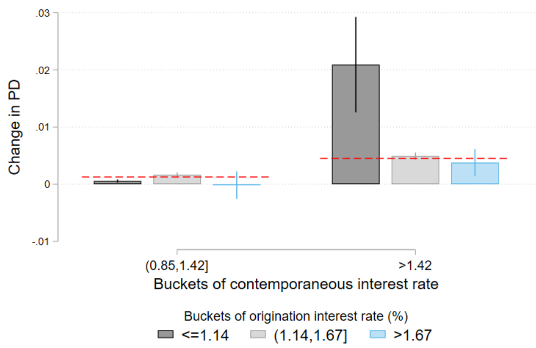
We verify that our results also hold against a possible self-selection into fixed or floating rate loans based on a Heckman analysis. Although our analysis focuses on countries with predominantly floating rate loans, a small share of fixed rate loans also exists in these countries (at approximately 7% of all floating rate loans). Our set-up relies on a probit specification both in the selection equation (first step) and the outcome equation (second step) akin to Van de Ven and Van Praag (1981). Using a probit probability of default model in lieu of our baseline logit model is crucial because the Heckman model assumes that the error terms of the selection equation and the outcome equation are jointly normally distributed. The probit model, which assumes a normal distribution of the error term, aligns with this assumption. Figure (C4) first shows that our baseline regression results are insensitive to the distributional assumption on the error term, i.e. the marginal effects are very similar irrespective of whether we assume a normal or logistic distribution of the error term.

Figure C4: Results based on a probit discrete choice model

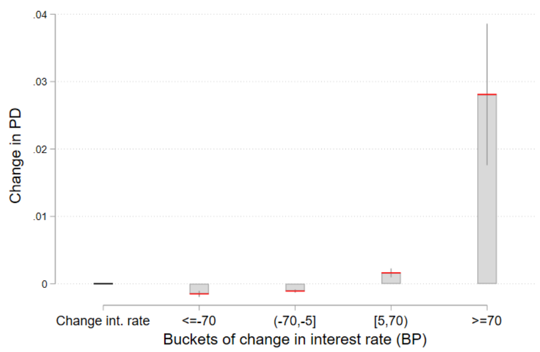
(a) Marginal effects of contemporaneous interest rate across its distribution



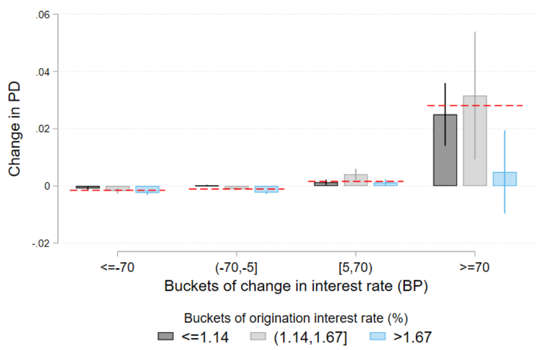
(b) Marginal effects of contemporaneous interest rate by origination interest rates



(c) Marginal effects of interest rate changes since origination



(d) Marginal effects of interest rate change by origination interest rates



Notes: See notes on Figure (7) and (8) in the main text. Results based on probit model.

To account for a possible self-selection bias of our results, we augment our baseline model by adding as a first layer a probit selection model for the discrete choice model between a fixed and a floating rate loan. All variables from our baseline regressions that capture characteristics at the time of origination of the loan are included in the selection equation. Following Van de Ven and Van Praag (1981), we model mortgage defaults as a discrete choice model with normally distributed errors

$$DF^*_{i,t+4} = 1|\mathbf{X_{i,c,t}} = (\theta \mathbf{X_{i,c,t}} + \rho_{\mathbf{i,c,t}} > 0|\mathbf{X_{i,c,t}}) \qquad \rho_{\mathbf{i,c,t}} \sim \mathcal{N}(\mathbf{0}, \mathbf{I}) \tag{1}$$

and similarly, the unobserved latent self-selection process as

$$\mathbf{y_{i,t}}^*|\mathbf{w_{i,c,t}} = (\beta \mathbf{w_{i,c,t}} + \mathbf{u_{i,c,t}} > 0|\mathbf{w_{i,c,t}}) \qquad \mathbf{u_{i,c,t}} \sim \mathcal{N}(\mathbf{0}, \mathbf{I}), \tag{2}$$

where $(DF^*_{i,t+4} = 1|\mathbf{X_{i,c,t}})$ denotes the one-year ahead default of a floating rate loan that may be affected by a selection bias. $\mathbf{X_{i,c,t}}$ holds the set of covariates we deem important in determining mortgage defaults, θ is the coefficient matrix on these covariates and $\rho_{\mathbf{i,c,t}}$ is the loan level error term. We do not observe the latent process underlying the decision in favour or against a floating rate loan, but we model this decision as in Equation (2) where $\mathbf{y_{i,t}}^*$ is an indicator variable indicating decision against $(y = 0)$ or in favour $(y = 1)$ of a variable rate loan. $\mathbf{w_{i,c,t}}$ collects relevant covariates and $\mathbf{u_{i,c,t}}$ is the loan level error term. Our preferred specification of the selection equation includes all control variables mentioned in the main text and as interest rate measure the interest rate at origination. We assume $\rho_{\mathbf{i,c,t}}$ and $\mathbf{u_{i,c,t}}$ to be both standard normally distributed with correlation $corr(\rho_{\mathbf{i,c,t}}, \mathbf{u_{i,c,t}}) = \rho$. If the correlation between the errors is in fact zero, any potential self-selection would not affect defaults.

Since we only observe defaults for variable rate loans if and only if a household chose to opt for a variable rate loan, default is more rigorously determined the following way:

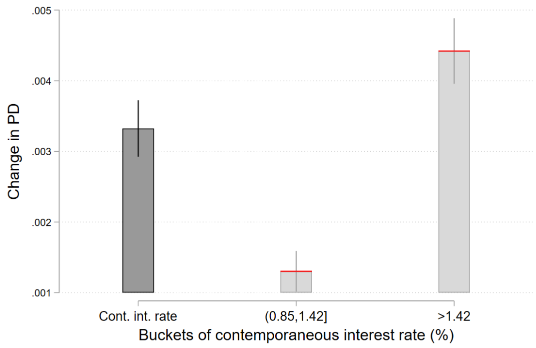
$$(DF^*_{i,t+4} = 1|\mathbf{X_{i,c,t}}, \mathbf{y_{i,t}}^* > 0) = (\theta \mathbf{X_{i,c,t}} + \rho_{\mathbf{i,c,t}} > 0)\,|\mathbf{X_{i,c,t}}. \tag{3}$$

Three cases can arise, first, households do not opt for variable rate loans and hence we do not observe their default behaviour had they opted for a variable rate loan instead. Second, households decide in favour of variable rate loans and default, or third, they decide for variable rate loans but do not default. Given the distributional assumptions on the error terms, we can construct the joint probability and the resulting log-likelihood function to assess the presence of a selection bias.

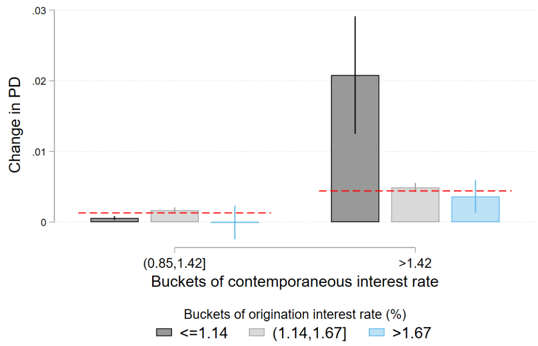
Table (C7) shows the results from the two-step probit specification. The upper part depicts the coefficients from the second stage regression, whereas the lower part of the Table shows the results from the first stage regression. In addition, Table (C8) displays the test-statistics along with their p-values from the log-likelihood of self-selection from our two-step approach. Concretely, the log-likelihood test is designed to test for the correlation between the errors of the two models. From a statistical perspective, we cannot deny that selection may be a concern. However, Figure (C5) replicates our main results based on the two step algorithm outlined above and our key message on the interplay between origination and contemporaneous interest rate burden is hardly affected, even after accounting for a possible self-selection into fixed and floating rate loans.

Figure C5: Results based on a probit discrete choice model with selection

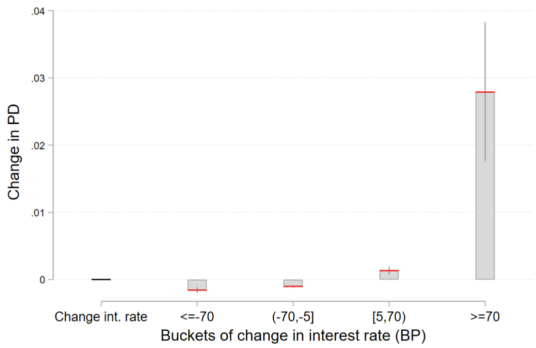
(a) Marginal effects of contemporaneous interest rate across its distribution



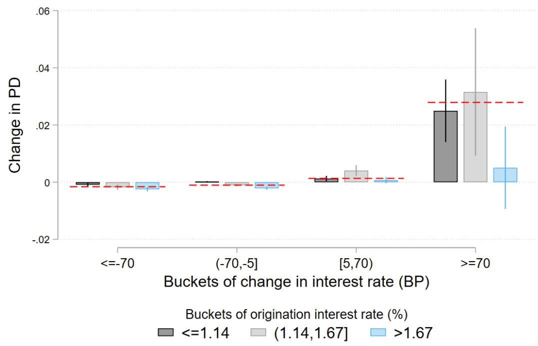
(b) Marginal effects of contemporaneous interest rate by origination interest rates



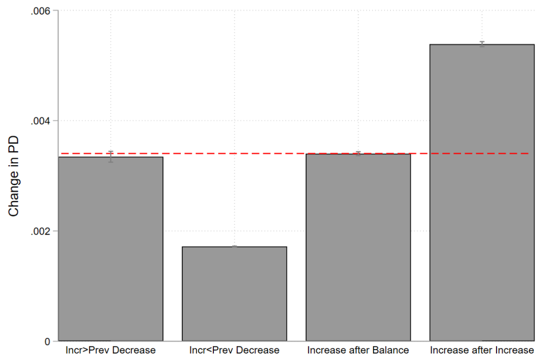
(c) Marginal effects of interest rate changes since origination



(d) Marginal effects of interest rate change by origination interest rates



(e) Marginal effects of increase in contemporaneous interest rate by past trajectory



Notes: See notes on Figure (7), (8) and (9) in the main text. Results based on probit model with selection.

Table C7: Regression results: Two-stage probit results

	(1)	(2)	(3)	(4)	(5)	(6)
2^{nd} stage results: mortgage defaults						
Cont. interest rate	1.174***					
	(0.011)					
Origination interest rate	1.009	1.184***				

Table C7: Regression results: Two-stage probit results

	(1)	(2)	(3)	(4)	(5)	(6)
	(0.010)	(0.005)				
Change in interest rate		1.002***				
		(0.000)				
Cont. interest rate buckets						
<=0.85 (ref)			1.000		1.000	
			(.)		(.)	
$(0.85, 1.42]$			1.086***		1.060***	
			(0.011)		(0.014)	
>1.42			1.260***		2.173***	
			(0.016)		(0.169)	
Origination interest rate buckets						
<=1.14 (ref)			1.000	1.000	1.000	1.000
			(.)	(.)	(.)	(.)
$(1.14, 1.67]$			1.233***	1.313***	1.210***	1.370***
			(0.012)	(0.012)	(0.018)	(0.019)
>1.67			1.297***	1.552***	1.409***	1.645***
			(0.017)	(0.014)	(0.077)	(0.023)
Change in interest rate buckets						
<=-70				0.923***		0.906*
				(0.011)		(0.037)
$(-70, -5]$				0.951***		1.014
				(0.006)		(0.014)
$(-5, 5)$ (ref)				1.000		1.000
				(.)		(.)
$[5, 70)$				1.061***		1.120**
				(0.014)		(0.041)
>=70				1.880***		2.301***
				(0.132)		(0.206)
Interactions						
Origination × cont. interest rate <=1.14 × <=0.85					1.000	
					(.)	
<=1.14 × $(0.85, 1.42]$					1.000	
					(.)	
<=1.14 × >1.42					1.000	
					(.)	
$(1.14, 1.67]$ × <=0.85					1.000	
					(.)	
$(1.14, 1.67]$ × $(0.85, 1.42]$					1.041*	
					(0.019)	
$(1.14, 1.67]$ × >1.42					0.585***	
					(0.047)	
>1.67 × <=0.63					1.000	
					(.)	
>1.67 × $(0.63, 1.00]$					0.941	
					(0.053)	
>1.67 × >1.56					0.530***	
					(0.050)	
<=1.14 × <=-70						1.000
						(.)
<=1.14 × $(-70, -5]$						1.000
						(.)
<=1.14 × $(-5, 5)$						1.000
						(.)
<=1.14 × $[5, 70)$						1.000
						(.)

Table C7: Regression results: Two-stage probit results

	(1)	(2)	(3)	(4)	(5)	(6)
<=1.14 × >=70						1.000
						(.)
$(1.14, 1.67]$ × <=-70						1.007
						(0.047)
$(1.14, 1.67]$ × $(-70, -5]$						0.937***
						(0.015)
$(1.14, 1.67]$ × $(-5, 5)$						1.000
						(.)
$(1.14, 1.67]$ × $[5, 70)$						1.047
						(0.051)
$(1.14, 1.67]$ × >=70						0.853
						(0.140)
>1.67 × <=-70						1.015
						(0.043)
>1.67 × $(-70, -5]$						0.918***
						(0.014)
>1.67 × $(-5, 5)$						1.000
						(.)
>1.67 × $[5, 70)$						0.913*
						(0.037)
>1.67 × >=70						0.498***
						(0.097)
1^{st} stage results: selection						
Origination interest rate	0.302***	0.302***	0.302***	0.302***	0.302***	0.302***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Controls	X	X	X	X	X	X
Country FE	X	X	X	X	X	X
Year origination FE	X	X	X	X	X	X
N	10252886	10252886	10252886	10252886	10252886	10252886

Signif. Codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Notes: Table reports odds ratios, with clustered standard errors at the loan level in parentheses. Dependent variable is one year ahead default (second stage) or selection into floating or fixed rate loan (first stage). Cont. interest rate is the contemporaneous interest rate (bucket). Apart from the respective interest rates variables, the following control variables are included in the regressions: country-level unemployment rate and real disposable income growth, and loan-level combined income at loan origination (deviation from time and country-specific median), remaining loan maturity, age of the borrower, LTV and LTI at origination, a dummy capturing the occupational status, and a dummy capturing the loan repayment type. All regressions include a constant.

C.2.2. Fixed effects and macroeconomic variables

Instead of controlling explicitly for macroeconomic factors, we verify the robustness of our results to a more general specifications including different sets of (interacted) fixed effects (Table (C9)). This way, we may capture a broader set of developments ensuring to capture

Table C8: Test for selection

Model specification	Interest rate specification	Test-statistic
Individual	Cont. interest rate	71.53 ***
	Cont. interest rate buckets	22.87 ***
	Change in interest rate buckets	22.49 ***
Interaction	Cont. interest rate buckets	23.21 ***
	Change in interest rate buckets	21.44 ***

Signif. Codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Notes: Table reports Chi-squared text statistics for the test of no sample selection for the regressions of Table (C7). Interest rate buckets as described in the main text. The first column identifies whether the interest rate measure is interacted with the origination interest rate variable or included as an individual variable only (but next to the origination interest rate measure).

dynamics within a narrowly defined set of loans, set apart by the different groups identified via the fixed effects. Importantly, our results hold even in the most saturated model.

Table C9: Robustness checks Model specification: Country - time fixed effects

	(1)	(2)	(3)	(4)	(5)	(6)
Origination interest rate	1.003	1.456***				
	(0.029)	(0.012)				
Cont. interest rate	1.451***					
	(0.043)					
Change in interest rate		1.004***				
		(0.000)				
Origination interest rate buckets						
<=1.14 (ref)			1.000	1.000	1.000	1.000
			(.)	(.)	(.)	(.)
(1.14,1.67]			1.795***	2.182***	1.851***	2.239***
			(0.050)	(0.055)	(0.081)	(0.085)
>1.67			2.207***	3.470***	2.816***	3.502***
			(0.082)	(0.091)	(0.433)	(0.135)
Cont. interest rate buckets						
<=0.85 (ref)			1.000		1.000	
			(.)		(.)	
(0.85,1.42]			1.331***		1.336***	
			(0.039)		(0.053)	
>1.42			1.859***		8.153***	
			(0.072)		(1.528)	
Change in interest rate buckets						
<=-70				0.784***		0.548***
				(0.028)		(0.074)
$(-70, -5]$				0.848***		0.861***
				(0.016)		(0.036)
$(-5, 5)$ (ref)				1.000		1.000
				(.)		(.)
$[5, 70)$				1.194***		1.363**
				(0.042)		(0.140)
>=70				4.691***		7.639***
				(0.774)		(1.638)
Interactions						
Origination × cont. interest rate						
<=1.14 × <=0.85					1.000	
					(.)	
<=1.14 × (0.85,1.42]					1.000	
					(.)	
<=1.14 × >1.42					1.000	
					(.)	
(1.14,1.67] × <=0.85					1.000	
					(.)	
(0.99,1.29] × (0.85,1.42]					0.973	
					(0.051)	
(0.99,1.29] × >1.42					0.221***	
					(0.043)	
>1.67 × <=0.85					1.000	
					(.)	
>1.67 × (0.85,1.42]					0.799	
					(0.128)	
>1.67 × >1.42					0.180***	
					(0.043)	
Origination × change in interest rate <=1.14× <=-70						1.000
						(.)
<=1.14 × $(-70, -5]$						1.000
						(.)

Table C9: Robustness checks Model specification: Country - time fixed effects

	(1)	(2)	(3)	(4)	(5)	(6)
<=1.14 × $(-5, 5)$						1.000
						(.)
<=1.14 × $[5, 70)$						1.000
						(.)
<=1.14 × >=70						1.000
						(.)
(1.14,1.67] × <=70						1.264
						(0.189)
(1.14,1.67] × $(-70, -5]$						0.958
						(0.043)
(1.14,1.67] × $(-5, 5)$						1.000
						(.)
(1.14,1.67] × $[5, 70)$						1.121
						(0.145)
(1.14,1.67] × >70						0.665
						(0.245)
>1.67 × <=-70						1.472**
						(0.203)
>1.67 × $(-70, -5]$						0.988
						(0.044)
>1.67 × $(-5, 5)$						1.000
						(.)
>1.67 × $[5, 70)$						0.822
						(0.091)
>1.67 × >=70						0.200***
						(0.096)
Controls	X	X	X	X	X	X
Country FE	X	X	X	X	X	X
Year origination FE	X	X	X	X	X	X
Quarter-Country FE	X	X	X	X	X	X
Pseudo R-sqr	0.059	0.059	0.063	0.063	0.064	0.063
N	9531845	9531845	9531845	9531845	9531845	9531845
AUROC	0.723	0.723	0.732	0.731	0.733	0.732

Signif. Codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Notes: Table reports odds ratios, with clustered standard errors at the loan level in parentheses. Dependent variable is one year ahead default. Apart from the continuous interest rates variables, the following control variables are included in the regressions: country-level unemployment rate and real disposable income growth, and loan-level combined income at loan origination (deviation from time and country-specific median), remaining loan maturity, age of the borrower, LTV and LTI at origination, a dummy capturing the occupational status, and a dummy capturing the loan repayment type. All regressions include a constant.

Table C10: Robustness checks Model specification: Country - time - year origination fixed effects

	(1)	(2)	(3)	(4)	(5)	(6)
Origination interest rate	1.042	1.487***				
	(0.031)	(0.012)				
Cont. interest rate	1.427***					
	(0.042)					
Change in interest rate		1.004***				
		(0.000)				
Origination interest rate buckets						
<=1.14 (ref)			1.000	1.000	1.000 1.000	
			(.)	(.)	(.)	(.)
(1.14,1.67]			1.792***	2.170***	1.866***	2.218***
			(0.051)	(0.056)	(0.082)	(0.086)
>1.67			2.258***	3.528***	2.755***	3.561***
			(0.085)	(0.095)	(0.428)	(0.139)
Cont. interest rate buckets						
<=0.85 (ref)			1.000		1.000	
			(.)		(.)	
(0.85,1.42]			1.342***		1.356***	
			(0.040)		(0.054)	
>1.42			1.872***		7.636***	
			(0.073)		(1.450)	
Change in interest rate buckets						
<=-70				0.814***		0.539***
				(0.030)		(0.073)
$(-70, -5]$				0.853***		0.867***
				(0.016)		(0.036)
$(-5, 5)$ (ref)				1.000		1.000
				(.)		(.)
$[5, 70)$				1.213***		1.407***
				(0.043)		(0.145)
>=70				4.458***		6.986***
				(0.738)		(1.525)
Interactions						
Origination × cont. interest rate						
<=1.14 × <=0.85					1.000	
					(.)	
<=1.14 × (0.85,1.42]					1.000	
					(.)	
<=1.14 × >1.42					1.000	
					(.)	
(1.14,1.67] × <=0.85					1.000	
					(.)	
(1.14,1.67] × (0.85,1.42]					0.958	
					(0.050)	
(1.14,1.67] × >1.42					0.235***	
					(0.046)	
>1.67 × <=0.85					1.000	
					(.)	
>1.67 × (0.85,1.42]					0.831	
					(0.135)	
>1.67 × >1.42					0.203***	
					(0.050)	
Origination × change in interest rate						
<=1.14 × <=-70						1.000
						(.)
<=1.14 × $(-70, -5]$						1.000

Table C10: Robustness checks Model specification: Country - time - year origination fixed effects

	(1)	(2)	(3)	(4)	(5)	(6)
						(.)
<=1.14 × $(-5, 5)$						1.000
						(.)
<=1.14 × $[5, 70)$						1.000
						(.)
<=1.14 × >=70						1.000
						(.)
(1.14,1.67] × <=-70						1.280
						(0.192)
(1.14,1.67] × $(-70, -5]$						0.964
						(0.043)
(1.14,1.67]] × $(-5, 5)$						1.000
						(.)
(1.14,1.67] × $[5, 70)$						1.084
						(0.140)
(1.14,1.67] × >=70						0.731
						(0.270)
>1.67 × <=-70						1.567**
						(0.216)
>1.67 × $(-70, -5]$						0.984
						(0.044)
>1.67 × $(-5, 5)$						1.000
						(.)
>1.67 × $[5, 70)$						0.808
						(0.090)
>1.67 × >=70						0.209**
						(0.100)
Controls	X	X	X	X	X	X
Country FE	X	X	X	X	X	X
Year origination FE	X	X	X	X	X	X
Quarter-Country FE	X	X	X	X	X	X
Year orig-Country FE	X	X	X	X	X	X
Pseudo R-sqr	0.061	0.061	0.065	0.065	0.066	0.065
N	9527725	9527725	9527725	9527725	9527725	9527725
AUROC	0.728	0.728	0.735	0.734	0.736	0.734

Signif. Codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Notes: Table reports odds ratios, with clustered standard errors at the loan level in parentheses. Dependent variable is one year ahead default. Apart from the continuous interest rates variables, the following control variables are included in the regressions: country-level unemployment rate and real disposable income growth, and loan-level combined income at loan origination (deviation from time and country-specific median), remaining loan maturity, age of the borrower, LTV and LTI at origination, a dummy capturing the occupational status, and a dummy capturing the loan repayment type. All regressions include a constant.

Table C11: Robustness checks Model specification: Bank Fixed Effects

	(1)	(2)	(3)	(4)	(5)	(6)
Origination interest rate	0.879***	1.443***				
	(0.026)	(0.013)				
Cont. interest rate	1.641***					
	(0.048)					
Change in interest rate		1.005***				
		(0.000)				
Origination interest rate buckets						
<=1.14 (ref)			1.000	1.000	1.000	1.000
			(.)	(.)	(.)	(.)
(1.14,1.67]			1.584***	1.917***	1.588***	2.033***
			(0.045)	(0.050)	(0.071)	(0.079)
>1.67			1.836***	3.053***	2.472***	3.351***
			(0.067)	(0.084)	(0.389)	(0.131)
Cont. interest rate buckets						
<=0.85 (ref)			1.000		1.000	
			(.)		(.)	
(0.85,1.42]			1.325***		1.308***	
			(0.039)		(0.052)	
>1.42			2.018***		7.006***	
			(0.074)		(1.317)	
Change in interest rate buckets						
<=-70				0.762***		0.555***
				(0.026)		(0.074)
$(-70, -5]$				0.830***		0.915*
				(0.013)		(0.036)
$(-5, 5)$ (ref)				1.000		1.000
				(.)		(.)
$[5, 70)$				1.315***		1.609***
				(0.046)		(0.173)
>=70				4.156***		6.389***
				(0.683)		(1.370)
Interactions						
Origination × cont. interest rate						
<=1.14 × <=0.85					1.000	
					(.)	
<=1.14 × (0.85,1.42]					1.000	
					(.)	
<=1.14 × >1.42					1.000	
					(.)	
(1.14,1.67] × <=0.85					1.000	
					(.)	
(1.14,1.67] × (0.85,1.42]					1.019	
					(0.053)	
(1.14,1.67] × >1.42					0.280***	
					(0.054)	
>1.67 × <=0.85					1.000	
					(.)	
>1.67 × (0.85,1.42]					0.732	
					(0.120)	
>1.67 × >1.42					0.215***	
					(0.052)	
Origination × change in interest rate						
<=1.14 × <=-70						1.000
						(.)
<=1.14 × $(-70, -5]$						1.000

Table C11: Robustness checks Model specification: Bank Fixed Effects

	(1)	(2)	(3)	(4)	(5)	(6)
						(.)
<=1.14 × $(-5, 5)$						1.000
						(.)
<=1.14 × $[5, 70)$						1.000
						(.)
<=1.14 × >=70						1.000
						(.)
(1.14,1.67] × <=-70						1.247
						(0.186)
(1.14,1.67] × $(-70, -5]$						0.917*
						(0.041)
(1.14,1.67] × $(-5, 5)$						1.000
						(.)
(1.14,1.67] × $[5, 70)$						0.869
						(0.115)
(1.14,1.67] × >=70						0.796
						(0.299)
>1.67 × <=-70						1.400*
						(0.190)
>1.67 × $(-70, -5]$						0.870**
						(0.038)
>1.67 × $(-5, 5)$						1.000
						(.)
>1.67 × $[5, 70)$						0.773*
						(0.089)
>1.67 × >=70						0.222**
						(0.106)
Country FE	X	X	X	X	X	X
Year origination FE	X	X	X	X	X	X
Bank FE	X	X	X	X	X	X
Pseudo R-sqr	0.065	0.065	0.069	0.068	0.069	0.068
N	9526138	9526138	9526138	9526138	9526138	9526138
AUROC	0.736	0.736	0.742	0.740	0.742	0.741

Signif. Codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Notes: Table reports odds ratios, with clustered standard errors at the loan level in parentheses. Dependent variable is one year ahead default. Apart from the continuous interest rates variables, the following control variables are included in the regressions: country-level unemployment rate and real disposable income growth, and loan-level combined income at loan origination (deviation from time and country-specific median), remaining loan maturity, age of the borrower, LTV and LTI at origination, a dummy capturing the occupational status, and a dummy capturing the loan repayment type. All regressions include a constant.

Table C12: Robustness checks Model specification: Alternative clustering of standard errors

	(1)	(2)	(3)	(4)	(5)	(6)
Origination interest rate	0.975	1.459***				
	(0.076)	(0.083)				

Table C12: Robustness checks Model specification: Alternative clustering of standard errors

	(1)	(2)	(3)	(4)	(5)	(6)
Cont. interest rate	1.496***					
	(0.136)					
Change in interest rate		1.004***				
		(0.001)				
Origination interest rate buckets						
<=1.14 (ref)			1.000	1.000	1.000	1.000
			(.)	(.)	(.)	(.)
(1.14,1.67]			1.802***	2.160***	1.763***	2.357***
			(0.148)	(0.202)	(0.159)	(0.261)
>1.67			2.124***	3.457***	2.750***	3.921***
			(0.228)	(0.476)	(0.368)	(0.618)
Cont. interest rate buckets						
<=0.85 (ref)			1.000		1.000	
			(.)		(.)	
(0.85,1.42]			1.749***		1.911***	
			(0.152)		(0.227)	
>1.42			1.907***		8.157***	
			(0.154)		(1.297)	
Change in interest rate buckets						
<=-70				0.827*		0.654*
				(0.069)		(0.108)
$(-70, -5]$				0.867**		1.006
				(0.038)		(0.067)
$(-5, 5)$ (ref)				1.000		1.000
				(.)		(.)
$[5, 70)$				1.194**		1.372
				(0.081)		(0.234)
>=70				4.750***		8.816***
				(0.827)		(1.574)
Interactions						
Origination × cont. interest rate						
<=1.14 × <=0.85					1.000	
					(.)	
<=1.14 × (0.85,1.42]					1.000	
					(.)	
<=1.14 × >1.42					1.000	
					(.)	
(1.14,1.67] × <=0.85					1.000	
					(.)	
(1.14,1.67] × (0.85,1.42]					1.059	
					(0.122)	
(1.14,1.67] × >1.42					0.234***	
					(0.049)	
>1.67 × <=0.85					1.000	
					(.)	
>1.67 × (0.85,1.42]					0.798	
					(0.161)	
>1.67 × >1.42					0.179***	
					(0.043)	
Origination × change in interest rate						
<=1.14 × <=-70						1.000
						(.)
<=1.14 × $(-70, -5]$						1.000
						(.)
<=1.14 × $(-5, 5)$						1.000

Table C12: Robustness checks Model specification: Alternative clustering of standard errors

	(1)	(2)	(3)	(4)	(5)	(6)
						(.)
<=1.14 $\times$ $[5, 70)$						1.000
						(.)
<=1.14 $\times$ >=70						1.000
						(.)
(1.14,1.67] $\times$ <=-70						1.189
						(0.168)
(1.14,1.67] $\times$ $(-70, -5]$						0.869
						(0.063)
(1.14,1.67] $\times$ $(-5, 5)$						1.000
						(.)
(1.14,1.67] $\times$ $[5, 70)$						1.058
						(0.200)
(1.14,1.67] $\times$ >=70						0.595
						(0.209)
>1.67 $\times$ <=-70						1.272
						(0.246)
>1.67 $\times$ $(-70, -5]$						0.823**
						(0.058)
>1.67 $\times$ $(-5, 5)$						1.000
						(.)
>1.67 $\times$ $[5, 70)$						0.809
						(0.130)
>1.67 $\times$ >=70						0.165***
						(0.067)
Controls	X	X	X	X	X	X
Country FE	X	X	X	X	X	X
Year origination FE	X	X	X	X	X	X
Pseudo R-sqr	0.056	0.056	0.061	0.061	0.061	0.061
N	9531845	9531845	9531845	9531845	9531845	9531845
AUROC	0.719	0.719	0.728	0.727	0.728	0.727

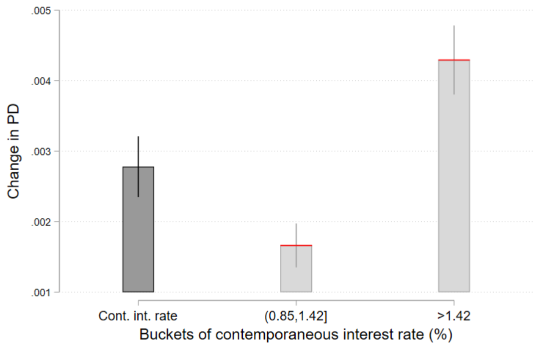
Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

*Notes:*Odds ratios. Clustered standard errors at the country- year origination level in parentheses. Dependent variable is one year ahead default. Cont. interest rate is the contemporaneous interest rate (bucket). Controls as mentioned in the main text: Unemployment rate, real disposable income growth, personal income, remaining maturity, age of borrower, LTI & LTV at origination, occupation of borrower and repayment schedule. All regressions include a constant.

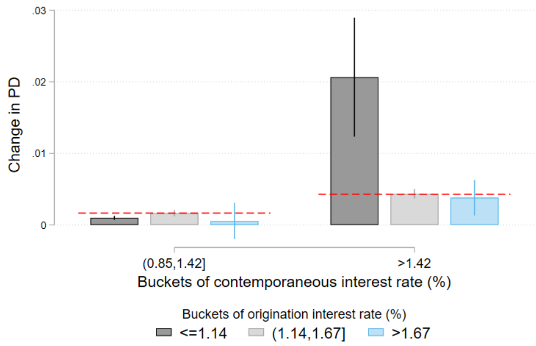
Figures (C6) to (C8) provide the marginal effects based on the regression involving different sets of fixed effects.

Figure C6: Results based on Quarter - Country FE, Table (C9)

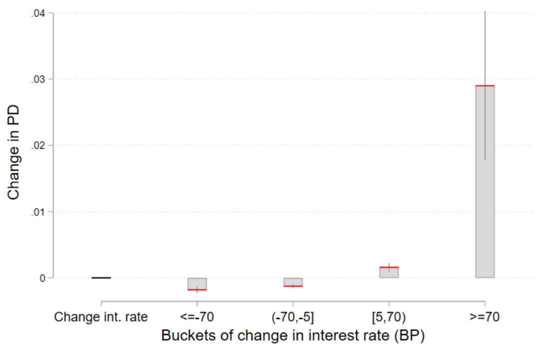
(a) Marginal effects of contemporaneous interest rate across its distribution



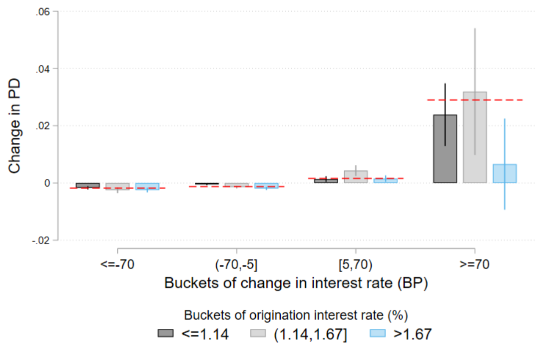
(b) Marginal effects of contemporaneous interest rate by origination interest rate



(c) Marginal effects of change in interest rate across its distribution



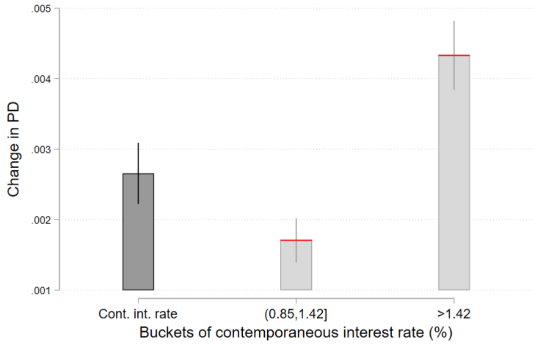
(d) Marginal effects of change in interest rate by origination interest rate



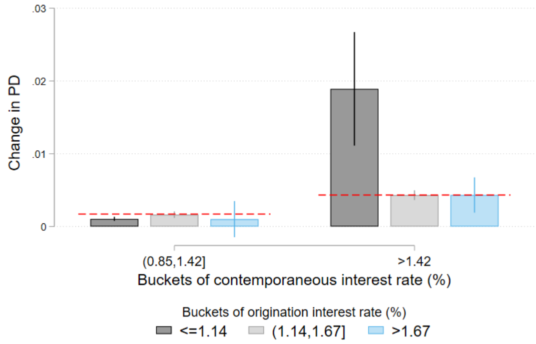
Notes: See notes on Figure (7) and (8) in the main text. This specification removes country level macroeconomic variables and instead includes a set of quarter and country fixed effects.

Figure C7: Results based on Quarter - Country FE and Year origination - Country FE, Table (C10)

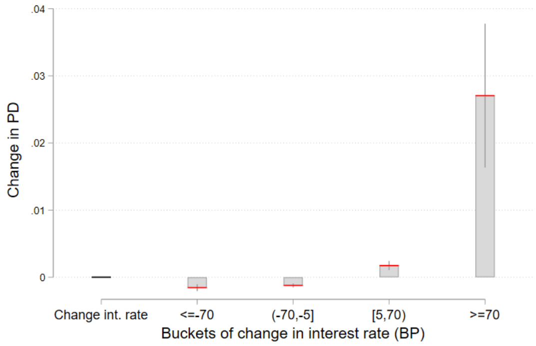
(a) Marginal effects of contemporaneous interest rate across its distribution



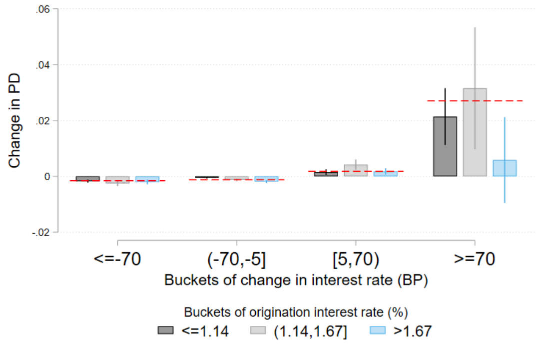
(b) Marginal effects of contemporaneous interest rate by origination interest rate



(c) Marginal effects of change in interest rate across its distribution



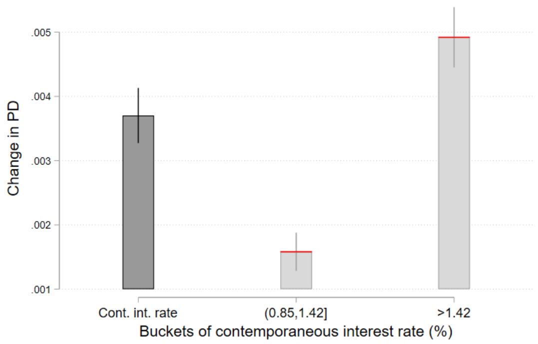
(d) Marginal effects of change in interest rate by origination interest rate



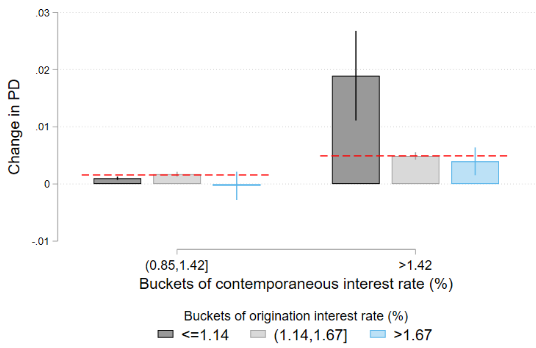
Notes: See notes on Figure (7) and (8) in the main text. This specification removes country level macroeconomic variables and instead includes a set of quarter and country fixed effects and a set of year origination and country fixed effects.

Figure C8: Results based on Bank FE, Table (C11)

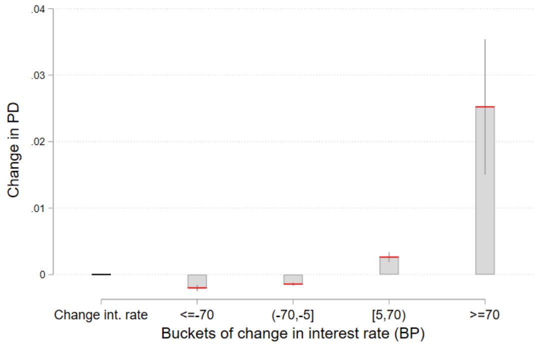
(a) Marginal effects of contemporaneous interest rate across its distribution



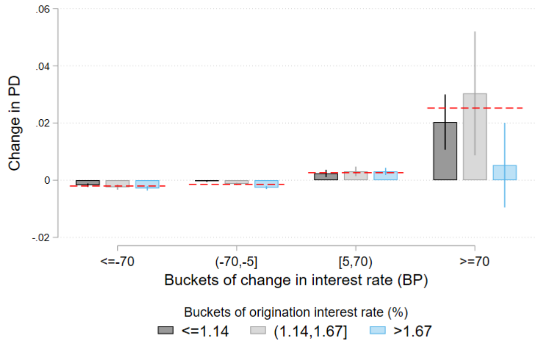
(b) Marginal effects of contemporaneous interest rate by origination interest rate



(c) Marginal effects of change in interest rate across its distribution



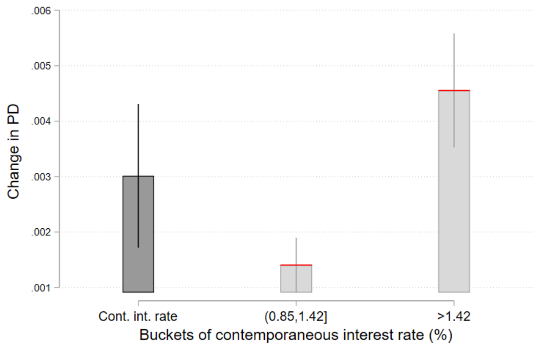
(d) Marginal effects of change in interest rate by origination interest rate



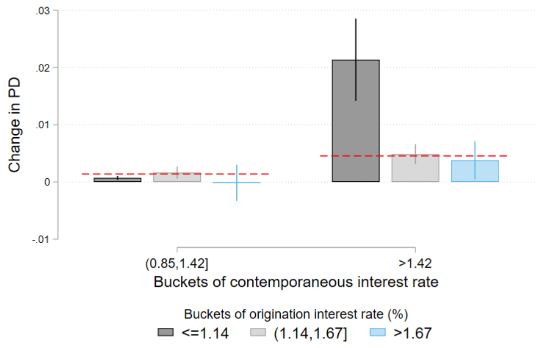
Notes: See notes on Figure (7) and (8) in the main text. Additionally, this specification includes bank fixed effects.

Figure C9: Results based on standard errors clustered by year origination and country, Table (C12)

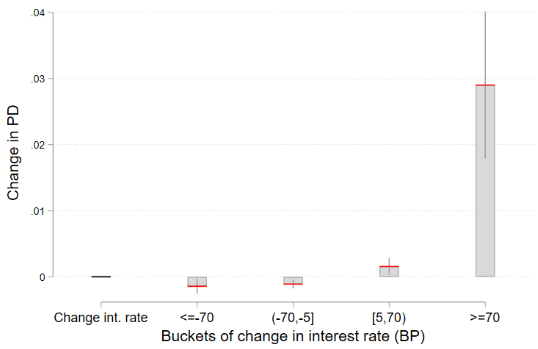
(a) Marginal effects of contemporaneous interest rate across its distribution



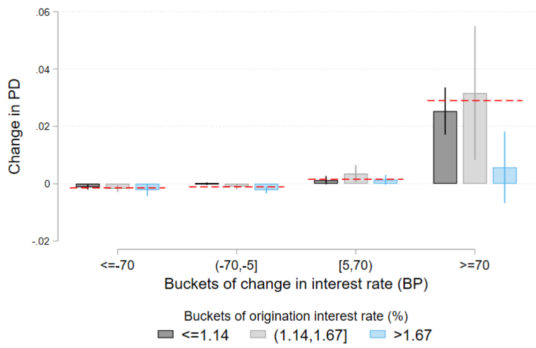
(b) Marginal effects of contemporaneous interest rate by origination interest rate



(c) Marginal effects of change in interest rate across its distribution



(d) Marginal effects of change in interest rate by origination interest rate



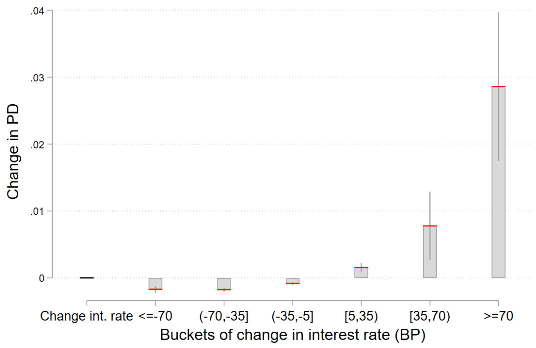
Notes: See notes on Figure (7) and (8) in the main text but standard errors clustered at the year of loan origination-country level.

C.2.3. Alternative definition of a change in interest rate

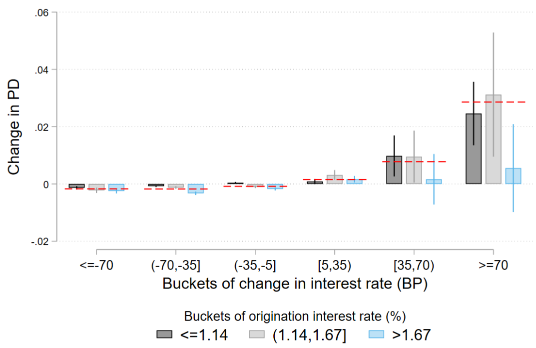
We complement our results on the effect of interest rate changes by providing additional results capturing more granular interest rate changes. This addresses the concern that the small effects we observe on small interest rate changes of below 70 basis points may in fact be driven by those experiencing almost no changes. Qualitatively, the results remain unchanged compared to those in the main text. The effect of an increase on default probabilities is considerably stronger than the effect of an interest rate decrease of similar magnitude. This effect is particularly pronounced for low origination interest rate loans. The effect of medium interest rate increases on default probabilities is still less than half of the size of the effect of sizeable interest rate increases. Decreases in the interest rate, if at all, benefit high origination interest rate loans. The full regression results for this specification are available in column (7) of table (C6).

Figure C10: Results based on alternative interest rate change

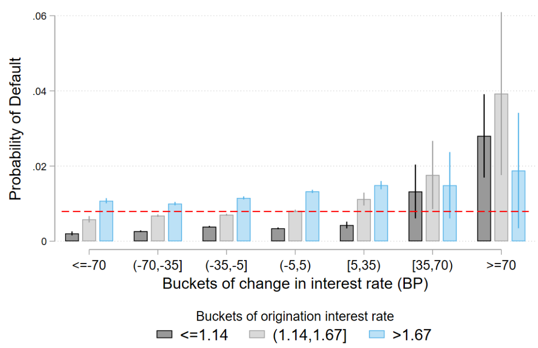
(a) Marginal effects of change in interest rate



(b) Marginal effects of change in interest rate by origination interest rates



(c) Predicted default probabilities by interest rate changes and origination interest rates



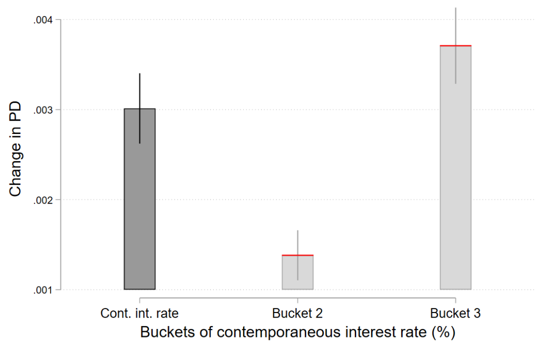
Notes: See notes on Figure (8) in the main text.

C.2.4. Results by country-specific thresholds

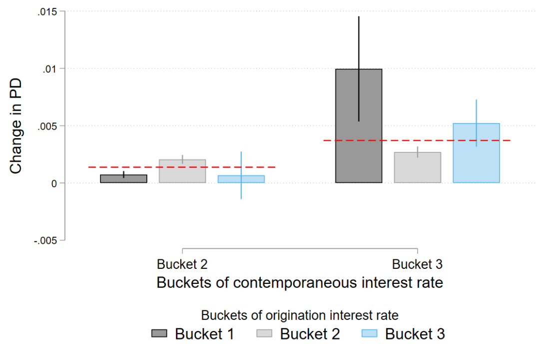
We repeat the analysis from the main text including categorical interest rate variables for contemporaneous and origination interest rate exposure that are based on country-specific thresholds to group loans into three buckets along the interest rate distribution. The key takeaways from section (5) remain unaffected.

Figure C11: Results using country-specific thresholds for interest rate buckets

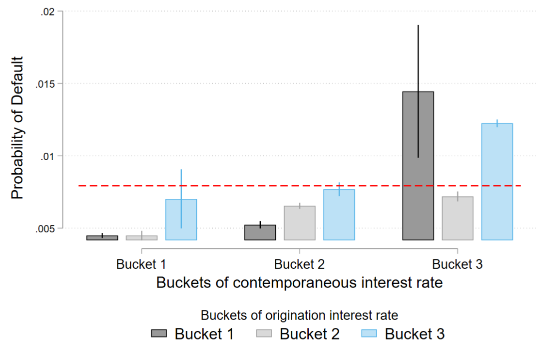
(a) Marginal effects of contemporaneous interest rate across its distribution



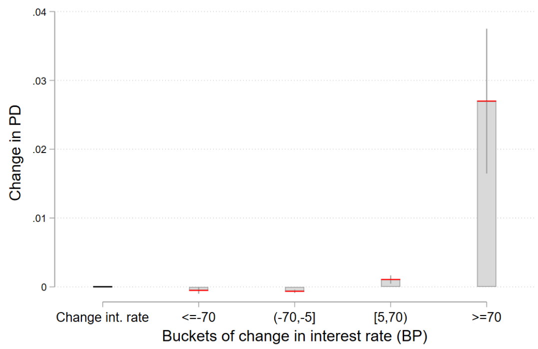
(b) Marginal effects of contemporaneous interest rate by origination interest rates



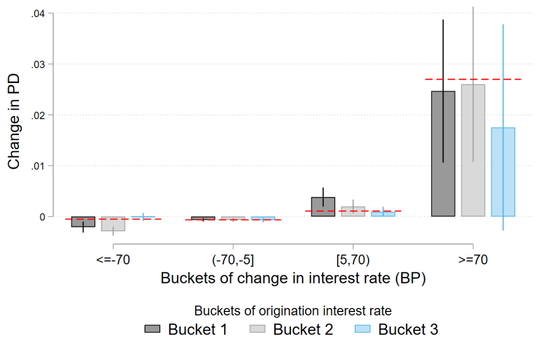
(c) Predicted default probabilities by contemporaneous and origination interest rates



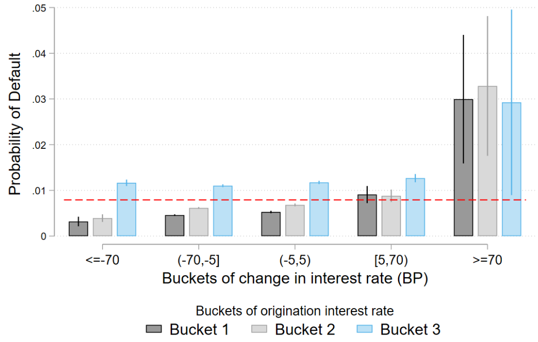
(d) Marginal effects of interest rate change across its distribution



(e) Marginal effects of interest rate change by origination interest rates



(f) Predicted default probabilities by interest rate change and origination interest rates



Notes: See notes on Figure (7) and (8) in the main text. Cutoffs are country-specific and listed in Table (B2).

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Emil Bandoni
Central Bank of Ireland, Dublin, Ireland; University College Dublin, Dublin, Ireland; email: emil.bandoni@centralbank.ie

Friederike Fourné
ifo Institute Munich, Munich, Germany; email: fourne@ifo.de

Barbara Jarmulska
European Central Bank, Frankfurt am Main, Germany; email: Barbara.Jarmulska@ecb.europa.eu

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

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