Who bears interest rate risk?*

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Abstract

We study the allocation of interest rate risk within the European banking sector using novel data. Banks' exposure to interest rate risk is small on aggregate, but heterogeneous in the cross-section. In contrast to conventional wisdom, net worth is increasing in interest rates for approximately half of the institutions in our sample. Cross-sectional variation in banks' exposures is driven by cross-country differences in loan-rate fixation conventions for mortgages. Banks use derivatives to share interest rate risk and partially hedge on-balance sheet exposures. Residual exposures imply that changes in interest rates have redistributive effects *within* the banking sector.

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1 Introduction

Who bears interest rate risk? Answering this question is important for at least two reasons. First, the allocation of interest rate risk affects the transmission of monetary policy. If interest rate risk is borne by banks, changes in interest rates affect bank net worth and ultimately the supply of loans via the bank balance sheet channel (Bernanke and Gertler, 1995; Jiménez et al., 2012). In contrast, if interest rate risk is primarily borne by households and firms, monetary policy transmits via borrowers' balance sheets, with consequences for consumption and investment (Auclert, 2017; Di Maggio et al., 2017; Ippolito et al., 2018). Second, the allocation of interest rate risk is important for financial stability. Concentrated exposures in the banking sector can give rise to simultaneous bank failures following sharp movements in interest rates. A well-known example is the S&L crisis (White, 1991).

There are two opposing views of banks' exposure to interest rate risk. Under the "traditional view", banks fund long-term loans with short-dated deposits. This maturity transformation exposes banks to interest rate risk. In contrast, the "matching view" argues that banks avoid interest rate risk by matching the interest rate risk exposure of their assets with that of their liabilities. In Hellwig (1994), banks are perfectly matched because they extend variable-rate loans financed by variable-rate deposits. Drechsler et al. (2018) argue that sight deposits effectively behave as term liabilities because banks are able to exert market power. They thus optimally invest into long-term assets. While this gives rise to maturity transformation from a contractual perspective, it does not expose banks to interest rate risk.

In this paper, we study the allocation of interest rate risk for a sample of 104 banks from 18 euro area countries, which together account for 80% of the currency union's total banking assets. Our empirical analysis relies on two novel supervisory datasets, which allow us to measure exposures with high accuracy, thus overcoming data limitations usually associated with the measurement of interest rate risk. The first dataset contains detailed balance sheet information on the re-pricing maturity of banks' assets and liabilities. The second provides transaction-level information on banks' positions in the interest rate derivatives market. We obtain qualitatively similar results using three different measures of interest rate risk.

We make three contributions to the literature. First, we document that banks' exposure to interest rate risk is small on aggregate, but heterogeneous in the cross-section. Approximately half of our sample banks benefit from an increase in interest rates, both in terms of higher net worth and income. This finding is at odds with the traditional view of maturity mismatching, according to which banks suffer from higher interest rates, either because the present value of their assets decreases more than the present value of their liabilities, or because the interest expense paid on their liabilities increases faster than the interest income earned from their assets.

Second, we study the determinants of banks' exposure to interest rate risk. We show that variation in exposures is greater across countries than across business models. We then assess the role of cross-country variation in mortgage markets, which we separate into countries in which fixed-rate contracts predominate and those in which variable-rate contracts are more common. A number of arguments suggest that these conventions are exogenous from banks' perspective. The difference in banks' exposures across the two country groups accounts for approximately one standard deviation of the cross-sectional distribution. Consistent with mortgage markets being the relevant channel, we find that variation is driven by banks with a larger share of retail loans, which are predominantly mortgages. In further tests, we show that the systematic cross-country heterogeneity in exposures on the asset side is due to loans, not securities, and is robust to controlling for heterogeneity on the liability side.

Third, we analyze hedging through interest rate swaps. We show that banks use derivatives to reduce the exposures to interest rate risk arising from granting loans and taking deposits. However, hedging eliminates only around 25% of on-balance sheet exposures, so that banks remain exposed to interest rate risk after hedging. When analyzing hedging activity in the cross-section, we find that banks hedge more if the magnitude of interest rate risk from their on-balance sheet positions is larger. We also document that banks engage in more hedging if their exposure is different from that of other banks in the same country, consistent with search frictions in over-the-counter markets. Finally, we show that banks with on-balance sheet exposures of opposite signs engage in mutually beneficial trades, but only 20% of the overall risk-sharing potential is realized on aggregate.

Our results have important policy implications. Recent models highlight the redistributive effects of monetary policy between banks and the non-financial sector (Diamond and Rajan, 2012; Farhi and Tirole, 2012; Brunnermeier and Sannikov, 2016). However, our results show that the effects of a "stealth recapitalization" of the banking sector may be quantitatively less important than previously thought. We estimate that our sample banks would lose €4.6 billion on aggregate following a 25 basis point increase in interest rates. At the same time, our findings imply quantitatively important transfers *within* the banking sector. We estimate these to be 40% larger, at €6.6 billion following a 25 basis point increase in interest rates.

In an additional exercise, we show that the observed cross-country heterogeneity in the banking sector is also reflected in households' interest rate risk exposures. Households in countries with predominantly variable-rate mortgages suffer (benefit) from higher (lower) interest rates as their portfolios are composed of sticky deposits on the asset side and variable-rate loans on the liability side. In contrast, households in other countries are relatively unexposed to interest rate risk on aggregate. The fact that household exposures mirror banks' exposures suggests that interest rate risk is structurally borne by different sectors in different euro area countries. This implies that the transmission of monetary policy is subject to considerable heterogeneity. In a currency union, policymakers should carefully study the distribution of interest rate risk to guide their monetary policy decisions.

Related literature and contribution

We primarily contribute to the literature on interest rate risk in banking. Existing work has faced significant data limitations: measuring the effective maturities of assets and liabilities, as well as exposures from derivatives, is often impossible from public data. To overcome these limitations, several papers use market data to document negative stock price reactions to surprise increases in interest rates (Flannery and James, 1984a; English et al., 2018; Ampudia and Van Den Heuvel, 2017). This result is consistent with the traditional view of banks as maturity transformers. Begenau et al. (2015) document significant exposures of U.S. banks to interest rates using a factor model estimated from public balance sheet data. Using data on short-term assets and liabilities, Gomez et al. (2016) show that banks' exposures to interest rate risk affect the transmission of monetary policy.

Hellwig (1994) questions the view that banks necessarily bear interest rate risk. In a Diamond-Dybvig model with aggregate risk, he shows that the optimal contract is such that banks are fully insulated from changes in interest rates. They take variable-rate deposits and make variable-rate loans. More recently, Drechsler et al. (2018) show that frictions in the deposit market enable banks to engage in maturity transformation without being exposed to interest rate risk. Banks' market power results in limited pass-through of market rates to deposit rates, so that deposits effectively behave like long-term fixed-rate liabilities. Consequently, holding long-term fixed-rate assets is a way for banks to hedge, not to take risk. Consistent with this view, the net interest margins of U.S. banks have been stable over time, despite significant swings in interest rates. This matching view is supported by Kirti (2017), who shows that banks with more floating-rate liabilities tend to extend more floating-rate loans. Di Tella and Kurlat (2017) also argue that maturity mismatching is akin to a hedging strategy, albeit in a different way. In their model, banks are willing to take one-off losses from interest rate changes because future earnings will be higher in a high-interest rate environment.

Our work is also related to several papers that study interest rate risk management through derivatives. Purnanandam (2007) shows that banks use derivatives to shield their lending decisions from monetary policy surprises. Rampini and Viswanathan (2013, 2010) show that financial constraints can impede hedging, and Rampini et al. (2017) provide evidence supporting this theory. Begenau et al. (2015) document that most U.S. banks do not use interest rate derivatives, and the ones that do take on additional risk.

While our paper is closest to Drechsler et al. (2018), there are a number of significant differences. First, our data allow us to compute several measures of interest rate risk, including a measure of net worth sensitivity based on present values. Second, we analyze the role of frictions on the asset side of banks' balance sheets, and show that they can prevent perfect maturity-matching. Third, we exploit cross-country variation by drawing on a sample from 18 different countries. The observed structural differences lead to important policy implications in the context of a currency union. Fourth, we are able to gauge the role of interest rate derivatives with high precision, and thus contribute to the literature on risk management. Fifth, we additionally provide limited evidence on households' exposures.

2 Data and descriptive statistics

We begin by describing our data. Our first supervisory dataset covers on-balance sheet exposures of all banks directly supervised by the European Central Bank (ECB).[1] This dataset provides a detailed breakdown of each banking book item into 14 maturity buckets (see Appendix A.1).[2] Importantly, these buckets refer to the re-pricing maturity (which is different from the contractual maturity for variable-rate instruments), enabling us to assess their interest rate sensitivity with high accuracy. We restrict attention to assets and liabilities denominated in euro, which comprise the vast majority of balance sheet items. Given the novelty of these data, we work with only one cross-section of banks as of 31 December 2015.

Our second dataset contains transaction-level data on interest rate derivatives. These data are obtained from two trade repositories, DTCC-DDRL and Regis-TR, which collect and maintain records of transactions conducted in derivatives markets (see Appendix A.2). Together, these two repositories cover virtually all trades in interest rate derivatives by European financial institutions. We restrict attention to interest rate swaps (IRS), which constitute the vast majority of interest rate derivatives and whose interest rate sensitivity can be computed from the data.[3] We further limit the sample to contracts referenced to Eonia and Euribor, which are the two most common benchmarks used for euro-denominated interest rate swaps. For each trade, we observe the identity of both counterparties, the residual maturity, the underlying benchmark rate (e.g. 6-month Euribor), and the fixed rate agreed upon at trade execution. After merging the two datasets, our sample covers 104 of the 129 banks directly supervised by the ECB at the end of 2015. These institutions represent 97% of the total assets of all banks under direct supervision

[1]The ECB directly supervises banks under the umbrella of the Single Supervisory Mechanism (SSM), which refers to the system of banking supervision in Europe that comprises the ECB as well as the national supervisory authorities of participating countries. As of 2015, it directly supervised 129 banks, representing 82% of all banking assets in the euro area. Among other criteria, at least the three largest banks in each country are directly supervised by the ECB. The set of banks under direct supervision changes over time.

[2]An asset enters a bank's *banking book* if it is expected to be held until maturity. In contrast, it enters the *trading book* if it is expected to be re-sold in the short term. The banking book dominates the balance sheet of most banks. This is also the case for our sample banks, where close to 90% of loans and securities holdings reside in the banking book. Our results are robust to the inclusion of trading book exposures for the subset of banks for which data are available (see the Online Appendix).

[3]Globally, interest rate swaps accounted for 71.9% of the notional amount and 88.5% of the gross market value of euro-denominated interest rate derivatives as of end-2015 (BIS, 2016).

of the ECB, and 80% of the total assets of all euro area banks.

We complement these two datasets with information from additional sources. We obtain yearly information on banks' interest income and expenses since the inception of the euro in 1999 from Orbis (formerly Bankscope). Finally, we obtain additional supervisory information from the ECB, including some information on the composition of loans and a classification of banks' business models into nine different categories.[4]

Table 1 contains summary statistics on our sample banks, with a breakdown of assets and liabilities into key categories. The average bank has total assets of €204bn. The median is €71bn, reflecting a highly skewed distribution. Loans and debt securities held represent on average 65% and 18% of total assets, respectively. Loans to households and non-financial firms account for the bulk of loans, with each representing around one quarter of total assets. Among liabilities, deposits account for 66%, while 18% are debt securities issued. Unlike bank size, the composition of assets and liabilities varies relatively little across banks. The average ratio of common equity to total assets is 7.8%.

Table 2 provides an overview of the derivative portfolios of our sample banks. As of 31 December 2015, our 104 sample banks were engaged in a total of 594,776 interest rate swap contracts, representing a gross notional value of €32.4tn. This amounts to over 40% of the global market for euro-denominated IRS, which was about US$84tn at the end of 2015 (BIS, 2016).[5] The average (median) bank holds a portfolio of 5,719 (1,502) interest rate swaps, involving 804 (80) counterparties and with a notional value of €311bn (€33bn). Most contracts are referenced to 3-month and 6-month Euribor. The portfolio of the average bank has a residual maturity of 9.8 years, with a mark-to-market value close to zero.

3 Measuring interest rate risk

In this section, we discuss the measurement of interest rate risk. We use a simple framework to present three different measures of interest rate risk. We then discuss the treatment of sight deposits and additional implementation details.

[4]This classification is based on a combination of cluster analysis and expert judgment. See Lucas et al. (2017) for a similar approach.

[5]The estimate of 40% represents a lower bound because the BIS double-counts centrally cleared exposures. However, most contracts in our sample are not centrally cleared.

3.1 A simple framework and three measures of interest rate risk

Consider the snapshot of a bank's balance sheet at time t with assets $\{A_{t+s}\}_{s=0}^{\infty}$ and liabilities $\{L_{t+s}\}_{s=0}^{\infty}$, where s denotes the re-pricing maturity in years and all quantities are expressed relative to total assets. Let Gap_{t+s} denote the difference between assets and liabilities with maturity s, that is,

$$Gap_{t+s} = A_{t+s} - L_{t+s}. \tag{3.1}$$

A widely used measure of interest rate risk is the projected change in net interest margin, which we denote by ΔNIM.[6] This measure is an *income sensitivity*, as it quantifies by how much a banks' income would change (relative to total assets) in the short run following a hypothetical change interest rates. It is frequently computed on the basis of the *income gap*, which refers to the difference between assets and liabilities with a re-pricing maturity of less than one year, Gap_{t+1}. We thus define

$$\Delta NIM = Gap_{t+1} \times \Delta r, \tag{3.2}$$

where Δr denotes an assumed change in interest rates. Intuitively, a positive (negative) income gap means that a bank has more (less) interest rate sensitive assets than liabilities, so that higher interest rates will lead to an increase (decrease) in interest income.

Alternatively, interest rate risk can be measured by examining the effects of changes in interest rates on banks' net worth, defined as the present value of assets minus liabilities.[7] In our notation, this is given by

$$PV = \sum_{s=0}^{\infty} \frac{Gap_{t+s}}{(1+r_s)^s}. \tag{3.3}$$

Accordingly, a measure of *net worth sensitivity* is the change in present value ΔPV in response to a perturbation Δr in interest rates (for ease of notation here assumed to be

[6] Variants of this measure are used, among others, in Flannery and James (1984b), Purnanandam (2007), and Gomez et al. (2016).

[7] Note that this definition does not include the value of growth opportunities (i.e., future assets and liabilities).

constant across maturities), which can be computed as

$$\Delta PV = \sum_{s=0}^{\infty} \frac{Gap_{t+s}}{(1 + r_s + \Delta r)^s} - \sum_{s=0}^{\infty} \frac{Gap_{t+s}}{(1 + r_s)^s}. \tag{3.4}$$

There is a direct relation between ΔPV and ΔNIM as both measures depend on the gap between assets and liabilities. Consequently, they tend to be highly correlated in practice. To see this, consider a stylized bank with a traditional maturity mismatch that holds long-term assets (with a maturity of more than 1 year) financed by short-term liabilities (with a maturity of one year or less). The income gap is negative, such that this bank will exhibit $\Delta NIM < 0$ for an increase in interest rates (the rates paid on liabilities adjust more quickly than the income from assets). Similarly, the maturity mismatch implies that $\Delta PV < 0$, as the present value of assets declines by more than the present value of liabilities in response to higher interest rates.

However, the two measures have a different focus. ΔNIM is concerned with the short-run change in income, which is only determined by the part of the balance sheet that will re-price within one year. In contrast, ΔPV measures the effect on net worth, which takes into account the entire maturity spectrum. Theoretically, present value measures are economically the most relevant in many contexts, including models of investment and asset pricing. For these reasons, ΔPV is our preferred measure of interest rate risk.

An alternative income-based measure of interest rate risk is based on recent work by Drechsler et al. (2018). They examine the pass-through of short-term interest rates to interest income and expenses. This suggests that banks' exposure to interest rate risk can be gauged by estimating the following time-series regression

$$\Delta NIM_t = \alpha + \sum_{s=0}^{S} \beta_s^{NIM} \cdot \Delta r_{t-s} + \epsilon_t. \tag{3.5}$$

The estimate of $\beta^{NIM} \equiv \sum_{s=0}^{S} \beta_s^{NIM}$ is the average sensitivity of interest income to changes in interest rates over time. Naturally, this measure is closely related to ΔNIM, as can be seen by comparing equations (3.2) and (3.5). Indeed, if β^{NIM} were to vary over time, it would be equal to the value of the income gap of the respective year (provided that $\alpha = 0$). Since β^{NIM} is estimated over multiple years, it accounts for a larger part of the maturity spectrum (as does ΔPV).

Notice that all three measures of interest rate risk can be decomposed. For example, we can re-write the net worth sensitivity as $\Delta PV = \Delta PV^{BS} + \Delta PV^{IRS}$, where ΔPV^{BS} and ΔPV^{IRS} denote the respective contributions of on-balance sheet items and interest rate swaps, respectively. Moreover, on-balance sheet exposures can be further decomposed into contributions from the asset and liability sides, that is $\Delta PV^{BS} = \Delta PV^{BS}_{Assets} - \Delta PV^{BS}_{Liabilities}$. The same applies to the income sensitivity ΔNIM. Similarly, following Drechsler et al. (2018), one can compute different betas for income (β^{Inc}) and expenses (β^{Exp}) by replacing the left hand side in equation (3.5) with interest income and expenses over total assets, respectively. Save for estimation error, we then have $\beta^{NIM} = \beta^{Inc} - \beta^{Exp}$.

3.2 The calibration of sight deposits

Banks' exposure to interest rate risk crucially depends on customers' behaviour. This is particularly relevant for their liabilities, which are often dominated by deposits (see Table 1). It is well-known that banks exert market power in retail deposit markets, which gives rise to limited pass-through of market rates to deposit rates (Hannan and Berger, 1991; Neumark and Sharpe, 1992; Driscoll and Judson, 2013; Drechsler et al., 2017). Accordingly, sight deposits tend to behave as term liabilities despite their overnight contractual maturity. To model the behaviour of sight deposits, banks construct replicating portfolios of fixed-income assets that mimic the interest rate sensitivity of their deposits (see, e.g., Kalkbrenner and Willing, 2004). Such models are widespread in the industry and subject to regulatory guidelines (Basel Committee on Banking Supervision, 2016b).

We calibrate the behaviour of sight deposits by drawing on supervisory data from the ECB. For each institution, these data provide an estimated duration for retail and corporate sight deposits based on banks' internal models. We assume that other sight deposits (from banks and non-bank financials) behave according to their contractual features and thus assign a duration of zero. Table 3 presents an overview of the cross-sectional distributions for different sight deposits. On average, retail sight deposits have an estimated duration of 2 years, compared to around 1 year for deposits by non-financial firms. We also observe significant variation across banks. For example, the bank at the 25th percentile has a retail sight deposit duration of 0.15 years, compared to 3.13 years for the bank at the 75th percentile. Overall, these results suggest that banks have significant market power in deposit markets (especially towards retail depositors), and that market power varies across institutions. Our numbers are also consistent with the results of a recent survey among global banks (Basel Committee on Banking Supervision, 2016a). In the Online Appendix, we show that banks' reported durations are correlated with pass-through rates in deposit markets for a subset of our sample banks. This confirms that these data capture cross-sectional variation in banks' market power on the liability side.

Other balance sheet items also require modelling, e.g. items with optionalities such as residential mortgages and other consumer loans that can be subject to pre-payments. When a loan is pre-paid, its actual maturity turns out to be shorter than its contractual maturity. However, there is no bank-level data available on the extent of such optionalities. We thus assume a constant annual pre-payment rate of 5% for retail loans across all banks, which is consistent with the aggregate estimates from a recent stress test exercise.[8]

Table 4 provides an overview of the re-pricing maturities of key items in the banking book. The bottom two rows illustrate how our modelling assumptions affect banks' maturity mismatch. While the average contractual maturity gap is close to one year, the modelled maturity gap is only around two and a half months (0.21 years) on average. In particular, we see that the first quartile is negative at -0.38 years.

3.3 Further Implementation details

For computing the present values of on-balance sheet items, we use the official euro area yield curve (computed by the ECB from AAA-rated government bond yields), and assign all items to the mid-point of the respective maturity bucket. For example, we assume a residual maturity of 1.5 years for instruments in the 1-2 year maturity bucket. For the valuation of interest rate swaps, we use a single-curve model where both the swap payments and the discount factors are based on the relevant euro forward curves of the underlying interest rate benchmarks (e.g. 3-month Euribor), obtained from Bloomberg.[9]

[8]For detailed information on this stress test, see https://www.bankingsupervision.europa.eu/press/pr/date/2017/html/ssm.pr171009.en.html. While the results of the stress test indicate a pre-payment rate of 7% for modelled euro-denominated loans, these only concern a fraction of the retail loans in our sample. We thus conservatively assume a 5% prepayment rate for the entire retail loan portfolio of our sample banks.

[9]Because financial counterparties are required to report daily valuations for each outstanding contract, we can backtest our valuation method and find that it is highly accurate. A univariate regression of our own valuations on bank-reported valuations, aggregated at the banking group level, yields a slope estimate of 1.03 (with a robust standard error of 0.06) and an R^2 of 0.89.

For these instruments, observed maturities are exact.

In principle, the methodology underlying ΔPV can be applied to any arbitrary perturbation of the yield curve. For simplicity, we focus on a one basis point increase in all relevant interest rates, corresponding to an upward parallel shift of the risk-free yield curve and perfect pass-through to other interest rates.

For comparability, we also compute ΔNIM based on a one basis point increase in interest rates. Unlike for ΔPV, the precise allocation of sight deposits plays a role, as ΔNIM only considers items with a re-pricing maturity of less than one year. In the supervisory data, the durations of sight deposits in Table 3 are reported as the weighted sum of two portfolios: a share of core deposits with a positive duration, and the rest with a duration of zero. We thus spread core deposits across maturity buckets according to a uniform distribution, and allocate the rest to the overnight maturity bucket.

For the estimation of β^{NIM}, we use annual data on banks' net interest margin (from Orbis) since the inception of the euro in 1999. We aggregate across multiple institutions to account for mergers and require at least 10 consecutive observations, leading us to discard two banks. We estimate the model using the 3-month Euribor rate and set $S = 1$.

4 Banks' exposures to interest rate risk

In this section, we present our empirical estimates for banks' exposure to interest rate risk. We first discuss existing theoretical work and then detail our empirical findings.

4.1 Theoretical considerations

Based on economic theory, should one expect banks to be exposed to interest rate risk? The textbook view of banking (e.g., Freixas and Rochet, 2008) suggests that banks face a natural exposure to interest rate risk because they engage in maturity transformation, extending long-term loans that are financed with short-term deposits. This renders their income and their net worth vulnerable to increases in interest rates. The S&L crisis is often considered as a prime example of this mechanism (White, 1991).

However, some existing models challenge this conventional wisdom. Two types of models predict that banks match the interest rate sensitivity of their assets and liabilities, and thus bear no interest rate risk. Importantly, this prediction holds for individual banks, and not only for the aggregate banking sector. First, in Hellwig (1994), banks offer variable-rate deposits and invest in variable-rate assets. This is natural since banks are pure intermediaries and have no capital. The duration of assets and liabilities is perfectly matched, and banks have no exposure to interest rate risk.

Second, in Drechsler et al. (2018), banks have market power in the deposit market, so that deposits behave as long-term liabilities. Therefore, banks optimally invest in long-term assets, and end up with no exposure to interest rate risk. In the cross-section, banks with more market power have de facto longer-term liabilities, and optimally invest in longer-term assets. While the models by Hellwig (1994) and Drechsler et al. (2018) both predict that banks are not exposed to interest rate risk, they differ regarding the maturity of banks' assets and liabilities: both are short-term in Hellwig (1994), and long-term in Drechsler et al. (2018).

Importantly, both models assume that assets can be chosen frictionlessly. This allows banks to choose assets that perfectly match the maturity of their liabilities, which is determined by consumers' liquidity needs or banks' market power (and thus subject to some friction). However, in principle, it is possible that banks also face constraints on the asset side, which would limit perfect maturity-matching and leave banks with some exposure to interest rate risk. Depending on the nature of the friction, the sign of banks' exposure could be either positive or negative.

4.2 Cross-sectional distributions

Panel A of Table 5 provides an overview of the cross-sectional distributions of our three measures of interest rate risk, which are also depicted in Figure 1. Panel B contains the pairwise correlation coefficients and reveals that all three measures are positively correlated. The strongest correlation (0.59) is found between ΔPV and ΔNIM. Correlations with β^{NIM} are of lower magnitude (0.18 and 0.22, respectively), but also statistically significant. Panel C provides the decomposition of each measure into individual contributions of assets and liabilities as well as derivatives (for the two measures based on balance sheet data). We discuss these in more detail below.

Turning to the distributions, we observe economically small average exposures for all three measures. We formally reject the hypothesis of a zero mean only for β^{NIM}, with a t-statistic of 3.22. While the prediction of zero exposures based on Hellwig (1994) and Drechsler et al. (2018) thus appears to approximately hold on aggregate, this is not the case for all institutions individually. We observe significant cross-sectional variation, indicating that individual banks *do* bear interest rate risk. While this is especially true for ΔPV with a cross-sectional standard deviation of 0.57 bps of total assets, the other two measures also display economically meaningful variation.[10] Interestingly, the cross-sectional distribution of ΔPV reveals that around half of the sample banks have an exposure that causes their net worth to *increase* when interest rates rise. This is in sharp contrast to the traditional view of banking. It is, in fact, as if these banks were engaging in *reverse* maturity transformation.

What are the sources of cross-sectional heterogeneity? There are two natural candidates. First, the euro area is characterized by cross-country heterogeneity stemming from local differences in preferences, business cycles, and legal frameworks (despite persistent efforts towards greater harmonization). Second, banks have different business models, they are active in different markets and cater to specific customers. Both dimensions can plausibly give rise to different exposures to interest rate risk.

To examine the empirical relevance of these two possible sources of heterogeneity, we regress each measure of interest rate risk separately on a set of country dummies and on a set of dummies representing different business models. Figure 2 graphs a comparison of the R-squared across interest rate risk measures and sources of variation. In general, the country dummies explain a much larger share (between 24% to 42%) of the cross-sectional variation in exposures than the business model dummies (7% to 14%). This conclusion does not change when we compare the adjusted R-squared across models to account for the difference in the number of explanatory variables (18 countries versus nine business model categories). Given these findings, we next turn to examining the sources of the considerable cross-country variation in detail.

[10] Based on the average equity ratio of 7.8% and a standard regulatory shock of 200 bps, an exposure of 0.57 bps of total assets corresponds to around 15% of equity ($\frac{0.57\times200}{0.078}$).

4.3 The role of loan-rate fixation conventions

The observation of significant cross-county variation in banks' exposures suggests the existence of country-specific factors that prevent banks from fully insulating their balance sheet from interest rate risk. Taking the frameworks of Hellwig (1994) and Drechsler et al. (2018) as a starting point, the fact that some banks do bear interest rate risk suggests that frictions prevent them from perfectly matching the interest rate sensitivity of assets and liabilities. Given that bank liabilities are typically modelled as given (i.e. exogenous), it is natural to consider that these frictions affect the asset side. In other words, banks may not be able to frictionlessly choose the maturity of their assets.

Jordà et al. (2016) show that mortgage lending constitutes a significant share of total bank lending in advanced economies. This is also the case for the euro area, where mortgage lending accounted for about 35% of total lending at the end of 2015.[11] Consistent with this, retail loans, which are almost exclusively mortgages, account for around 40% of total loans among our sample banks (see Table 1).[12] Campbell (2012) shows that mortgage contract design differs markedly across countries, in particular with respect to re-pricing maturities. Mortgage rates tend to be fixed in some countries and variable (indexed to short-term interest rates) in other countries. This heterogeneity is also observed in the euro area. Figure 3 plots the average share of new residential mortgages with variable interest rate over the period 2011-15 for all euro area countries. Two groups are clearly distinct: five countries (Belgium, Germany, France, the Netherlands, and Slovakia) exhibit a relatively low share of variable-rate mortgages (between 7% and 21%), while the remaining countries have shares between 71% and 96%.[13]

Henceforth we refer to the phenomenon that mortgages in a particular country predominantly have a fixed or variable interest rate as *loan-rate fixation conventions*. An important question is whether these country-level conventions constitute a friction that

[11] See items A20 and A22 of the ECB's MFI Balance Sheet Statistics, available at http://sdw.ecb.europa.eu.

[12] According to the Eurosystem's latest Household Finance and Consumption survey, mortgages account for more than 85% of household debt in the euro area. See https://www.ecb.europa.eu/pub/pdf/scpsps/ecbsp18.en.pdf for details. Similarly, mortgages accounted for more than 82% of new bank loans in the period 2011-15 according to the ECB's MFI Interest Rate Statistics (Series A2B, A2BC, A2C, A2CC).

[13] While there is also some heterogeneity in the market for corporate loans, the gap between both groups is significantly smaller at around 20%. Consistent with this, we show in the Online Appendix that that there is only weak evidence that loan-rate fixation conventions in the corporate loan market affects banks' exposure to interest rate risk.

is exogenous from the perspective of individual banks. Existing empirical evidence suggests that this is indeed the case. Campbell (2012) shows that cross-country differences in loan-rate fixation conventions are explained by past macroeconomic experiences, such as inflation volatility, which are exogenous for individual banks. More recently, Albertazzi et al. (2017) show that the local subsidiaries of cross-border banks tend to make variable-rate loans in variable-rate countries and fixed-rate loans in fixed-rate countries. Given that funding conditions are usually determined at the parent level, this observation is inconsistent with banks determining loan-rate fixation conventions. Finally, the cross-country differences depicted in Figure 3 are very persistent over time.[14] We therefore consider loan-rate fixation conventions as an exogenous friction that affects the re-pricing maturity of banks' assets and thus their exposure to interest rate risk.

To test the effect of loan-rate fixation conventions on banks' exposures, we regress our three measure of interest rate risk on a dummy variable, denoted VRM, that takes a value of one for banks residing in countries where mortgages predominantly have a variable interest rate, and zero otherwise.[15] The results are tabulated in column (1) of Table 6, where the individual panels refer to the three different measures of interest rate risk. Standard errors are clustered at the country level. Panel A reveals that the estimated coefficient of VRM is equal to 0.35 for ΔPV (significant at the 5% level), consistent with loan-rate fixation conventions significantly affecting exposures. The effect is economically sizable, as the difference between the two country groups amounts to more than 60% of one standard deviation of ΔPV. Panels B and C show that similar results are obtained for the other two measures, where the economic magnitudes associated with loan-rate fixation conventions are even larger, accounting for between 70% (ΔNIM) and 107% (β^{NIM}) of one standard deviation.

If the loan-rate fixation conventions prevailing in mortgage markets are the source of heterogeneity in exposures, we should observe that the effect of VRM varies across banks depending on their activity in the residential mortgage market. We test this in column (2), where we include the share of retail loans (predominantly mortgages) to total assets as an additional explanatory variable, as well as its interaction with the VRM dummy. We

[14]The monthly standard deviations at the country level since the beginning of the data collection in 2003 range from 2% to 23%.

[15]In the Online Appendix, we show that we obtain qualitatively similar results when using the country-specific percentage of variable-rate loans instead.

also depict these results in Figure 4, where the respective exposure measure is plotted on the vertical axis, and the share of retail lending on the horizontal axis. We indicate banks from different country groups with different markers and additionally plot the regression fit for each group.

Our estimates are consistent with loan-rate fixation conventions being a key driver of cross-country heterogeneity. The coefficients of the interaction terms are positive and statistically significant at the 5% level or better for all three measures. Banks granting mortgages in countries with predominantly variable-rate contracts tend to benefit from higher interest rates, as the income on these assets reprices quickly and the present value loss from higher interest rates is less severe than for fixed-rate assets. The effect is also sizeable in terms of economic magnitude. For a bank with retail loans amounting to 25% of total assets (the sample mean, see Table 1), a coefficient of 1.82 on the interaction term for ΔPV implies a difference in exposures of 0.46 across country groups, or around 80% of one standard deviation. The economic magnitudes using the two other measures range from 62% (ΔNIM) to 99% (β^{NIM}) of one standard deviation.

In column (3), we additionally control for differences in bank characteristics by adding the set of dummy variables for different business models.[16] The results remain both qualitatively and quantitatively similar. Finally, we show that these results also hold when only considering on-balance sheet exposures (which is only possible for ΔPV and ΔNIM). The results, presented in column (4) of Table 6, are consistent with those obtained for total exposures. The magnitude of the regression coefficients is slightly larger, and the R^2 of the regression increases. Both findings are consistent with banks hedging some, but not all, of their exposures. We examine hedging in more detail in Section 5.

4.4 Further evidence – Explaining variation on the asset side

In both Hellwig (1994) and Drechsler et al. (2018), banks' liabilities are formed of deposits, and their maturity structure is determined either by perfectly predictable liquidity shocks or banks' local market power. Banks then choose assets whose maturity matches that of their liabilities, which are taken as given. Here, we follow this rationale by examining the

[16]Controlling for the share of loans and retail deposits leads to similar results.

role of loan-rate fixation conventions in explaining cross-sectional variation on the asset side after controlling for the maturity of banks' liabilities.

We begin by examining the maturity-matching of assets and liabilities highlighted in the models of Hellwig (1994) and Drechsler et al. (2018) by using the decompositions of our three interest rate risk measures discussed at the end of Section 3.1. The cross-sectional distributions of the individual contributions of assets and liabilities are tabulated in Panel C of Table 5. Column (1) in Table 7 contains the coefficient estimates from a regression of the interest rate risk contribution of the asset side on the contribution of the liability side. For all three measures, we observe that banks indeed engage in strong maturity-matching, with coefficients between 0.74 and 1.07. This is consistent with the main result in Drechsler et al. (2018). Next, we include the VRM dummy variable to test whether loan-rate fixation conventions can explain cross-sectional variation on the asset side even after controlling for banks' liability structure. The results in column (2) reveal that this is indeed the case, with the coefficient on the VRM dummy statistically significant across the board. In a last step, we additionally include the fraction of retail loans relative to total assets and its interaction with the VRM dummy to corroborate that heterogeneity on the asset side is indeed driven by retail loans. We find that for all three variables, the coefficient of the interaction terms is significant at the 5% level or better.

In a next step, we further decompose the asset side into contributions due to loans and securities. If loan-rate fixation conventions prevent banks from choosing their desired exposures, we expect the contribution of loans to be significantly different from that of securities holdings. More specifically, we expect only loans to exhibit the cross-country variation documented so far. In fact, banks may even try to neutralize the impact of unwanted exposures from loans through securities holdings (e.g. by adding short-maturity securities to a portfolio of long-maturity loans). This test is similar in spirit to the analysis in Kirti (2017). The decomposition of ΔPV^{BS}_{Assets} and ΔNIM^{BS}_{Assets} into contributions due to loans and securities is straightforward. Moreover, we obtain time-series information on income from loans and other income for 79 of our sample banks from Orbis, allowing us to estimate $\beta^{IncLoans}$ and $\beta^{IncOther}$.

We then repeat the previous regressions for the two different contributions (loans and securities held) to the asset side. The resulting coefficients are tabulated in columns (4) and (5) of Table 7. The results are consistent with exposures of loan portfolios, but not those of securities portfolios, being driven by loan-rate fixation conventions. The loan portfolios of banks in variable-rate countries have a lower exposure to interest rate risk, reflected in less negative net-worth and income sensitivities, and a higher income beta. Moreover, this effect is stronger for banks with more retail loans. In contrast, these effects are absent for banks' security portfolios. The interaction terms of the VRM dummy in column (5) are either statistically insignificant or have a negative sign (for $\beta^{IncOther}$), indicating that the interest rate risk borne through securities holdings does not exhibit the systematic cross-country heterogeneity found for loans. There is even some limited evidence that banks hedge some of the unwanted exposures from loans by entering offsetting positions through securities.

5 Hedging with derivatives

In this section, we investigate banks' use of derivatives. We examine whether they are used for hedging or risk-taking, and explore the determinants of hedging. Moreover, we analyze risk sharing across groups of banks with opposite on-balance sheet exposures.

5.1 Joint behavior of on- and off-balance sheet exposures

We study the joint distribution of banks' on- and off-balance sheet exposures to shed light on whether banks use derivatives to hedge their on-balance sheet positions or to take additional risk. In the absence of frictions in the market for interest rate swaps, on-balance sheet exposures alone should not necessarily predict total exposures. By entering into appropriate derivative contracts, banks can theoretically reach any desired target exposure.

We start by describing exposures arising from interest rate swap positions. Table 5 tabulates the cross-sectional distributions of ΔPV^{IRS} and ΔNIM^{IRS}. On average, ΔPV^{IRS} is equal to 0.09 bps of total assets. Its sign is the opposite of that documented for ΔPV^{BS}, and therefore indicates that banks hedge on average. In contrast, ΔNIM^{IRS} averages -0.002 in the cross-section, which is quantitatively very small and has the same sign as ΔNIM^{BS}. That said, both ΔPV^{IRS} and ΔNIM^{IRS} exhibit significant cross-sectional variation, similar to that for on-balance sheet exposures.

To examine the joint distribution of on- and off-balance sheet exposures more precisely, we estimate univariate linear regressions of derivatives exposures (ΔPV^{IRS} and ΔNIM^{IRS}) on banking book exposures (ΔPV^{BS} and ΔNIM^{BS}). We cluster standard errors at the country level. Figure 5 depicts the scatter plots together with the regression fit and the associated coefficient estimates. For the net-worth sensitivity ΔPV, we find a negative and statistically significant coefficient of -0.71, together with an R-squared of 0.56. Therefore, cross-sectional variation in derivatives exposures is explained well by variation in on-balance sheet exposures, and the negative sign is consistent with hedging. In contrast, the results for the income sensitivity ΔNIM show no significant relation between on- and off-balance sheet exposures.

Next, we examine whether and by how much banks' exposures shrink after accounting for derivatives positions. Intuitively, hedging should reduce exposures, irrespective of their sign. From this perspective, over-hedging (e.g., 150%) or imperfect hedging (e.g., 50 %) should be treated similarly, since in both cases some exposure is retained. We therefore focus on the absolute value of exposures before and after hedging. Panel A of Table 8 reports summary statistics for the cross-sectional distributions of $|\Delta PV^{BS}|$ (before hedging) and $|\Delta PV|$ (after hedging). In line with the regression estimates, accounting for derivatives positions leads to a significant reduction in total exposures from a present value perspective. The mean of $|\Delta PV|$ is 0.40, which represents a reduction in exposure to interest rate risk of slightly more than one quarter, based on an average $|\Delta PV^{BS}|$ of 0.54. The difference of -0.14 is statistically significant at the 5% level, using standard errors clustered at the country level. We also compute the average percentage change across all banks as the log-difference in absolute exposures. This yields an estimate of -0.29 (significant at the 1% level), confirming our conclusion. Figure 6 provides an illustration of the effect of derivatives on the cross-sectional distribution of banks' net worth sensitivity by plotting both ΔPV^{BS} and ΔPV. We observe that the support of the distribution shrinks and its mass is shifted towards zero, consistent with a reduction in exposures. Finally, Panel B of Table 8 provides the corresponding estimates for exposures based on ΔNIM. In line with the summary statistics, accounting for derivatives has no significant impact in terms of income risk.

In sum, our results show that banks use derivatives to hedge present value risk, but not income risk.[17] This focus on the hedging of net worth is consistent with theoretical models in which equity value is the relevant state variable (Rampini and Viswanathan, 2010). Different accounting rules for "fair value hedging" and "cash flow hedging" may also play a role.[18]

More generally, our results support the view that deposit-taking and lending activities give rise to undesired inventories of interest rate risk, and banks use derivatives to reduce some of these exposures. This finding contrasts with the analysis of Begenau, Piazzesi, and Schneider (2015), who document that large U.S. banks tend to increase their exposure with derivatives. One explanation for this discrepancy is that the exposures of euro area banks are more heterogeneous than those of U.S. financial institutions. Hedging requires another counterparty to take the opposite side of a trade. If all banks have similar exposures, opportunities for interbank risk-sharing via interest rate swaps are more limited. Consistent with this, the contractual maturity gaps of U.S. banks documented by English et al. (2018) are considerably larger than those of euro area banks (see Table 4), suggesting that the risk profile of most U.S. banks corresponds more closely to the textbook maturity mismatch. In part, this may be driven by the predominance of 30-year fixed-rate mortgages in the U.S. housing market (Badarinza et al., 2017). In contrast, cross-country variation in mortgage market structure in the euro area creates risk-sharing potential, which can be realized by trading in derivatives markets.

5.2 Cross-sectional variation in hedging

Next, we investigate heterogeneity in banks' use of derivatives for hedging. We restrict the analysis to the hedging of present value risk, as we have shown that banks do not hedge income risk. To this end, we regress the log change in absolute exposures on bank characteristics. The corresponding results are shown in Table 9. The first characteristic is the absolute size of banks' on-balance sheet exposure, $|\Delta PV^{BS}|$. We obtain a negative and statistically significant (at the 10% level) coefficient, suggesting that banks with larger exposures tend to hedge more. The point estimate of -0.348 indicates that for each 0.1

[17] Two contracts with identical ΔPV can involve very different notional amounts and thus greatly differ in their effects on income. For example, the notional of a 2-year interest rate swap is up to five times as large as the one of a 10-year contract with the same present-value sensitivity.

[18] See, for example, "IAS 39 - Achieving hedge accounting in practice", PricewaterhouseCoopers, available at https://www.pwc.com/gx/en/ifrs-reporting/pdf/ias39hedging.pdf

bps in total exposure, hedging increases by around 3.5%.

In column (2), we explore the potential role of capacity constraints and segmentation in derivatives markets. We define a dummy variable called *Opp.Sign*, which is equal to one for banks whose on-balance sheet exposure differs in sign from that which one would expect based on our findings from Section 4, and zero otherwise.[19] We find a negative and statistically significant coefficient of -0.57, indicating that banks whose exposure has a different sign from that which prevails locally tend to hedge more, consistent with more trading opportunities in a segmented market.

Column (3) investigates whether there is a difference in the extent of hedging between banks from the two different country groups based on loan-rate fixation conventions, and finds no difference. Hence, cross-country variation in total exposures is not driven by differences in hedging.

Finally, we investigate the roles of moral hazard and financial constraints in columns (5) and (6). Moral hazard, for example due to government guarantees, is a potential source of risk-taking (Farhi and Tirole, 2012), and should thus be associated with less hedging. Financially constrained banks face a tighter trade-off between financing and hedging, and may optimally choose to hedge less (Rampini and Viswanathan, 2010). We use bank size (in logs) as a measure of moral hazard and find no evidence that larger banks (presumably more exposed to moral hazard from too-big-to-fail guarantees) hedge less. We proxy for the presence of financial frictions using the share of non-performing loans, a potential measure of bank risk, and find no evidence that financially constrained banks hedge less. That said, a better test of theories based on financial frictions would need to exploit within-bank variation over time (Rampini et al., 2017).

5.3 Risk-sharing in the interest rate swap market

To conclude this section, we analyze the sharing of interest rate risk in the IRS market, both within the banking sector and between banks and non-banks. To account for the over-the-counter nature of interest rate swaps, we split our sample banks into three groups: dealer banks, non-dealer banks with $\Delta PV^{BS} > 0$, and non-dealer banks with $\Delta PV^{BS} < 0$. We define dealer banks as institutions that have at least 2,000 outstanding contracts with

[19] More specifically, $Opp.Sign = 1$ for banks with $\Delta PV^{BS} > 0$ in fixed-rate countries or $\Delta PV^{BS} < 0$ in variable-rate countries.

the largest clearing house in the euro interest rate swap market, LCH.Clearnet.[20] Aside from managing counterparty risk, dealers value the possibility of compressing redundant contracts via the clearing house to economize on collateral. They therefore have an incentive to engage in central clearing of their swap portfolios.

In addition, we define the following groups of counterparties, which we identify by matching the IRS data with information from Bureau van Dijk's Orbis dataset: insurance companies and pension funds (ICPFs), non-SSM banks and CCPs, and "other" (comprising governments, non-financial corporations, asset managers, and counterparties that cannot be classified).[21] We then compute the exposures among our three groups of sample banks, as well as their exposures to the groups of non-bank counterparties.

Figure 7 summarizes risk-sharing in the IRS market across sectors. The numbers represent the aggregate value transfers (in €mn) between groups following a 1 bp parallel upward shift in the yield curve, and arrows indicate the direction of the transfers. For example, the modelled increase in interest rates implies an aggregate value transfer of €28.1mn from the group of SSM dealer banks to non-SSM banks and CCPs. Though stylized, this picture of inter-sector transfers delivers several interesting insights.

First, the aggregate IRS portfolios of both groups of non-dealer SSM banks are consistent with our findings in the previous subsection. The derivatives positions of banks with $\Delta PV^{BS} < 0$ vis-à-vis dealer banks, non-SSM banks, and banks with $\Delta PV^{BS} > 0$ appreciate in value following an increase in interest rates. The opposite is true for banks with $\Delta PV^{BS} > 0$. This reflects hedging activity.

Second, we observe that ICPFs hold an aggregate IRS portfolio resembling a fixed-rate receiver position. This is consistent with this sector having a maturity mismatch due to long-dated liabilities (e.g. future life insurance and pension payouts) and relatively short-dated assets, so that they use swaps to hedge the underlying interest rate risk. In line with the over-the-counter nature of the IRS market, we observe that ICPFs only trade with dealer banks.[22] Accordingly, dealers intermediate between ICPFs and the group of banks

[20] Defining dealers based on the ratio of gross to net exposures identifies a similar set of banks.

[21] We group non-SSM banks and CCPs into a single group because there are few non-bank clearing members, so that any exposures to CCPs are ultimately exposures to banks (save for counterparty risk). Note that our sample banks will have a non-zero exposure to CCPs because CCPs also have non-SSM clearing members (e.g. large non-euro area banks).

[22] The exposures of ICPFs vis-à-vis the two other groups of sample banks are negligible (less than €0.5mn each in absolute value). Hence, they are not included in Figure 7 for improved readability.

with $\Delta PV^{BS} < 0$, which take the opposite position to that of ICPFs. This underscores the central role of dealers in the over-the-counter IRS market.

Third, we observe that the aggregate position of the group of other institutions—including governments, non-financial corporations, and asset managers—resembles a fixed-rate payer position. Asset managers take this position to immunize parts of their fixed-income portfolios against interest rate risk. Moreover, the direction of this exposure is consistent with evidence from the U.S. on the use of IRS by non-financial firms (Hentschel and Kothari, 2001; Chernenko and Faulkender, 2011). In addition, part of the exposures of governments may be explained by hedging of interest rate risk due to publicly-owned asset management companies ("bad banks"). Unlike ICPFs, the "Other" group holds significant swap positions against all three groups of our sample banks, although the exposure towards dealers is naturally the largest one.

We conclude this section by contrasting actual risk-sharing in the swaps market between $\Delta PV^{BS} > 0$ and $\Delta PV^{BS} < 0$ non-dealer SSM banks with the *potential* for risk-sharing. Based on the numbers in Figure 7, we obtain a risk transfer of €20.9mn between the two groups (€1mn directly, €13.5mn through dealers, and €6.4mn through other banks and CCPs).[23] Given aggregate ΔPV^{BS} of €116.9mn for non-dealer banks with $\Delta PV^{BS} > 0$ and €-288.9mn for non-dealer banks with $\Delta PV^{BS} < 0$, the theoretical risk-sharing potential between the groups is €116.9mn. Accordingly, only 18% of the total risk-sharing potential is realized. We obtain a very similar estimate when re-allocating dealer banks to each group based on their banking book exposures (i.e. realized risk-sharing of €62.4mn compared to potential risk-sharing of €327.4mn).

6 Policy implications

In this section, we discuss the policy implications arising from our analysis. We start with implications based on our findings for the banking sector, and then discuss the role of households.

[23]Note that both groups have exposures with opposite signs to the groups of dealers and other banks and CCPs. Hence, we can directly compute the risk-sharing *through* these groups by taking the minimum of the absolute value of the exposures of each group. For example, the risk-sharing via dealers is formally computed as $min(13.5, |-99.7|) = 13.5$.

6.1 Redistributive effects of monetary policy – banks

Our results have important implications for monetary policy. Recent banking theories have highlighted redistributive effects of monetary policy between the banking sector and non-financial sectors. For example, in Diamond and Rajan (2012) and Brunnermeier and Sannikov (2016), monetary policy can boost the net worth of financial institutions when they turn illiquid, at the expense of the non-financial sector. However, the efficiency of such "stealth recapitalizations" critically relies on an assumption that bank equity value increases when interest rates decrease (Brunnermeier and Koby, 2017). Our results show that this assumption may not hold for all banks, at least when interest rate exposures are measured using the valuation and income sensitivity of assets in place.[24]

Instead, our findings highlight that monetary policy can have important redistributive effects *within* the banking sector. Due to the heterogeneity of banks' exposures, some institutions benefit from a decrease in interest rates, while others lose. Given that a key determinant of banks' exposures in the euro area—loan-rate fixation conventions—is country-specific, monetary policy has heterogeneous effects on national banking systems. Following a monetary policy shock, the financial position of banks will be affected differentially across countries, which implies that monetary policy is transmitted heterogeneously to the real economy. The relative strengths of the main channels at play—the bank balance sheet channel and the borrower balance sheet channel—are therefore likely to differ across countries.

The magnitude of transfers within the banking sector due to changes in interest rates is economically significant. A simple approximation based on our ΔPV measure shows that they are quantitatively larger, in aggregate, than transfers between the banking sector and non-financial sectors. For an increase in interest rates by 25 bps, banks with $\Delta PV > 0$ gain €6.6bn, while banks with $\Delta PV < 0$ lose €11.2bn. These numbers imply net transfers within the banking sector of €6.6bn, while net transfers between the banking sector and the rest of the economy only amount to €4.6bn. Therefore, at our measurement date, redistributive effects of changes in interest rates within the banking sector are about 40%

[24]Monetary policy can also affect banks' market value of equity via other channels, for example by increasing loan demand and asset quality (since the debt burden of borrowers is reduced). These effects are not captured by ΔPV and ΔNIM, but should be reflected in β^{NIM}. Studies on the market value of equity show that banks' stocks experience negative returns upon interest rate increases (English et al., 2018; Ampudia and Van Den Heuvel, 2017). However, Drechsler et al. (2018) show that *abnormal* returns are not significantly different from zero.

larger in magnitude than standard redistributive effects. These intra-sectoral transfers are important for policymakers to consider.

6.2 Redistributive effects of monetary policy – households

While our analysis has focused on the interest rate risk exposure of banks, it also carries implications for non-bank sectors. Banks' balance sheets contain information on the interest rate risk exposures of other sectors of the economy that obtain funding from banks (e.g., via loans) and that use banks as an investment vehicle (via deposits). Given the heterogeneity of mortgage markets in the euro area, we focus on households. For simplicity, we restrict attention to households' exposures as captured by a present value measure, denoted ΔPV^{HH}.

The computation of ΔPV^{HH} at the bank-level is straightforward. Households' assets comprise their sight and term deposits, and liabilities are represented by their loans. Unfortunately, our data do not provide a breakdown between loans to households and to other sectors for individual maturity buckets. We therefore assume a pro-rata allocation based on the bank-level share of retail loans. We apply the same method to term deposits, while sight deposits are broken down into individual categories in the raw data. As before, we express all exposures relative to bank assets.[25]

Panel A of Figure 8 plots the distribution of ΔPV^{HH} for the cross-section of banks. These estimates, which are also reported in Table 10, show that the net worth of households decreases with increases in interest rates. Following our earlier analysis, we split the sample into two country groups based on loan-rate fixation conventions (denoted $\Delta PV^{HH}_{Variable}$ and ΔPV^{HH}_{Fixed}). We see that higher interest rates particularly hurt households in countries with predominantly variable-rate mortgages. This is because the repricing maturity of their assets (sticky sight deposits and term deposits) exceeds that of their liabilities, such that their net worth declines. Households in the other country group have a relatively balanced position on aggregate, as they are protected by a better maturity-matching of assets and liabilities. This suggests that the balance sheet channel of monetary policy (Bernanke and Gertler, 1995)—operating via the balance sheet strength of borrowers—may affect the real economy differentially across countries. For

[25]Notice that these exposures aggregate a large number of households, which will tend to be individually either net savers or net borrowers.

example, the dynamics of consumption following an interest rate change are likely to differ across fixed-rate and variable-rate countries. This is also consistent with the analysis in Calza et al. (2013).

A limitation of this analysis is that bank balance sheets do not reveal all relevant information on households' balance sheets, particularly the asset side. However, the inclusion of additional asset holdings would likely amplify the adverse consequences of higher interest rates for household net worth in countries with variable-rate mortgages. Indeed, the omitted assets primarily comprise real estate, the duration of which is very long.[26] Moreover, relatively low home ownership rates in some fixed-rate countries (notably Germany) imply that household asset duration is higher on average in variable-rate countries. We are thus likely to underestimate heterogeneity across country groups.

Taken together with the results for banks, our findings reveal that the distribution of interest rate risk in the euro area is highly heterogeneous. In particular, increases in interest rates tend to hurt banks in fixed-rate countries and households in variable-rate countries. This implies that the transmission of monetary policy via the balance sheets of borrowers and banks is subject to considerable heterogeneity, which can pose challenges for policymakers.

7 Conclusion

We study the allocation of interest rate risk within the European banking sector using novel supervisory data. While we find that banks' exposures are limited on aggregate, there is considerable heterogeneity across individual institutions. In contrast to conventional wisdom, roughly half of the banks in our sample would benefit from an increase in interest rates (in terms of both net worth and income). This "reverse maturity transformation" arises for institutions that hold variable-rate assets funded by sticky sight deposits. We identify loan-rate fixation conventions as a significant driver of cross-sectional heterogeneity which affects banks' ability to match the maturities of assets and liabilities. Finally, we examine hedging via interest rate swaps, and find that banks hedge around

[26]The results from the Eurosystem's Household Finance and Consumption Survey (available at https://www.ecb.europa.eu/stats/ecb_surveys/hfcs/html/index.en.html) from 18 euro area countries show that households' non-financial assets are dominated by residential real estate. Households' financial assets are dominated by bank deposits (with the exception of the wealthiest decile of households), and are thus reflected in our data.

one quarter of the exposure arising from deposit-taking and lending activities.

Our findings have important implications. In particular, the observed cross-country heterogeneity suggests that monetary policy in the euro area may transmit via different channels in different parts of the currency union. Our results also point to monetary policy generating significant transfers *within* the banking sector, a mechanism that has so far not received any attention in the literature. These findings represent promising avenues for future research.

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Table 1: Balance sheets—descriptive statistics

	Mean	StDev	P25	Median	P75
Total assets (TA)	204.4	352.3	33.6	70.6	177.6
Loans (% of TA)	66.1	19.1	57.7	65.9	71.3
Retail loans (% of TA)	*25.2*	*17.2*	*12.8*	*25.6*	*36.1*
Corporate loans (% of TA)	*23.4*	*12.3*	*15.0*	*23.8*	*33.5*
Debt securities held (% of TA)	17.7	12.2	11.5	15.9	22.4
Other assets (% of TA)	16.1	21.3	12.1	16.7	24.0
Deposits (% of TA)	68.7	23.8	59.7	70.1	81.6
Debt securities issued (% of TA)	18.3	24.3	3.1	13.1	21.8
Equity (% of TA)	7.8	4.0	5.3	7.0	9.2
Other liabilities (% of TA)	5.1	34.1	3.5	6.4	11.6

This table provides summary statistics for the cross-section of the 104 euro area banks in our sample. The data are taken from supervisory statistics of the ECB, and the snapshot date is 31/12/2015.

Table 2: Descriptive statistics on banks' use of interest rate swaps

	Mean	StDev	P25	Median	P75
Number of outstanding contracts	5,719	10,245	103	1,502	5,959
of which:					
3M Euribor (% of total)	41.9	26.3	21.7	38.4	61.6
6M Euribor (% of total)	47.2	27.1	26.3	44.6	66.7
Eonia (% of total)	3.3	7.6	0.0	0.9	3.2
Centrally cleared (% of total)	12.4	20.0	0.0	0.1	22.2
Number of counterparties	804	1,467	21	80	712
Average residual maturity (in years)	9.8	3.3	7.6	9.7	10.9
Gross notional (in €bn)	311.3	758.3	4.6	33.3	155.7
Mark-to-market value (in €mn)	-6	2,595	-143	3	418

This table provides cross-sectional summary statistics on the interest rate swap portfolios of the 104 euro area banks in our sample. The underlying data are obtained from DTCC-DDRL and Regis-TR, and the snapshot date is 31/12/2015. Positions are consolidated at the group level. Details of the data cleaning procedure are provided in the Appendix.

Table 3: Deposits – breakdown and duration of sight deposits

	Mean	StDev	P25	Median	P75
Panel A: Breakdown of deposits					
Term Deposits (% of Total)	52.8	24.5	35.0	54.4	67.5
Sight Deposits (% of Total)	47.2	24.5	32.6	45.6	65.03
of which:					
Retail Sight Deposits (% of Sight)	54.6	27.0	43.3	58.4	73.4
Corporate Sight Deposits (% of Sight)	25.1	18.5	12.0	22.2	35.9
Other Sight Deposits (% of Sight)	20.3	26.8	3.4	10.3	22.4
Panel B: Duration of sight deposits (in years)					
Retail Sight Deposits	2.00	1.56	0.15	2.03	3.13
Corporate Sight Deposits	1.02	1.24	0.00	0.33	1.82
Other Sight Deposits	0.00	0.00	0.00	0.00	0.00
Total Sight Deposits	1.48	1.32	0.01	1.45	2.48

This table provides an overview of the deposits in the euro-denominated banking book for the cross-section of the 104 euro area banks in our sample. Panel A details the breakdown into term and sight deposits, and provides a further breakdown of sight deposits into three categories: retail, corporate, and other. Panel B provides an overview of banks' estimates of the effective duration of sight deposits (in years). The data are taken from ECB supervisory statistics, and the snapshot date is 31/12/2015.

Table 4: Re-pricing maturity – descriptive statistics

	Mean	StDev	P25	Median	P75
Assets:	2.21	1.74	1.08	1.58	3.13
Loans*	1.90	1.94	0.53	1.05	2.95
Debt securities held	3.38	1.93	1.88	3.33	4.66
Liabilities:	2.00	1.51	1.19	1.68	2.29
Debt securities issued	2.67	2.11	1.27	2.50	3.75
Term deposits	1.68	2.06	0.55	0.86	1.80
Sight deposits*	1.48	1.32	0.01	1.45	2.48
Difference	0.21	1.05	-0.38	0.05	0.62
Difference (contractual)	0.95	1.16	0.24	0.60	1.51

This table provides an overview of the re-pricing maturity of key items in the euro-denominated banking book for the cross-section of the 104 euro area banks in our sample. All numbers are expressed in years. The underlying data are taken from ECB supervisory statistics, and the snapshot date is 31/12/2015. All items in a given maturity bucket are assumed to a have a re-pricing maturity corresponding to the mid-point. Items subject to modelling are marked with an asterisk. We assume a constant annual prepayment rate of 5% for retail loans.

Table 5: Banks' exposure to interest rate risk

Panel A: Exposures					
	Mean	StDev	P25	Median	P75
ΔPV	-0.09	0.57	-0.38	-0.07	0.22
ΔNIM	-0.003	0.15	-0.09	-0.01	0.09
β^{NIM}	0.04	0.12	-0.03	0.03	0.11
Panel B: Correlations					
$\rho(\Delta PV, \Delta NIM)$	0.586^{***}	(0.000)			
$\rho(\Delta PV, \beta^{NIM})$	0.175^{*}	(0.078)			
$\rho(\Delta NIM, \beta^{NIM})$	0.223^{**}	(0.024)			
Panel C: Decomposition of exposures					
	Mean	StDev	P25	Median	P75
ΔPV^{Assets}	-1.39	1.10	-1.86	-1.03	-0.66
$\Delta PV^{Liabilities}$	-1.23	0.88	-1.62	-1.11	-0.66
ΔPV^{BS}	-0.17	0.80	-0.32	-0.01	0.27
ΔPV^{IRS}	0.09	0.77	-0.24	-0.01	0.13
ΔNIM^{Assets}	0.47	0.21	0.29	0.51	0.64
$\Delta NIM^{Liabilities}$	-0.47	0.19	-0.32	-0.52	-0.61
ΔNIM^{BS}	-0.0007	0.14	-0.07	0.01	0.08
ΔNIM^{IRS}	-0.002	0.08	-0.04	-0.00	0.02
β^{Inc}	0.57	0.49	0.32	0.59	0.73
β^{Exp}	0.54	0.45	0.35	0.51	0.69

This table presents summary statistics on banks' exposure to interest rate risk for the cross-section of the 104 euro area banks in our sample. Panel A provides an overview of the cross-sectional distribution of total exposures. ΔPV is a net-worth sensitivity based on changes in present values. ΔNIM is an income sensitivity and computed based on the income gap (assets and liabilities with a re-pricing maturity of less than one year). β^{NIM} is the sum of the regression coefficients from a regression of change in net interest income on changes in the 3-month Euribor rate. Panel B tabulates the pairwise correlation coefficients, where p-values based on standard errors clustered at the country level are given in parentheses. Panel C provides a decomposition of each measure. ΔPV^{Assets}, $\Delta PV^{Liabilities}$, ΔPV^{BS}, ΔPV^{IRS} refer to the contributions of assets, liabilities, on-balance sheet positions (assets plus liabilities), and interest rate swaps to ΔPV. We use the same notation for ΔNIM. β^{Inc} and β^{Exp} refer to the sensitivities of interest income and interest expenses to changes in interest rates based on time-series regressions.

Table 6: Explaining banks' exposure to interest rate risk

	(1)	(2)	(3)	(4)
	Panel A: ΔPV			
	ΔPV	ΔPV	ΔPV	ΔPV^{BS}
Constant	-0.306**	-0.015	0.298***	-0.162
	(-2.71)	(-0.07)	(2.91)	(-1.63)
VRM	0.348**	-0.066	0.020	-0.035
	(2.40)	(-0.25)	(0.12)	(-0.13)
Retail Loans/Assets		-1.390*	-1.768***	-1.585*
		(-2.07)	(-3.09)	(-2.00)
$VRM \times$ *Retail Loans/Assets*		1.824**	1.748**	2.182**
		(2.20)	(2.59)	(2.18)
R-squared	0.096	0.210	0.306	0.386
N	104	104	104	104
BM FE	No	No	Yes	Yes
	Panel B: ΔNIM			
	ΔNIM	ΔNIM	ΔNIM	ΔNIM^{BS}
Constant	-0.070**	-0.005	0.073***	-0.048**
	(-3.10)	(-0.19)	(-7.00)	(-2.17)
VRM	0.105***	-0.009	0.025	-0.013
	(3.97)	(-0.24)	(0.86)	(-0.26)
Retail Loans/Assets		-0.311**	-0.308***	-0.297**
		(-2.58)	(-3.35)	(-2.72)
$VRM \times$ *Retail Loans/Assets*		0.478***	0.472***	0.640***
		(3.24)	(3.77)	(3.52)
R-squared	0.130	0.226	0.323	0.399
N	104	104	104	104
BM FE	No	No	Yes	Yes
	Panel C: β^{NIM}			
	β^{NIM}	β^{NIM}	β^{NIM}	
Constant	-0.037**	0.005	0.005	
	(-5.68)	(0.47)	(0.28)	
VRM	0.129***	0.039	0.022	
	(8.86)	(1.64)	(0.99)	
Retail Loans/Assets		-0.201***	-0.239***	
		(-3.28)	(-3.60)	
$VRM \times$ *Retail Loans/Assets*		0.365***	0.367***	
		(4.01)	(3.68)	
R-squared	0.273	0.339	0.350	
N	102	102	102	
BM FE	No	No	Yes	

This table provides the coefficient estimates for cross-sectional regressions of bank-level exposures to interest rate risk on a set of determinants. Panel A presents the results for the net-worth sensitivity ΔPV, while Panels B and C refer to the income sensitivity ΔNIM and β^{NIM}, respectively. VRM denotes a dummy variable that is equal to one for banks located in countries where mortgages are predominantly variable-rate loans, and zero otherwise. *Retail Loans/Assets* denotes the ratio of retail loans to total assets. $VRM \times Retail\ Loans/Assets$ denotes the product of the previous two variables. Columns (1) to (3) refer to total exposures, while (4) refers to exposures based on on-balance sheet items only (not available for β^{NIM}). BM FE refers to the inclusion of nine dummy variables relating to different business models following the internal classification maintained at the ECB. t-statistics in parentheses are based on standard errors clustered at the country level.

Table 7: Explaining the asset side

	(1)	(2)	(3)	(4)	(5)
			Panel A: ΔPV		
	ΔPV^{Assets}	ΔPV^{Assets}	ΔPV^{Assets}	ΔPV^{Loans}	ΔPV^{Sec}
Constant	-0.331**	-0.889***	0.576***	-0.416***	-0.160***
	(-2.58)	(-3.68)	(10.05)	(3.31)	(-1.13)
$\Delta PV^{Liabilities}$	0.736***	0.606***	0.617***	0.405***	0.212***
	(10.17)	(8.24)	(9.75)	(4.42)	(4.55)
VRM		0.668***	0.189	0.364***	-0.175
		(3.49)	(1.08)	(3.81)	(-1.05)
Retail Loans/Assets			-1.386*	-1.586***	0.199
			(-1.89)	(-3.22)	(0.52)
$VRM \times$ *Retail Loans/Assets*			2.003**	1.811***	0.192
			(2.35)	(3.36)	(0.36)
R-squared	0.519	0.636	0.681	0.675	0.281
N	104	104	104	104	104
			Panel B: ΔNIM		
	ΔNIM^{Assets}	ΔNIM^{Assets}	ΔNIM^{Assets}	ΔNIM^{Loans}	ΔNIM^{Sec}
Constant	0.075***	0.085***	0.101***	0.081**	0.021*
	(1.55)	(2.91)	(3.99)	(2.85)	(1.89)
$\Delta NIM^{Liabilities}$	0.830***	0.540***	0.584***	0.457***	0.126***
	(7.08)	(5.92)	(5.94)	(3.93)	(2.92)
VRM		0.218***	0.091	0.108*	-0.017
		(6.90)	(1.70)	(1.89)	(-0.86)
Retail Loans/Assets			-0.152*	-0.073	-0.079***
			(-1.78)	(-0.93)	(-3.77)
$VRM \times$ *Retail Loans/Assets*			0.441**	0.410**	0.031
			(2.82)	(2.56)	(0.54)
R-squared	0.575	0.769	0.794	0.735	0.167
N	104	104	104	104	104
			Panel C: β^{NIM}		
	β^{Inc}	β^{Inc}	β^{Inc}	β^{Loans}	β^{Other}
Constant	-0.041*	-0.061	-0.027	0.075	0.005
	(-1.74)	(-1.37)	(-0.95)	(1.04)	(0.10)
β^{Exp}	1.065***	1.056***	1.044***	0.088	0.937***
	(51.50)	(46.05)	(51.34)	(1.24)	(14.56)
VRM		0.095***	0.004	-0.011	-0.053
		(4.47)	(0.18)	(-0.09)	(-0.48)
Retail Loans/Assets			-0.173***	-0.190	-0.173
			(-4.25)	(-0.90)	(-1.10)
$VRM \times$ *Retail Loans/Assets*			0.342***	1.193**	-0.740*
			(4.05)	(2.76)	(-1.77)
R-squared	0.958	0.963	0.966	0.481	0.725
N	104	104	104	79	79

This table provides the coefficient estimates for cross-sectional regressions of asset side contributions to banks' interest rate risk exposure on a set of determinants. Panel A presents the results for the net-worth sensitivity ΔPV, while Panels B and C refer to β^{NIM} and the income sensitivity ΔNIM. VRM denotes a dummy variable that is equal to one for banks located in countries where mortgages are predominantly variable-rate loans, and zero otherwise. See Figure 3 for an illustration. ΔPV^{Assets}, ΔPV^{Loans},

ΔPV^{Sec} and $\Delta PV^{Liabilities}$ denote the contributions of asset, loans, securities held and liabilities to banks' net-worth sensitivity ΔPV. ΔNIM^{Assets}, ΔNIM^{Loans}, ΔNIM^{Sec} and $\Delta NIM^{Liabilities}$ denote the corresponding contributions to ΔNIM. β^{Inc}, β^{Loans}, β^{Other}, and β^{Exp} refer to the sensitivities of interest income, interest income from loans, other interest income and interest expenses to changes in interest rates based on time-series regressions, see Section 3.1 for details. $Retail\ Loans/Assets$ denotes the ratio of retail loans to total assets. $VRM \times Retail\ Loans/Assets$ denotes the product of the previous two variables. t-statistics in parentheses are based on standard errors clustered at the country level.

Table 8: Hedging

	Mean	StDev	P25	Median	P75
Panel A: ΔPV					
$\lvert\Delta PV^{BS}\rvert$	0.54	0.62	0.16	0.28	0.72
$\lvert\Delta PV\rvert$	0.40	0.39	0.09	0.27	0.57
$\lvert\Delta PV\rvert - \lvert\Delta PV^{BS}\rvert$	-0.14	0.44	-0.21	-0.04	0.04
$log(\lvert\Delta PV\rvert) - log(\lvert\Delta PV^{BS}\rvert)$	-0.29	1.02	-0.63	-0.24	0.25
H0: $\lvert\Delta PV^{BS}\rvert - \lvert\Delta PV\rvert = 0$	p-value = 0.030, t-statistic = -2.36				
H0: $log(\lvert\Delta PV\rvert) - log(\lvert\Delta PV^{BS}\rvert) = 0$	p-value = 0.008, t-statistic = -3.02				
Panel B: ΔNIM					
$\lvert\Delta NIM^{BS}\rvert$	0.10	0.09	0.04	0.08	0.13
$\lvert\Delta NIM\rvert$	0.11	0.09	0.05	0.09	0.15
$\Delta NIM\rvert - \lvert\Delta NIM^{BS}\rvert$	0.01	0.07	-0.02	0.01	0.03
$log(\lvert\Delta NIM\rvert) - log(\lvert\Delta NIM^{BS}\rvert)$	0.09	1.18	-0.24	0.08	0.48
H0: $\lvert\Delta NIM^{BS}\rvert - \lvert\Delta NIM\rvert = 0$	p-value = 0.331, t-statistic = 1.00				
H0: $log(\lvert\Delta NIM\rvert) - log(\lvert\Delta NIM^{BS}\rvert) = 0$	p-value = 0.369, t-statistic = 0.92				

This table presents cross-sectional summary statistics on banks' absolute exposures to interest rate risk and the effects of hedging through interest rate swaps. Panel A refers to the net-worth sensitivity ΔPV, while Panel B refers to ΔNIM. p-values are based on standard errors clustered at the country level.

Table 9: Intensity of hedging in the cross-section

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	0.368	0.463**	0.274	0.196	-2.514	0.624***	0.747***	0.583***	-0.817
	(1.44)	(2.42)	(1.15)	(0.75)	(-0.86)	(3.28)	(4.11)	(3.17)	(-0.38)
$\lvert\Delta PV^{BS}\rvert$	-0.348*					-0.396**	-0.462**	-0.384**	-0.392**
	(-1.88)					(-2.26)	(-2.35)	(-2.21)	(-2.30)
Opp. Sign		-0.570**				-0.621**	-0.636**	-0.667**	-0.593**
		(-2.24)				(-2.53)	(-2.60)	(-2.55)	(-2.83)
VRM			-0.099				-0.304		
			(-0.40)				(-1.34)		
$\%NPL$				0.980				1.132	
				(0.97)				(1.56)	
Size					0.110				0.057
					(0.99)				(0.70)
R-squared	0.111	0.132	0.079	0.089	0.089	0.174	0.186	0.191	0.177
N	104	104	104	104	104	104	104	104	104

This table reports the regression coefficients from univariate cross-sectional regressions of the intensity of hedging on various characteristics for our sample of 104 banks. The intensity of hedging is measured as $log(|\Delta PV|) - log(|\Delta PV^{BS}|)$ (see Table 8), where $|\Delta PV^{BS}|$ and $|\Delta PV|$ denote banks' absolute exposure before and after hedging, respectively. *Opp.Sign* is a dummy variable equal to one for banks from countries with predominantly fixed-rate mortgages and $\Delta PV^{BS} > 0$ as well as banks from countries with predominantly variable-rate mortgages and $\Delta PV^{BS} < 0$, and zero otherwise. VRM is a dummy variable taking the value of one for banks located in countries with predominantly variable-rate mortgages, and zero otherwise. $\%NPL$ denotes the share of non-performing loans (expressed in percentage points), and *Size* denotes the natural logarithm of total assets. *t*-statistics based on robust standard errors are given in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively.

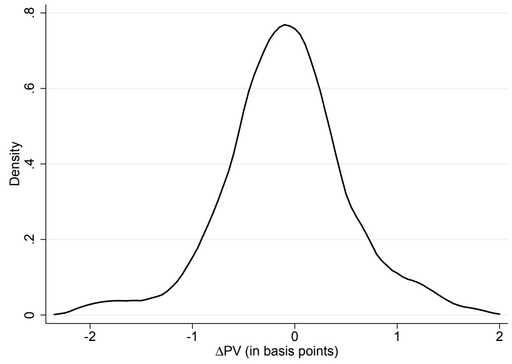
Table 10: Households' exposure to interest rate risk—ΔPV^{HH}

	Mean	StDev	P25	Median	P75
ΔPV^{HH}	-1.52	5.14	-3.87	-1.17	0.16
$\Delta PV^{HH}_{Variable}$	-3.21	3.59	-4.66	-2.89	-0.88
ΔPV^{HH}_{Fixed}	0.87	6.03	-0.98	0.00	1.38

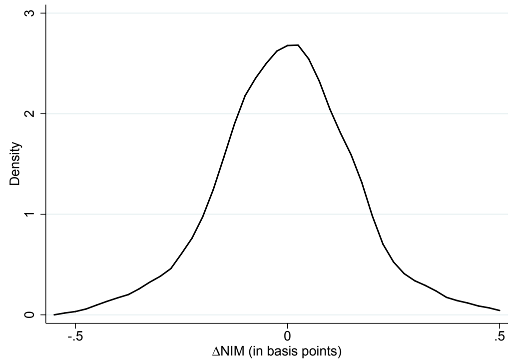
This table provides cross-sectional summary statistics for the interest rate risk exposures of households (ΔPV^{HH}) based on their assets (sight and term deposits) and liabilities (loans) on the balance sheet of our 104 sample banks. Numbers are expressed in bps (i.e. 1/10000) of total bank assets. These sensitivities are computed as the change in present value following a 1 bp parallel upward shift in the yield curve. $\Delta PV^{HH}_{Variable}$ and ΔPV^{HH}_{Fixed} denote the exposures based on banks residing in countries with predominantly variable-rate and fixed-rate mortgages, respectively.

Figure 1: Banks' exposure to interest rate risk

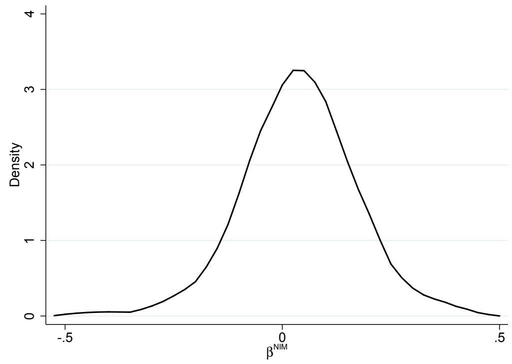
Panel A: ΔPV



Panel B: ΔNIM



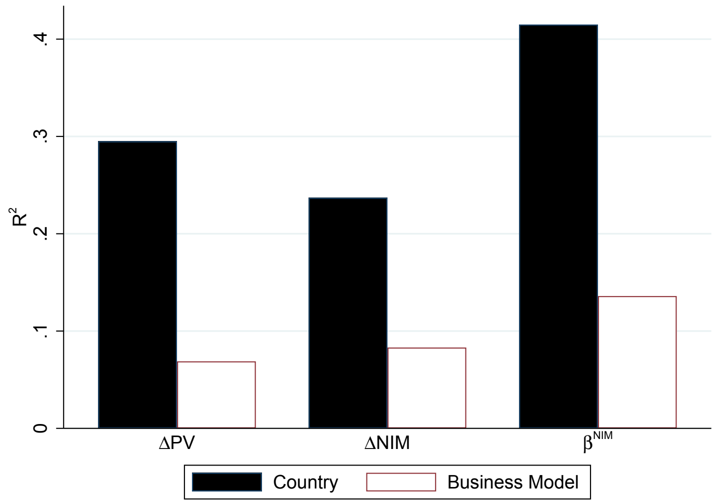
Panel C: β^{NIM}



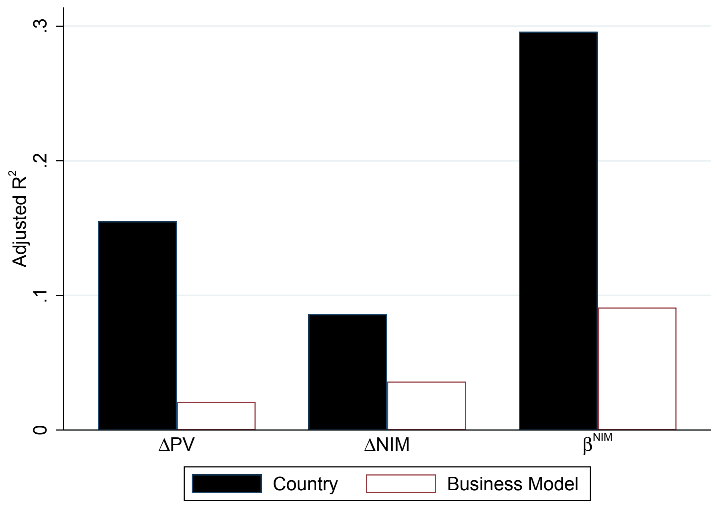
This figure depicts the kernel density estimates for the cross-sectional distributions of three different measures of interest rate risk for the 104 sample banks. Panel A refers to ΔPV, Panel B to ΔNIM, and Panel C to β^{NIM}. Panels A and B are expressed in basis points relative to bank assets. All figures were generated using an Epanechnikov kernel with optimal bandwidth.

Figure 2: Variation across countries and business models

Panel A: R-squared

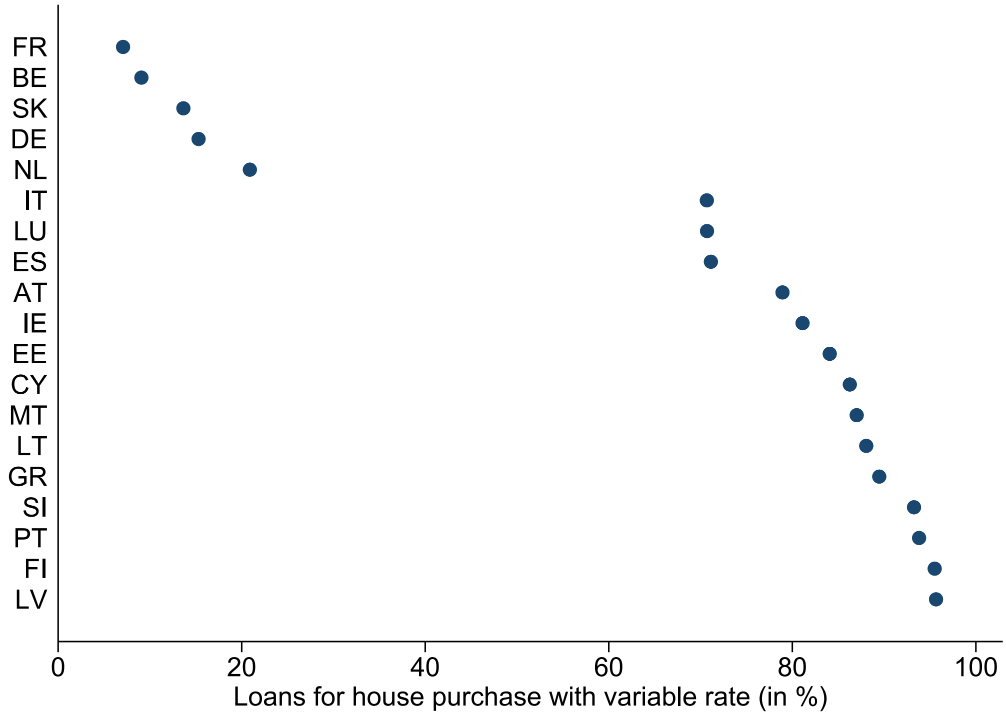


Panel B: Adjusted R-squared



This figure depicts the R-squared (Panel A) and adjusted R-squared (Panel B) resulting from cross-sectional regressions of the three different measures of interest rate risk on sets of 18 country and 9 business model dummy variables, respectively.

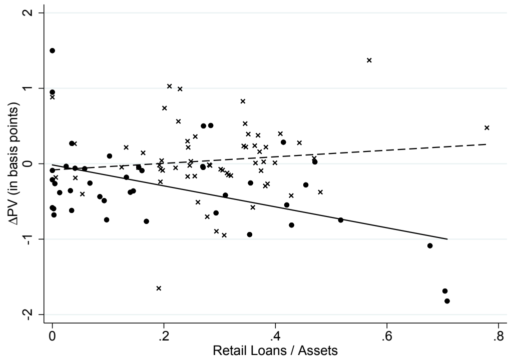
Figure 3: Variable-rate mortgages in euro area countries



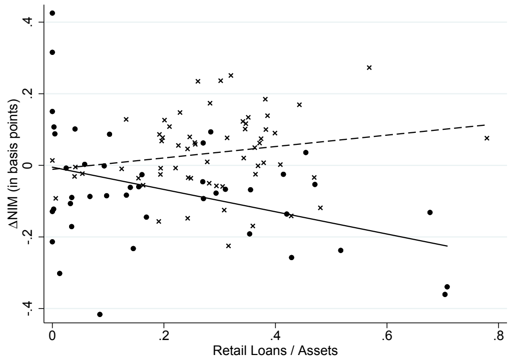
This figure reports the share of new mortgages with variable interest rate averaged over the period 2011-15 for individual euro area countries. A loan is defined to have a variable rate if the initial period of rate fixation is one year or less. The data are taken from the ECB's Statistical Data Warehouse (Series SVLHPHH), available at http://sdw.ecb.europa.eu.

Figure 4: Banks' exposure to interest rate risk and retail lending

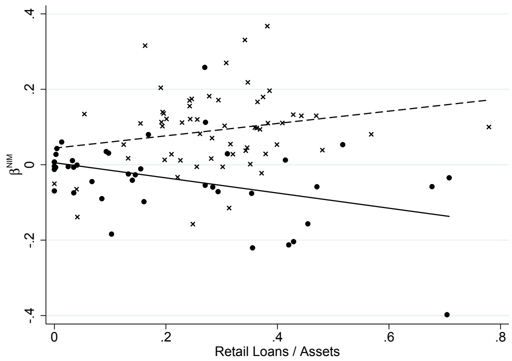
Panel A: ΔPV



Panel B: ΔNIM



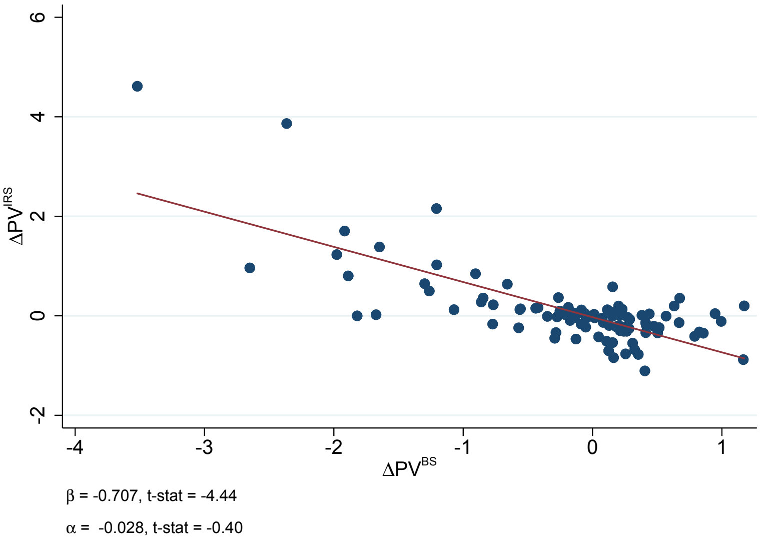
Panel C: β^{NIM}



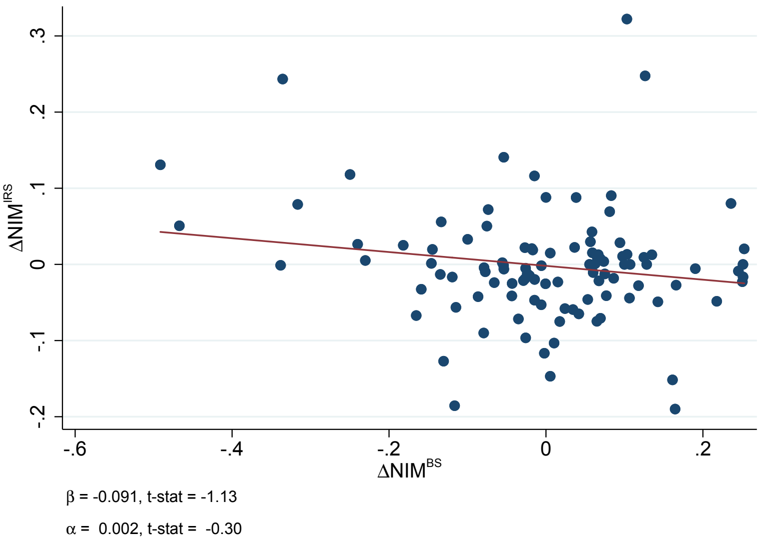
This figure presents scatterplots with banks' exposure to interest rate risk on the vertical axis, and the share of retail lending on the horizontal axis. Panel A refers to ΔPV, Panel B to ΔNIM, and Panel C to β^{NIM}. Circles (Xs) represent banks residing in countries with predominantly fixed-rate (variable-rate) mortgages, and the solid (dashed) line indicates the associated regression line for this group.

Figure 5: On- vs. off-balance sheet exposures to interest rate risk

Panel A: PV^{IRS} vs PV^{BS}

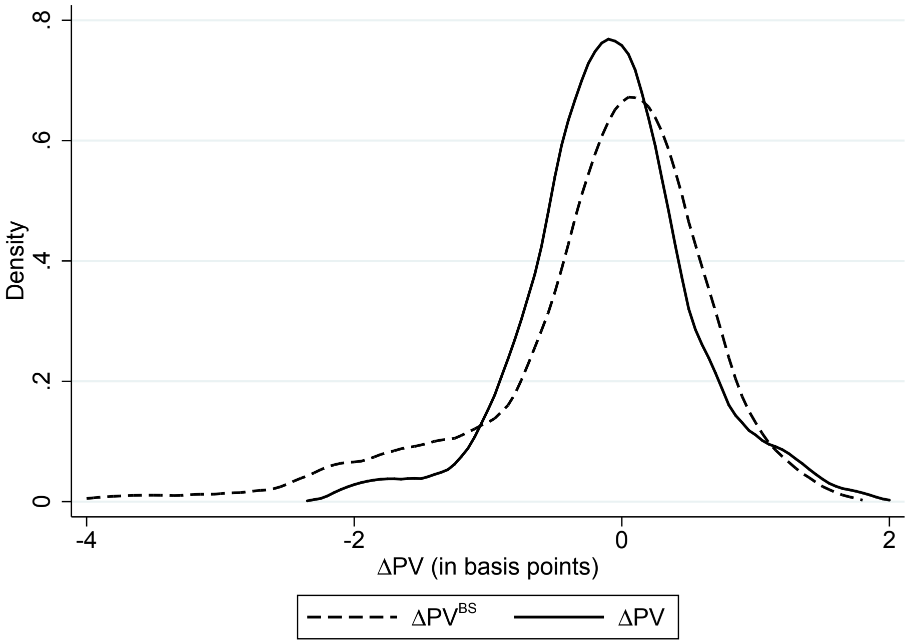


Panel B: ΔNIM^{IRS} vs ΔNIM^{BS}



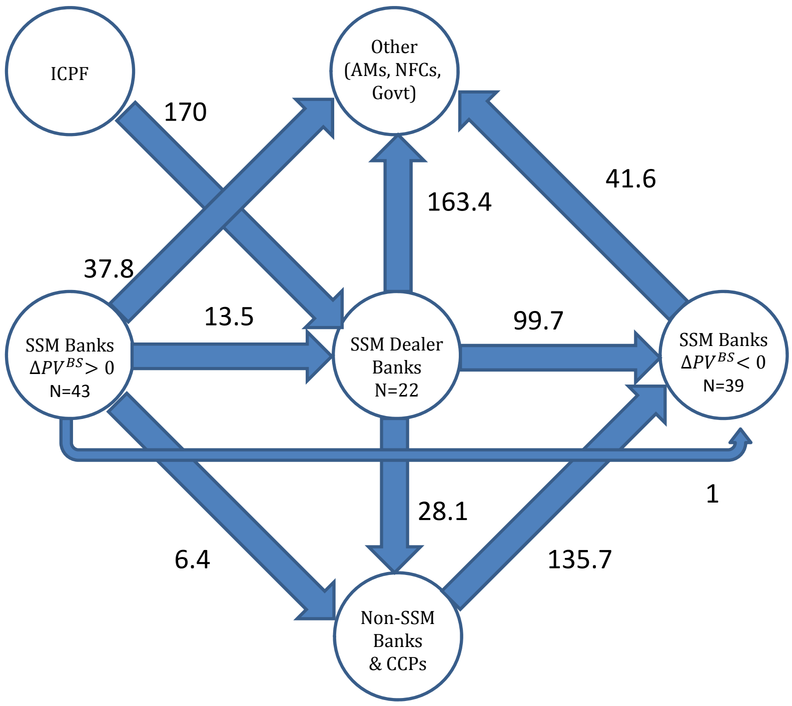
Panel A (B) of this figure presents a scatter plot with ΔPV^{IRS} (ΔNIM^{IRS}) on the vertical axis, and ΔPV^{BS} (ΔNIM^{BS}) on the horizontal axis for our sample of 104 euro area banks. Numbers are given in basis points. The solid line indicates the respective fit of a linear regression. The coefficient estimates for slope and constant are given below the graph, together with t-statistics based on standard errors clustered at the country-level.

Figure 6: Banks' exposures before and after hedging



This figure plots the kernel density estimates for the cross-sectional distributions of ΔPV^{BS} (dashed line) and ΔPV (solid line). Numbers are expressed in basis points. The figures were generated using an Epanechnikov kernel with optimal bandwidth.

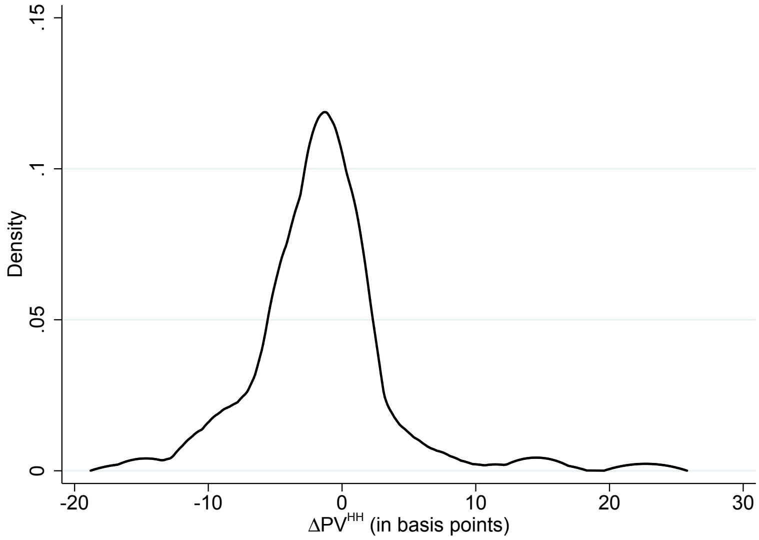
Figure 7: Risk sharing in the IRS market



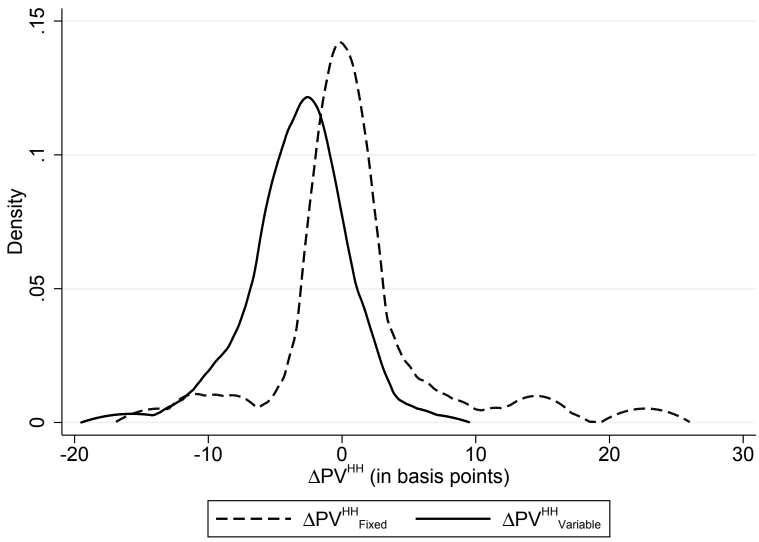
This figure depicts a stylized representation of risk sharing in the interest rate swap market. The numbers denote the wealth transfers (in €mn) between groups of market participants arising from a 1 bp parallel upward shift in the yield curve, while the arrows indicate the direction of the transfer. The 104 sample banks are split into three groups: "SSM Dealer Banks" are banks with more than 2,000 outstanding derivatives contracts with the largest CCP. "SSM Banks $\Delta PV^{BS} > 0$" ("SSM Banks $\Delta PV^{BS} < 0$") represents the group of banks whose value of the banking book appreciates (depreciates) following an increase in interest rates. "ICPF" denotes insurance companies and pension funds; "Other" comprises asset managers, governments, non-financial corporations, and non-classified counterparties; while "Non-SSM Banks & CCPs" includes banks other than those in our sample, as well as central clearing counterparties. These numbers are based on trade-level trade repository data as of 31/12/2015 and were obtained from DTCC-DDRL and Regis-TR.

Figure 8: On- vs. off-balance sheet exposures to interest rate risk

Panel A: ΔPV^{HH}



Panel B: ΔPV^{HH} across country groups



This figure the kernel density estimates of the cross-sectional distribution of ΔPV^{HH} for the 104 sample banks. Numbers are expressed in basis points. Panel A refers to the entire sample, while Panel B splits the sample into banks from countries with predominantly fixed-rate mortgages (dashed lines) and variable-rate mortgages (solid line). The figures were generated using an Epanechnikov kernel with optimal bandwidth.

Appendix

A Construction of the data

In this section, we provide additional information on our two main datasets.

A.1 Maturity breakdown of items in the banking book

Assets and liabilities residing in the banking book are broken down into 14 buckets based on their re-pricing maturity. These buckets are defined as follows: at sight, <1m, 1m-3m, 3m-6m, 6m-1y, 1y-2y, 2y-3y, 3y-4y, 4y-5y, 5y-7y, 7y-10y, 10y-15y, 15y-20y, >20y. For comparison, there are only 6 maturity buckets in the U.S. call reports, and the decomposition is not available for all assets and liabilities (English, Van den Heuvel, and Zakrajsek, 2018). Furthermore, assets are partitioned into loans and debt securities held, while liabilities are categorized into sight deposits, term deposits, and securities issued. Sight deposits are further decomposed into the following four groups: retail, corporate, banks, and other (mostly non-bank financial institutions). Amortizing loans are split across different buckets according to their amortization schedule.

A.2 Derivatives data

Since February 2014, all derivatives transactions (both new and outstanding) with at least one counterparty residing in the European Union have to be reported under the European Markets Infrastructure Regulation (EMIR). EMIR is the European analogue of the U.S. Dodd-Frank Act, and implements the G20 pledge to increase transparency and resilience in global OTC derivatives markets. See Abad, Aldasoro, Aymanns, D'Errico, Fache Rousova, Hoffmann, Langfield, Neychev, and Roukny (2016) for a detailed description of the data reported under EMIR.

We use data provided by DTCC-DDRL and Regis-TR, the two trade repositories to which virtually all euro area banks report their interest rate derivatives transactions.[27]

[27] The only other trade repository with a significant share of the European interest rate swap market is Unavista. However, its market share is driven by the activity of Europe's largest clearing house, LCH.Clearnet, which reports all of its activity to Unavista. Due to the two-sided nature of the reporting obligation under EMIR, our data already capture trades cleared with LCH.Clearnet. Indeed, all clearing members report to either DTCC-DDRL or Regis-TR.

Each transaction report contains about 80 variables. Given that the balance sheets of most institutions in our sample are heavily concentrated in euro-denominated instruments, we restrict the dataset to derivatives contracts using the euro interbank offered rate (Euribor) or the euro overnight index average (Eonia) as reference rates. Moreover, we disregard cross-currency swaps, basis swaps, and contracts with embedded options.

Our data provide comprehensive coverage of interest rate swaps. Unlike Dodd-Frank, EMIR requires both counterparties to report every transaction. This implies that we observe a derivative transaction when at least one of the counterparties is resident in the European Union. In addition, the double-sided reporting obligation allows us to complete missing information by matching, on a transaction-by-transaction basis, the individual reports submitted by both counterparties. Finally, we perform a number of data quality checks and discard a few erroneous reports (e.g. contracts with implausible notional values).

In the last stage, we consolidate swap portfolios at the group level, that is, we include positions held by subsidiaries and exclude intragroup trades. Our mapping of banking groups is based on supervisory information available at the ECB. Whenever possible, we cross-check this information with data on ownership structure from Orbis. In addition, we manually scan banks' largest swap exposures and cross-check the data with annual reports in order to identify other consolidated entities, e.g., special purpose vehicles.

B Online Appendix for "Who bears interest rate risk"

For online publication only.

In this Online Appendix, we provide additional material not reported in the main text for brevity.

B.1 Deposit durations and pass-through rates

In order to verify that the estimated durations of sight deposits are related to banks' market power, we examine their correlation with the pass-through from market interest rates to institutions' own deposit rates. To this end, we collect monthly data on interest rates paid on retail and corporate sight deposits from the "Individual MFI Interest Rate Statistics" (IMIR) maintained by the ECB. We require these data to have a complete history since inception in 2007, which is the case for 73 banks in the case of retail deposits and 66 banks for corporate deposits. We then estimate time-series regressions at the bank level of changes in deposit rates on contemporaneous changes in the 3-month Euribor rate and two lags and define pass-through as the sum of the resulting regression coefficients. In a second step, we run cross-sectional regressions of deposit durations on the estimated pass-through rates. Table B.1 shows that higher reported deposit durations are associated with lower pass-through rate, and thus reflect banks' market power in both retail and corporate deposit markets.

Table B.1: Deposit durations and pass-through rates

	(1) Duration Retail	(2) Duration Corporate
PT^{Retail}	-2.438***	
	(3.04)	
$PT^{Corporate}$		-1.170**
		(-2.70)
Constant	2.953	2.027
	(6.61)	(7.59)
R-squared	0.177	0.070
N	73	66

This table contains the estimated coefficients from a cross-sectional regression of sight deposit durations (detailed in Table 3) on the corresponding pass-through coefficients. Colum (1) refers to retail deposits, while column (2) refers to deposits by non-financial corporations. The pass-through coefficients PT^{Retail} and $PT^{Corporate}$ are estimated by regressions of bank-level changes in deposit rates on changes in the 3-month Euribor rate and two lags using monthly data from the ECB individual interest rate statistics (IMIR). Standard errors are clustered at the country level.

B.2 Continuous variable for loan-rate fixation conventions

Throughout the paper, we have used a dummy variable (VRM) to capture the effect of loan-rate fixation conventions. Here, we present the main results from column (2) of Table 6 when using a continuous variable instead. Here, $\%VRM$ denotes the 5-year average of the share of variable-rate mortgages at the country level. The results are given in the table below. They are very similar to those obtained using the dummy variable.

Table B.2: Explaining banks' exposure to interest rate risk - VRM as continuous variable

	ΔPV	ΔNIM	β^{NIM}
Constant	0.023	-0.002	0.005
	(0.08)	(-0.08)	(0.25)
$\%VRM$	-0.002	-0.000	0.001
	(-0.64)	(-0.21)	(1.03)
Retail Loans/Assets	-1.642*	-0.375**	-0.261***
	(-2.07)	(-2.37)	(-3.48)
$\%VRM \times$ *Retail Loans/Assets*	0.028**	0.006**	0.005***
	(2.52)	(2.73)	(3.25)
R-squared	0.174	0.195	0.303
N	104	104	102

This table provides the coefficient estimates for cross-sectional regressions of bank-level exposures to interest rate risk on a set of determinants. Column (1) presents the results for the net-worth sensitivity ΔPV, while columns (2) and (3) refer to the income sensitivity ΔNIM and β^{NIM}, respectively. $\%VRM$ denotes the average fraction of mortgage loans with variable interest rate at the country level for the period 2011-15. *Retail Loans/Assets* denotes the ratio of retail loans to total assets. $\%VRM \times$ *Retail Loans/Assets* denotes the product of the previous two variables. t-statistics in parentheses are based on standard errors clustered at the country level.

B.3 Loan-rate fixation conventions in corporate loans

In Section 4.3, we show that loan-rate fixation conventions in mortgage markets are a key driver of banks' expossure to interest rate risk. While there is also some cross-country heterogeneity in loan-rate fixation conventions for corporate loans, the differences across the two country groups are much more muted (the difference in the means of the two groups is around 35% for loans, compared to 71% for mortgages). The following table presents the coefficient estimates from regressions of exposures on the VRM dummy, retail and corporate loans (relative to total assets) as well as their interaction with the VRM dummy. As can be seen, there is only weak evidence that loan-rate fixation conventions for corporate loans significantly affect banks' exposure to interest rate risk. The coefficient of the interaction between corporate loans and the VRM dummy is only statistically significant for one measure (i.e. β^{NIM}).

Table B.3: The role of loan-rate fixation conventions in corporate loans

	ΔPV	ΔNIM	β^{NIM}
Constant	-0.305*	0.0365	0.0234*
	(-2.02)	(0.49)	(1.99)
VRM	0.145	-0.0482	-0.0649
	(0.46)	(-0.50)	(-1.39)
Retail Loans/Assets	-1.869***	-0.325**	-0.220***
	(-3.72)	(-2.29)	(-3.47)
VRM × *Retail Loans/Assets*	1.740**	0.490**	0.438***
	(2.53)	(2.74)	(4.59)
Corporate Loans/Assets	0.0892	-0.213	-0.0610
	(0.33)	(-0.74)	(-0.93)
VRM × *Corporate Loans/Assets*	-0.533	0.208	0.334**
	(-0.76)	(0.64)	(2.20)
R-squared	0.338	0.243	0.372
N	104	104	102

This table provides the coefficient estimates for cross-sectional regressions of bank-level exposures to interest rate risk on a set of determinants. ΔPV, β^{NIM} and ΔNIM denote the three measures of interest rate risk defined in Section 3.1. VRM denotes a dummy variable that is equal to one for banks located in countries where mortgages are predominantly variable-rate loans, and zero otherwise. *Retail Loans/Assets* and *Corporate Loans/Assets* denote the ratio of retail and corporate loans to total assets, respectively. t-statistics in parentheses are based on standard errors clustered at the country level.

B.4 Weighted distributions

Table 1 reveals that banks are quite heterogeneous in terms of size. A natural question is thus whether the documented cross-sectional is mainly driven by smaller banks. Below, we tabulate the same cross-sectional distributions of banks' exposures, but weighted by bank size. We also re-estimate the regressions from column (2) of Table 6 with observations weighted by assets. The results are very similar those reported in the main text.

Table B.4: Banks' exposure to interest rate risk - weighted by assets

	Mean	StDev	P25	Median	P75
ΔPV	-0.11	0.48	-0.36	-0.09	0.24
ΔNIM	-0.02	0.11	-0.08	-0.03	0.06
β^{NIM}	0.00	0.10	-0.06	-0.02	0.10

This table presents summary statistics on banks' total exposure to interest rate risk for the cross-section of the 104 euro area banks in our sample, weighted by total assets. ΔPV is a net-worth sensitivity based on changes in present values. ΔNIM is an income sensitivity and computed based on the income gap (assets and liabilities with a re-pricing maturity of less than one year). β^{NIM} is the sum of the regression coefficients from a regression of change in net interest income on changes in the 3-month Euribor rate.

Table B.5: Explaining banks' exposure to interest rate risk - weighted by assets

	ΔPV	ΔNIM	β^{NIM}
Constant	0.0455	-0.182	-0.000
	(-0.78)	(0.38)	(-0.00)
VRM	-0.176	-0.028	0.099***
	(-0.78)	(-0.25)	(4.02)
Retail Loans/Assets	-1.303	-0.328	-0.231**
	(-1.36)	(-1.36)	(-2.76)
VRM × *Retail Loans/Assets*	2.211**	0.465**	0.241**
	(2.14)	(2.20)	(2.63)
R-squared	0.263	0.282	0.573
N	104	104	102

This table provides the coefficient estimates for cross-sectional regressions of bank-level exposures to interest rate risk on a set of determinants. Column (1) presents the results for the net-worth sensitivity ΔPV, while Column (2) and (3) refer to the income sensitivity ΔNIM and β^{NIM}, respectively. *VRM* denotes a dummy variable that is equal to one for banks located in countries where mortgages are predominantly variable-rate loans, and zero otherwise. *Retail Loans/Assets* denotes the ratio of retail loans to total assets. *VRM* × *Retail Loans/Assets* denotes the product of the previous two variables. t-statistics in parentheses are based on standard errors clustered at the country level.

B.5 Adding information on the trading book

We show that our results are robust to the inclusion of trading book exposures to interest rate risk. Banks face different reporting requirements for interest rate risk in the trading book, and are thus not required to report the maturity breakdown. Fortunately, 86 of our sample banks provide a maturity breakdown on a voluntary basis. We therefore replicate our main results after adding trading book exposures for this subset of banks.

We compute the interest rate sensitivity of trading book exposures, denoted ΔPV^{TB}, using the same methodology used for the banking book. We then re-compute the on-balance sheet exposure based on exposures from both the trading and the banking book, denoted $\Delta PV^{BS'}$. The revised total exposure is then given by

$$\Delta PV' = \Delta PV^{BS'} + \Delta PV^{IRS}.$$

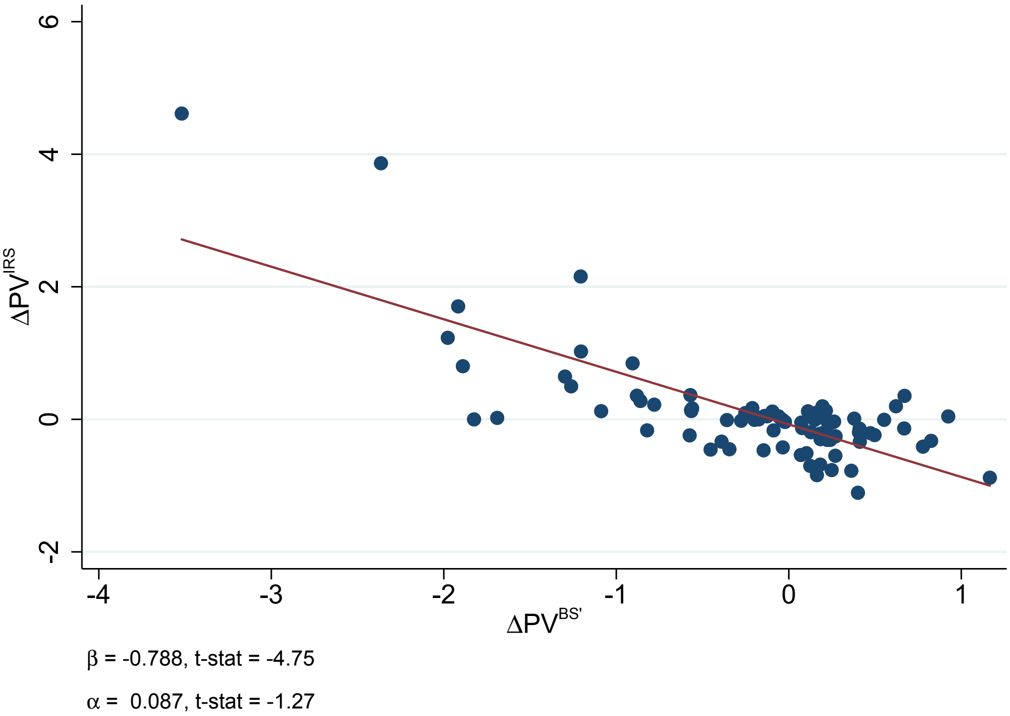
Table B.6 shows that accounting for trading book positions has a minor effect on banks' exposures. For illustration, Figure B.1 shows a scatterplot of ΔPV^{IRS} on the vertical axis and $\Delta PV^{BS'}$ on the horizontal axis and the associated fit from a linear regression. The resulting estimates are very close to those obtained without considering information from the trading book.

Table B.6: Adding information on the trading book

	Mean	StDev	P25	Median	P75
ΔPV^{TB}	-0.02	0.05	-0.02	-0.01	-0.00
$\Delta PV^{BS'}$	-0.21	0.79	-0.56	-0.03	0.24
$\Delta PV'$	-0.13	0.55	-0.47	-0.09	0.21

This table presents the cross-sectional distributions for the subsample of 86 banks for which the breakdown of assets and liabilities in the trading book into maturity buckets is available. ΔPV^{TB} denotes the interest rate risk sensitivity of the trading book; $\Delta PV^{BS'}$ denotes the interest rate risk sensitivity of on-balance sheet items from both the trading book and the banking book; and $\Delta PV'$ denotes the total exposure, computed as $\Delta PV^{BS'} + \Delta PV^{IRS}$.

Figure B.1: Adding information on the trading book: on- and off-balance sheet exposures



This figure presents a scatter plot with PV^{IRS} on the vertical axis, and $PV^{BS'}$ on the horizontal axis for the subsample of 86 banks with available information on the trading book. Numbers are expressed in basis points relative to total assets. The solid line indicates the fit of a linear regression. The coefficient estimates for slope and constant are given below the graph, together with t-statistics based on standard errors clustered at the country level.

B.6 Differences between ΔPV and income-based measures

ΔPV is net-worth sensitivity based on the NPV of the Gap (see Section refsec:measures). It can from income-based measures for a number of reasons. While we do not aim to be comprehensive, we highlight three different channels. First, ΔPV consider the entire balance sheet, while income-based measure have a more short-term focus. This is especially true for ΔNIM, but data limitations also require us to estimate β^{NIM} on a relatively short time series. Second, we have shown in Section 5 that banks hedge present-value risk, but not income risk. Hence, derivative positions are likely to explain discrepancies across measures. Third, ΔPV assumes perfect pass-through of interest rate changes to all interest rates. However, β^{NIM} may pick up variation in income that arises from changes credit spreads that is not captured by ΔPV (and neither by ΔNIM). To assess for which banks measures display higher (lower) variation, we define the composite index CI and then compute the within-bank standard deviation σ to assess how much measures disagree for a given bank. More specifically, we define

$$CI^{\Delta} = \frac{1}{2}\widehat{\Delta PV} + \frac{1}{2}\widehat{\Delta NIM} \tag{B.1}$$
$$CI^{\beta} = \frac{1}{2}\widehat{\Delta PV} + \frac{1}{2}\widehat{\beta^{NIM}} \tag{B.2}$$

and

$$\sigma^{\Delta} = \sqrt{\frac{1}{2}(\widehat{\Delta PV} - CI^{\Delta})^2 + \frac{1}{2}(\widehat{\Delta NIM} - CI^{\Delta})^2} \tag{B.3}$$
$$\sigma^{\beta} = \sqrt{\frac{1}{2}(\widehat{\Delta PV} - CI^{\beta})^2 + \frac{1}{2}(\widehat{\beta^{NIM}} - CI^{\beta})^2} \tag{B.4}$$

where hats denote variables standardized by subtracting the cross-sectional mean and dividing by the cross-sectional standard deviation. We then regress the σ on the following three explanatory variables. First, we use $|\Delta PV^{IRS}|$, defined in Section 5 in order to proxy for the magnitude of banks' derivative activity. Second, we define $|\Delta Gap| = |\sum_{s=0}^{\infty} Gap_{t+s} - Gap_{t+5}|$ as the absolute value of the difference in the Gap (defined in 3.1) across the entire balance sheet and the Gap up to a maturity of five years.

This captures the "long-term" part of net worth. Finally, we use the ratio of total assets to risk-weighted assets, denoted by $Risk$, to proxy for banks' exposure to credit spreads. The table below details the regression results. Overall, the results are consistent with the various sources of discrepancies mentioned above. We also verify column(5) that there is no structural difference across country groups in terms of how well measures line up.

Table B.7: Differences between ΔPV and income-based measures of IRR

	(1)	(2)	(3)	(4)	(5)
			Panel A: σ^{Δ}		
Constant	0.423***	0.345***	0.610***	0.336**	0.327**
	(8.72)	(4.75)	(5.35)	(2.24)	(2.16)
$\|\Delta PV^{IRS}\|$	0.135**			0.125*	0.124*
	(2.13)			(1.76)	(1.74)
$\|\Delta Gap\|$		0.046**		0.047**	0.048**
		(2.16)		(2.25)	(2.28)
Risk			-0.309	-0.096	-0.009
			(-1.27)	(-0.36)	(-0.03)
VRM					-0.0549
					(-0.53)
R-squared	0.043	0.044	0.016	0.089	0.091
N	104	104	104	104	104
			Panel B: σ^{β}		
Constant	0.601***	0.509***	0.630***	0.042	0.034
	(9.18)	(5.15)	(3.99)	(0.21)	(0.17)
$\|\Delta PV^{IRS}\|$	0.241***			0.356***	0.355***
	(2.82)			(3.80)	(3.77)
$\|\Delta Gap\|$		0.068**		0.070**	0.071**
		(2.37)		(2.58)	(2.59)
Risk			0.152	0.754**	0.827*
			(0.45)	(2.11)	(1.94)
VRM					-0.0444
					(-0.32)
R-squared	0.074	0.054	0.002	0.177	0.178
N	102	102	102	102	102

This table presents coefficient estimates from regressions of bank-level disagreement in interest rate risk measures on a number of explanatory variables. All variables are defined above. Standard errors are clustered at the country level.