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# What drives the short-term fluctuations of banks' exposure to interest rate risk?

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## Abstract

We investigate whether banks actively manage their exposure to interest rate risk in the short run. Using bank-level data of German banks for the period 2011Q4–2017Q2, we find evidence that banks actively manage their interest rate risk exposure in their banking books. Specifically, they adjust their exposure to the earning opportunities presented by this risk, take account of their regulatory situation, and manage this exposure using interest swaps. We also find that the fixed-interest period of housing loans has an impact on the banks' overall exposure to interest rate risk. This last finding, in combination with the empirical evidence that customer preferences predominantly determine the fixed-interest period of these loans, is not in line with active interest rate risk management.

## KEYWORDS

fixed-interest period of housing loans, interest rate risk in the banking book, interest swaps, regulation of interest rate risk

## JEL CLASSIFICATION

G21

## 1 | INTRODUCTION

Banks usually grant long-term loans and finance their operations with short-term deposits. This maturity mismatch exposes them to interest rate risk, leaving them vulnerable to sudden increases in the interest level. This issue is relevant not only for banking supervisors, but for macro-prudential supervisors as well because—unlike credit risk, which has a huge bank-specific component—this risk is barely diversifiable (see Hellwig (1994)) and, therefore, affects many banks at the same time and in same way.

In this paper, we investigate the short-run changes in the exposure to this risk. In particular, we explore whether banks actively manage this risk in the short term. The answer to this question is less trivial than it might seem. Instead of actively managing its exposure to interest rate risk, a bank may treat interest rate risk as a by-product of the loan-granting business and let its exposure to this risk fluctuate randomly, depending on the demand for long-term loans.

To learn about the banks' management of interest rate risk, we look at four issues which are closely connected to the question of whether or not banks actively manage their exposure to interest rate risk in the short run.

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First, earnings from bearing interest rate risk are one component of a bank's overall earnings, and Busch and Memmel (2016) show that this contribution can be huge, amounting to around one-third of net interest income for the average bank in Germany. If this source of income is relevant for a bank, it will adjust its exposure to this risk when its remuneration increases or decreases.

Second, a bank's exposure to interest rate risk is monitored by the supervisor. Until recently, there had been no obligation to back this exposure (in the banking book) with regulatory capital. There was, however, a threshold for the Basel interest coefficient, a measure for a bank's exposure to interest rate risk, above which banks ranked among banks with elevated interest rate risk exposure. We look whether banks whose exposure exceeded this threshold reduced their exposure in the subsequent quarter.

Third, a lot of banks use interest swaps, and we check whether they use them to hedge their interest rate risk exposure.

Fourth, if banks try to keep their interest rate risk exposure at what they feel to be an ideal level and, at the same time, fulfill their customers' wishes regarding the loans' fixed-interest periods, they will pass through possible changes in their customers' desired fixed-interest periods to the anonymous financial markets, for instance, by way of appropriate interest swap positions. In other words, we look at the hypothesis according to which customers from the real economy predominantly determine the fixed-interest period of their loans and banks offset the resulting interest rate risk imbalances with suitable transactions in the capital market. According to Basten, Guin, and Koch (2017), this hypothesis is widespread. However, there is empirical evidence that market frictions make banks prefer certain fixed-interest periods for their loans. For instance, Fuster and Vickery (2015) find that banks are reluctant to grant fixed-rate mortgages if these mortgages cannot be readily securitized.

We investigate the above hypothesis because if this hypothesis were supported, it would provide additional evidence that banks actively manage their interest rate risk exposure. This hypothesis is checked using housing loans to private households. We believe that housing loans are the most suitable bank product from which to infer preferred fixed-interest periods for the following reasons. First, changes in market interest rates are passed through almost entirely to the corresponding bank rates (see Schlueter, Busch, Hartmann-Wendels, and Sievers (2016)). This means that the fixed-interest periods of housing loans mirrors the actual length of the fixed-interest period, unlike, for instance, customer deposits where *de jure* and *de facto* maturities and thus the fixed-interest periods largely differ. Second, housing loans represent a huge part of banks' loans to non-banks, with the result that their fixed-interest periods have a significant impact on banks' interest rate risk position.<sup>1</sup> If the above hypothesis holds, then changes in these loans' fixed-interest period will not have any impact on the banks' overall exposure to this risk.

We have at our disposal a measure for a bank's exposure to interest rate risk, namely the present value change of a bank's assets and liabilities (including derivatives, but without trading book positions) as a consequence of a parallel shift of the term structure. In our empirical study of German banks for the period 2011Q4–2017Q2, we find evidence that banks actively manage their exposure to interest rate risk in the short run. Specifically, banks adjust their interest rate risk exposure to the remuneration of this risk, take account of their regulatory situation when they adjust their interest rate risk exposure, and manage their exposure to this risk with interest swaps. We also find that the fixed-interest periods of housing loans are predominantly determined by the customers and that the overall exposure of a bank to interest rate risk rises when the fixed-interest period of its new housing loans increases. The last result, in combination with the finding that it is primarily the customers (and not the banks) who determine the fixed-interest period of housing loans, is evidence against active interest rate risk management and indicates that there is still a connection between the granting of housing loans and a bank's overall exposure to interest rate risk. Our results suggest that, within one quarter, banks offset only 11.4% of those changes in interest rate risk exposure that result from the housing loan business.

The paper is structured as follows: Section 2 gives a brief overview of the literature in this field. The empirical models are described in Section 3. Section 4 explains the data used and Section 5 provides the empirical results. Section 6 concludes.

## 2 | LITERATURE

This paper contributes to the literature on how the customer preferences concerning interest rate risk determine bank exposure to this risk. Basten et al. (2017) analyze customers' choice of fixed versus variable interest rate mortgages in Switzerland where their data allows them to distinguish between demand and supply. They find that the customer demand for a certain fixed-interest period is largely determined by the steepness of the term structure—the greater the steepness, the lower the fixed-interest period which customers demand. We also explore this question by investigating the fixed-interest periods of housing loans, and we look whether their fixed-interest periods become smaller or larger when the steepness of the term structure increases. We do not have separate data on demand and supply like Basten et al. (2017) do, but only data on the market outcome. We try to derive statements on the relationship of the fixed-interest periods of loans and the steepness of the term structure, using only this limited information. In this context, we make use of the character of bank loans: for a bank, they are an asset and, for the customers, they are a liability, meaning a change in the term structure that is beneficial for the banks is detrimental to their customers and vice versa. What we see is that there is a strongly negative relationship between the steepness of the term structure and the fixed-interest period of new

German housing loans, meaning that the determination of the fixed-interest periods seems to be mainly demand driven. This need not be in contrast with the finding in the literature that some market imperfections mean that banks also have an impact on the market outcome of fixed-interest periods. We are not claiming that banks have no influence at all, but that the empirical results suggest that the influence of customers is stronger. By contrast, Kirti (2017) theoretically and empirically shows that firms' decisions to take out floating interest rate loans are driven predominantly by banks' supply of these loans. In our empirical study, we further show that customers' fixed-interest period preferences are not only a determinant of banks' on-balance-sheet interest rate risk exposure, but also they have an impact on banks' overall interest rate risk exposure as well. We quantify the part of the change in interest rate risk exposure resulting from housing loans that is closed by appropriate on- and off-balance-sheet positions.

This paper also contributes to the literature by exploring whether and how firms tactically manage their interest rate risk (see for banks, e.g., Brewer, Jackson, and Moser (2001), Brewer, Minton, and Moser (2000), Begenau, Piazzesi, and Schneider (2015) and Drechsler, Savov, and Schnabl (2018) and for non-financial firms, e.g., Oberoi (2018)). Purnanandam (2007), Memmel and Schertler (2013), and Hoffmann, Langfield, Pierobon, and Vuillemeys (2018) show that US, German and European banks, respectively, use interest rate swaps, on average, for hedging purposes. However, Begenau et al. (2015) find the opposite for US banks, that is, that US banks use interest swaps to increase their position in interest rate risk. As to this risk, Memmel (2011) finds that the exposure to interest rate risk in the subsequent quarter is reduced when the exposure exceeds a regulatory threshold. In our study, we provide evidence that banks use swaps to manage their interest rate risk and that the exceedance of this regulatory threshold has the expected impact on a bank's exposure to overall interest rate risk.

Finally, this paper contributes to the question of what determinants drive banks' net interest margins (see, e.g., Maudos and de Guevara (2004)) where the earnings from bearing interest rate risk represent a substantial part; for instance, Busch and Memmel (2016) find that these earnings accounted for around one-third of the average German bank's net interest margin in 2012 and 2013. Memmel (2011) and Chaudron (2018) find that a bank's interest rate risk exposure moves in sync with the earning opportunities from interest rate risk. We also find evidence that banks' exposure to interest rate risk depends on the earning opportunities from bearing interest rate risk: Establishing a passive trading strategy that consists in investing in default-free par-yield bonds with a maturity of 10 years in a revolving manner and in financing this investment by issuing bonds with 1 year of maturity in a revolving manner, we find that banks increase their interest rate risk exposure when the earnings of this passive trading strategy go up.

In this paper, we look at interest rate risk. This risk can be, but need not be, bundled together with the risk from maturity transformation. For instance, a 10-year bond with a floating interest rate, that is, a coupon that is linked to a short-term interest rate like the 3-month Euribor, has zero or little interest rate risk. However, owing to its long capital commitment period, it bears a great deal of risk from maturity transformation.

### 3 | EMPIRICAL MODEL

#### 3.1 | Managing interest rate risk

In our empirical study, we explain the change in a bank's exposure to interest rate risk, where we quantify the exposure to this risk using a measure *irr* which is much like the Basel interest rate coefficient. This measure can be seen as a bank's present value losses due to a standardized interest rate shock, normalized with the bank's equity (see Section 4 for a detailed description). It can also be interpreted as a multiple of the duration of the banking book (normalized with the bank's equity), meaning that the exposure to interest rate risk is separated from the volatility of the interest level. This can be compared to the risk of a stock position, which is the risk of the stock times the position in the stock. In this analogy, our measure *irr* corresponds to the position in interest-bearing assets and liabilities.

Specifically, we run the following panel regression, where the indexes *t* and *i* stand for the point in time and the bank, respectively.

$$\Delta irr_{t,i} = \alpha + \beta_1 \cdot \Delta \mu_t + \beta_2 \cdot \Delta reg_{t,i} + \beta_3 \cdot \Delta swap_{t,i} + \beta_4 \cdot \Delta fip_{t,i} + \gamma_1 \cdot \Delta CR_{t,i} + \varepsilon_{t,i} \quad (1)$$

The explanatory variables are described in the following.<sup>2</sup> Interest rate risk is sometimes interpreted as a market risk like any of the others that banks are exposed to. In this case, we would expect the exposure to this risk to increase as the remuneration for bearing this risk rises (see, e.g., Fishburn and Porter (1976)).<sup>3</sup> Therefore, we include the earning opportunities from interest rate risk in Equation (1), where the variable  $\Delta \mu_t$  denotes the change in the earnings from a passive trading strategy in German government bonds that is only subject to interest rate risk (see Section 4 for a description and Memmel (2011) for an application of this trading strategy in this context).

A bank may be prevented from extending or maintaining its exposure to interest rate risk for regulatory reasons. As done in Memmel (2011), we introduce the dummy variable  $reg_{t,i}$  which takes the value 1 if bank  $i$ 's interest rate risk exposure in time  $t-1$ , that is, in the previous quarter, was higher than 20%, a regulatory threshold above which a bank ranks among the banks with elevated interest rate risk exposure.

To explore whether banks use derivatives to manage their interest rate risk exposure, we include the dummy variable  $\Delta swap_{t,i}$  in the regression (1). The dummy variable  $swap_{t,i}$  takes the value of 1 if bank  $i$  in time  $t$  has a strictly positive notional amount of interest rate swaps, that is, a bank reports either zero (if it has no interest swaps at all) or a strictly positive number if it uses swaps irrespective of how the present value of its swap position reacts to changes in the interest level. If the coefficient in front of the variable  $\Delta swap_{t,i}$  is different from zero, there is evidence that banks use interest swaps to steer their interest rate risk exposure; if it is negative, this suggests that they use it—on average—to hedge this risk. Note that, in the panel regression (1), we make use of the time serial variation in this variable, that is, the change from 0 to 1 and vice versa. By contrast, if a bank has never used interest swaps during the sample period or has used those swaps in every quarter, there is no change in the variable  $\Delta swap_{t,i}$  and the first difference of this variable is always zero.

In addition, we introduce the variable  $\Delta fip_{t,i}$  in regression (1), where  $fip_{t,i}$  is the average fixed-interest period of new housing loans that bank  $i$  grants in time  $t$ . The impact of this variable on a bank's overall exposure to interest rate risk is not clear from a theoretical viewpoint. According to the above hypothesis, the customers get their wishes as to the fixed-interest period of their loans fulfilled and the banks offset any open interest rate risk positions they do not want by performing suitable transactions in the capital market. If this is true in reality, we do not find that changes in the fixed-interest periods of a bank's loans have any impact on its overall exposure to interest rate risk. By contrast, it may be that banks see the fixed-interest periods of their loans as an instrument to promote certain fixed-interest periods. In this case, there is a (positively) significant relationship between a bank's overall interest rate risk exposure and the fixed-interest periods of its new housing loans.

The fixed-interest period of housing loans  $fip_{t,i}$  has a close connection to these loans' duration  $D_{t,i}$  (see Appendix B). In an additional specification, we replace the measure  $\Delta fip_{t,i}$  in regression (1) with the standardized duration  $\Delta D_{t,i}^s$ , where the standardization is done in the same way as with the bank's overall interest rate risk  $irr$  in the banking book. Thus, the coefficient can be interpreted as the share of the interest rate risk resulting from housing loans that is not hedged in a given quarter. As a control variable, we introduce the change in a bank's capital ratio  $\Delta CR_{t,i}$ .

By using proxy variables to indirectly investigate the banks' risk management, there is the issue of measurement errors which can lead to distorted estimates of the coefficients. To mitigate this problem, in most cases, we do not interpret the concrete size of the estimated coefficient, but only its sign.

### 3.2 | Fixed-interest periods of housing loans

As stated above, the interpretation of the variable  $fip$  in Equation (1) makes it necessary to know whether it is predominantly the bank or its customers which determine the fixed-interest period profile of the bank's assets and liabilities. To empirically determine how the average fixed-interest period is influenced by the steepness of the term structure of interest rates, we run the following regression:

$$\Delta fip_t = \alpha + \beta \cdot \Delta st_t + \gamma \cdot \Delta r_{10y,t} + \varepsilon_t, \quad (2)$$

where  $\Delta fip_t$  is (again, but this time the cross-sectional weighted average over the banks in Germany) the change in the average of the fixed-interest period of new housing loans granted in  $t$  and the variable  $\Delta st_t$  is the change in the steepness of the term structure, measured as the spread between 1-year and 10-year German government bond yields (zero coupon bonds). We estimate this relationship in first differences because the levels of the variables do not seem to be stationary (see Table A1 in Appendix A). In addition, we include the variable  $\Delta r_{10y,t}$  which is the change in the yield of the German government bond with a 10-year maturity. We do so because, in the literature, the interest level is often included when the choice between fixed and variable rate mortgages are empirically modeled, see, for instance, Campbell and Cocco (2003); Koijen, Hemert, and Nieuwerburgh (2009). The following equation adds a cross-sectional dimension to the pure time series relation in Equation (2):

$$\Delta fip_{t,i} = \tilde{\alpha} + \tilde{\beta} \cdot \Delta st_{t,i}^b + \tilde{\gamma} \cdot \Delta r_{lg,t,i}^b + \varepsilon_{t,i}, \quad (3)$$

where  $i$  stands for the banks,  $t$  for the respective quarter, and  $r_{lg,t,i}^b$  is the rate that bank  $i$  charges in quarter  $t$  for new housing loans with a long fixed-interest period. Again, depending on the relative importance of supply and demand, we expect a positive or negative sign



of  $\tilde{\beta}$ . The steepness of the bank-specific term structure can be split into a part that is common to all banks  $st_t^b$  and a deviation from this average, that is,  $st_{t,i}^b \equiv st_t^b + (st_{t,i}^b - st_t^b)$ ; correspondingly, that can be done for the long-term bank rate:  $r_{lg,t,i}^b \equiv r_{lg,t}^b + (r_{lg,t,i}^b - r_{lg,t}^b)$ . This split makes it possible to see whether the general economic conditions or whether bank-specific factors drive the results. With these replacements, Equation (3) becomes.

$$\Delta fip_{t,i} = \alpha + \tilde{\beta}_1 \cdot \Delta st_t^b + \tilde{\beta}_2 \cdot (\Delta st_{t,i}^b - \Delta st_t^b) + \tilde{\gamma}_1 \cdot \Delta r_{lg,t}^b + \tilde{\gamma}_2 \cdot (\Delta r_{lg,t,i}^b - \Delta r_{lg,t}^b) + \varepsilon_{t,i}. \quad (4)$$

If a bank use the steepness of the term structure of its bank rates as an instrument to manage its exposure to interest rate risk, we will observe a significant coefficient  $\tilde{\beta}_2$  in Equation (4).

## 4 | DATA

All data in the paper (except for the housing loans' initial redemption rate  $red_t^4$ ) are provided by the Deutsche Bundesbank. They are taken from regular supervisory reports and periodic estimates of the term structure for German government bonds. Additionally, for some banks and sometimes aggregated to the nation-wide level, data from the German contribution to the MFI statistics are used. The data at the bank level are confidential, whereas the time series aggregates and the data on interest rates are publicly available. In Table 1, we show summary statistics of the various variables.

In every quarter since end-2011, each bank in Germany has had to report its exposure to interest rate risk in its banking book. In doing so, the bank has to determine the changes in present values of the asset and liabilities in its banking book as a consequence of interest rate shocks. The shocks consist of parallel overnight shifts in the entire term structure by +200 basis points and by −200 basis points, respectively. The more adverse of the two outcomes is chosen and normalized with the bank's regulatory capital, known as the Basel interest rate coefficient. As the standardized present value change in each of the two scenarios is nearly proportional to the bank's modified duration of its equity, we use the (standardized) present value losses of the scenario with the increasing interest level in our paper as the measure  $irr$ .<sup>5</sup> We also keep those observations where a bank gains in present value as a consequence of an increase in interest rates. Our measure  $irr$  can be interpreted as a bank's exposure to interest rate risk, separated from the dynamics of the term structure. Our dependent variable in the panel regression,  $irr_{t,i}$ , determines the sample period (2011Q4–2017Q2) and the frequency (quarterly). According to Table 1, the mean value of this exposure measure was around 18.8% in the sample period. It turned out that it is more sensible from an econometric point of view not to use the level, but the first differences of this variable: the first differences are barely autocorrelated whereas the

**TABLE 1** Summary statistics

Variable	Period	Observations	Mean	Std.
$irr_{t,i}$	2011Q4–2017Q2	34,724	18.844	7.970
$\mu_t$	2011Q4–2017Q2	23	3.044	0.220
$red_t$	2011Q4–2017Q2	23	2.563	0.403
$swap_{t,i}$	2011Q4–2017Q2	34,724	0.460	0.498
$CR_{t,i}$	2011Q4–2017Q2	34,724	14.637	5.043
$fip_t$	2003Q1–2017Q2	58	7.547	0.616
$fip_{t,i}$	2003Q1–2017Q2	9,253	7.331	1.801
$st_t$	2003Q1–2017Q2	58	1.408	0.787
$st_{t,i}^b$	2003Q1–2017Q2	9,253	0.238	0.470
$r_{10y,t}$	2003Q1–2017Q2	58	2.677	1.508
$r_{lg,t,i}^b$	2003Q1–2017Q2	9,253	3.689	1.240

*Note:* This table shows summary statistics:  $irr_{t,i}$  is a bank's exposure to interest rate risk,  $\mu_t$  is the earnings of a passive trading strategy in government bonds (in % p.a.),  $red_t$  is the average initial amortization of housing loans (in % p.a.),  $swap_{t,i}$  is a dummy variable indicating that a bank has a strictly positive notional amount of interest rate swaps,  $CR_{t,i}$  is the capital ratio (in %),  $fip_t$  and  $fip_{t,i}$  (in years) are the fixed-interest period of newly granted German housing loans (weighted average in the cross-section of banks (index  $t$ ) and bank-specific (index  $t,i$ )),  $st_t$  (in % p.a.) is the steepness of the German term structure (10 years to 1 year),  $st_{t,i}^b$  is the steepness of the term structure of housing loans (fixed-interest periods of more than 10 years to fixed-interest periods of 1–5 years), the  $r_{10y,t}$  (in % p.a.) is the return on German 10-year government bonds, and  $r_{lg,t,i}^b$  is the interest level of housing loans with a fixed-interest period of 5–10 years; quarterly data. For reasons of confidentiality, the variable  $reg_{t,i}$  is not included in the table above.

autocorrelation of the levels is close to 1. Moreover, the variation of the first differences are almost completely in the time-series dimension whereas the variation in the level is mostly due to cross sectional heterogeneity.

Using the following example, we explain the calculation of our measure. We assume a bank whose assets consist of a bullet bond with a principal of €100, a coupon of 4% and a residual maturity of 5 years and whose liabilities consist of a bullet bond with a principal of €95, a coupon 4% and a residual maturity of 4 years. Under the assumption of a flat term structure of 4%, the equity as the difference between the two bonds on the asset side and liability side is €5.00 ( $=€100.00 - €95.00$ ). After a 200-bp shock, the interest level is at 6% ( $=4\% + 200$  bps) and the equity present value drops to €3.16 ( $=€91.58 - €88.42$ ), yielding a present value loss as a consequence of the shock of €1.84 ( $=€5.00 - €3.16$ ). In principal, banks can determine the changes in present value for each interest-bearing position, be it on- or off-balance, by replicating the positions' cash flows with standard interest rate instruments; for instance, the cash flows of an interest swap can be replicated by a long position in a par-yield bond and a short position in a floating rate note. For some positions, especially for the customer deposits where the de facto and de jure maturities, and thus fixed-interest periods, largely differ, the cash flows cannot be easily determined. In these cases, the reliance on the banks' internal models is crucial. Only the interest rate risk in the banking book is covered, including positions of the banking book in interest rate derivatives, while a bank's trading activities in the trading book are not included.

During much of our sample period, interest rate risk in the banking book did not need to be backed by regulatory capital, but the supervisors used the Basel interest rate coefficient and related figures to check whether a bank had sufficient capital to bear its interest rate risk in the banking book. A bank is said to have elevated interest rate risk if the change in present values exceeds 20 per cent of its regulatory capital, which we capture with the dummy variable  $reg_{t,i}$  that takes on the value of 1 in case bank  $i$  in time  $t - 1$  exceeds this regulatory threshold. Since the end of 2016, banks have had to back their exposure to interest rate risk in the banking book with regulatory capital. In subsection 2, we analyze the implications of this change in the regulation.

The banks' earnings from bearing interest rate risk are measured by the variable  $\mu_t$ . This variable gives the earnings of a passive investment strategy which consists in investing in German 10-year government par-yield bonds on a revolving basis and financing this investment by constantly issuing 1-year par-yield bonds, which we assume to have the yield of corresponding German government bonds.<sup>6</sup> In the sample period, the average earning of this strategy was more than 3% p.a. relative to the book value of the long position. Note that this variable has no cross-sectional variation.

Concerning interest rate derivatives, only the nominal amount of swaps a bank is holding in a given quarter (interest rate, currency and combined swaps) is available. As the notional amount says little about the swaps' net effect, we only make use of the information whether or not a bank holds swaps at all in a given quarter. We construct the dummy variable  $swap_{t,i}$  which takes the value of 1 if bank  $i$  in time  $t$  has a strictly positive nominal amount of interest rate and/or currency swaps. This was the case for 46% of the observations in our sample. In around 1.2% of the observations, there is a change in this variable compared to the status in the previous quarter, meaning that in the current quarter, there is a positive swap position while in the previous quarter there was no swap position or vice versa.

We measure the outcome of the length of the fixed-interest period of housing loans by the variable  $fip_{t,i}$  which is the average fixed-interest period of newly granted housing loans. According to Deutsche Bundesbank (2004), a sample of around 200 banks in Germany (of the then total number of around 2,200 (12/2003)) is chosen for the MFI statistics such that regional criteria and the categories of banks are representatively reflected. This means that the data from the MFI statistics are only available for a small fraction of the banks in Germany. For each bank contributing data to the German part of the MFI statistics and for every month, we have data on the amount of newly granted housing loans in four buckets of fixed-interest periods: up to 1 year, 1 year to 5 years, 5 years to 10 years, and over 10 years, where we assume fixed-interest periods for the four different buckets of 0.5, 3, 7.5, and 13 years. To obtain quarterly data, we sum up the volumes in the 3 months belonging to the respective quarters. In the sample period, the average fixed-interest period was 7.33 years.

The average capital ratio, measured as a bank's Tier 1 capital over its risk-weighted assets, amounts to 14.6%.

We apply mild outlier treatment by removing observations below the first percentile and above the 99th percentile for the non-dummy variables.

For regression (2), we use variables that have variation only in the time dimension, but not in the cross-sectional dimension. Here—unlike above—the variable  $fip_t$ , the fixed-interest period of newly granted housing loans, is the nation-wide average where the Deutsche Bundesbank determines the weights of the aggregation (see Deutsche Bundesbank (2004) and Deutsche Bundesbank (2011)); in the period 2003Q1–2017Q2, this average was 7.55 years. Concerning the steepness of the term structure  $st_t$ , measured as the spread between the zero-coupon bond returns of a 10-year and a 1-year German government bonds, it was 1.41% p.a. and the return of the 10-year government zero-coupon bond was 2.68% p.a. For regressions (3) and (4), we use corresponding data at bank-level (for the German banks that report to the MFI statistics). Note that the steepness of the term structure at bank-level ( $st_{t,i}^b$ ) is measured as the difference between the rate of the respective bank for housing loans with a

fixed-interest period of more than 10 years relative to the corresponding bank rate for housing loans with a fixed-interest period of 1 to 5 years. The interest level is measured as the rate of the respective bank for housing loans with a fixed-interest period of 5 to 10 years ( $r_{lg,t,i}^b$ ).

## 5 | RESULTS

### 5.1 | Baseline results

Table 2 shows the results of the panel analysis from regression (1), where the change in a bank's exposure to interest rate risk  $\Delta irr_{t,i}$  in its banking book is explained. The change in the earning opportunities from interest rate risk  $\Delta \mu_t$  has the expected positive sign and is highly significant (at least in the sample with all banks), that is, when the earning opportunities improve, the exposure to interest rate risk increases. In the sample period 2011Q4–2017Q2, there was no major shift in this variable compared to the outcomes observed in the periods before, and yet we find a significant impact like Memmel (2011) and Chaudron (2018). Note that we cannot extend the sample period in the past because the measure *irr* was not regularly reported before 2011. In line with previous analyses, we find that the regulatory threshold of 20% has a strong influence: if a bank had an interest rate risk exposure exceeding this threshold in the previous quarter, the bank—on average—reduces its exposure in the following quarter. In accordance with Purnanandam (2007) (US banks),<sup>7</sup> Memmel and Schertler (2013) (German banks) and Hoffmann et al. (2018) (large European banks), we find evidence that banks use, on average, interest rate swaps to hedge, and not to speculate on interest rate risk, as can be seen from the (at least in the sample with all banks) significantly negative coefficient for the variable  $\Delta swap_{t,i}$  (however, Begenau et al. (2015) find the opposite effect). All these results are in line with the idea that banks actively manage their exposure to interest rate risk in the short run, thereby considering the earning opportunities of this risk and regulatory issues.

**TABLE 2** Results: Change in interest rate risk exposure

Variables	$\Delta irr_{t,i}$	$\Delta irr_{t,i}$	$\Delta irr_{t,i}$
$\Delta \mu_t$	0.786*** (0.151)	0.863 (0.507)	0.647 (0.501)
$\Delta reg_{t,i}$	−0.647*** (0.041)	−0.652*** (0.137)	−0.671*** (0.131)
$\Delta swap_{t,i}$	−0.257* (0.147)	0.162 (0.137)	0.208 (0.584)
$\Delta fip_{t,i}$		0.136* (0.082)	
$\Delta D_{t,i}^*$			0.886*** (0.124)
$\Delta CR_{t,i}$	−0.593*** (0.021)	−0.575*** (0.069)	−0.503*** (0.069)
<i>constant</i>	0.212*** (0.005)	0.175*** (0.018)	0.158*** (0.017)
Observations	34,724	3,502	3,502
Banks	1,773	185	185
R-squared (within)	0.051	0.044	0.073
Sample	All banks	Only banks contrib. to the MFI statistics	

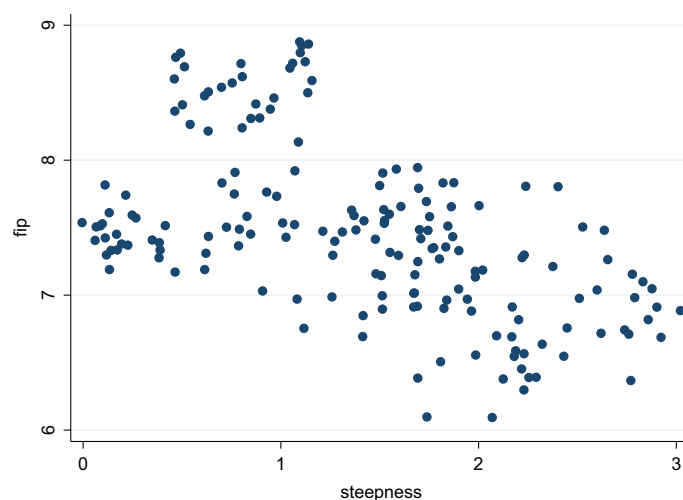
*Note:* This table shows the results of the regressions (2), (3), and (4).  $\Delta fip_{t,i}$  and  $\Delta fip_t$  are the changes in the fixed-interest periods of new housing loans (bank-specific (index  $t,i$ ) and weighted average in the cross-section of banks (index  $t$ ));  $\Delta st_t$  is the change in the steepness of the term structure (German government zero-coupon bond yields, 10 years to 1 year),  $\Delta st_{t,i}^b$  and  $\Delta st_t^b$  are the changes in the steepness of the term structure of housing loans (fixed-interest periods of more than 10 years to fixed-interest periods of 1–5 years; bank-specific (index  $t,i$ ) and weighted average in the cross-section of banks (index  $t$ ));  $\Delta r_{10,y}$  is the change in the German government 10-year bond yield, and  $\Delta r_{lg,t,i}^b$  and  $\Delta r_{lg,t}^b$  are the changes in the interest level of housing loans with a fixed-interest period of 5–10 years (bank-specific (index  $lg,t,i$ ) and weighted average in the cross-section of banks (index  $lg,t$ )); in column 1: Newey–West standard errors in brackets (4 as maximum lag order of autocorrelation); in columns 2 in 3: within R-squared; quarterly data; period 2003Q1–2017Q2; \*\*\* and \* denote significance at the 1% and 10% level, respectively.



We investigate the relationship between customers' fixed-interest period preferences and the banks' on-balance-sheet interest rate risk exposure. Looking at the Germany-wide aggregate data from January 2003 to June 2017, we find, in line with Banca d'Italia (2016), a strongly negative relationship between the average fixed-interest period of new housing loans to households and the steepness of the term structure (see Figure 1).<sup>8</sup> This is confirmed when we look at the corresponding regression (see Equation (2) and Table 3, column 1): The steepness of the term structure has a highly significantly negative impact on the average fixed-interest period of new housing loans.<sup>9</sup> Similar results are found when we investigate the issue at bank level (see Table 3, column 2). These results shed some light on the question of who determines the housing loans' fixed-interest period, the banks or the customers. According to these results, it seems that the customers predominantly determine the fixed-interest period, because otherwise, that is, if the banks were the decisive determinants, we would observe a rising and not a falling relationship.<sup>10</sup> We would observe a rising relationship because during periods when the term structure is very steep, banks tend to increase their overall exposure to interest rate risk (as the results in Table 2 suggest). However, note that the steepness of the term structure may not be the only determinant of the decision regarding the fixed-interest period of housing loans. As to the supply side (banks), Sartoris (1995) and Chang, Rhee, and Wong (1995) show that also the volatility of the interest rates are crucial; as to the demand side, Koijen et al. (2009) and Foà, Gambacorta, Guiso, and Mistrulli (2015) empirically show that the long-term bond risk premium—a concept related to, but not equal to the steepness of the term structure—seems to drive the demand for fixed rate mortgages.

It may be that banks manage their exposure to this risk by setting the bank rates for the various fixed-interest periods of their housing loans in a way that their customers choose the length of the fixed-interest periods the bank wants them to choose. In this case, we would observe a positive relationship between  $\Delta fip_{t,i}$  and the  $\Delta irr_{t,i}$ . Therefore, we split up the changes in the steepness and in the level of the bank rates as in Equation (4). According to Table 3, column 3, this steering is not done by deviating from the average steepness of the term structure of bank rates,  $\Delta st_{t,i}^b - \Delta st_t^b$ , but by deviating from the average long-term bank rate  $\Delta r_{lg,t,i}^b - \Delta r_{lg,t}^b$ . We test whether the impact of general economic conditions and bank-specific factors, that is, the models in columns (2) and (3) of Table 3, are statistically the same, and clearly reject this hypothesis. The change in the long-term bank rate is negatively associated with the change in the length of fixed-interest period. One possible explanation is that low bank rates for housing loans attract customers who prefer long-fixed-interest periods and who could not afford to buy a house in normal circumstances. However, we do not find any significant relationship with the change in the new business of housing loans, which cast some doubts on this interpretation.

Having established that demand for housing loans is the primary determinant of the fixed-interest period, we turn again to the issue of how the fixed-interest period of housing loans impacts the banks' overall interest rate exposure. To do so, we introduce the variable  $\Delta fip_{t,i}$  in regression (1), that is, the change in the fixed-interest period of newly granted housing loans (see column 2 in Table 2). We observe a significantly positive impact, meaning that the banks' overall interest rate risk exposure increases when the exposure of this part of its balance sheet goes up. This finding refutes the irrelevance of the fixed-interest period of housing loans and indicates that there is still some connection between the granting of long-term loans and the banks' total interest rate risk exposure. It seems as if banks are unable or unwilling to completely offset the customers' fixed-interest period choices without delay by engaging in suitable transactions in the capital market or at the interbank market. From column



**FIGURE 1** Fixed-interest period and steepness of the term structure. [Colorfigure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

In this figure, the nation-wide average fixed-interest period ('fip', in years) of newly granted housing loans is plotted against the steepness (in per cent) of the German term structure (German government zero-coupon bonds, 10 years vs. 1 year); monthly data; period January 2003–June 2017

TABLE 3 Results: fixed-interest period

Variables	$\Delta fip_t$	$\Delta fip_{t,i}$	$\Delta fip_{t,i}$
$\Delta st_t$	-0.207*** (0.067)		
$\Delta st_{t,i}^b$		-0.132*** (0.040)	
$\Delta st_t^b$			-0.745*** (0.063)
$\Delta st_{t,i}^b - \Delta st_t^b$			-0.065 (0.042)
$\Delta r_{10y,t}$	-0.116 (0.094)		
$\Delta r_{lg,t,i}^b$		-0.433*** (0.059)	
$\Delta r_{lg,t}^b$			-0.374*** (0.044)
$\Delta r_{lg,t,i}^b - \Delta r_{lg,t}^b$			-0.492*** (0.119)
Constant	0.023 (0.022)	0.008** (0.004)	0.006** (0.003)
R-squared	0.154	0.023	0.036
Observations	57	9,002	9,002
Banks		206	206

Note: This table shows the results of the regressions (2), (3) and (4).  $\Delta fip_{t,i}$  and  $\Delta fip_t$  are the changes in the fixed-interest periods of new housing loans (bank-specific (index  $t,i$ ) and weighted average in the cross-section of banks (index  $t$ ));  $\Delta st_t$  is the change in the steepness of the term structure (German government zero-coupon bond yields, 10 years to 1 year),  $\Delta st_{t,i}^b$  and  $\Delta st_t^b$  are the changes in the steepness of the term structure of housing loans (fixed-interest periods of more than 10 years to fixed-interest periods of 1–5 years; bank-specific (index  $t,i$ ) and weighted average in the cross-section of banks (index  $t$ ));  $\Delta r_{10y,t}$  is the change in the German government 10-year bond yield, and  $\Delta r_{lg,t,i}^b$  and  $\Delta r_{lg,t}^b$  are the changes in the interest level of housing loans with a fixed-interest period of 5–10 years (bank-specific (index  $lg,t,i$ ) and weighted average in the cross-section of banks (index  $lg,t$ )); in column 1: Newey–West standard errors in brackets (4 as maximum lag order of autocorrelation); in columns 2 in 3: within  $R$ -squared; quarterly data; period 2003Q1–2017Q2; \*\*\* and \*\* denote significance at the 1% and 5% level, respectively.

3 in Table 2, we can obtain an estimate of the extent of this hedging (having in mind that the coefficient may be estimated with a bias owing to possible endogeneity issues, see below): the coefficient in front of  $\Delta D_{t,i}^s$  is highly significant and amounts to 0.886, meaning that 88.6% of the change in the exposure to interest rate risk that results from housing loans is not, on average, offset, but impacts a bank's overall exposure. It seems as if in a quarter only 11.4% (=100%–88.6%) of this change in exposure is hedged.

The variable  $fip$ , the length of the fixed-interest period of new housing loans, may be determined—at least in part—by the bank itself, for instance, as an instrument to manage its interest rate risk (see above). In this case, this variable would not be exogenous from the bank's perspective and the estimates of the coefficient and its standard deviation may be distorted. However, we believe that the results have value in their own right. First, under our starting hypothesis, which posited that customers entirely determine the fixed-interest periods of the loans, this variable is completely exogenous for the banks. Second, we find little empirical evidence that banks use the variable  $fip$  as a control quantity for their exposure to interest rate risk. For instance, we find only little evidence that banks deviate the steepness of their bank rates from the national average steepness of bank rates (see above) or that this variable depends on the bank's exposure to interest rate risk (see the second robustness check where we show that the impact on a bank's exposure to interest rate risk does not depend on its regulatory situation).

The economic significance of the variables differs a lot, defining this significance as the expected change in the dependent variable  $\Delta irr_{t,i}$  if the respective variable changes by one standard deviation (concerning its time series dimension). It turns out that (for the first column) the change in the regulatory situation  $\Delta reg_{t,i}$  is nearly four times as high as the change in the earning opportunities from term transformation  $\Delta \mu_t$  and nearly nine times as high as the change in the swap usage  $\Delta swap_{t,i}$ . In the third column, the economic significance of the variable  $\Delta D_{t,i}^s$  is twice as high as that of the regulatory situation  $\Delta reg_{t,i}$ .

## 5.2 | Robustness checks

Some of the limitations of this study cannot be solved, for instance, the indirect method to learn something about the risk management in banks or the relatively short time span of the sample period. Nevertheless, the results passed the following robustness checks:

The regulation of the interest rate risk in the banking book has changed recently. Germany's national supervisory agency BaFin issued a general administrative measure (*Allgemeinverfügung*, see BaFin (2016)) in December 2016 stating that interest rate risk in the banking book has to be backed by regulatory capital, depending on the bank's present value losses standardized with the bank's risk-weighted assets (*RWAs*) that result from the scenarios assumed for the Basel interest coefficient, that is, parallel shifts of the term structure of  $\pm 200$  bps. Therefore, for the last three quarters in our sample (2016Q4–2017Q2), we replace the variable  $reg_{t,i}$  with the variable  $sur_{t,i}$  which gives the capital charge (relative to the bank's *RWAs*) due to interest rate risk in the banking book (in the previous period). This variable turns out to be negatively significant. As the variables  $reg_{t,i}$  and  $sur_{t,i}$  are highly correlated, it is not surprising to obtain similar results when replacing the variable  $reg_{t,i}$  with the variable  $sur_{t,i}$ .<sup>11</sup> To see whether banks have reacted to the new regulatory regime, we make use of the design of this new regime, namely that the capital charge  $sur_{t,i}$  does not linearly increase with the exposure to interest rate risk, but in steps depending on the exceedance of certain thresholds. We investigate whether we find more observations of interest rate risk exposure just below, rather than above these thresholds, and we notice that there is no significant difference. However, we find that the share of exposure observations that are close to the thresholds (no matter whether the exposures are below or above the thresholds) declined significantly under the new regulatory regime. One possible explanation for this finding is that banks trade off the risk of breaching the different thresholds (which calls for a large distance to the next higher threshold) against the earning opportunities from increasing the exposure to the maximum level just below the different thresholds.

Banks already highly exposed to interest rate risk may be more likely to hedge additional exposure resulting from new housing loans (see Basten et al. (2017)). To test this hypothesis, we introduce an additional explanatory variable in Equation (1), namely the interaction term of the variables  $reg$  and  $D^s$ . This variable is there to indicate whether banks that exceeded the regulatory exposure threshold of 20% in the previous quarter show a different response to changes in the fixed-interest periods of their housing loans than the remaining banks. The first difference of this interaction term turns out to be insignificant, meaning that we do not find any significant difference concerning this reaction between banks with low exposure and banks with high exposure to interest rate risk.

Low bank rates (yields) for housing loans may attract borrowers who cannot afford to buy houses in normal circumstances. As the monthly installment for housing loans consists of the sum of the yield and the initial redemption rate (see Equation (A4) in Appendix B), the monthly installment does not go down as much as bank rates (yields), if the dynamics of the initial redemption rate run contrary to those of bank rates (which is the case). This mitigates the effect from above.

The German banking sector is characterized by three banking groups (called pillars): the commercial, the savings, and the cooperative banks, where more than 80% of the institutes (but not of total assets) belong to the savings banks and cooperative banks sector. Banks from these two sectors dominate the results, especially concerning the impact of the regulatory situation. In addition, for the cooperative banks, we find a highly significant coefficient for the earning opportunities  $\Delta\mu$ , but no such relationship for the savings banks. Moreover, if broken down into the three banking groups, the variable  $\Delta swap$  is no longer significant.

When we look not only at the decision whether or not to use interest swaps, but also at the decision of adjusting existing swap positions (more precisely: we insert the change in the logarithmized notional amount of swaps for those banks which have a strictly positive notional swap amount into regression (1)), we find that increasing the notional amount of the swap positions (relative to the previous quarter) is associated with a reduction in a bank's exposure to interest rate risk. As we do not have information about the direction of the position (i.e., whether a bank hedges or increase its exposure to interest rate risk), we report the results of this exercise only as a robustness check.

As a further robustness check, we replace the variable  $\Delta st_t$ , the change in the steepness of the term structure in Equation (2), with  $\Delta\mu_t$ , the change in the earning opportunities from interest rate risk. In the specification with the earning opportunities from interest rate risk, the relationship is no longer significant. One reason for this finding may be that the earning opportunities from interest rate risk, the variable  $v$ , are based on a continuous business model where the investment and financing is done in a revolving manner, whereas the households' decisions about the length of the fixed-interest periods are made at a concrete point in time (which is better captured by the steepness of the term structure).<sup>12</sup> Moreover, again in Equation (2), we replace  $\Delta st_t$  and  $\Delta r_{10y,t}$  with (the change in) the nation-wide averages of the steepness of the term structure and of the interest level of mortgage loans, that is, with  $\Delta st_t^b$  and  $\Delta r_{lg,t}^b$ . Both variables are significant and have the economically expected sign. However, the coefficient of determination,  $R^2$ , is higher (15.4% vs. 14.9%) in the original specification with the variables  $\Delta st_t$  and  $\Delta r_{10y,t}$ . Therefore, we decided to use these variables in the baseline specification, albeit cognizant that households are charged the bank rates, not the interest rates in the capital market. Another reason for using the capital market variables  $\Delta st_t$  and  $\Delta r_{10y,t}$  is that they can be

seen as exogenous with respect to the real estate market. Additionally, we split the sample in two halves (2003Q1–2010Q1 and 2010Q2–2017Q2). We find that the impact of the steepness of the yield curve is more pronounced in the second subsample. If the steepness of the term structure is not calculated as the spread over the yield on 1-year government bonds, but over the yield on 3-month government bonds, this variable is no longer significant in the first differences, but only in the levels.

## 6 | CONCLUSION

This paper analyses the short-term fluctuations in banks' exposure to interest rate risk. We carry out an empirical study of German banks for the period 2011Q4–2017Q2. We find evidence that banks actively manage their interest rate risk exposure, for instance, with interest rate swaps, and that they raise their exposure to interest rate risk when its remuneration increases. We also find evidence that banks whose exposure to interest rate risk in the banking book exceeds a regulatory threshold tend to decrease their risk exposure in the subsequent quarter. However, these adjustments to a bank's exposure to interest rate risk explain only about 5% of the quarterly variation in the change of this exposure to risk. This gives reasons to believe that banks see interest rate risk as a risk that is not of primary concern as long as it stays within a certain limit.

In addition, we find evidence which is in line with the hypothesis that the fixed-interest period of housing loans is largely determined by the customers, not by the banks, and that the fixed-interest period of housing loans has an impact on the overall interest rate risk exposure of a bank. The combination of these two findings is not in line with the idea that banks actively manage their exposure to interest rate risk and indicates that there is still a connection between loan granting and banks' interest rate risk exposure and that banks do not appear to fully mitigate this additional exposure—without delay—by using appropriate off-balance sheet positions or interbank loans.

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## ENDNOTES

- <sup>1</sup> In June 2017, the volume of loans granted by banks in Germany to domestic firms and households amounted to €2,559.7 billion, of which €1,143.6 billion (share: 44.7%) were housing loans to households (see Deutsche Bundesbank (2017)).
- <sup>2</sup> The operator  $\Delta$  gives the difference between the variable in time  $t$  and its value in the previous quarter (time  $t-1$ ). Fixed effects for the banks are included in regression (1).
- <sup>3</sup> If, however, a bank's market value is maximised as in the framework of Froot and Stein (1998), its exposures to any risks that can be completely hedged are irrelevant because they do not change the market value.
- <sup>4</sup> The duration  $D_{i,t}$  of the housing loans depends on the annual instalment  $a_{i,t}$  (see Equation (A2) in Appendix B), which we calculate as the sum of the initial redemption rate and the bank rate (see Equation (A4) in Appendix B), where the initial redemption rate  $red_i$  is not loan- or bank-specific, but constant in the cross-section of banks and has only a time-series variation (source: Dr. Klein Trendindikator Baufinanzierung (DTB)).
- <sup>5</sup> As described above, for the calculation of the Basel interest rate coefficient, the more adverse outcome of the two scenarios is chosen. This leads to non-linearities which we want to avoid. Therefore, we choose one scenario.
- <sup>6</sup> It is common in the literature to measure the steepness of the term structure by the spread of the yield on a 10-year-government bonds over a short-term interest rate, for instance the yield on 1-year-government bonds (see, e.g., Campbell and Cocco (2003)).
- <sup>7</sup> Purnanandam (2007) writes that “this finding suggests that by using derivatives, banks are able to ‘insulate’ their maturity GAP policy from external shocks.”
- <sup>8</sup> However, Campbell and Cocco (2003) find little correlation between the share of fixed-rate mortgage loans and the steepness of the term structure for the US (period: 1985–2001). Instead, they find a strong negative correlation between the long-term interest rate and the share of fixed-rate mortgages.
- <sup>9</sup> For the variables  $fip_{i,t}$ ,  $st_{i,t}$ , and  $r_{10y,t}$ , the hypothesis of a unit-root process cannot be rejected. Therefore, the relationship is estimated in first differences which seem to be stationary; see Table A1 in Appendix A.
- <sup>10</sup> Based on a different reasoning, Kojen et al. (2009) also argue that banks do not predominantly determine the loans' fixed-interest periods.
- <sup>11</sup> For the three quarters (2016Q4–2017Q2), the correlation between these variables in levels is 0.7358 and 0.3940 for the first differences of these variables.

<sup>12</sup> The variable  $\mu_t$  is closely connected to the steepness  $st_t$  of the term structure. Concerning the first differences, the correlation between these two variables is 0.3695.

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TABLE A1 Stationarity test

Variable	Level	First difference
$fp_t$	-1.387	-3.537***
$st_t$	-2.594*	-3.056**
$r_{10y,t}$	-0.107	-4.037***

Note: This table shows the test statistics of the augmented Dickey-Fuller test for the variables  $fp_t$ ,  $st_t$ , and  $r_{10y,t}$  (4 lags, constant, but no trend). 2003Q1–2017Q2; quarterly data; 58 (57) observations in the level (first difference). \*\*\*, \*\* and \* denote significance at the 1%, 5%, and 10% level, respectively.

## APPENDIX A

### Dickey-Fuller-Test

Table A1 reports the results of the augmented Dickey–Fuller test. For the three variables  $fp_t$ ,  $st_t$ , and  $r_{10y,t}$ , the null hypotheses of a unit process can only be rejected for their first differences, not for the levels, except for the variable  $st_t$ , where the null hypothesis of a unit root process can be rejected at the 10% level.

## APPENDIX B

### Duration and Fixed-Interest Period

In this appendix, we derive the relationship between a loan's duration  $D$  and its fixed-interest period  $fp$ . In this setting,  $PV$  denotes the present value of a loan with fixed-interest period  $fp$ ,  $r$  is the yield of the loan,  $a$  the time-constant rate of installments and  $d$  the share of the repayment of the principal (normalized to 1) at the end of the fixed-interest period. For ease of exposition, we remove the indexes  $t$  and  $i$ . The present value  $PV$  of such a loan (in continuous time) is

$$PV = \int_0^{fp} a \cdot \exp(-r \cdot t) dt + d \cdot \exp(-r \cdot fp) \\ = \frac{a}{r} (1 - \exp(-r \cdot fp)) + d \cdot \exp(-r \cdot fp).$$

$$\frac{\partial PV}{\partial r} = -\frac{a}{r^2} (1 - \exp(-r \cdot fp)) + \left(\frac{a}{r} - d\right) \cdot fp \cdot \exp(-r \cdot M) \quad (A1)$$

In the case of  $PV = 1$  (which we assume in the following), that is, the loan is at par when granted, there are two implications: (a) the derivative in Equation (A1) equals the negative modified duration  $D$  of the loan, and (b) the share  $d$  of the repayment of the principal is

$$d = \exp(r \cdot fp) - \frac{a}{r} (\exp(r \cdot fp) - 1). \quad (A2)$$

Combining Equations (A1) and (A2) and setting  $D = -\frac{\partial PV}{\partial r}$ , we obtain

$$D = \frac{a}{r^2} (1 - \exp(-r \cdot fp)) - \left(\frac{a}{r} - 1\right) \cdot fp. \quad (A3)$$

For  $a = r$ , we obtain  $d = 100\%$  (see Equation (A2)) and  $D = 1/r \cdot (1 - \exp(-r \cdot fp))$ , that is, the modified duration of a par yield bond (see Memmel (2011)); and for  $a = 0$ , the modified duration  $D$  equals the fixed-interest period  $fp$ , that is, the loan becomes a zero coupon bond and the share  $d$  of the repayment of the principal is  $>100\%$ . For small values of  $r$ , Equation (A3) becomes

$$\lim_{r \rightarrow 0} D = fp - \frac{a}{2} \cdot fp^2, \quad (A4)$$

which can be seen when the rule of L'Hôpital is twice applied to Equation (A3). For the empirical implementation, we set

$$a_{t,i} = r_{t,i}^b + red_t,$$

where the installment  $a_{t,i}$  is the sum of the bank rate  $r_{t,i}^b$  for housing loans of bank  $i$  (for the corresponding fixed-interest period) and of the nationwide average of the initial redemption rate  $red_t$ .