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Why are interest rates on bank deposits so low?

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Non-technical summary

Research Question

The bank interest rates on customer deposits are usually markedly below the corresponding market interest rates. This difference in the interest rates is probably due to the observation that banks offer many services together with the customer deposits especially with sight deposits, i.e. the customers forgo higher remuneration to make use of these services.

Contribution

We investigate in a study (period: 2003-2018) of German banks that take part in the interest rate statistics of the European Central Bank (ECB), on which market and bank characteristics it depends how large the rates on customer deposits are in relation to market interest rates.

Results

We find that bank rates on sight deposits are lower if a bank is located in a rural district, if it is not exposed to strong competition and if it offers above-average customer services. For term deposits, there seems to be the cost situation of the bank that is important. Banks with above-average costs remunerate these customer deposits at lower rates.

Nichttechnische Zusammenfassung

Fragestellung

Die Bankzinssätze für Kundeneinlagen liegen gewöhnlich deutlich unter den entsprechenden Marktzinssätzen. Dieser Unterschied in den Zinssätzen dürfte auch darauf zurückzuführen sein, dass Banken zusammen mit den Kundeneinlagen, besonders mit den Sichteinlagen, eine Vielzahl von Bankdienstleistungen anbieten, d.h. die Bankkunden nehmen die geringere Verzinsung in Kauf, um diese Bankdienstleistungen nutzen zu können.

Beitrag

In einer Studie (Zeitraum: 2003-2018) für Banken in Deutschland, die an der Erhebung im Euroraum über Bankzinssätze teilnehmen, untersuchen wir, von welchen Markt- und Bankeigenschaften es abhängt, wie hoch die Bankzinssätze für Kundeneinlagen im Verhältnis zu den Marktzinssätzen sind.

Ergebnisse

Wir finden, dass Banken Sichteinlagen umso weniger verzinsen, wenn die Bank in einem ländlich geprägten Kreis liegt, wenn sie keinem scharfen Wettbewerb ausgesetzt ist und wenn sie überdurchschnittlich viele Dienstleitungen bereitstellt. Für Termingelder scheint die Kostensituation der Bank wichtig zu sein. Banken mit überdurchschnittlich hohen Kosten verzinsen diese Kundeneinlagen geringer.

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Abstract

Using granular data of German banks for the 2003 to 2018 period, we analyse the determinants of bank rates on retail deposits. We find that a bank's rate on sight deposits is especially low if the bank operates in rural districts, if it is not exposed to strong competition and if it provides much service. Regarding the rates on term deposits, we find that the bank's cost situation plays a role: if the bank's costs are high, its deposit rates are low. By transferring concepts from portfolio theory to the pass-through topic, we show that replicating portfolio approaches, which are used mainly by small banks, are often equivalent to regression approaches and that, under some assumptions, the classical regression approach corresponds to a replicating portfolio approach.

Keywords: Pass through, bank deposits, replicating portfolio approach

JEL classification: G21.

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1 Introduction

Bank rates on retail deposits, especially sight deposits, are low compared to market interest rates, at least prior to the low-interest-rate environment. Empirically, the remuneration of (sight) deposits is found to be only loosely connected to the corresponding market interest rates – the pass-through in Germany is estimated to lie between one-third and one-half (see, for instance, Busch and Memmel (2017), Sopp (2018) and Heckmann-Draisbach and Moertel (2020)).[1] It seems as if deposits, especially sight deposits, are closer to money than to short-term bonds. One likely reason is that customers forgo higher remuneration of their sight deposits in exchange for services around their liquidity and payment needs.[2]

In this paper, we want to explore retail bank deposits in more detail; we especially set out to investigate the bank and market characteristics that determine the level of these rates. This paper has two main contributions. First, we introduce variables to measure a bank's customer services in payment and liquidity management. As far as we know, we are the first to use such variables in the context of deposit products. Second, we show that replicating portfolio approaches to quantify the markdown of deposits are often equivalent to regression approaches and that – under some additional assumptions – one of them is closely related to the classical pass-through approach.

The issue of banking deposits is crucial for understanding bank profitability.[3] First, it seems that a large part of banks' net interest income is due to reduced interest payments in connection with payment and liquidity management for its retail customers, i.e. the low remuneration of bank deposits, especially sight deposits, seems to be a way to indirectly charge customers for these services. Second, the imperfect pass-through of changes in market interest rates to deposit rates – even in the long run – may be the main reason for the empirical finding that a bank's net interest margin depends positively on the interest level (see, for instance, Albertazzi and Gambacorta (2009)). This is so because, on the asset side, which is much characterized by loans, a bank's pass-through tends to be much larger than on the liability side, which is strongly characterized by deposits. Therefore, a change in the interest level leads to changes in a bank's net interest margin. Claessens, Coleman, and Donnelly (2018) estimate this relationship at 8 bp per 100 bp change in the interest level.

In a theoretical model, we find that a bank's location, the behaviour of its competitor and the payment and liquidity services it provides impact the remuneration of its deposits: If customers cannot easily change their bank (because they live, for example, in rural areas with few alternatives) and if a bank provides a lot of services, the customers are satisfied if banks pass through only a small part of the market rates and, as a consequence, banks' deposit rates are relatively low. In addition, a bank's cost situation plays a role: To maximize its profit, a bank with high costs does not pass on a lot of the changes in the market rates.

In the empirical implementation, we use the sample of banks in Germany that report to the German part of the MFI interest rate statistics (MIR statistics) in the euro area.

[1] See Drechsler, Savov, and Schnabl (2017) for similar US figures.

[2] This reasoning is in line with Klein (1971), but different to that of Diamond and Dybvig (1983), who argue that the remuneration of bank deposits is low because of customers' uninsurable liquidity needs.

[3] See Saunders and Schumacher (2000) for a discussion of the welfare implications of bank profitability.

We cover the period from 2003 (when the MIR statistics started) to 2018, which means that the period of low interest rates is in the sample, but does not dominate it. We use a replicating portfolio approach for every type of deposit and every bank in the sample to estimate the markdowns relative to portfolios of government bonds. As to sight deposits, we find that – as predicted by the theoretical model – a bank's competitive situation, its location and the services it provides are important determinants of the markdown. The cost situation, however, does not seem to play a role for the rate of sight deposits, but for the rate of term deposits, it turns out to be a crucial determinant. The results are in line with common sense and broadly consistent with the literature; for instance, Gigineishvili (2011) finds in an international study that per capita GDP, the interest level, competition and costs, among other factors, are positively correlated with the pass-through. Our main contribution here is to introduce variables that measure the payment and liquidity management services a bank provides, as these services seem to be important. Busch and Memmel (2016) estimate it to account for about 50% of the median German bank's net interest income.

We also contribute to the literature on the pass-through of deposit rates (see, for instance, de Bondt (2002), De Graeve, De Jonghe, and Vennet (2007) and Heckmann-Draisbach and Moertel (2020)). In this paper, we are not focused on the short-term pass-through, but on the long-term level of deposit rates. We do not answer the question of the immediate pass-through to the deposits rates after a change in the policy rate or market interest rates, but are instead more interested in the question as to the level of deposit rates relative to the level of the market interest rates. We use a statistical approach to relate the deposit rates to the market interest rates, the replicating portfolio approaches (see Maes and Timmermans (2005)). Our main contribution here is to show the equivalence to regression approaches and the relation to the classical pass-through measures. By transferring concepts of portfolio optimizing (Britten-Jones (1999) for the Sharpe ratio of the markdown and Kempf and Memmel (2006) for its variance), we show that the portfolio replicating approaches are often equivalent to regression approaches, which considerably facilitates their implementation.

In the paper, we abstract from mismatches in the fixed-interest periods of the assets and liabilities which expose the bank to interest rate risk. Busch and Memmel (2016) find the remuneration of this risk to account for about one-third of German banks' net interest income. Kerbl, Simunovic, and Wolf (2019) shows that the duration of deposits, especially for outsiders, is difficult to determine and that it is to some extent at the discretion of the banks.

As, unlike Schlueter, Busch, Hartmann-Wendels, and Sievers (2016), we do not look at the asset side, but concentrate on the liability side as do Drechsler, Savov, and Schnabl (2018), we do not have to deal with the credit risk of the loans and its remuneration.

The paper is structured as follows. In Section 2, the model we use in this paper is described and the data that are used are explained in Section 3. In Section 4, the empirical results are given. Section 5 concludes.

2 Modeling

2.1 General setting

In his model, Klein (1971) considers the assets and liabilities of a bank when he shows how this bank maximizes its profits. By contrast, we restrict ourselves to a bank's liabilities, more specifically to its deposits, but model the supply and demand of deposits in a concrete way, thereby obtaining determinants that we can use for an empirical study.

A bank, located in x_{bank}, accepts customer deposits and remunerates them at r_{bank} which differs from the market interest rate r by the markdown md_{bank}:

$$r_{bank} = r - md_{bank} \tag{1}$$

We consider a customer that is located in x. Her utility u derived from placing her deposits in a given bank depends on the services s_{bank} the bank provides, her distance to the bank $\Delta = |x - x_{bank}|$, the remuneration r_{bank} and the opportunity costs of not investing at the market rate r:

$$u(x) = s_{bank} - k \cdot (x - x_{bank})^2 + r_{bank} - r \tag{2}$$

where k is a positive constant that gives the relative importance that the customer attaches to the distance to the bank she chooses.[4] Note that the customers are assumed to be equally distributed over the linear interval from 0 to 1 and that they each invest one unit that cannot be spread over several banks, but can only be invested in exactly one bank. We consider a Bank B that offers services s_B, is located in $x_{bank} = x_B > 0$, chooses the remuneration $r_{bank} = r_B$ and has unit costs of c_B and fixed costs C. The resulting utility for the consumers as a function of their location x is:

$$u_B(x) = s_B - k \cdot (x - x_B)^2 + r_B - r \tag{3}$$

Bank B can invest the deposits at the market rate r. Its profit π_B is

$$\pi_B = (r - r_B - c_B) \cdot a_B - C, \tag{4}$$

where a_B is the market share of Bank B (see Equation (7)).

Assume that there is an exogenous bank, denoted by the index 0, located in $x_{bank} = x_0 = 0$ and charging the markdown md_0, i.e. $r_0 = r - md_0$, which means that a customer located in x derives the following utility:

$$u_0(x) = s_0 - k \cdot x^2 + r_0 - r \tag{5}$$

Note that this model contains a whole host of simplifying assumptions: The investors are linearly located and their behavior is represented by a utility function. The concept of utility maximization is likely not to adequately represent human behavior. This holds

[4] The utility function depending negatively on the squared distance $\Delta = |x - x_{bank}|$ raises the question as to whether the standard assumptions of a utility function are fulfilled. If we define nearness as $n = \Delta_{max} - \Delta$, the utility becomes $u(n) = a - \Delta^2 = a - (\Delta_{max} - n)^2$ (where a is a term, not depending on the bank's and the customer's location) and we see that the marginal utility $u'(n) = 2(\Delta_{max} - n)$ is always positive, but diminishing ($u''(n) = -2 < 0$), which is in accordance with the classical assumptions.

especially true of situations where the gains resulting from optimal decisions are relatively minor compared to the costs, as in our model, where the gain is a better remuneration of the investor's bank deposits in the range of some basis points compared to the non-negligible costs of switching a bank relationship (see Brunetti, Ciciretti, and Djordjevic (2016)). This leads to the concept of bounded rationality (see Selten (1990) and Conlisk (1996)), where individuals rationally forgo to search for the optimal decision and try to reach a satisfactory solution. In addition, there are only two banks of which one is not profit-maximizing, but sets its rates exogenously. Nevertheless, these simplifying assumptions allows us to keep the model tractable; for instance, if we gave up the assumption of one-dimensionally located investors and replaced it by the more realistic assumption of two-dimensional location, the model would become less tractable with not much gain in insight.

2.2 Optimization

The customers decide whether to deposit their funds in Bank B or in Bank 0, depending on the comparison of the utility derived from choosing Bank B or 0, i.e. by comparing u_B to u_0. One can show that there is a unique x^+ for which customers located in $0 \leq x \leq x^+$decide for Bank 0 and customers located in $x^+ < x \leq 1$ decide for Bank B. This x^+ is given by

$$x^+ = 0.5 \cdot x_B - \frac{(r_B - r_0) + (s_B - s_0)}{2 \cdot x_B \cdot k}. \tag{6}$$

Bank B has therefore the fraction of customers $a_B := 1 - x^+$:

$$a_B = 1 - 0.5 \cdot x_B + \frac{(r_B - r_0) + (s_B - s_0)}{2 \cdot x_B \cdot k} \tag{7}$$

Equation (7) implies a linear relationship between quantity (here: the fraction of customers or market share a_B) and price ($p_B = md_B$):[5]

$$a_B(p_B) = c - d \cdot p_B \tag{8}$$

with $c = 1 - 0.5 \cdot x_B + \frac{r - r_0 + (s_B - s_0)}{2 \cdot x_B \cdot k}$ and $d = \frac{1}{2 \cdot x_B \cdot k} > 0$. According to Bulow and Pfleiderer (1983), this leads to a constant pass-through of less than one if the costs (here: the market interest rate r and marginal costs c_B) change.

Bank B can choose how it sets its deposit rate r_B.[6] It can be shown (see Appendix 1, Equation (23), see also Klein (1971) for a more abstract solution) that the bank maximizes its profits by setting the deposit rate r_B^* equal to

$$r_B^* = \frac{1}{2} \left(-k \cdot x_B \cdot (2 - x_B) + r + r_0 - (s_B - s_0) - c_B \right). \tag{9}$$

Even in this simple model, we see that the immediate pass-through from the market rates is not complete; it is 0.5 (assuming the competitor does not adjust its deposit rate

[5] To have access to the financial services s_B the customer has (implicitly) to pay r (as opportunity costs of not being able to invest at the market rate r), but she receives r_B. So the (net) price is $md_B = r - r_B$.

[6] Note that the fixed costs C are irrelevant to the optimization, as the bank provides services (at least in the short run), even if the fixed costs C are not covered.

r_0). Although the deposit rate is an affine function of the market interest rate, the deposit rate is usually not a constant multiple of the market interest rate; the other determinants like, for instance, the marginal costs c_B prevent a linear relationship. Further, we see that the optimal deposit rate is the lower, (i) the more importance its customers attach to the vicinity of the bank and the larger the distance x_B, that the customers have to cover, (ii) the stronger the bank's competitive position, measured by the reaction of the variable r_0 to changes in the interest level r, (iii) the more services the bank provides (relative to its competitors) $s_B - s_0$, and (iv) the higher the bank's marginal costs c_B. Hence, low deposit rates may be a sign of a bank's strong competitive position, but also a sign of this bank's weak cost situation.

2.3 Low-interest-rate environment

In the model described above (see Equation (4)), we assume that banks offer deposits because their remuneration is low so that banks can make a profit by investing the resources at higher rates, for instance the market interest rates for government bonds, that additionally cover the (marginal) costs of the deposits. However, in recent years, the market interest rates have been very low, even negative, making it difficult to maximize profits by means of lowly remunerated deposits and higher-yield investments. From the banks' perspective, other motives must prevail; for instance, they see deposits as a stable source of funding. However, in our empirical analysis (see Section 4.2), the banks' loan-to-deposit ratio turns often out to be insignificant.

From the perspective of the customers, low interest rates mean that cash becomes very attractive compared to deposits, and so they hold cash instead of bank deposits. In the view of Assenmacher and Krogstrup (2021), the decisive interest rate is likely to be below zero as dealing with cash may cause other costs (such as the threat of theft) compared to using deposits. Nevertheless, customers will sooner or later likely switch to cash if deposit interest rates become negative. This may be one central reason why banks are reluctant to introduce negative rates on their deposits and charge fees for the banking services instead.

As a robustness check (see Section 4.3), we analyze the period before June 2014 and find that the relationship to explain the banks' rates on sight deposits is qualitatively the same as compared with the whole period that includes the period with negative interest rates on the ECB's deposit facility.

3 Data

3.1 The German banking system

The German banking system consists of universal banks that operate nationwide and of universal banks that are regionally focused. The category of regionally focused universal banks comprises regional private commercial banks, savings banks and cooperative banks. For a bank's location and its competitive situation, we use the sample of regional banks (regional private commercial banks, savings and cooperative banks). We do so because we can assume that regional banks do most of their business in the district where their

Table 1: Summary statistics: Domestic individuals' deposits with German banks

Type of deposit	Banking system	Regional banks
Sight deposits	1396	1102
Savings accounts (notice per. of up to 3 m.)	526	445
Savings account (long-term)	35	30
Term deposits (short-term)	44	30
Term deposits (medium-term)	10	5
Term deposits (long-term)	193	13
All deposits to domestic individuals	2203	1625
Relative to all liabilities (incl. equity)	28.2%	51.3%

This table shows summary statistics of deposits of German banks from domestic individuals. All figures (apart from the percentages) are in EUR billion. "Regional banks" consists of regional commercial banks, savings banks and cooperative banks. Date: December 2018. Source: Deutsche Bundesbank (2019)

headquarters are located. By contrast, we cannot draw such a conclusion from the district where the headquarters of a nationwide bank is located.

During the sample period from January 2003 to December 2018, the number of banks in Germany decreased from 2355 to 1583. In Table 1, we show the importance of deposits from domestic individuals for the financing of banks in Germany. In particular, the regional banks finance more than half of their operations with deposits from domestic individuals.

3.2 Main variable

We use as our primary dataset the German part of the MIR statistics which comprises monthly reports of effective interest rates in new business and the corresponding volumes for 266 banks. These banks constitute a part of the more than 2000 banks that existed during the sample period (see the section above). The panel is unbalanced as the sample of banks reporting to the MIR statistics changes over time. For our analysis, we use only those banks that report deposit rates for at least 5 years (60 months).

We use interest rates (zero coupon returns) derived from German government bonds (see Schich (1997)) with the method according to Svensson (1994) (see Table 2). Our sample period started in January 2003 (when the MIR statistics started) and ended in December 2018. During this period, we observe that the term structure derived from the median interest rate (in the time dimension) is normal, i.e. the interest rates strictly increase with the maturity. We also see the impact of the low-interest-rate environment: the tenth percentiles of the interest rates up to $6\frac{1}{2}$ years are negative.

We calculate for each individual bank and for each of the six types of retail deposits[7] the markdown md_B (see Table 3) using the replicating portfolio approach described in Maes and Timmermans (2005). They describe two objective functions, the standard deviation of the markdown and its Sharpe ratio. In the following, we deal with the standard deviation (or equivalently with the variance) of the markdown because this objective function is far

[7]One type of sight deposits, two types of savings accounts (up to / more than three months' notice) and three types of term deposits (up to 1 year, more than 1 year and and up to 2 years, more than 2 years).

Table 2: Interest rates of German government bonds

Maturity	10th percentile	Median	90th percentile
6	-0.683	0.460	3.747
12	-0.680	0.643	3.749
18	-0.659	0.765	3.718
24	-0.624	0.904	3.675
30	-0.583	1.092	3.668
36	-0.535	1.237	3.682
42	-0.471	1.379	3.710
48	-0.416	1.524	3.745
54	-0.367	1.701	3.785
60	-0.309	1.870	3.793
66	-0.227	2.030	3.804
72	-0.145	2.180	3.885
78	-0.065	2.321	3.950
84	0.004	2.451	4.006
90	0.081	2.570	4.062
96	0.155	2.668	4.125
102	0.225	2.759	4.191
108	0.279	2.845	4.235
114	0.330	2.924	4.297
120	0.376	2.998	4.333

This table shows summary statistics of the interest rates of German government bonds (zero bond returns in % p.a.; method according to Svensson (1994) applied to German government bonds (see Schich (1997)) with different maturities (in months). Monthly data; period: January 2003 - December 2018.

more widespread. In Appendix 3, we show that the Sharpe Ratio and a certain regression approach are equivalent. As stated above, the objective is to minimize the empirical variance of the markdown, i.e. to have, to the greatest extent possible, a timely constant markdown.

$$\underset{m_1,m_2}{min}\left(\underset{md_B,w_1,w_2,w_P}{min}\frac{1}{T}\sum_{t=1}^{T}\varepsilon_t^2\right) \tag{10}$$

The following constraints obtain:

$$\begin{aligned} \varepsilon_t &= r_{B,t}-(-md_B+w_1\cdot r_{m_1,t}+w_2\cdot r_{m_2,t}+w_P r_{P,t}) & (11)\\ 1 &= w_1+w_2+w_P & (12)\\ w_i &\geq 0 \;\; i=1,2,P & (13) \end{aligned}$$

The markdown md_B can be seen as the rate that is above the one set aside for the tracking portfolio, where the tracking portfolio consists of three shares: (i) an investment of share w_1 in German government bonds of maturity m_1, (ii) an investment of share w_2 in German government bonds of maturity m_2 and (iii) an investment of share w_P in an arbitrary asset. The inner optimization of (10), i.e. the determination of md_B, w_1, w_2 and w_P given the maturities m_1 and m_2, is done in a regression approach already used in Busch and Memmel (2017). The inner optimization of (10) combined with the definition (11) corresponds to the OLS regression:

$$r_{B,t}=-md_B+w_1\cdot r_{m_1,t}+w_2\cdot r_{m_2,t}+w_P\cdot r_{P,t}+\varepsilon_t \tag{14}$$

Using the budget constraint $w_1+w_2+w_P=1$ (see Equation (12)), we can transform this regression into (see Kempf and Memmel (2006))

$$r_{B,t}-r_{P,t}=-md_B+w_1\cdot(r_{m_1,t}-r_{P,t})+w_2\cdot(r_{m_2,t}-r_{P,t})+\varepsilon_t. \tag{15}$$

If, additionally, $r_{P,t}$ is time-constant, i.e. $r_{P,t}=r_P\,\forall t$, we can run the following regression

$$r_{B,t}=\alpha+\beta_1\cdot r_{m_1,t}+\beta_2\cdot r_{m_2,t}+\varepsilon_t \tag{16}$$

with $w_1=\beta_1$, $w_2=\beta_2$ and $md_B=(1-\beta_1-\beta_2)\cdot r_P-\alpha$. The regression (16) resembles the relationship derived from the paper by Rousseas (1985). Using this regression approach (which can be easily extended to three or more bond positions), we are able to determine the portfolio weights in a continuous manner, not only for a discrete selection of portfolio weights. In addition, we impose the three non-negative constraints of (13). These non-negative constraints make the estimation more stable and make sure that the tracking portfolio does not consists of large long and short positions which would make the practical implementation difficult. Note that these non-negative constraints are not part of the regression approach.

The optimal maturities, i.e. the outer optimization in (10), are determined by trying out all relevant maturity combinations (m_1 and m_2) in steps of 6 months of up to 10 years (which yields 190 relevant combinations; see Appendix 2) and choosing the combination of m_1^* and m_2^* which yields the highest coefficient of determination R^2 in the regression (16) of the tracking portfolio.

We interpret the sum of the shares w_1 and w_2, i.e. the share of the tracking portfolio invested in government bonds, as the pass-through pt_B. We do so because the tracking portfolio's long-run pass through is equal to pt_B, i.e. the share of the tracking portfolio that is invested in government bonds has a pass-through of one (by definition, because the term structure is based on government bonds) and the investment in the asset with time-constant return (share w_P) has by definition a pass-through of zero. Setting $\bar{r} = \frac{1}{2} \cdot (E(r_{m_1,t}) + E(r_{m_2,t}))$ as the average interest level, we obtain (using the expectation of Equation (16)):

$$md_B = (1 - pt_B) \cdot r_P + pt_B \cdot \bar{r} - E(r_{B,t}) + Rest \tag{17}$$

with $Rest = w_1 \cdot (\bar{r} - E(r_{m_2,t})) + w_2 \cdot (\bar{r} - E(r_{m_1,t}))$.[8] Both measures, i.e. md_B and pt_B, are in principle derived from the same regression approach. Whereas pt_B corresponds to the classical pass-through measure, the measure md_B encompasses not only the slope coefficients, but the intercept as well.

As to the comparison between the measures md_B and pt_B, we can name the following points:

- For our research question, i.e. the long-run relationship between deposit rates and interest levels, md_B seems to be more comprehensive than pt_B in the sense that the level of deposit rates is also accounted for. An example may explain this: suppose there are two banks. The first bank remunerates its deposits at the short-term market interest rate. The second bank remunerates its deposits at the moving average of this market interest rate. In the long run, the remuneration of both banks is equal and corresponds to the average interest rate, i.e. $E(r_{B,t,1}) = E(r_{B,t,2}) = \bar{r}$, yielding a markdown md_B of zero for both banks (see Equation (17), provided that $r_P = \bar{r}$ and $Rest = 0$). By contrast, the pass-through of the first bank, which is close to one, is likely to be much higher than that of the second bank, i.e. $1 = pt_{B,1} > pt_{B,2}$. In other words, two banks with the same average remuneration of deposits have the same markdown, whereas the pass-through need not be the same.

- It is an empirical question of whether the markdown and the pass-through are interchangeable in the sense that they contain the same information. For the sight deposits, the pass-through pt_B and the markdown md_B convey nearly the same information, in our study – the correlation is close to one (94.6%). However, for the other deposits, the correlation is much lower, ranging from 41.2% (medium-term deposits) to 73.4% (savings accounts at up to 3 months' notice).

- From a practical point of view, the solution of the approach in (10) not only yields the markdown, but the portfolio weights of the replicating portfolio as well, i.e. the bank's risk manager is provided with the detailed composition of the tracking portfolio.

[8] The term *Rest* is exactly zero if the portfolio shares w_1 and w_2 are equal or the term structure is flat. In case, in the tracking portfolio, the longer maturities outweigh the short maturities the term *Rest* is systematically positive (given a normal term structure).

- As to cointegration (the same applies to pt_B if not estimated in an error correction model): The portfolio replicating approach can be written as an OLS regression. Therefore, the slope coefficients are super consistent.[9] If the interest and deposit rates are integrated of degree 1 and there exists a cointegration relationship (see Stock (1987)). This means, the weights derived from the replicating portfolio approach quickly converge to the true ones.

From Table 3, we see that, with sight deposits and savings accounts, banks earn more than with term deposits, at least concerning the net interest income (high estimated values for md_B, namely for the median bank 2.458% (in case of sight deposits) and 1.438% (in case of savings accounts at 3 months' notice)).

The pass-through pt_B is the lowest for sight deposits with a median of 0.311, which is close to earlier findings of about ⅓ to $\frac{1}{2}$. This means that the composition of the tracking portfolio of the median bank is 31.1% government bonds and 68.9% investment in the asset with the time constant return.

N gives the number of monthly observations for each bank. If a bank reports every month for the whole sample period under investigation (i.e. from January 2003 to December 2018), it has 192 = 16 years x 12 observations/year. This is the case for the median bank concerning sight deposits and savings accounts, but not for term deposits.

For the median bank, the fit for the six types of deposits – measured by the coefficient of determinant R^2 of regression (16) – is relatively high, about 85% (ranging from 83.9% to 87.5%). For sight deposits, we see a pronounced decrease in R^2 to 18.2%, if we look at the tenth percentile of banks. By contrast, for savings accounts and term deposits, the R^2 stays above 50%, even at the tenth percentile.

As regards the variable *size*, which we will later use to weigh the components for savings accounts and term deposits, we see that in Germany savings accounts with a notice period of up to 3 months are far more widespread than long-term savings accounts (median size EUR 813.4 million vs. EUR 109.5 million). Concerning term deposits, there seems to be emphasis on short- and medium-term maturities, not on long maturities (EUR 94.7 million and EUR 85.5 million vs. EUR 11.7 million for the median bank). The last observation – when compared with Table 1 – shows that the banks reporting to the MIR statistics are not a random sample of the banks in Germany and that they are not equally weighted when looking at the whole banking system (see Deutsche Bundesbank (2004)).

3.3 Explanatory variables

As explanatory variables, we use dummy variables. We do so for three reasons: (i) As we have only a limited number of observations (depending on the specification between 119 and 222, see Table 4), we can refrain from an outlier correction of the explanatory variables by using dummy variables. (ii) In the event we do not use dummy variables, but, for instance, the log variables, the assumed functional form may not be correct, especially not for extreme values of the explanatory variables. (iii) The coefficients are straightforward to interpret.

A bank's location is proxied by the dummy variable $x_{B,i}$ which takes the value of one if the regional Bank i is not headquartered (at district level) in a medium-sized or big city

[9] Super consistency in this context means that the estimated parameters converge in probability to the true parameters at the speed T (instead of the usual speed $\sqrt{T}$ for the convergence in distribution).

Table 3: Estimates and figures per bank

Deposit	Variable	Unit	10th percentile	Median	90th percentile	Number of banks
Sight deposits	md_B	% p.a.	1.110	2.458	3.244	222
	pt_B	1	0.060	0.311	0.635	222
	N	1	103	192	192	222
	R^2	1	0.182	0.839	0.944	222
	$size$	EUR million	22.0	939.3	4491.6	222
Savings accounts (notice period of up to 3 months)	md_B	% p.a.	0.465	1.438	2.351	173
	pt_B	1	0.268	0.518	0.726	173
	N	1	103	192	192	173
	R^2	1	0.574	0.843	0.942	173
	$size$	EUR million	66.5	813.4	2612.9	173
Savings account (long-term)	md_B	% p.a.	0.238	0.793	1.694	167
	pt_B	1	0.352	0.694	0.828	167
	N	1	102	192	192	167
	R^2	1	0.532	0.846	0.933	167
	$size$	EUR million	4.7	109.5	497.3	167
Term deposits (short-term)	md_B	% p.a.	-0.075	0.282	1.581	189
	pt_B	1	0.471	0.770	0.906	189
	N	1	83	177	192	189
	R^2	1	0.522	0.837	0.939	189
	$size$	EUR million	16.2	94.7	446.7	189
Term deposits (medium-term)	md_B	% p.a.	-0.188	0.057	0.381	133
	pt_B	1	0.675	0.826	0.953	133
	N	1	77	142	192	133
	R^2	1	0.699	0.875	0.949	133
	$size$	EUR million	6.8	85.5	688.6	133
Term deposits (long-term)	md_B	% p.a.	-0.312	0.140	0.833	170
	pt_B	1	0.443	0.817	0.965	170
	N	1	84	170	192	170
	R^2	1	0.595	0.854	0.955	170
	$size$	EUR million	0.5	11.7	189.1	170

This table shows summary statistics for the variables md_B, pt_B, N, R^2 and $size$. The variable pt_B is the share of the tracking portfolio invested in government bonds. The variable N is the number of months for which a bank reports to the MIR statistics; the minimum is 60 (otherwise, the bank is dropped from the sample). The variable $size$ is given in EUR million and is the stock of the respective position in the balance sheet. Period: January 2003 - December 2018.

(which is a “kreisfreie Stadt”), but instead in a rural district. More concretely, Germany is divided into 401 districts, of which 294 are not “kreisfreie Städte”. The idea is that in rural districts the distances to the next banks are larger than in district-free cities (“kreisfreie Städte)”, so that customers in rural districts have to cover greater distances in order to reach a bank.

A bank's competitive situation is characterized by the two dummy variables com_i^1 and com_i^2. The dummy variable com_i^1 takes the value one, if in the district of the regional Bank i the number of regional banks headquartered in the district of Bank i is above the median. The dummy variable com_i^2 takes the value one if all groups of regional banks (regional private commercial banks, savings banks and cooperative banks) are present in regional Bank i's district. The dummy variables com_i^1 and com_i^2 proxy the variable r_0 in Equation (9), meaning the more Bank i is exposed to competition, the more the variable r_0 reacts, here: the average deposit rate of the relevant competitors, to changes in the interest level r. Note that there exists other variables in the literature to measure competition (see Kleimeier and Sander (2017) for an overview). The measures in this paper are especially relevant for the German market.

We characterize the services a bank provides by the two dummy variables $s_{B,i}^1$ and $s_{B,i}^2$. The dummy variable $s_{B,i}^1$ is one if Bank i provides more automated teller machines (ATMs) accounting for the number of accounts than the median bank. We run the following regression

$$ln\left(atm_i\right) = \alpha + \beta \cdot ln\left(accounts_i\right) + \varepsilon_i \tag{18}$$

where atm_i is the average number of ATMs of Bank i (from the sample of all German banks) and $accounts_i$ is the average number of accounts Bank i has. For every Bank i, we calculate the variable $hatm_i = ln\left(atm_i\right) - \hat{\beta} \cdot ln\left(accounts_i\right)$ and check whether it lies above the cross-sectional median. By the way, we find that $\hat{\beta}$ is significantly smaller than one – about 0.896, leading to the conclusion that there exist returns to scale concerning the availability of ATMs.

The dummy variable $s_{B,i}^2$ is one if Bank i's euro amount (deflated by the harmonized index of consumer prices (HICP) for Germany) of counter cash transactions (accounted for the number of accounts) is larger than that of the median bank. Similar to the case with the ATMs, we run the following regression

$$ln\left(countercashtransactions_i\right) = \alpha + \beta \cdot ln\left(accounts_i\right) + \varepsilon_i \tag{19}$$

where the variable $countercashtransaction_i$ is the average of customer counter cash transactions, deflated by the HICP.

A bank's cost situation is characterized by the dummy variable c_B. This dummy variable takes the value one if the ratio of bank's costs over its total assets is above the median.

For each of the fields *competition* and *service*, there are two dummy variables. We chose the specification with the highest coefficients of determination in the multivariate regressions for sight deposits (see Section 4.2). Table 6 shows the pairwise correlations of the explanatory variables. We see that the correlations of the dummy variables for the same field are large, especially for the two dummy variables that cover *competition* ($com^1$and com^2).

Regarding control variables, we apply the age and sex structure for each district (dummies *age* and *sex*). We make the assumption that the age and sex structure in a given district corresponds to the age and sex structure of the regional bank that is located in this district. The two variables are transformed into dummy variables, where we use the cross-sectional medians as the thresholds. In addition, we introduce the dummy variable *loan to deposit* for a bank's loan-to-deposit ratio as a control variable. This variable is equal to one if a bank's (time series) average of its loan-to-deposit ratio is above the cross-sectional median.

4 Results

4.1 Univariate analysis

For the empirical implementation, we resort to the estimated markdown $\widetilde{md}_B$, instead of the actual level of the deposit rate as in Equation (9). We do so to achieve independence of the interest level which fluctuates in the course of time. For the analysis, we calculate the mean for the variable markdown $\widetilde{md}_B$ for the two different values ($d = 0$ or $d = 1$) of the explanatory dummy variables. For the empirical implementation of the theoretical concepts of Section 2, we use as empirical operationalisation of Equation (9) the following variables (see Subsection 3.3): the location of a regional bank is proxied by the dummy variable x_B, which is 1 if the bank is headquartered in a rural district, the pricing reaction r_0 of the other banks is proxied by the two dummy variables for competition com^1 and com^2, the services a bank provides by the two dummy variables s_B^1 and s_B^2 and the bank's cost situation by the dummy variable c_B. In Table 4, we report the results of the univariate analysis. An example to explain this: concerning the sight deposits, the variable com^2 (row 3 in Table 4) takes the value zero ($d = 0$) in 48 cases and one ($d = 1$) in 123 cases, i.e. for $171 = 48 + 123$ regional banks we have 60 or more observations on their deposit rate. The mean markdown, as a function of com^2, is 2.586% (if $com^2 = 0$) and 2.314% (if $com^2 = 1$), yielding a difference of 0.272 percentage points and a value of the test statistics of equal means of 2.430, which is significant at the 1% level.

Note that for the dummy variables com_i^1, com_i^2 and $x_{B,i}$, we restrict the sample to the regional banks in the sample (regional private commercial banks, savings banks and cooperative banks). By contrast, for the dummy variables $s_{B,i}^1$, $s_{B,i}^2$ and $c_{B,i}$, we use the full sample of banks that belong to the German part of the MIR statistics.

As to sight deposits, we see that banks in rural districts, banks not exposed to strong competition and banks providing above-average service to customers have higher markdowns. The cost situation of the bank does not seem to be relevant for the remuneration of the sight deposits. However, for the short- and long-term term deposits, a banks costs situation plays a role.

4.2 Multivariate analysis

As most explanatory variables we use don't change at all, or only change slowly, in the course of time, we restrict the analysis to the cross section of banks. In the multivariate case, the cross-sectional regression looks as follows:[10]

[10]We cover all four fields with exactly one variable. We chose the specification of explanatory variables with the highest coefficient of determination for the sight deposits. According to Table 6, the pairwise

Table 4: Univariate analysis

Deposit	Variable	Number of banks		Mean $\widetilde{md}_B$			
		$d=0$	$d=1$	$d=0$	$d=1$	Difference	Test statistics
Sight deposits	x_B	123	48	2.309	2.598	-0.290	2.842***
	com^1	92	79	2.530	2.227	0.303	2.939***
	com^2	48	123	2.586	2.314	0.272	2.430***
	s_B^1	142	80	2.245	2.535	-0.290	3.092***
	s_B^2	146	76	2.198	2.640	-0.442	4.789***
	c_B	194	28	2.336	2.444	-0.107	0.657
Savings accounts (up to 3 months' notice)	x_B	111	45	1.472	1.290	0.182	1.355
	com^1	87	69	1.381	1.468	-0.087	0.68
	com^2	45	111	1.331	1.456	-0.125	1.015
	s_B^1	93	80	1.460	1.396	0.064	0.546
	s_B^2	98	75	1.513	1.323	0.190	1.588
	c_B	152	21	1.404	1.623	-0.219	0.992
Savings accounts (long-term)	x_B	106	44	0.842	0.789	0.052	0.517
	com^1	85	65	0.777	0.891	-0.114	0.969
	com^2	45	105	0.858	0.813	0.046	0.394
	s_B^1	88	79	0.841	0.856	-0.015	0.135
	s_B^2	92	75	0.840	0.858	-0.017	0.156
	c_B	148	19	0.827	1.012	-0.185	0.745
Term deposits (short-term)	x_B	114	46	0.389	0.677	-0.288	2.196**
	com^1	86	74	0.487	0.453	0.034	0.301
	com^2	46	114	0.450	0.480	-0.031	0.244
	s_B^1	111	78	0.463	0.434	0.029	0.300
	s_B^2	115	74	0.435	0.476	-0.041	0.403
	c_B	166	23	0.406	0.776	-0.370	1.867*
Term deposits (medium-term)	x_B	84	35	0.062	0.201	-0.139	1.513
	com^1	67	52	0.151	0.041	0.110	1.507
	com^2	34	85	0.185	0.070	0.115	1.51
	s_B^1	70	63	0.036	0.127	-0.091	1.304
	s_B^2	79	54	0.051	0.120	-0.068	0.997
	c_B	119	14	0.061	0.232	-0.171	1.082
Term deposits (long-term)	x_B	99	42	0.069	0.137	-0.068	1.127
	com^1	80	61	0.113	0.059	0.055	0.869
	com^2	44	97	0.153	0.061	0.092	1.417
	s_B^1	95	75	0.318	0.126	0.192	1.983**
	s_B^2	99	71	0.329	0.101	0.228	2.385***
	c_B	155	15	0.252	0.047	0.205	1.740*

This table shows the results of the univariate analysis. x_B is a dummy variable, indicating whether a regional bank is located in a rural district. The variables $com^1$and $com^2$are dummy variables, indicating whether a bank is exposed to strong competition. The variables s_B^1 and s_B^2 indicate whether a bank provides above-average services, and c_B is a dummy variable that depends on the bank's cost situation (see Section 3.3). The test statistics in the last column refers to a t-test of equal means. Period: January 2003 - December 2018. ***, ** and * denote significance at the 1%, 5% and 10% level.

Table 5: Multivariate analysis

Variable	Sight deposits	Savings accounts	Term deposits
x_B	0.357***	-0.232	0.436***
	(0.104)	(0.144)	(0.145)
com^2	-0.232**	0.138	-0.064
	(0.103)	(0.108)	(0.108)
s_B^2	0.471***	-0.200*	0.031
	(0.089)	(0.116)	(0.097)
c_B	0.129	0.269	0.363**
	(0.171)	(0.218)	(0.175)
age	-0.079	0.066	0.071
	(0.108)	(0.141)	(0.117)
sex	-0.069	0.086	-0.167
	(0.106)	(0.124)	(0.134)
loan to deposit	-0.113	0.079	-0.215**
	(0.102)	(0.129)	(0.093)
constant	2.357***	1.237***	0.358***
	(0.128)	(0.139)	(0.124)
R^2	0.192	0.062	0.147
NoBs	171	156	161

This table shows the results of Equation (20). The dependent variable in the regressions is the estimated markdown $\widetilde{md}_B$ of the different products. x_B is a dummy variable, indicating whether a regional bank is located in a rural district. The variable com^2 is a dummy variable, indicating whether a bank is exposed to strong competition. The variable s_B^2 indicates whether a bank provides above-average services and c_B is a dummy variable that depends on the bank's cost situation; the dummy variables *age* and *sex* are to proxy the age and sex structure in the district where the regional bank is located; the dummy variable *loan to deposit* is one if a bank's loan-to-deposit ratio is above the median (see Section 3.3). Period: January 2003 - December 2018. Robust standard errors in brackets. ***, ** and * denote significance at the 1%, 5% and 10% level.

$$\widetilde{md}_{B,i} = \alpha + \beta_1 \cdot x_{B,i} + \beta_2 \cdot com_i^2 + \beta_3 \cdot s_{B,i}^2 + \beta_4 \cdot c_{B,i} + \gamma' X_i + \varepsilon_i \tag{20}$$

where X_i is a vector of bank-specific control variables (age and sex structure in the district where the bank is located and the loan-to-deposit ratio).

According to the theoretical model, we expect for β_2 a negative sign and for β_1, β_3 and β_4 a positive one. The coefficients and the constant can be immediately interpreted. A coefficient of 0.357 (first column, first row in Table 5) means that banks located in rural districts have on average a markdown for sight deposits compared to banks in non-rural districts that is higher by 0.357 percentage points. Instead of the six types of deposits, we report only three deposit classes, namely sight deposits, savings deposits (composed of the two types of savings accounts) and term deposits (composed of the three types of term deposits), where the markdowns of the different types of deposits are weighted with their average *size* reported in Table 3. The results are displayed in Table 5.

correlations are moderate in this specification.

Note that we are dealing with correlations, not causalities. We find that, as regards sight deposits, the banks' markdown depends on the location (located in rural districts (+35.7 bp)), on the competitive situation (exposed to strong competition (-23.2 bp); here: at least one bank for each of the three regional banking categories are present in the respective district) and the provision of services (above average: +47.1 bp). As regards term deposits, we see that a bank's cost situation is important. If bank's costs per total assets are higher than that of the median bank, a bank charges a higher markdown. This last finding is in line with Mojon (2000).

The multivariate results are qualitatively the same as in the univariate case; for instance, we obtain in both cases the result that banks in rural districts, not exposed to much competition and providing much service, charge large markdowns regarding their sight deposits. One can think of two causes: i) The results are robust and the variables have little correlation among each other or ii) the control variables are not able to capture the heterogeneity that is not explicitly modeled. As the control variables are often insignificant, there is reason to believe that the heterogeneity that is not explicitly modeled, especially concerning the customers, for instance their educational background, is not adequately described. However, there are no more granular data regarding the customers' characteristics at district level, let alone at bank level.

4.3 Robustness checks

If we replace the dependent variable md_B with pt_B, the explanatory power of the multivariate analysis as regards sight deposits goes down (from 19.2% to 15.8%). What is more, concerning saving accounts, we observe that banks located in rural districts and banks with above-average cash transactions have a significantly higher pass-through, which is against what common sense predicts.

If we look only at the period January 2003 - May 2014, the period before the European Central Bank (ECB) introduced negative rates on the deposit facility, the results remain qualitatively unchanged; the explanatory power of the regression for the sight deposits goes up to 24.6% (see Table 7), which seems due to the strong impact of the variable s_B that measures the services provided by the banks.

If we replace the dummy variables in the fields for competition and services by the ones we have not chosen in the multivariate analysis, i.e. com^2 and s_B^2 are replaced by com^1 and s_B^1, the significances concerning the regression for sight deposits become weaker and the R^2 falls from 19.2% to 10.9%.

When small German banks apply the replicating portfolio approach, they often use moving averages of interest rates instead of interest rates themselves, i.e. $q_{m,t} = \frac{1}{m}\sum_{i=1}^{m} r_{m,t-i+1}$ (see Memmel (2008)). If we replace the interest rates with their corresponding moving averages, we observe that the fit, measured by the R^2 of the regressions, becomes better. For all six types of deposits, the median R^2 goes up by between 2.6 and 8.9 percentage points (see Table 8). For instance, the median R^2 for savings accounts is 84.3% if using interest rates and 92.7% if using moving averages of interest rates, yielding an improvement of 8.4 percentage points. Nevertheless, we stick to the interest rates because interest rates are more common in this field of the academic literature.[11]

[11] See, for example, de Bondt, Mojon, and Valla (2005) and De Graeve et al. (2007). However, Memmel

The optimization in Section 2 relies on the positive dependence between the deposit rate r_B and the market share a_B (see Equation (7)). In the panel logit regression

$$I_{\{a_{B,t,i}>a_{B,t-1,i}\}} = \alpha + \sum_{k=0}^{K} \beta_k \cdot I_{\{r_{B,t-k,i}-\bar{r}_{B,t-k}>r_{B,t-k-1,i}-\bar{r}_{B,t-k-1}\}} + \varepsilon_{t,i}, \tag{21}$$

(where $I_{\{\}}$ is an indicator function) we find that the coefficients for the contemporary and lagged changes of the remuneration $(\beta_0, ..., \beta_K)$ are highly significant for all six types of deposits we look at. These results show that there is strong relationship between extending Bank i's market share, i.e. $a_{B,t,i} > a_{B,t-1,i}$, and the improvement of its remuneration of the deposits relative to the cross-sectional average, i.e. $r_{B,t-k,i} - \bar{r}_{B,t-k} > r_{B,t-k-1,i} - \bar{r}_{B,t-k-1}$.

5 Conclusion

In the period before the low-interest-rate environment, bank retail deposit rates tend to be much lower than the corresponding market interest rates. We try to explain this finding by theoretically identifying determinants of the markdowns a bank charges for its deposits, namely a bank's location, its competitive situation, the services it provides and its cost situation. Looking at banks that report to the German part of the MIR statistics, we see that banks which are located in rural districts, which are not exposed to strong competition and which provide much service charge a larger markdown for their sight deposits. As for term deposits, we find that a bank's cost situation is positively correlated with the markdown it charges. Comparing the sample period that includes a part of the low-interest-rate environment with the sample before, we have reason to believe that the determinants are also valid in the low-interest-rate environment.

We introduce two variables to measure the services a bank provides, namely the standardized number of ATMs and the customers' counter cash transactions. At least concerning the markdown of sight deposits, they have the expected sign and are highly significant, but there is reason to believe that other customer characteristics are not adequately accounted for.

By transferring concepts from portfolio theory to the pass-through topic, we show that the replicating portfolio approach is often equivalent to regression approaches and that the classical regression approach corresponds under some assumptions to the replicating portfolio approach.

For the issue of comparing the deposit rates to the interest level, the measure md_B seems to be more comprehensive than the classical pt_B measure and can be determined by using a regression approach, which is advantageous in the practical implementation.

(2014) finds that the moving averages of interest rates better describe the German banks' exposure to interest rate risk than the interest rates. From this observation, one may conclude that moving averages of interest rates play a role in bank management.

Appendix

Appendix 1

Replacing a_B in Equation (4) by the term of Equation (7) and then differencing Equation (4) with respect to the deposit rate r_B, we obtain

$$\frac{\partial \pi_B}{\partial r_B} = -\left(1 - 0.5 \cdot x_B + \frac{(r_B - r_0) + (s_B - s_0)}{2 \cdot x_B \cdot k}\right) + \frac{r - r_B - c_B}{2 \cdot x_B \cdot k}. \tag{22}$$

Setting Equation (22) equal to zero, we obtain the following expression:

$$x_B k \left(2 - x_B\right) + \left(r_B^* - r_0\right) + \left(s_B - s_0\right) = r - r_B^* - c_B, \tag{23}$$

where r_B^* denotes the optimal deposit rate.

Appendix 2

In this appendix, we describe how the optimization is practically implemented in this paper. As in Busch and Memmel (2017), we choose the maturities of the market interest rates r_{m_1} and r_{m_2} by comparing the coefficient of determination R^2 of the regression (16) for all relevant pairs of maturities (m_1, m_2) of up to 10 years in steps of 6 months (which yields 190 = 19 x 10 relevant comparisons[12]).[13] For the empirical implementation, we run regression (16), observing the non-negative constraints (13), and replace α, β_1 and β_2 by their OLS estimates; r_P is replaced by the time-series average of a passive trading strategy which consists in investing in 10-year par-yield government bonds in a revolving manner as described in Memmel (2014).

$$\widetilde{md}_B = \left(1 - \hat{\beta}_1 - \hat{\beta}_2\right) \cdot \bar{S}(120) - \hat{\alpha} \tag{24}$$

Appendix 3

In this appendix, we describe how a different target in the inner optimization (10), namely the Sharpe ratio instead of the variance, can be solved by a regression approach.

$$1 = \beta_0 \cdot (r_{B,t} - r_{P,t}) + \beta_1 \cdot (r_{m_1,t} - r_{P,t}) + \beta_2 \cdot (r_{m_2,t} - r_{P,t}) + \varepsilon_t. \tag{25}$$

or

$$1 = \beta' r_t + \varepsilon_t \tag{26}$$

[12]There are 20 different maturities for the market interest rates, i.e. starting with 6 months in steps of 6 months to 120 months = 10 years. This yields 400 = 20 x 20 comparisons of pairs of maturities (m_1, m_2). However, 20 cases where m_1 is equal to m_2 are not considered (because this would mean only one position in government bonds). In addition, the cases where the two maturities are only interchanged, i.e. (m_1, m_2) and (m_2, m_1), only one of the two is considered, meaning that there are (400-20)/2=190 relevant combinations.

[13]Note that the deposit rates and the market interest rates do not seem to be stationary, but seem to have a unit root (Sopp (2018)). Therefore, we refrain from using the estimated standard errors, and only use the coefficient of determination R^2 as a measure of variance reduction.

Table 6: Correlations of explanatory variables

	x_B	com^1	com^2	s_B^1	s_B^2	c_B
x_B	1.000					
com^1	-0.034	1.000				
com^2	0.040	0.450	1.000			
s_B^1	0.256	-0.243	-0.125	1.000		
s_B^2	0.050	-0.295	-0.155	0.289	1.000	
c_B	-0.118	0.192	0.045	-0.114	-0.161	1.000

This table shows pairwise correlation for all the regional banks (NoBs = 172). x_B is a dummy variable, indicating whether a regional bank is located in a rural district. The variables com^1 and com^2 are dummy variables, indicating whether a bank is exposed to strong competition. The variables s_B^1 and s_B^2 indicate whether a bank provides above-average services and c_B is a dummy variable that depends on the bank's cost situation (see Section 3.3)

where $\beta = (\beta_0, \beta_1, \beta_2)'$ and $r_t = (r_{B,t} - r_{P,t}, r_{m_1,t} - r_{P,t}, r_{m_2,t} - r_{P,t})'$. Britten-Jones (1999) shows that weights derived from the Ordinary Least Squares (OLS) estimator $\hat{\beta} = (r'r)^{-1} r'\underline{1}$ maximize the in-sample Sharpe ratio, i.e. $\hat{SR} = \hat{\beta}'\hat{\mu}/\sqrt{\hat{\beta}'\hat{\Sigma}\hat{\beta}}$ with $r = (r_1, ..., r_T)$, $\underline{1} = (1, ..., 1)'$, $\mu = E(r_t)$ and $\Sigma = var(r_t)$.

Every positive multiple of the weight vector $\hat{\beta}$ maximizes the in-sample Sharpe Ratio. A natural scaling factor in our case would be $1/\hat{\beta}_0$, i.e. such that the weight for the deposits is always one, $w_0 = 1$. The other weights are then $w_1 = \hat{\beta}_1/\hat{\beta}_0$, $w_2 = \hat{\beta}_2/\hat{\beta}_0$ and $w_P = 1 - \hat{\beta}_1/\hat{\beta}_0 - \hat{\beta}_2/\hat{\beta}_0$.

As Britten-Jones (1999) writes, regression (25) is unusual (having no constant and a non-stochastic dependent variable). This approach has merely been cited to show that the replicating portfolio approaches are often closely connected to regression approaches with various target functions.

Appendix 4

In this appendix, we report tables concerning the correlation (Table 6) and concerning some robustness checks (Table 7 and Table 8).

Table 7: Multivariate analysis (period up to May 2014)

Variable	Sight deposits	Savings accounts	Term deposits
x_B	0.387*** (0.136)	-0.179 (0.131)	0.083 (0.081)
com^2	-0.256** (0.129)	0.044 (0.094)	-0.067 (0.091)
s_B^2	0.604*** (0.111)	-0.073 (0.102)	0.042 (0.073)
c_B	-0.056 (0.246)	0.067 (0.147)	0.043 (0.087)
age	-0.141 (0.135)	0.010 (0.130)	0.080 (0.081)
sex	0.002 (0.126)	0.240** (0.110)	-0.146 (0.111)
$loan\,to\,deposit$	-0.068 (0.123)	0.065 (0.111)	-0.110 0.075
constant	2.632*** (0.168)	1.667*** (0.124)	0.360*** (0.117)
R^2	0.246	0.042	0.057
NoBs	130	122	127

This table shows the results of Equation (20). The dependent variable in the regressions is the estimated markdown $\widetilde{md}_B$ of the different products. x_B is a dummy variable, indicating whether a regional bank is located in a rural district. The variable com^2 is a dummy variable, indicating whether a bank is exposed to strong competition. The variable s_B^2 indicates whether a bank provides above-average services and c_B is a dummy variable that depends on the bank's cost situation; the dummy variables age and sex are to proxy the age and sex structure in the district where the regional bank is located; the dummy variable $loan\,to\,deposit$ is one if a bank's loan-to-deposit ratio is above the median (see Section 3.3). Period: January 2003 - May 2014. Robust standard errors in brackets. ***, ** and * denote significance at the 1%, 5% and 10% level.

Table 8: Coefficient of determination using moving averages of interest rates

Type of deposit	10th percentile	Median	90th percentile	Number of banks
Sight deposits	0.351	0.913	0.970	222
Savings accounts (up to 3 months' notice)	0.743	0.927	0.980	173
Savings account (long-term)	0.663	0.935	0.978	167
Term deposits (short-term)	0.561	0.891	0.963	189
Term deposits (medium-term)	0.753	0.907	0.956	133
Term deposits (long-term)	0.591	0.880	0.947	170

This table shows summary statistics for the measure of fit, i.e. the variable R^2, corresponding to the rows R^2 in Table 3 with the difference that the results in Table 3 are based on interest rates as regressors and the results in Table 8 are based on moving averages of interest rates. Period: January 2003 - December 2018.

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