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Loss Averse Depositors and Monetary Policy around Zero

Christian Stettler*

April 2020

Abstract

Recent experience from Europe and Japan shows that commercial banks generally pass negative short-term policy rates on to wholesale depositors, such as insurances and pension funds. Yet, they refrain from charging negative rates to ordinary retail customers. This paper asks whether the existing evidence on the inverse relationship between market experience and the degree of loss aversion can explain this transmission pattern. To this end, I allow for loss averse depositors within a simple two-period differentiated products duopoly with switching costs. It turns out that if depositors are especially averse to negative deposit rates, banks keep deposit rates at zero as policy rates decline, while accepting squeezed and possibly negative deposit margins. The lowest current policy rate at which the banking-system is willing to shield depositors from a negative deposit rate decreases with increasing i) degrees of loss aversion; ii) levels of switching costs; and iii) market expectations about the future policy rate. A calibration of the model indicates how low central banks could effectively go without taking steps to make paper currency more costly.

Keywords: Deposits, effective lower bound, loss aversion, negative interest rates

JEL Classification: D43, E43, E52, E58, G21, L13

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1 Introduction

In recent years, several central banks – including the European Central Bank, the Swiss National Bank, the Swedish Riksbank and Danmarks Nationalbank – pushed policy rates below zero. The observed transmission pattern to deposit rates is strongly heterogeneous across customer categories. Commercial banks are able to pass negative policy rates on to a large fraction of corporate depositors without experiencing a contraction in funding (Altavilla et al., 2019). Yet, banks almost universally refrain from passing negative rates on to ordinary retail customers (Bech and Malkhozov, 2016; Eggertsson et al., 2019). In recent years, this observation became pivotal in the discussion on the effectiveness of monetary policy at low and negative policy rates. On the one hand, it allows central banks to lower interest rates below zero without having to fear that some retail depositors would start to hoard cash. On the other hand, there is growing evidence that if policy rate cuts do not pass on to deposit rates, sapping net interest margins may impede or even reverse the usual functioning of the bank lending channel (Borio and Gambacorta, 2017; Brunnermeier and Koby, 2018; Eggertsson et al., 2019; Heider et al., 2019).

Former and current central bankers often highlight the lack of public acceptance for paying an interest on deposits. The chairman of the Governing Board of the Swiss National Bank, Thomas Jordan (2016), for example, states that “at first glance, imposing a charge on deposits appears to turn the logic and laws of economics on their head. It seems unnatural to pay interest on deposits”. Some stress the implication for central banks. Among others,¹ Krogstrup (2017) states that “the public lack of understanding and acceptance of negative interest rates has been palpable, raising concerns about a public backlash against central banks”. Others emphasize the role of market experience. Bernanke (2016), for example, states that “the idea of negative interest rates strikes many people as odd. Economists are less put off by it, perhaps because they are used to dealing with real interest rates, which are often negative”.

This paper expands on this intuition by explaining the observed transmission pattern of near zero policy rates to deposit rates on the base of loss aversion, people’s higher sensitivity to losses than to gains (Kahneman and Tversky, 1979).² The model focuses

¹Danthine (2018) states that “negative nominal rates are so unpopular that a democratic majority in favor of any legal measure permitting the direct exposure of the person in the street to negative interest rates is unreachable”. Similarly, Ball et al. (2016) note that “perhaps the strongest de facto impediment to cutting rates further into negative territory is the lack of public acceptance and understanding of such measures. Partly due to pervasive money illusion, negative interest rates seem counter-intuitive to the general public and are perceived in many countries as an unfair tax on savings”.

²In the deposits market context, the kink of account holders’ preferences at their endowment level is sometimes also referred to as retail deposits endowment effect. It derives from the general endowment effect anomaly (Thaler, 1980; Knetsch et al., 1989; Kahneman et al., 1990) and became a quite prominent explanation for the observed positive relationship between banks’ retail deposit margins and the level of the nominal interest rate (Borio et al., 2017; Borio and Gambacorta, 2017).

on the competitive situation among depository institutions. Therefore, it is based on the intuition that, at non-negative deposit rates, two electronic accounts are much closer substitutes than an electronic account and physical currency.³ In my model banks respond to a special aversion of customers to pay interest on their savings by keeping deposit rates at zero up to some policy rate lower bound to preserve market share that is valuable later. Since bank deposits are priced as a markdown on market rates, this results in squeezed and possibly even negative deposit margins. The policy rate lower bound up to which banks shield depositors from a negative rate decreases in banks' expectations about the future policy rate and the magnitude of depositors' loss aversion.

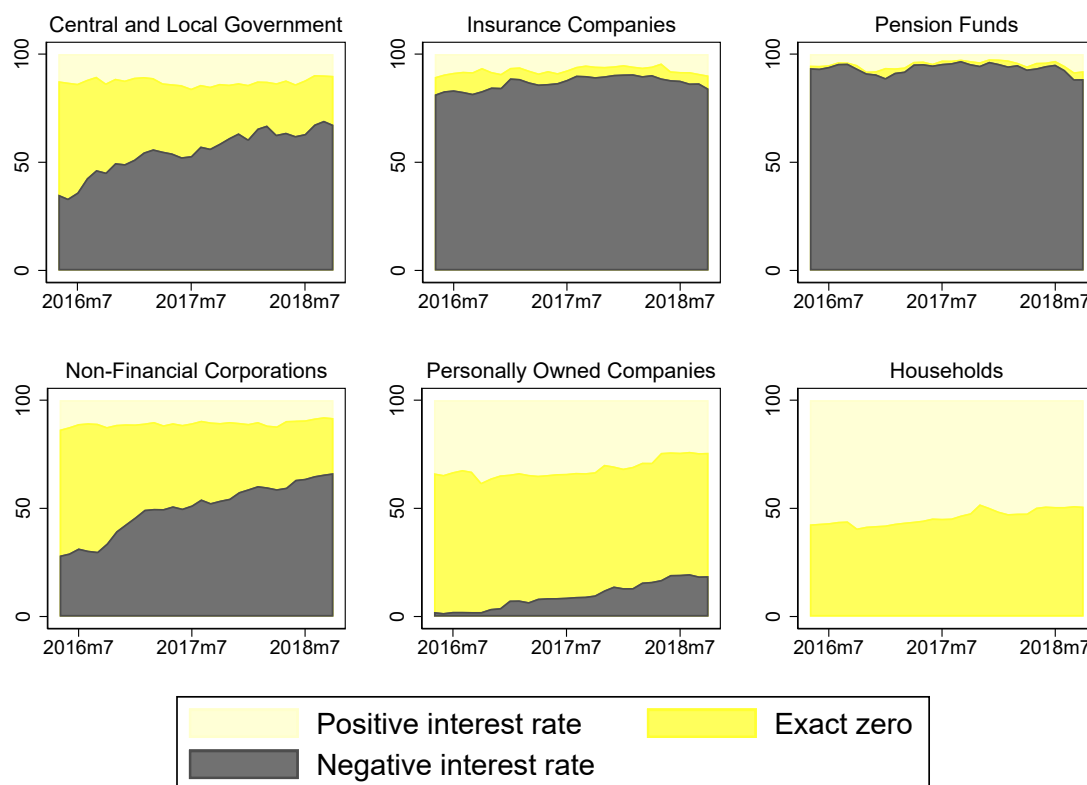


Figure 1: Share of negative, zero and positive deposit rates in Denmark

Notes: The figure shows the share of deposits - in Denmark and DKK - for which the accrued nominal interest over monthly periods was negative, exactly zero and positive by depositor category. During the observed time period (May 2016 to October 2018) the main policy rate remained constant at -0.65 percent. *Source:* Danmarks Nationalbank.

³Saving or checking accounts of different depository institutions generally offer similar services such as online payments, web access and a safe storage of wealth. By contrast, cash is costly to transport, vulnerable to theft and can be lost or destroyed. Moreover, even moderately negative rates do not seem to trigger large-scale hoardings of paper currency. In Switzerland, for example, depository institutions forward negative policy rates (-0.75 percent) to a large part of institutional depositors and to excess amounts of large deposits from households. Yet, this did not leave an obvious mark on the hoarding share estimates of highly denominated CHF 1000, CHF 200 and CHF 100 banknotes (Assenmacher et al., 2019). In other countries, most notably in Sweden, the use of cash is already very limited (Rogoff, 2016). Yet, depository institutions in Sweden also refrain from passing negative rates on to retail depositors. Finally, the global trend towards electronic payment systems is likely to continue and cash may become increasingly vestigial outside small transactions and illegal activities (Rogoff, 2017)

The literature on behavioral economics provides substantial experimental and empirical evidence that suggests the presence of loss aversion among inexperienced market participants, while individuals with intense market experience largely seem to behave in accordance with neoclassical predictions (List, 2003, 2004; Genesove and Mayer, 2001; Shapira and Venezia, 2001). In light of my model, these findings are also reflected in the transmission pattern of negative policy rates to depositors with presumably different levels of market experience. Figure 1 shows the share of deposits in Denmark for which the accrued interest (over one month periods) was positive, negative and exactly at zero for six different depositor categories.⁴ Denmark’s commercial banks generally pass negative policy rates⁵ on to deposited funds of insurance companies and pension funds. The picture gets more mixed for categories that consist of rather heterogeneous clients, such as “central, state and local governments” and “non-financial corporations”. Finally, Denmark’s banks completely (households) or largely (personally owned companies) refrain from charging negative rates to ordinary retail customers.

From a microeconomic perspective, the paper’s modeling stands on the shoulders of Klemperer (1987), who introduces switching costs⁶ into a two-period differentiated-products duopoly. In my model two banks compete over nominal deposit rates for loss averse customers with intertemporally changing tastes. The bank accounts are substitutes but the cost of changing banks partially forces depositors to remain at the bank they initially selected. This in turn results in a dependence of banks’ second-period profits from their first-period customer base.

I solve the model by backward induction. In the subgame perfect Nash-equilibrium of the second period, the bank with the lower market share is relatively more interested in attracting new customers than in exploiting the existing ones. However, due to depositors’ loss aversion the fairly general result that the competitor with the lower market share offers better conditions to customers, obtained in models with switching costs (Klemperer, 1987, 1995), might not hold. By contrast, offered deposit rates might not only remain non-responsive to a change in the policy rate, but also to changes in the banks’ market shares. For policy rates well above zero, these findings are consistent with the relative market power hypothesis advanced by Berger (1995), which states that banks with higher market shares set interest rates less competitively. Yet, these findings are also consistent with the recent observation that these differences narrow or disappear when policy rates

⁴The data are available under: http://www.nationalbanken.dk/da/statistik/find_statistik/Documents/Rentestatistik.

⁵Danmarks Nationalbank reduced the certificates of deposit rate to -0.75 percent in February 2015. On 8 January 2016, Danmarks Nationalbank slightly increased the interest rate on certificates of deposit by 0.1 percentage points to -0.65 percent, which then applied throughout the survey period.

⁶Switching costs are quite prominent in the deposits market context (Sharpe, 1997; Kim et al., 2003; Shy, 2002; Hannan and Adams, 2011). One may interpret them as the costs of closing an account at one bank and opening another at a competitor bank.

are low or negative. The intuition for this reduced or eliminated variation in deposit rates is similar to the one in paper of [Heidhues and Kőszegi \(2008\)](#), in which consumers special aversion to pay a price that exceeds their expectations reduces or eliminates price variation.

The equilibrium of the first period, and therefore the whole game, is symmetric. If there were no switching costs, depositors' loss aversion would induce banks to keep deposit rates at zero for a range of low but positive policy rates. However, second-period profits would be independent of first-period market shares. Hence, without switching costs, banks would not shield their customers from negative policy rates. By contrast, if customers are partially locked in by switching costs, which they face in the second period, first-period market share becomes valuable to banks. Due to account holders' special aversion to pay a negative rate – and therefore in contrast to the model of [Klemperer \(1987\)](#) – this value is not constant, but larger when expectations about the future policy rate are high. If market share becomes sufficiently valuable, then the Nash-equilibrium at zero is sustained even as policy rates turn negative.

The paper provides a country-specific calibration of the model for Switzerland, Sweden, Denmark, the euro area and its five largest economies. Since depository institutions do not charge negative rates to ordinary retail customers, actual loss aversion coefficients cannot be inferred. However, I can infer lower bounds of the actual loss aversion coefficients based on the lowest observed policy rates in each economy. A comparison of these values across economies and with commonly found loss aversion coefficients from the literature provides some indication about how low central banks could effectively lower policy rates without taking steps to make paper currency more costly. Most notably, the results suggest some additional room of maneuver for the euro area.

The rest of the paper is organized as follows. Section 2 introduces loss averse depositors into a two period differentiated-products duopoly adopted to the deposits market. Section 3 provides a calibration of the model. Section 4 concludes.

2 The Model

A) Set-up

The model builds on [Klemperer \(1987\)](#) who introduces switching costs to a spatial location model of product differentiation. The model is restricted to two periods. In the first period, two banks, A and B , are located on a line segment of length one at 0 and 1, respectively. They compete for customers over the nominal deposit rate denoted by r_1^A

and r_1^B , respectively.⁷ The central bank directly determines the risk-free rate, r_1^F . Each bank's deposit margin is the risk-free rate minus the deposit rate and each bank's profit consists of the deposit margin multiplied by the amount of deposits. Banks have rational expectations and maximize total profits from both periods given the market's belief about the distribution of the second-period risk-free rate.

Depositors with tastes $x_1 \in [0, 1]$, each endowed with one unit of wealth, are uniformly distributed along the line. Hence, their position on the line represents their tastes for the underlying characteristics of the two bank accounts. They can choose to store their unit of wealth at either bank A or B . Therefore, x_1 is the distance between an individual with taste x_1 and bank A and $(1 - x_1)$ is its distance to bank B . To overcome one unit of distance, depositors face the cost t . Hence, t is a measure of differentiation between the two bank accounts. Depositors value gains and losses on their savings according to

$$v(r_1) = \begin{cases} r_1 & \text{if } r_1 \geq 0 \\ \lambda r_1 & \text{if } r_1 < 0, \end{cases}$$

where $\lambda \in (1, \infty)$ is the loss aversion parameter. Therefore, depositors face a gain on their savings if $r_1 > 0$, a loss if $r_1 < 0$, or neither of the two if the nominal deposit rate is zero. In contrast to banks, depositors do not take the second period into account when making first-period decisions.

In the second period, banks A and B are again located at 0 and 1, respectively. After observing the second-period risk-free rate, r_2^F , each bank decides on their second-period deposit rate denoted by r_2^A and r_2^B , respectively. These rates can be different from the one they offered in the first period. Depositors are, independent of their position in the first period, again uniformly distributed along the line. They again value gains and losses on their savings according to the same value function as in the first period. However, depositors additionally face a switching cost s if they want to change their bank after the first period. I solve the model by backward induction. In the following subsection I analyze how the second-period equilibrium depends on first-period market shares and second-period policy rates. I present the equilibrium of the first period, and hence of the whole game, in Subsection C.

B) The Second Period

In the second period, an account-holder of bank A is indifferent between staying at bank A or switching to bank B if $v(r_2^A) - tx_2^A = v(r_2^B) - t(1 - x_2^A) - s$. Equiv-

⁷While all interest rates are in nominal values, I use the letter r instead of i for readability.

alently, a holder of an account at bank B is indifferent between keeping the account at bank B and switching to bank A if $v(r_2^A) - tx_2^B - s = v(r_2^B) - t(1 - x_2^B)$. Therefore, from the point of view of bank A , the indifferent current client is located at $\hat{x}_2^A = \frac{1}{2t} [v(r_2^A) - v(r_2^B) + t + s]$, while an indifferent current customer of competitor bank B is located at $\hat{x}_2^B = \frac{1}{2t} [v(r_2^A) - v(r_2^B) + t - s]$. Since the line segment is normalized to one, one can interpret \hat{x}_2^A as bank A 's second-period market share on its own customer base from the first period (denoted by \hat{x}_1). Similarly \hat{x}_2^B denotes the share which bank A gained from the first-period customer base of bank B (denoted by $1 - \hat{x}_1$).

Bank A 's second-period profit is composed of its total market share times its mark-down, therefore $\pi_2^A = [\hat{x}_1\hat{x}_2^A + (1 - \hat{x}_1)\hat{x}_2^B] (r_2^F - r_2^A)$. Similarly bank B 's second-period profit is $\pi_2^B = [\hat{x}_1(1 - \hat{x}_2^A) + (1 - \hat{x}_1)(1 - \hat{x}_2^B)] (r_2^F - r_2^B)$. Considering the definitions for the indifferent depositors and after simplifying bank A 's second-period profit amounts to $\pi_2^A = \frac{1}{2t} [v(r_2^A) - v(r_2^B) + t + s(2\hat{x}_1 - 1)] (r_2^F - r_2^A)$. Similarly, bank B 's second-period profit is $\pi_2^B = \frac{1}{2t} [v(r_2^B) - v(r_2^A) + t - s(2\hat{x}_1 - 1)] (r_2^F - r_2^B)$. I leave the derivation of the banks' deposit rate setting rules, stated in Proposition 1, to Appendix A.

PROPOSITION 1: Second-period deposit rates

Let $s \in [0, t]$ and $\theta = (s/3)(2\hat{x}_1 - 1)$. Allowing for asymmetric first-period market shares, bank A (with at least half of the first-period market share, that is $\hat{x}_1 \in [\frac{1}{2}, 1]$), and bank B ($\hat{x}_1 \in [0, \frac{1}{2}]$) set their deposit rates according to

$$r_2^A = \begin{cases} r_2^F - (t + \theta) > 0 \\ 0 \\ 0 \\ \frac{(2\lambda+1)}{3\lambda} r_2^F - \frac{(t+\theta)}{\lambda} < 0 \\ \frac{1}{2} [r_2^F - \frac{(t+3\theta)}{\lambda}] < 0 \\ r_2^F - \frac{(t+\theta)}{\lambda} < 0 \end{cases} \quad r_2^B = \begin{cases} r_2^F - (t - \theta) > 0, & \text{if } r_2^F \geq t + \theta \\ \frac{1}{2} [r_2^F - (t - 3\theta)] > 0, & \text{if } t + \theta > r_2^F \geq \max \left[t - 3\theta, \frac{3(t+\theta)}{(2\lambda+1)} \right] \\ 0, & \text{if } t - 3\theta > r_2^F \geq \frac{(t+3\theta)}{\lambda} \\ \frac{(2+\lambda)}{3} r_2^F - (t - \theta) > 0, & \text{if } \frac{3(t+\theta)}{(2\lambda+1)} > r_2^F \geq \frac{3(t-\theta)}{(2+\lambda)} \\ 0, & \text{if } \min \left[\frac{(t+3\theta)}{\lambda}, \frac{3(t-\theta)}{(2+\lambda)} \right] > r_2^F \geq \frac{(t-\theta)}{\lambda} \\ r_2^F - \frac{(t-\theta)}{\lambda} < 0, & \text{if } r_2^F < \frac{(t-\theta)}{\lambda}. \end{cases}$$

Proof: See Appendix A.

Figure 2 illustrates Proposition 1 with parameters values leading to a focal-rate equilibrium for policy rates as described in Corollary 1. In other words, for some policy rate range the deposit rates stick at zero. Within this range banks do not react to a marginal change in the policy rate. Instead, when policy rates increase, the trade-off between a high market share and a high interest rate margin entirely goes at the expense of the latter.

Through the term $\theta = (s/3)(2\hat{x}_1 - 1)$ the banks' second-period deposit rates also depend on their first-period market shares. Compared to its smaller competitor, the bank with

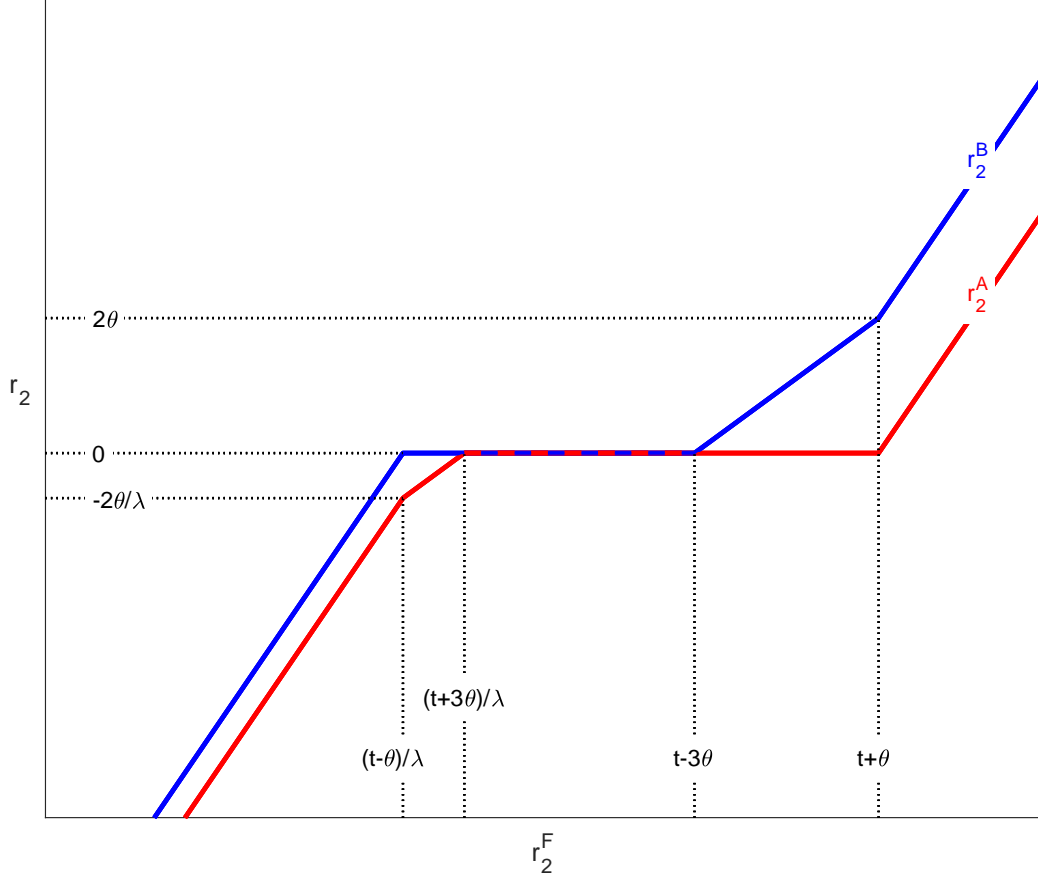


Figure 2: r_2^A and r_2^B as functions of r_2^F in the second-period subgame equilibrium

Notes: The figure illustrates Proposition 1 with parameter values that lead to a focal-rate equilibrium. The line in red shows the second-period deposit rate of market-leader A as a function of the second-period policy rate; The corresponding function of the smaller bank B is in blue. parameter values: $t = 3$, $\lambda = 3$, $s = 2$ and $\hat{x}_1 = 2/3$.

the larger market share is relatively more interested in exploiting old customers than in attracting new ones. The term therefore causes a downward (upward) shift of the larger (smaller) bank's deposit rate offerings. If the second-period policy rate is lower than $t + \theta$ but higher or equal to $t - 3\theta$, then the smaller bank offers their customers a positive deposit rate while the larger banks sets a rate of zero. Similarly, for second-period policy rates lower than $(t + 3\theta)/\lambda$ but higher or equal to $(t - \theta)/\lambda$, the smaller bank sets a deposit rate of zero, while the larger bank charges negative rates. Therefore, if r_2^F is sufficiently low or high, then the smaller bank's second-period market share is higher than its first-period market share and vice versa.

The result that the competitor with a higher market share conducts a more aggressive pricing-strategy is fairly general in models with switching costs (Klemperer, 1995). It is also consistent with the relative market power hypothesis (Berger, 1995; De Graeve et al., 2007) stating that banks with higher market shares set interest rates less competitively at times when nominal policy rates are largely above zero. The reason is that the bank with the lower first-period market share is relatively more interested in attracting new

customers than in exploiting the old ones. However, due to consumer loss aversion this result may not always hold in my model. Instead, even under heterogeneous first-period market shares, there may exist an interval in which both banks set a common deposit rate of zero. The condition for the existence of such a focal-rate equilibrium is stated in Corollary 1.

COROLLARY 1: Second-period focal-rate equilibrium

If $r_2^F \in \left[\frac{t+3\theta}{\lambda}, t-3\theta \right]$, which implies $\frac{(\lambda-1)t}{(\lambda+1)3} \geq \theta$, then there is a focal-rate equilibrium with $r_2^A = r_2^B = 0$.

In this paper depositors' value function implies a reference point at zero. Nevertheless, the intuition for the focal-rate equilibrium in this paper is similar to the focal-price equilibrium of [Heidhues and Köszegi \(2008\)](#), in which consumers are loss averse relative to a reference point given by their price expectations. As account holders are especially averse to interest rates below zero, their responsiveness to a change in the interest rate is greater for rates below zero. This higher sensitivity to rates below zero not only leads to an unresponsiveness of deposit rates to changing policy rates. It may also lead to a common rate for both banks even if first-period market shares are asymmetric. Since $\frac{\partial \frac{(\lambda-1)t}{(\lambda+1)3}}{\partial \lambda} = \frac{2t}{3(\lambda+1)^2} > 0$, the larger the degree of loss aversion, the greater differences in first-period market shares can be in order to sustain the focal-rate equilibrium. As I will show in the following subsection, banks set symmetric deposit rates in the first period. Hence, as in [Klemperer \(1987\)](#), banks equally split the market ($\hat{x}_1 = \hat{x}_2 = 0.5$, and therefore $\theta = 0$).

C) The First Period

Depositors do not take the second period into account when making first-period decisions. Hence, they are indifferent between the two banks if $v(r_1^A) - tx_1 = v(r_1^B) - t(1-x_1)$ and the indifferent depositor is located at $\hat{x}_1 = \frac{1}{2t}(v(r_1^A) - v(r_1^B) + t)$. By contrast, banks have rational expectations and maximize total profits from both periods given the probability distribution for the future short-term policy rate. By doing so, banks not only take into account the direct effect of their deposit rate offerings on their first-period profits, but also the indirect effect on expected second-period profits through first-period market shares. Hence, bank *A*'s expected total profit is defined as the sum of its profit in the first period and its expected profit in the second period

$$E[\pi^A(r_1^A; r_1^B, r_2^F)] = \pi_1^A(r_1^A; r_1^B, r_2^F) + E[\pi_2^A(x_1(r_1^A; r_1^B, r_2^F))],$$

and accordingly for Bank *B*. Appendix B provides the derivation of the symmetric first-period deposit rate setting rules stated in Proposition 2.

PROPOSITION 2: First-period deposit rates

In equilibrium banks set symmetric first-period deposit rates according to

$$r_1 = \begin{cases} r_1^F - t + \frac{2}{3}s\rho & \text{if } r_1^F > t - \frac{2}{3}s\rho \\ 0 & \text{if } t - \frac{2}{3}s\rho \geq r_1^F \geq \frac{t}{\lambda} - \frac{2}{3}s\rho \\ r_1^F - \frac{t}{\lambda} + \frac{2}{3}s\rho & \text{if } \frac{t}{\lambda} - \frac{2}{3}s\rho > r_1^F. \end{cases}$$

with $\rho = \frac{1}{\lambda}P(t/\lambda > R_2^F) + \frac{3}{2t}P(t \geq R_2^F \geq t/\lambda) E[R_2^F | t \geq R_2^F \geq t/\lambda] + P(R_2^F > t)$.

Proof: See Appendix B.

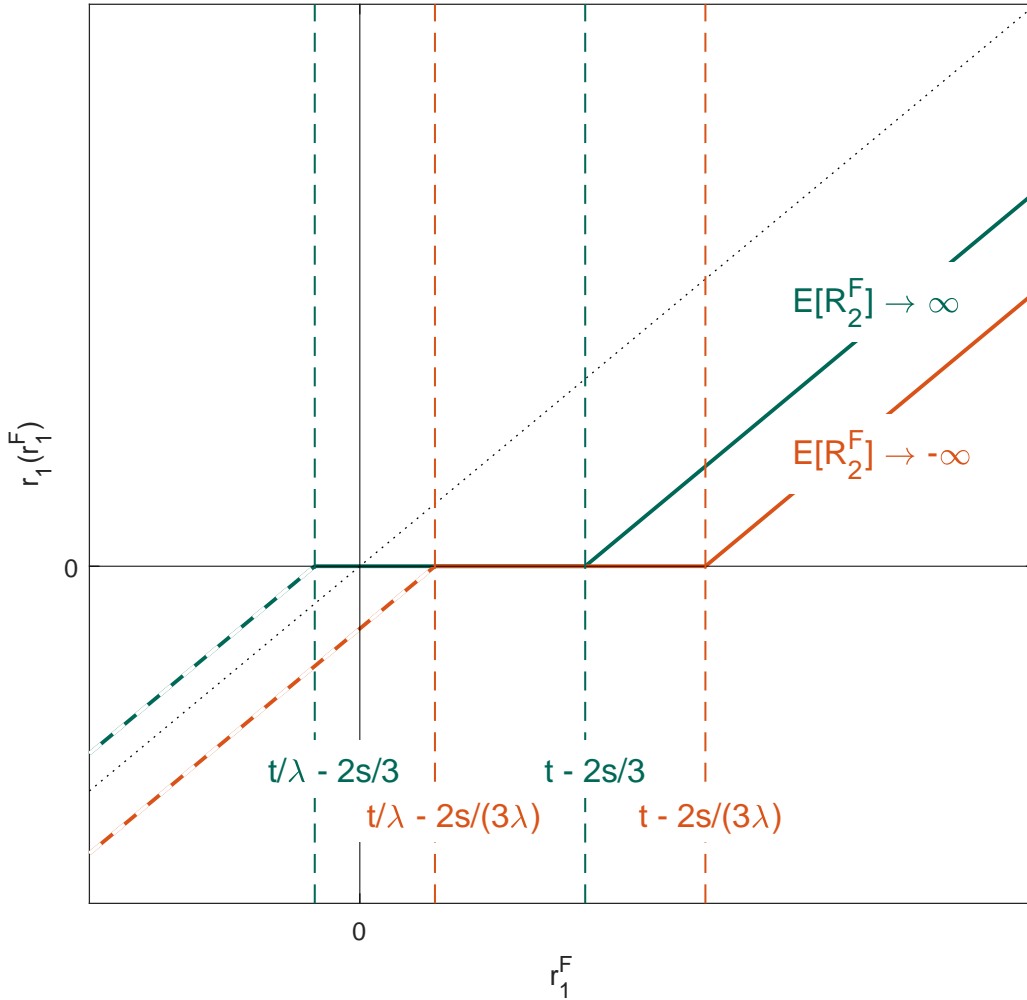


Figure 3: First-period equilibrium deposit rates

Notes: The figure illustrates Proposition 2. The green line shows the first-period equilibrium deposit rate ($r_1 = r_1^A = r_1^B$) as a function of the first-period policy rate (r_1^F) if expectations about the future policy rate are high. As expectations decrease, the function shifts to the right. Dashed lines indicate (partially hypothetical) negative deposit rates; parameter values: $t = 3$, $\lambda = 3$, $s = 2$.

Figure 3 illustrates Proposition 2. The deposit rate increases in the policy rate if the latter is sufficiently high or low.⁸ By contrast, the deposit rate remains non-responsive to a change in policy rates around zero. As stated in Corollary 2, the range of this focal-rate equilibrium at zero increases in the degree of loss aversion.

Moreover, switching costs cause banks to compete more aggressively for depositors than they otherwise would to capture market share that becomes valuable in the future period. The additional intensity of competition results in a shift of equilibrium deposit rates by $2s\rho/3$. Through ρ the value of market share depends on the market's belief about the future policy rate. The reason is that depositors are also especially averse to negative deposit rates in the second period. Hence, in the future period deposit margins are again dependent on policy rates. If banks expect sufficiently high second-period policy rates, then their incentive to capture market share might outweighs the deposit margin they would charge in the absence of switching costs. If so, then the focal-rate equilibrium at zero is sustained even as the policy rate turns negative.

COROLLARY 2: First-period focal-rate equilibrium

For $r_1^F \in [\frac{t}{\lambda} - \frac{2}{3}s\rho, t - \frac{2}{3}s\rho]$ there is a focal-rate equilibrium at zero. The first-period policy rate range for which banks set a deposit rate of zero is $\frac{t(\lambda-1)}{\lambda}$. This range increases in λ since $\partial \frac{t(\lambda-1)}{\lambda} / \partial \lambda = t/\lambda^2 > 0$.

Corollary 3 formulates the lowest possible current policy rate for which commercial banks are willing to offer their customers a deposit rate of zero. With increasing expectations about the future policy rate, the upward shift in offered deposit rates converges towards $2s/3$ (as illustrated by the green line in Figure 3). By contrast, if banks anticipate that the future policy rate will be low, market share becomes less valuable and the upward shift lowers to $2s/3\lambda$ (as illustrated by the orange line in Figure 3).

COROLLARY 3: Lower bound of the focal-rate equilibrium

The lowest possible current policy rate for which the banking-system sets a deposit rate of zero is: $\min(r_1^F | r_1 = 0) = \frac{t}{\lambda} - \frac{2}{3}s\rho$.

Figure 4 illustrates this lower bound of the focal-rate equilibrium assuming that market expectations about the future policy rate are represented by a normal distribution with a standard deviation of one and a mean of r_2^F . The visible dip results from an additional competition effect that arises when market's belief imply a positive probability for a second-period focal rate equilibrium. If banks anticipate that a deviation from a

⁸Deposit rates below zero are represented by dashed-lines in order to indicate the conditionality on a sufficiently high cost on cash.

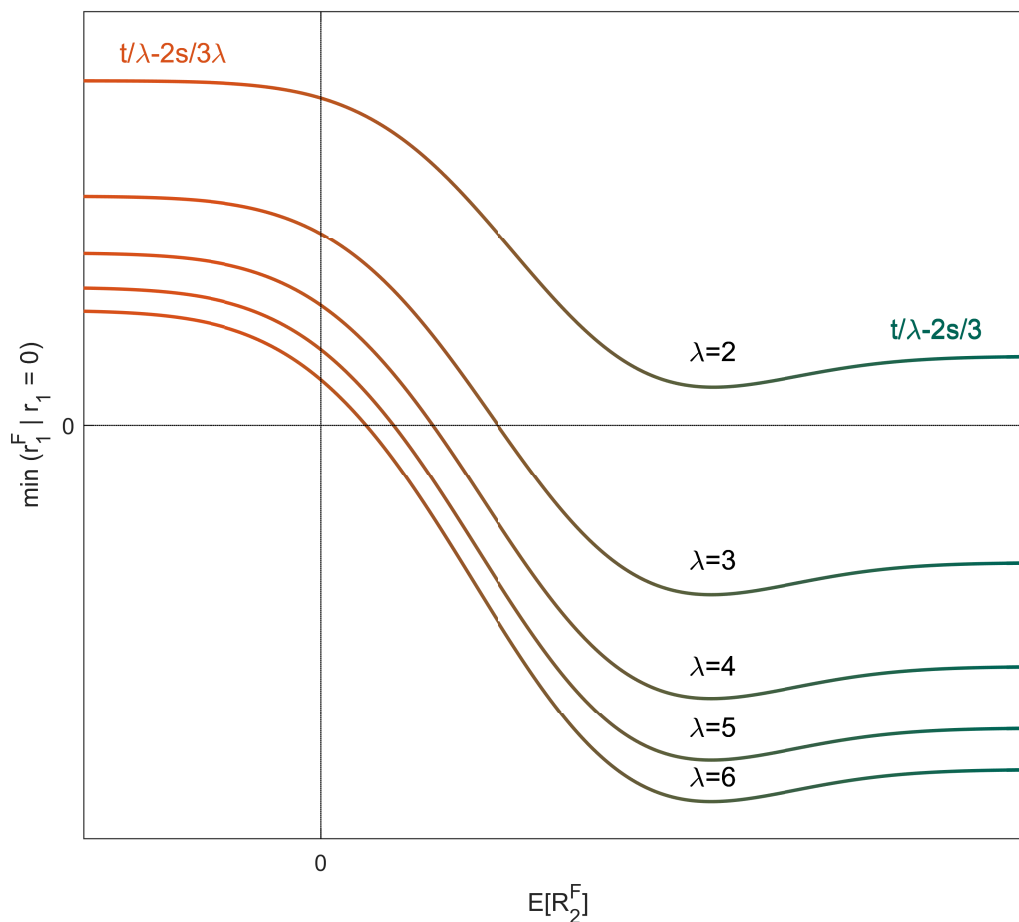


Figure 4: Lower bound of the focal-rate equilibrium

Notes: This figure illustrates Corollary 3. The lines show the lowest first-period policy rates for which banks set a deposit rate of zero as functions of $E[R_2^F]$ for different magnitudes of loss aversion with $R_2^F \sim N(r_2^F, 1)$; parameter values: $t = 3$, $s = 2$.

second-period deposit rate of zero will be an inferior strategy, the usual mechanism that the bank with the lower market share offers higher second-period deposit rates breaks down. As banks anticipate to effectively lose the second-period deposit rate as a choice variable, first-period market-share becomes more important and hence competition gets fiercer.

In general, the lowest level of current short-term policy rates at which banks are willing to offer their customers a non-negative deposit rate decreases in the level of switching costs, the degree of loss aversion and market expectations about the future policy rate. Hence, if central banks want to avoid negative retail deposit rates, they may face a trade-off between the current and future short-term policy rate. In other words, there may be a conflict between a too low short-term policy rate and lowering market expectations for the future rate through forward guidance.

3 Conditional Policy Rate Lower Bound

This section provides a separate calibration of the model for several retail deposit markets. I restrict the analysis to currency areas that experienced negative policy rates below -0.1 percent. For the observed period between January 2013 and September 2019 this includes Switzerland, Sweden, Denmark and the euro area. In addition, I provide a separate calibration for the five largest economies of the euro area (Germany, France, Italy, Spain and the Netherlands). Since depository institutions refrain from negative retail deposit rates, I cannot infer actual degrees of loss aversion. However, I can estimate lower bounds of the loss aversion coefficients based on the lowest observed money market rates in each economy. Subsequently, I provide an indication about how low central banks could effectively lower policy rates without exposing ordinary retail customers to negative deposit rates by comparing the obtained coefficients across countries and with the existing literature.

A) Calibration

I calibrate the model based on the following three equations:

$$\eta = t - \frac{2}{3}s\rho, \quad \mu = \frac{t}{\lambda} - \frac{2}{3}s\rho, \quad \hat{x}_2 = \frac{1}{2t}(t + s).$$

η and μ denote restricted and unrestricted first-period equilibrium deposit spreads, respectively. They can be derived from the first-period deposit rate setting rules stated in Proposition 2. The transition equation, $\hat{x}_2 = \frac{1}{2t}(t + s)$, describes the share of customers who do not switch banks after the first period. Solving this system of 3 equations for t , s and λ provides:

$$t = \frac{3\eta}{3 - 2\rho(2\hat{x}_2 - 1)}, \quad s = \frac{3\eta(2\hat{x}_2 - 1)}{3 - 2\rho(2\hat{x}_2 - 1)}, \quad \lambda = \frac{3\eta}{3\mu + 2\rho(2\hat{x}_2 - 1)(\eta - \mu)}.$$

I make the assumption that financial markets expected unrestricted future deposit spreads, $P(R_2^F > t) = 1$, and hence $\rho = 1$.⁹ I use data on the share of individuals that do not switch deposit accounts after one year from the [European Commission \(2018\)](#) for countries belonging to the European Union and from [Brown et al. \(2020\)](#) for Switzerland. I present this shares in the first column of Table 1. The data range from 84 percent for Spain to 98 percent for Germany and suggest a high level of inertia in the market for retail deposits. I provide information on retail deposit and money market rates with comparable maturity which I use to estimate deposit spreads in Appendix C.

⁹In Sweden, for example, markets and forecasting institutions expected increasing future short-term market rates at almost any time between 2007 and 2016 ([Alsterlind, 2017](#)).

Since the banking-systems largely refrain from charging negative deposit rates to ordinary retail customers, the true values for μ are unknown. However, the lowest observed money market rates in each economy provide upper bounds for μ . I denote these values by $\bar{\mu}$ and present them in the second column of Table 1. Finally, I estimate η using monthly data on retail deposit and money market rates between January 2003 and September 2019. I start by estimating $r_t^D = \eta + \gamma r_{1,t}^F + \epsilon_t$ by constrained least squares (with $\gamma = 1$). To ensure consistency with the model, I subsequently estimate η again based on the observations for which the predicted values of the previous regression are non-negative and repeat the iterative estimation procedure until η is stable (see Figure C.2 of Appendix C for the predicted values of all iterations).

Table 1: Deposit spreads and model parameters

	\hat{x}_2	Spreads		Model Parameters		
		$\bar{\mu}$	$\hat{\eta}$	t	s	$\underline{\lambda}$
Switzerland	0.95	-0.786	1.277	3.193	2.873	2.827
Sweden	0.92	-0.607	1.518	3.450	2.898	2.604
Denmark	0.89	-0.470	0.999	2.081	1.623	3.399
Euro Area	0.94		2.010	4.863	4.279	1.994
<i>Germany</i>	0.98		1.484	4.122	3.957	1.853
<i>France</i>	0.97		4.047	10.840	10.190	1.699
<i>Italy</i>	0.95	-0.414	2.049	5.123	4.610	1.926
<i>Spain</i>	0.84		3.384	6.190	4.209	2.588
<i>Netherlands</i>	0.95		3.280	8.200	7.380	1.820

Notes: Information on used money market rates and the source and key of retail deposit rates are provided in Table C.1. Observation period: January 2013 to September 2019

Why is it so important to condition on $r_{1,t}^F \geq \hat{\eta}$? As an example, Figure 5 depicts money market rates together with actual and predicted deposit rates in Sweden. The panel on the left shows the predicted values based on all observations. Deposit margins are largely under-predicted when the money market rate is well above zero, but over-predicted when the money market rate is low or negative. By contrast, the more accurate prediction shown in the right panel ensures consistency with the model by conditioning on $r_{1,t}^F \geq \hat{\eta}$. I show the stable estimates of η in the third column of Table 1. They range from about 1 (for Denmark) to about 4 (for France). An illustration of deposit rates, money market rates with a comparable maturity and the predicted values of deposit rates can be found in Figure C.1 of Appendix C.

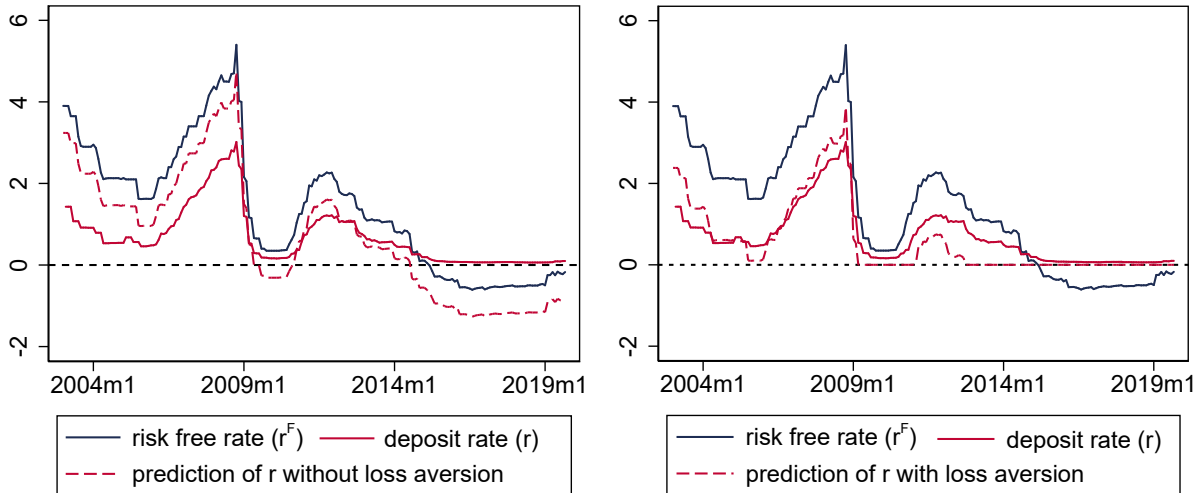


Figure 5: Actual and predicted retail deposit rates in Sweden

Notes: This figure compares the predicted values from constrained linear regressions of the deposit rate on the policy rate: $r_t^D = \eta + \gamma r_{1,t}^F + \epsilon_t$ with $\gamma = 1$. The left panel shows the predicted values from the regression using the entire period from January 2003 (first month for which deposit rates are available for each of the 8 countries) to September 2019. The right panel shows the predicted values from iterated regressions. The regression of each iteration is based on the observations for which the predicted values from the regression of the previous iteration were non-negative (stable value achieved after 4 iterations).

Sources: Statistics Sweden, Riksbank.

B) Results

Columns 4 to 6 of Table 1 report the values for t , s and $\underline{\lambda}$. As shown in the previous subsection, t and s are independent of the lowest observed money market rate. However, this is not true for the loss aversion coefficient. Since $\bar{\mu}$ is an upper bound of the actual μ , $\underline{\lambda}$ represents a lower bounds of the actual degree of depositors' loss aversion. The values for $\underline{\lambda}$ range from 1.7 (for France) to 3.4 (for Denmark). I find the lowest coefficients for the economies belonging to the euro area, where money-market rates have not been as negative as in the two Nordic countries and Switzerland. Among the euro area economies I obtain the highest coefficients for Spain, where the percentage of people who switch the provider for bank accounts per year is relatively high (and thus \hat{x}_2 is low).

Figure 6 plots the lowest money market rate at which banks refrain from a negative deposit rate as a function of retail depositors' degree of loss aversion. For each economy the lines are solid up to the lowest observed level of the money market rate (for the time period between January 2003 to September 2019) and dotted for more negative rates. Actual loss aversion coefficients may be similar across retail depositors of different countries. Hence, taking the calibrated lower bound for Denmark as the reference, retail deposit rates in the euro area should remain at zero up to a drop in money market rates to at least -1.5 percent.

Except for the euro area, the inferred values for $\underline{\lambda}$ are at the upper end of the range of

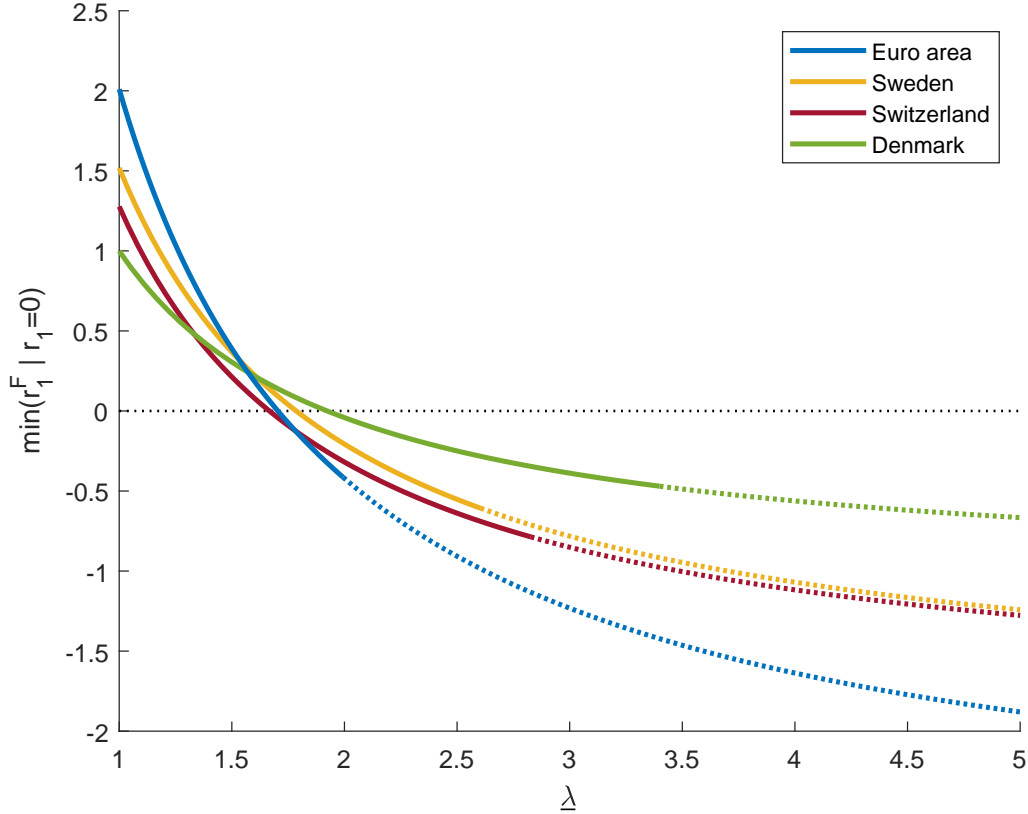


Figure 6: Lowest money market rates with non-negative deposit rates as functions of λ

Notes: This figure plots the equation $\min(r_1^F | r_1 = 0) = \frac{t}{\lambda} - \frac{2}{3}s\rho$ using the parameter values for t and s reported in Table 1 and with $\rho = 1$. Lines are solid up to the lowest observed money market rates (up until September 2019) and dotted for more negative values.

commonly found loss aversion coefficients and above the most prominently reported value of 2.25 from [Tversky and Kahneman \(1992\)](#). However, estimated degrees of loss aversion vary considerably. [Merkle \(2020\)](#) provides a recent overview of reported coefficients which range between 1.2 and 4.8. In the context at hand, loss aversion might be large for several reasons: most notably, losses may loom particularly large when they are perceived as unfair. In other words, a public lack of acceptance and understanding for a negative interest rate on savings may amplify magnitudes of loss aversion. Moreover, despite the cost associated with hoarding cash, negative rates are may also be perceived as counter-intuitive due to the (historical) availability of a zero-interest paying option. Finally, a move to negative nominal rates for retail customers has been unprecedented and might be particularly salient. Media coverage would likely be extensive and legislative norms of many countries require prior consent of bank customers on a change in the terms of contract.¹⁰

¹⁰For example in Germany the Tübingen Regional Court ruled that negative interest on deposits imposed by a German bank by unilaterally changing the bank's general terms and conditions was unlawful (Az. 4 O 187/17). Legal research points to a similar legal situation in Switzerland ([Schaller, 2016](#)).

4 Conclusion

This paper described transmission effects of monetary policy to deposit rates within a low interest rate environment. The effects result from the competitive situation among commercial banks when the market for bank deposits is characterized by two features: switching costs and loss aversion. This paper argued that the empirically observed differences in the transmission of monetary policy to retail and wholesale deposit rates may be a result of both features applying to the former market, but less so to the latter.

Financially more experienced depositors may suffer from a lower degree of loss aversion. In addition, compared to the amount of deposited funds, wholesale depositors presumably also face low costs of switching bank accounts. Consequently, low and moderately negative policy rates transmit to these customers mostly in the same way that positive rates do. By contrast, depositors may be more prone to loss aversion as market experience decreases. As a consequence, a cut of the retail deposit rate to negative territory would cause over-proportionally many customers to switch to the competitor. This loss in market share would be hard to regain once the policy rate raises again. Up to some policy rate lower bound this mechanism causes the banking-system to shield retail customers from negative policy rates.

The paper provided a calibration of the model for economies that experienced negative policy rates. A main insight results from a cross-country comparison of calibrated lower bounds of depositors' loss aversion. Actual degrees of loss aversion may be similar across retail depositors of different countries. Therefore, the comparison may provide some indication for how low central banks could effectively lower their interest rates without taking steps to make paper currency more costly. However, as the general level of nominal interest rates is likely to remain around zero for a long time to come, the topic deserves more attention in future research.

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Appendix

This Appendix is organized as follows. Appendix A provides the derivation of the second-period deposit rates (Proposition 1). Knowing the subgame-perfect equilibrium of the second period allows to solve for the equilibrium of the first period, and hence the whole game, in Appendix B (Proposition 2). Finally, I present the data and the structural prediction of deposit rates in Appendix C. Stata and MATLAB code is available on request.

Appendix A: Second Period

Since the market share of bank B is one minus the market share of bank A , it suffices to derive the equilibrium for $x_1 \in [0.5, 1]$. Hence, the first-period market share of bank A is no less than the one of bank B . Denoting $\theta = \frac{2}{3}(2\hat{x}_1 - 1) \in [0, t/3]$ and

$$\lambda_j^i = \begin{cases} 1 & \text{if } r_j^i \geq 0 \\ \lambda & \text{if } r_j^i < 0 \end{cases} \quad \text{for } i = \{A, B\} \text{ and } j = \{1, 2\}$$

bank A 's and bank B 's second-period profit amount to

$$\pi_2^A = \frac{1}{2t} [\lambda_2^A r_2^A - \lambda_2^B r_2^B + t + 3\theta] (r_2^F - r_2^A),$$

$$\pi_2^B = \frac{1}{2t} [\lambda_2^B r_2^B - \lambda_2^A r_2^A + t - 3\theta] (r_2^F - r_2^B).$$

Each player can chose a deposit rate that is positive, zero or negative, resulting in 9 possible cases. π_2^A and π_2^B are not continuous and hence not differentiable at $r_2^A = 0$ and $r_2^B = 0$, respectively. Hence, equilibrium deposit rates must be derived separably for each of the 9 possible cases and then be verified on their consistency with the assumptions made on r_2^A and r_2^B in the respective case. Table A.1 (illustrated by Figure A.1) provides the resulting intervals for each case dependent on the exogenous variables.

Taking the derivatives of banks' profit functions with respect to their own second-period deposit rate, except at zero, provides

$$\frac{\partial \pi_A}{\partial r_2^A} = \frac{1}{2t} [\lambda_2^A (r_2^F - r_2^A) - \lambda_2^A r_2^A + \lambda_2^B r_2^B - t - 3\theta] = 0 \quad \text{if } r_2^A \neq 0,$$

$$\frac{\partial \pi_B}{\partial r_2^B} = \frac{1}{2t} [\lambda_2^B (r_2^F - r_2^B) - \lambda_2^B r_2^B + \lambda_2^A r_2^A - t + 3\theta] = 0 \quad \text{if } r_2^B \neq 0.$$

Rearranging provides

$$R^A(r_2^B) = \frac{1}{2} [r_2^F - t/\lambda_2^A + (\lambda_2^B/\lambda_2^A)r_2^B - 3\theta/\lambda_2^A] \quad \text{if } r_2^A \neq 0,$$

$$R^B(r_2^A) = \frac{1}{2} [r_2^F - t/\lambda_2^B + (\lambda_2^A/\lambda_2^B)r_2^A + 3\theta/\lambda_2^B] \quad \text{if } r_2^B \neq 0.$$

Hence, in equilibrium if $r_2^A \neq 0$ and $r_2^B = 0$:

$$r_2^A = \frac{1}{2} [r_2^F - t/\lambda_2^A - 3\theta/\lambda_2^A], \quad r_2^B = 0;$$

if $r_2^A = 0$ and $r_2^B \neq 0$:

$$r_2^A = 0, \quad r_2^B = \frac{1}{2} [r_2^F - t/\lambda_2^B + 3\theta/\lambda_2^B];$$

if $r_2^A \neq 0$ and $r_2^B \neq 0$:

$$r_2^A = r_2^F \left[\frac{2\lambda_2^A + \lambda_2^B}{3\lambda_2^A} \right] - \frac{t}{\lambda_2^A} - \frac{\theta}{\lambda_2^A}, \quad r_2^B = r_2^F \left[\frac{2\lambda_2^B + \lambda_2^A}{3\lambda_2^B} \right] - \frac{t}{\lambda_2^B} + \frac{\theta}{\lambda_2^B};$$

and for completeness if $r_2^A = 0$ and $r_2^B = 0$:

$$r_2^A = 0, \quad r_2^B = 0.$$

Hence, denoting $\Phi_1 = \max \left[t - 3\theta, \frac{3(t+\theta)}{(2\lambda_2+1)} \right]$ and $\Phi_2 = \min \left[\frac{(t+3\theta)}{\lambda_2}, \frac{3(t-\theta)}{(2+\lambda_2)} \right]$ the larger bank A (with $\hat{x}_1 \in [\frac{1}{2}, 1]$) and the smaller bank B (with $(1 - \hat{x}_1) \in [0, \frac{1}{2}]$) set second-period deposit according to

$$r_2^A = \begin{cases} r_2^F - (t + \theta) > 0 \\ 0 \\ 0 \\ \frac{(2\lambda_2+1)}{3\lambda_2} r_2^F - \frac{(t+\theta)}{\lambda_2} < 0 \\ \frac{1}{2} [r_2^F - \frac{(t+3\theta)}{\lambda_2}] < 0 \\ r_2^F - \frac{(t+\theta)}{\lambda_2} < 0 \end{cases} \quad r_2^B = \begin{cases} r_2^F - (t - \theta) > 0, & \text{if } r_2^F \geq t + \theta \\ \frac{1}{2} [r_2^F - (t - 3\theta)] > 0, & \text{if } t + \theta > r_2^F \geq \Phi_1 \\ 0, & \text{if } t - 3\theta > r_2^F \geq \frac{(t+3\theta)}{\lambda_2} \\ \frac{(2+\lambda_2)}{3} r_2^F - (t - \theta) > 0, & \text{if } \frac{3(t+\theta)}{(2\lambda_2+1)} > r_2^F \geq \frac{3(t-\theta)}{(2+\lambda_2)} \\ 0, & \text{if } \Phi_2 > r_2^F \geq \frac{(t-\theta)}{\lambda_2} \\ r_2^F - \frac{(t-\theta)}{\lambda_2} < 0, & \text{if } r_2^F < \frac{(t-\theta)}{\lambda_2}. \end{cases}$$

Plugging the second-period deposit rate setting rules back into the profit equations provides the equilibrium profits of the second-period subgame

$$\pi_2^A = \begin{cases} \frac{1}{2t} [t + \theta]^2 \\ \frac{r_2^F}{4t} [3t + 3\theta - r_2^F] \\ \frac{r_2^F}{2t} [t + 3\theta] \\ \frac{1}{2t\lambda_2} \left[t + \theta + \frac{(\lambda_2-1)}{3} r_2^F \right]^2 \\ \frac{1}{8t\lambda_2} [t + 3\theta + \lambda_2 r_2^F]^2 \\ \frac{1}{2t\lambda_2} [t + \theta]^2 \end{cases} \quad \pi_2^B = \begin{cases} \frac{1}{2t} [t - \theta]^2, & \text{if } r_2^F \geq t + \theta \\ \frac{1}{8t} [t - 3\theta + r_2^F]^2, & \text{if } t + \theta > r_2^F \geq \Phi_1 \\ \frac{r_2^F}{2t} [t - 3\theta], & \text{if } t - 3\theta > r_2^F \geq \frac{(t+3\theta)}{\lambda_2} \\ \frac{1}{2t} \left[t - \theta - \frac{(\lambda_2-1)}{3} r_2^F \right]^2, & \text{if } \frac{3(t+\theta)}{(2\lambda_2+1)} > r_2^F \geq \frac{3(t-\theta)}{(2+\lambda_2)} \\ \frac{r_2^F}{4t} [3t - 3\theta - \lambda_2 r_2^F], & \text{if } \Phi_2 > r_2^F \geq \frac{(t-\theta)}{\lambda_2} \\ \frac{1}{2t\lambda_2} [t - \theta]^2, & \text{if } r_2^F < \frac{(t-\theta)}{\lambda_2}. \end{cases}$$

Table A.1 and Figure A.1 present the different intervals of the second-period equilibrium deposit rate setting rules.

Table A.1: Intervals of the Second-Period Subgame Equilibrium

	$r_2^A > 0$	$r_2^A = 0$	$r_2^A < 0$
$r_2^B > 0$	$r_2^F > t + \theta$	$t + \theta > r_2^F \geq \Phi_1$	$\frac{3(t+\theta)}{(2\lambda_2+1)} > r_2^F \geq \frac{3(t-\theta)}{(2+\lambda_2)}$
$r_2^B = 0$	contradiction	$t - 3\theta > r_2^F \geq \frac{(t+3\theta)}{\lambda_2}$	$\Phi_2 > r_2^F \geq \frac{(t-\theta)}{\lambda_2}$
$r_2^B < 0$	contradiction	contradiction	$r_2^F < \frac{(t-\theta)}{\lambda_2}$

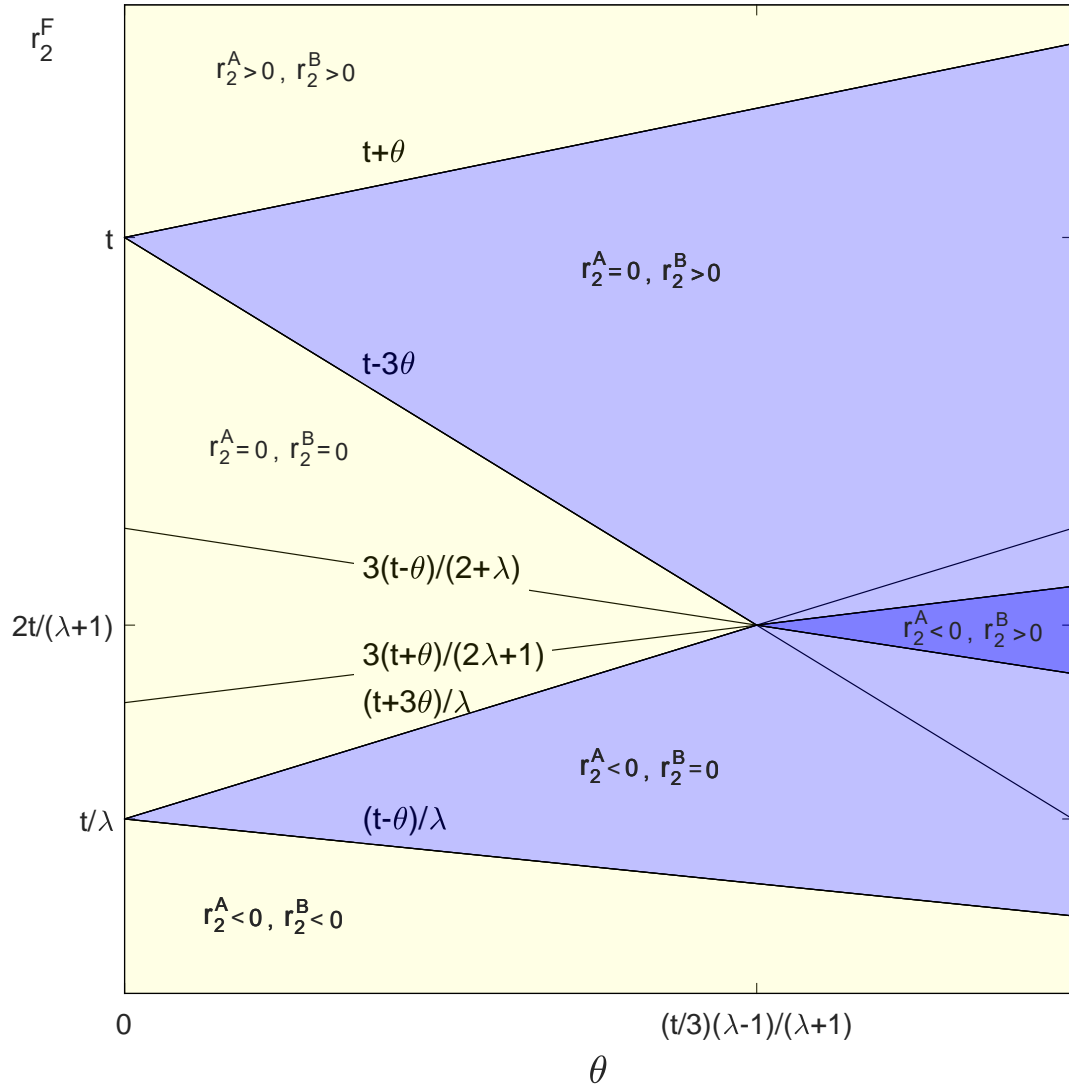


Figure A.1: Intervals of the Second-Period Subgame Equilibrium

Notes: The figure illustrates the different intervals of the second-period subgame equilibrium presented in Table A.1. The areas in yellow represent the entries of the main diagonal of Table A.1, which include all symmetric first-period deposit rates ($\theta = 0$). The areas in blue represent the entries outside the main diagonal of Table A.1.

Appendix B: First Period

Knowing the subgame-perfect equilibrium of the second period allows to solve for the equilibrium of the first period, and hence of the whole game. In the first period, depositors are indifferent between the two banks if $\lambda_1^A r_1^A - t x_1 = \lambda_1^B r_1^B - t(1 - x_1)$. Thus, the indifferent depositor is located at $\hat{x}_1 = \frac{1}{2t}(\lambda_1^A r_1^A - \lambda_1^B r_1^B + t)$ and the banks' first period profits amount to $\pi_1^A = \frac{1}{2t}(\lambda_1^A r_1^A - \lambda_1^B r_1^B + t)(r_1^F - r_1^A)$ and $\pi_1^B = \frac{1}{2t}(\lambda_1^B r_1^B - \lambda_1^A r_1^A + t)(r_1^F - r_1^B)$, respectively. Adding expected profits for the second-period provides

$$E[\pi^A(r_1^A; r_1^B, r_2^F)] = \pi_1^A(r_1^A; r_1^B, r_2^F) + E[\pi_2^A(x_1(r_1^A; r_1^B, r_2^F))],$$

$$E[\pi^B(r_1^B; r_1^A, r_2^F)] = \pi_1^B(r_1^B; r_1^A, r_2^F) + E[\pi_2^B(x_1(r_1^B; r_1^A, r_2^F))].$$

Hence,

$$\begin{aligned} E[\pi^A(r_1^A; r_1^B, r_2^F)] &= \left[\frac{s + 3\theta}{2s} \right] (r_1^F - r_1^A) \\ &+ E[\pi_2^A | R_2^F \geq t + \theta] P(R_2^F \geq t + \theta) \\ &+ E[\pi_2^A | t + \theta > R_2^F \geq t - 3\theta] P(t + \theta > R_2^F \geq \Phi_1) \\ &+ E\left[\pi_2^A \left| t - 3\theta > R_2^F \geq \frac{(t + 3\theta)}{\lambda_2} \right. \right] P\left(t - 3\theta > R_2^F \geq \frac{(t + 3\theta)}{\lambda_2}\right) \\ &+ E\left[\pi_2^A \left| \frac{3(t + \theta)}{(2\lambda_2 + 1)} > R_2^F \geq \frac{3(t - \theta)}{(2 + \lambda_2)} \right. \right] P\left(\frac{3(t + \theta)}{(2\lambda_2 + 1)} > r_2^F \geq \frac{3(t - \theta)}{(2 + \lambda_2)}\right) \\ &+ E\left[\pi_2^A \left| \frac{(t + 3\theta)}{\lambda_2} > R_2^F \geq \frac{(t - \theta)}{\lambda_2} \right. \right] P\left(\Phi_2 > R_2^F \geq \frac{(t - \theta)}{\lambda_2}\right) \\ &+ E\left[\pi_2^A \left| \frac{(t - \theta)}{\lambda_2} > R_2^F \right. \right] P\left(\frac{(t - \theta)}{\lambda_2} > R_2^F\right), \end{aligned}$$

$$\begin{aligned} E[\pi^B(r_1^B; r_1^A, r_2^F)] &= \left[\frac{s - 3\theta}{2s} \right] (r_1^F - r_1^B) \\ &+ E[\pi_2^B | R_2^F \geq t + \theta] P(R_2^F \geq t + \theta) \\ &+ E[\pi_2^B | t + \theta > R_2^F \geq t - 3\theta] P(t + \theta > R_2^F \geq \Phi_1) \\ &+ E\left[\pi_2^B \left| t - 3\theta > R_2^F \geq \frac{(t + 3\theta)}{\lambda_2} \right. \right] P\left(t - 3\theta > R_2^F \geq \frac{(t + 3\theta)}{\lambda_2}\right) \\ &+ E\left[\pi_2^B \left| \frac{3(t + \theta)}{(2\lambda_2 + 1)} > R_2^F \geq \frac{3(t - \theta)}{(2 + \lambda_2)} \right. \right] P\left(\frac{3(t + \theta)}{(2\lambda_2 + 1)} > r_2^F \geq \frac{3(t - \theta)}{(2 + \lambda_2)}\right) \\ &+ E\left[\pi_2^B \left| \frac{(t + 3\theta)}{\lambda_2} > R_2^F \geq \frac{(t - \theta)}{\lambda_2} \right. \right] P\left(\Phi_2 > R_2^F \geq \frac{(t - \theta)}{\lambda_2}\right) \\ &+ E\left[\pi_2^B \left| \frac{(t - \theta)}{\lambda_2} > R_2^F \right. \right] P\left(\frac{(t - \theta)}{\lambda_2} > R_2^F\right). \end{aligned}$$

Defining the indicator function $\mathbf{1}(\theta) = 1$ if $\theta \leq \frac{(\lambda-1)t}{(\lambda+1)3}$ and $\mathbf{1}(\theta) = 0$ if $\theta > \frac{(\lambda-1)t}{(\lambda+1)3}$, one can rewrite these equations as

$$\begin{aligned}
E[\pi^A(r_1^A; r_1^B, r_2^F)] &= \left[\frac{s+3\theta}{2s} \right] (r_1^F - r_1^A) \\
&+ \frac{(t+\theta)^2}{2t} \int_{t+\theta}^{\infty} f(r_2^F) dr_2^F \\
&+ \frac{1}{4t} \int_{\Phi_1}^{t+\theta} f(r_2^F) r_2^F (3t+3\theta-r_2^F) dr_2^F \\
&+ \frac{(t+3\theta)}{2t} \int_{\frac{(t+\theta)}{\lambda_2}}^{t-3\theta} f(r_2^F) r_2^F dr_2^F \mathbf{1}(\theta) \\
&+ \frac{1}{2t\lambda_2} \int_{\frac{(t+3\theta)}{\lambda_2}}^{\frac{3(t+\theta)}{(2\lambda_2+1)}} f(r_2^F) \left[t+\theta + \frac{(\lambda_2-1)}{3} r_2^F \right]^2 dr_2^F (1-\mathbf{1}(\theta)) \\
&+ \frac{1}{8t\lambda_2} \int_{\frac{(t-\theta)}{\lambda_2}}^{\Phi_2} f(r_2^F) [t+3\theta+\lambda_2 r_2^F]^2 dr_2^F \\
&+ \frac{(t+\theta)^2}{2t\lambda_2} \int_{-\infty}^{\frac{(t-\theta)}{\lambda_2}} f(r_2^F) dr_2^F,
\end{aligned}$$

$$\begin{aligned}
E[\pi^B(r_1^B; r_1^A, r_2^F)] &= \left[\frac{s-3\theta}{2s} \right] (r_1^F - r_1^B) \\
&+ \frac{(t-\theta)^2}{2t} \int_{t+\theta}^{\infty} f(r_2^F) dr_2^F \\
&+ \frac{1}{8t} \int_{\Phi_1}^{t+\theta} f(r_2^F) (t-3\theta+r_2^F)^2 dr_2^F \\
&+ \frac{(t-3\theta)}{2t} \int_{\frac{(t+\theta)}{\lambda_2}}^{t-3\theta} f(r_2^F) r_2^F dr_2^F \mathbf{1}(\theta) \\
&+ \frac{1}{2t} \int_{\frac{(t+3\theta)}{\lambda_2}}^{\frac{3(t+\theta)}{(2\lambda_2+1)}} f(r_2^F) \left[t-\theta - \frac{(\lambda_2-1)}{3} r_2^F \right]^2 dr_2^F (1-\mathbf{1}(\theta)) \\
&+ \frac{1}{4t} \int_{\frac{(t-\theta)}{\lambda_2}}^{\Phi_2} f(r_2^F) [3t-3\theta-\lambda_2 r_2^F] dr_2^F \\
&+ \frac{(t-\theta)^2}{2t\lambda_2} \int_{-\infty}^{\frac{(t-\theta)}{\lambda_2}} f(r_2^F) dr_2^F.
\end{aligned}$$

Applying the Leibniz integral rule (the indirect effects cancel out) provides

$$\begin{aligned}
\frac{\partial \pi^A}{\partial r_1^A} &= \frac{\lambda_1^A r_1^F - 2\lambda_1^A r_1^A + \lambda_1^B r_1^B - t}{2t} \\
&+ \frac{\lambda_1^A s(t + \theta)}{3t^2} \int_{t+\theta}^{\infty} f(r_2^F) dr_2^F \\
&+ \frac{\lambda_1^A s}{4t^2} \int_{\Phi_1}^{t+\theta} f(r_2^F) r_2^F dr_2^F \\
&+ \frac{\lambda_1^A s}{2t^2} \int_{\frac{t+\theta}{\lambda_2}}^{t-3\theta} f(r_2^F) r_2^F dr_2^F \mathbf{1}(\theta) \\
&+ \frac{\lambda_1^A s(t + \theta)}{3t^2 \lambda_2} \int_{\frac{(t+3\theta)}{\lambda_2}}^{\frac{3(t+\theta)}{(2\lambda_2+1)}} f(r_2^F) dr_2^F (1 - \mathbf{1}(\theta)) + \frac{\lambda_1^A s(\lambda_2 - 1)}{9t^2 \lambda_2} \int_{\frac{(t+3\theta)}{\lambda_2}}^{\frac{3(t+\theta)}{(2\lambda_2+1)}} f(r_2^F) r_2^F dr_2^F (1 - \mathbf{1}(\theta)) \\
&+ \frac{\lambda_1^A s(t + 3\theta)}{4t^2 \lambda_2} \int_{\frac{t-\theta}{\lambda_2}}^{\Phi_2} f(r_2^F) dr_2^F + \frac{\lambda_1^A s}{4t^2} \int_{\frac{t-\theta}{\lambda_2}}^{\Phi_2} f(r_2^F) r_2^F dr_2^F \\
&+ \frac{\lambda_1^A s(t + \theta)}{3t^2 \lambda_2} \int_{-\infty}^{\frac{t-\theta}{\lambda_2}} f(r_2^F) dr_2^F = 0 \quad \text{if } r_1^A \neq 0,
\end{aligned}$$

$$\begin{aligned}
\frac{\partial \pi^B}{\partial r_1^B} &= \frac{\lambda_1^B r_1^F - 2\lambda_1^B r_1^B + \lambda_1^A r_1^A - t}{2t} \\
&+ \frac{\lambda_1^B s(t - \theta)}{3t^2} \int_{t+\theta}^{\infty} f(r_2^F) dr_2^F \\
&+ \frac{\lambda_1^B s(t - 3\theta)}{4t^2} \int_{\Phi_1}^{t+\theta} f(r_2^F) dr_2^F + \frac{\lambda_1^B s}{4t^2} \int_{\Phi_1}^{t+\theta} f(r_2^F) r_2^F dr_2^F \\
&+ \frac{\lambda_1^B s}{2t^2} \int_{\frac{t+\theta}{\lambda_2}}^{t-3\theta} f(r_2^F) r_2^F dr_2^F \mathbf{1}(\theta) \\
&+ \frac{\lambda_1^B s(t - \theta)}{3t^2} \int_{\frac{(t+3\theta)}{\lambda_2}}^{\frac{3(t+\theta)}{(2\lambda_2+1)}} f(r_2^F) dr_2^F (1 - \mathbf{1}(\theta)) - \frac{\lambda_1^B s(\lambda_2 - 1)}{9t^2} \int_{\frac{(t+3\theta)}{\lambda_2}}^{\frac{3(t+\theta)}{(2\lambda_2+1)}} f(r_2^F) r_2^F dr_2^F (1 - \mathbf{1}(\theta)) \\
&+ \frac{\lambda_1^B s}{4t^2} \int_{\frac{t-\theta}{\lambda_2}}^{\Phi_2} f(r_2^F) r_2^F dr_2^F \\
&+ \frac{\lambda_1^B s(t - \theta)}{3t^2 \lambda_2} \int_{-\infty}^{\frac{t-\theta}{\lambda_2}} f(r_2^F) dr_2^F = 0 \quad \text{if } r_1^A \neq 0.
\end{aligned}$$

In the symmetric equilibrium the two banks offer the first-period deposit rates

$$r_1 = \begin{cases} r_1^F - t + \frac{2}{3}s\rho & \text{if } r_1^F > t - \frac{2}{3}s\rho \\ 0 & \text{if } t - \frac{2}{3}s\rho \geq r_1^F \geq \frac{t}{\lambda_1} - \frac{2}{3}s\rho \\ r_1^F - \frac{t}{\lambda_1} + \frac{2}{3}s\rho & \text{if } \frac{t}{\lambda_1} - \frac{2}{3}s\rho > r_1^F \end{cases}$$

and their first-period profits amount to

$$\pi_1 = \begin{cases} \frac{1}{2} \left(t - \frac{2}{3}s\rho \right) & \text{if } r_1^F > t - \frac{2}{3}s\rho \\ \frac{1}{2} r_1^F & \text{if } t - \frac{2}{3}s\rho \geq r_1^F \geq \frac{t}{\lambda_1} - \frac{2}{3}s\rho \\ \frac{1}{2} \left(\frac{t}{\lambda_1} - \frac{2}{3}s\rho \right) & \text{if } \frac{t}{\lambda_1} - \frac{2}{3}s\rho > r_1^F \end{cases}$$

with

$$\begin{aligned} \rho &= \frac{1}{\lambda_2} P(t/\lambda_2 > R_2^F) + \frac{3}{2t} P(t \geq R_2^F \geq t/\lambda_2) E[R_2^F | t \geq R_2^F \geq t/\lambda_2] + P(R_2^F > t) \\ &= \frac{1}{\lambda_2} \int_{-\infty}^{t/\lambda_2} f(r_2^F) dr_2^F + \frac{3}{2t} \int_{t/\lambda_2}^t f(r_2^F) r_2^F dr_2^F + \int_t^{\infty} f(r_2^F) dr_2^F. \end{aligned}$$

Appendix C: Dataset and Estimation of Deposit Spreads

Table C.1: Data on money market and retail deposit rates

country	money market	retail deposits	
		key	source
Switzerland	SARON	EPB@SNB.zikrepro{M.S1}	SNB
Sweden	STIBOR	saving deposits/private clients	SCB
Denmark	CIBOR	DNRNIPI: outstanding/households	DanNB
Euro Area		MIR.M.U2.B.L21.A.R.A.2250.EUR.N	ECB
<i>Germany</i>		MIR.M.DE.B.L21.A.R.A.2250.EUR.N	ECB
<i>France</i>	EURIBOR	MIR.M.FR.B.L21.A.R.A.2250.EUR.N	ECB
<i>Italy</i>		MIR.M.IT.B.L21.A.R.A.2250.EUR.N	ECB
<i>Spain</i>		MIR.M.ES.B.L21.A.R.A.2250.EUR.N	ECB
<i>Netherlands</i>		MIR.M.NL.B.L21.A.R.A.2250.EUR.N	ECB

Notes: Observation period: January 2013 to September 2019. Maturities - STIBOR, CIBOR and EURIBOR: 1 week; SARON is overnight.

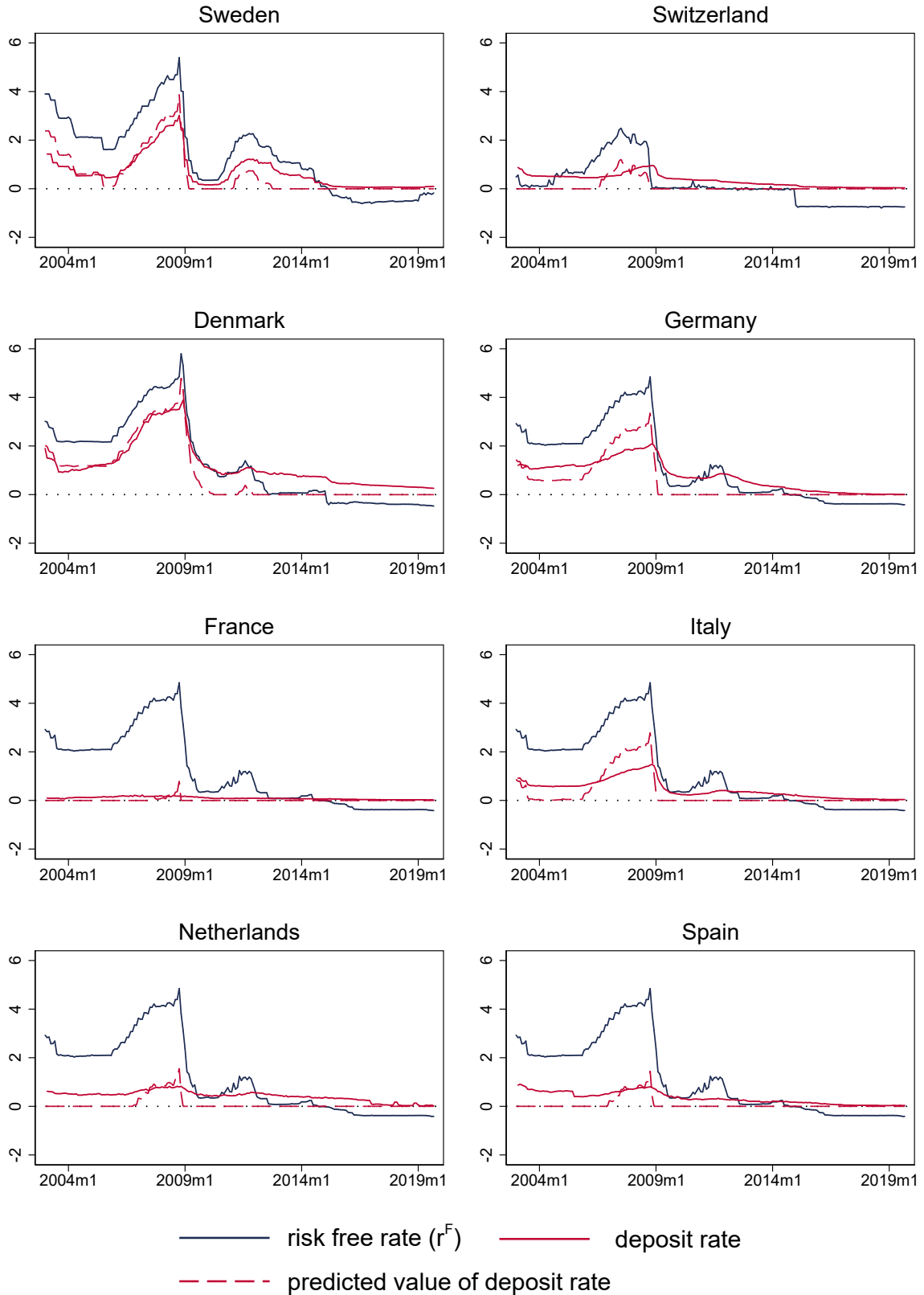


Figure C.1: r , r^F and predicted values of r

Notes: This figure shows r , r^F and non-negative predicted values of r from an iterative constrained least squares regression: $r_t^D = \eta + \gamma r_{1,t}^F + \epsilon_t$ with $\gamma = 1$. The regression of each iteration is based on the observations for which the predicted values from the regression of the previous iteration were non-negative (stable values are achieved after 3 to 9 iterations). Observation period: January 2003 (first month for which r is available for all countries) to September 2019.

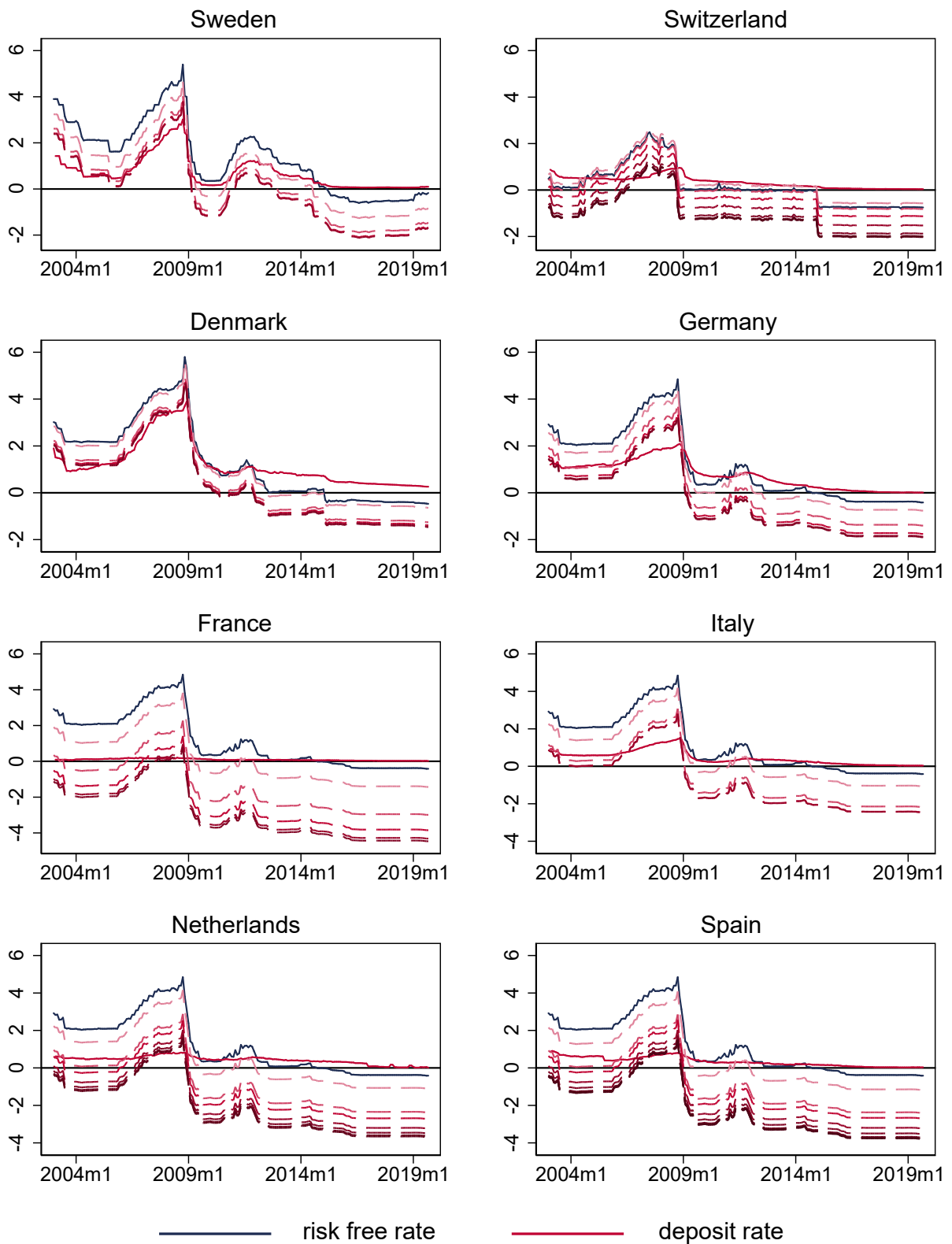


Figure C.2: r , r^F and predicted values of r

Notes: This figure shows r , r^F and the predicted values of r from *all iterations* of constrained least squares regressions: $r_t^D = \eta + \gamma r_{1,t}^F + \epsilon_t$ with $\gamma = 1$. The regression of each iteration is based on the observations for which the predicted values from the regression of the previous iteration were non-negative (stable values are achieved after 3 to 9 iterations). The color intensity of predicted values increases with each iteration. Observation period: January 2003 (first month for which r is available for all countries) to September 2019.