# The Deposits Channel of Monetary Policy
# A Critical Review

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**Abstract**

Drechsler, Savov, and Schnabl (2017) claim that increases in the monetary policy rate lead to reductions in bank deposits, which account for the subsequent contraction in lending. This paper reviews their theoretical analysis, based on a model of imperfect competition in a local banking market, showing that the relationship between the policy rate and the equilibrium amount of deposits is in general either flat or increasing in the relevant range. Moreover, this is consistent with their panel regression results showing that an increase in the policy rate leads to smaller changes in deposits at branches with high market power. These results question the theoretical underpinnings of the "deposits channel" of monetary policy transmission.

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> "When the Fed funds rate rises, banks widen the interest spreads they charge on deposits, and deposits flow out of the banking system. Since banks rely heavily on deposits for their funding, these outflows induce a contraction in lending."
>
> Drechsler, Savov, and Schnabl (2017)

# 1 Introduction

The paper by Drechsler, Savov, and Schnabl (2017), henceforth DSS, presents a novel empirical analysis of the effect of changes in the monetary policy rate on the amount of bank deposits in local markets characterized by different degrees of market power. In particular, they show in a panel regression that increases in the Federal funds rate lead to smaller changes in deposits at bank branches located in concentrated counties relative to those in less concentrated counties. This result is then used to propose a novel explanation of the effect of monetary policy on bank lending, called the "deposits channel" of monetary policy. In their words: "Deposits are the main source of funding for banks. Their stability makes them particularly well suited for funding risky and illiquid assets. As a result, when banks contract deposit supply they also contract lending." The paper also constructs a theoretical model of imperfect competition in a local banking market to account for their empirical findings.

This paper presents a critical review of DSS's theoretical model, showing that *the relationship between the policy rate and the equilibrium amount of deposits is in general either flat or increasing in the relevant range*. The model features a representative household with an initial wealth that can be invested in three types of assets: cash that pays a zero interest rate, deposits of a set of $n$ banks that pay the equilibrium deposit rates, and bonds that pay the policy rate set by the central bank. The demand for bank deposits is derived from a utility function that depends on final wealth and liquidity services provided by cash and deposits. Banks offer differentiated deposits and compete by setting deposit rates, earning the policy rate on their investments. Equilibrium deposit rates are derived from the symmetric Nash equilibrium of the game played by the banks. The key question is: What is the effect on equilibrium deposits of an exogenous change in the policy rate?

The contrast with the results in DSS is explained by the introduction of two reasonable assumptions not considered by them. The first assumption is a borrowing constraint stating that the household cannot borrow at the policy rate to overinvest in cash and deposits. The second assumption is that banks cannot pay negative deposit rates. These assumptions are binding for low values of the policy rate: if cash and deposits yield valuable liquidity services and pay a similar return as bonds, the household would want to short a very large amount of bonds to invest the proceeds in the liquid assets. If this is not possible, the household would have to invest all her wealth in cash and deposits. For sufficiently low values of the policy rate, the banks would set a zero deposit rate, in which case the equilibrium amount of cash and deposits would not change with the policy rate. Beyond this threshold, deposit rates would start to go up, and the household would increase her holdings of deposits and reduce her holdings of cash. Hence, the flat and then increasing relationship between the policy rate and the equilibrium amount of deposits.

Before explaining the effect of market power on this relationship, I would like to briefly comment on DSS's empirical results. Their paper starts presenting some suggestive time series evidence showing a negative correlation between changes in the Federal funds rate and changes in various types of bank deposits. But since business cycle developments may be driving all these variables, they propose an identification strategy that relies on panel data on deposit rates and deposit holdings at bank branches in different counties. Exploiting the variation in market power at the county level, they compare the effect of changes in the Federal funds rate in branches of the same bank located in different counties.

The key panel regressions have as dependent variables (i) the quarterly change in the spread $s_{it}$ between the Federal funds rate $r_t$ and the deposit rate of a bank's branch $i$, and (ii) the annual log change in the deposits $D_{it}$ of branch $i$. The main explanatory variable is an interaction term between the change in the Federal funds rate $r_t$ and the Herfindahl index $\text{HHI}_i$ computed with the deposit market shares of the banks operating in the county where branch $i$ is located. Thus, they estimate the following equation

$$\Delta y_{it} = \alpha_i + \gamma(\Delta r_t \times \text{HHI}_i) + \text{ Controls } + \varepsilon_{it},$$

where $\Delta y_{it}$ is either $\Delta s_{it}$ or $\Delta \ln D_{it}$, and the controls include bank-time fixed effects. Bank-specific characteristics (such as lending opportunities) are controlled by comparing branches of the same bank in different counties.

The results for the *spreads equation* show that $\gamma_s$ is positive and statistically significant, which means that an increase in the Federal funds rate leads to larger changes in spreads (and smaller changes in deposit rates) at branches located in high concentration counties. The results for the *deposits equation* show that $\gamma_D$ is negative and statistically significant, which means that an increase in the Federal funds rate leads to smaller changes in deposits at branches located in high concentration counties.[1]

The problem arises with DSS's interpretation of these empirical results. They write: "Following an increase in the Federal funds rate, the bank's branches in more concentrated counties (...) experience *larger outflows* relative to its branches in less concentrated counties" (my italics). More importantly, from here they jump to the conclusion that these results imply that "when the Federal funds rate rises, banks widen the interest spreads they charge on deposits, and *deposits flow out of the banking system*" (my italics). But the fact that coefficient $\gamma_D$ is negative and statistically significant does not imply that increases in the Federal funds rate lead to reductions in the aggregate amount of deposits. The panel regressions only imply a relative effect when comparing counties with high and low market power, not an absolute effect of the policy rate on bank deposits.[2]

To rationalize these empirical results, I analyze the effect of a change in the number $n$ of banks on the relationship between the policy rate and equilibrium spreads and deposits in DSS's theoretical model modified by the introduction of a borrowing constraint and a zero lower bound on deposit rates. In line with their empirical results, I show that increasing the number of banks (i) reduces the slope of the relationship between the policy rate and equilibrium spreads, and (ii) increases the slope of the relationship between the policy rate

[1] These empirical results have been criticized by Begenau and Stafford (2023) because of the widespread use of uniform deposit pricing among large commercial banks. See Drechsler et al. (2024) for a response to this criticism. See also d'Avernas et al. (2023) for a model with large and small banks, where the former provide superior liquidity services, face higher costs, and pay lower deposit rates under uniform pricing.

[2] This is closely related to the so-called 'missing intercept' problem; see, for example, Guren et al. (2021), and Wolf (2023).

and equilibrium deposits. The first result follows from the fact that the relationship between the policy rate and equilibrium spreads follows first the $45^o$ line (when the deposit rate is at the zero lower bound) and then becomes flatter (when the deposit rate becomes positive), with the kink moving to the right for higher market power. The second result follows from the fact that the relationship between the policy rate and equilibrium deposits is first flat (when the deposit rate is at the zero lower bound) and then becomes increasing (when the deposit rate becomes positive), with the kink moving to the right for higher market power. Thus, the predictions of the model are consistent with the empirical results in DSS's regressions: spreads are more sensitive and deposits are less sensitive to changes in the policy rate when banks' market power is high than when it is low. More importantly, my results show that, in the relevant range of policy rates and for a wide range of parameter values, increases in the policy rate do not lead to a reduction in bank deposits, questioning the theoretical underpinnings of the "deposits channel" of monetary policy transmission.

This paper is related to the growing literature on the transmission of monetary policy when banks have market power; see, for example, Corbae and Levine (2018), Wang et al. (2022), and Abadi et al. (2023). It is also related to papers that analyze the pass-through from policy rates to deposits and loan rates; see, for example, Ulate (2021) and Eggertsson et al. (2023). In terms of results, it is closer to the papers that emphasize the heterogeneous effects of monetary policy, such as Kashyap and Stein (2000), for large and small banks, Jiménez et al. (2012), for banks with different levels of capital, Martinez-Miera and Repullo (2020), for banks with different degrees of market power, and Heider et al. (2019), for banks with different balance sheet structures.

The remainder of the paper is structured as follows. Section 2 presents DSS's theoretical model. Section 3 analyzes the equilibrium of the model in the special case of a monopoly bank. Section 4 analyzes the equilibrium in the general oligopoly case. Section 5 discusses the role of the two assumptions not considered by DSS, and Section 6 concludes. The proofs of all the results are in the Appendix.

# 2 DSS's Model

Consider a representative household with *initial wealth* $W_0$ and preferences described by a CES utility function over *final wealth* $W$ and *liquidity services* $L$ such that

$$U(W,L) = \left(W^{\frac{\rho-1}{\rho}} + \lambda L^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}, \tag{1}$$

where $\lambda > 0$ captures the utility of liquidity services relative to final wealth. Following DSS, it is assumed that final wealth and liquidity services are complements, so the elasticity of substitution satisfies $0 < \rho < 1$.[3]

Liquidity services $L$ are characterized by a CES function over *cash* $M$ and *deposits* $D$ such that

$$L(M,D) = \left(M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}}, \tag{2}$$

where $\delta > 0$ captures the liquidity services of deposits relative to cash. Following DSS, it is assumed that cash and deposits are substitutes, so the elasticity of substitution satisfies $\epsilon > 1$.

Deposits $D$ are a composite good produced by a set of $n$ banks according to a CES function of the deposits $D_i$ of the $i = 1, ..., n$ banks with

$$D = \left(\frac{1}{n}\sum_{i=1}^{n} D_i^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}. \tag{3}$$

Following DSS, it is assumed that the deposits of the different banks are substitutes, so the elasticity of substitution satisfies $\eta > 1$.

The representative household can invest her initial wealth $W_0$ in three types of assets: *cash* $M$ that pays a zero interest rate, *deposits* $D_i$ of bank $i = 1, 2, ..., n$ that pay an interest rate $r_i$, and *bonds* that pay an interest rate $r \geq 0$ which is interpreted as the monetary policy

[3]Note that for this specification of the utility function we have $\lim_{\rho\to 0} U(W,L) = \min\{W, L\}$, so in the limit the value of $\lambda$ would be irrelevant. An alternative specification would be

$$U(W,L) = \left(W^{\frac{\rho-1}{\rho}} + (\lambda L)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}},$$

in which case $\lim_{\rho\to 0} U(W,L) = \min\{W, \lambda L\}$. In this case, in the limit liquidity services would be a proportion $1/\lambda$ of final wealth.

rate set by the central bank. Final wealth $W$ is then given by

$$W = M + \sum_{i=1}^{n} D_i(1 + r_i) + (W_0 - M - \sum_{i=1}^{n} D_i)(1 + r).$$

Letting $s_i = r - r_i$ be the *deposit spread* charged by bank $i$, final wealth simplifies to

$$W = W_0(1 + r) - \sum_{i=1}^{n} D_i s_i - Mr. \tag{4}$$

According to this expression, final wealth $W$ equals the market return of the initial wealth $W_0(1 + r)$ minus the opportunity cost of deposit holdings $\sum_{i=1}^{n} D_i s_i$ and the opportunity cost of cash holdings $Mr$.

One feature of DSS's specification of the composite deposits (3) is that $D_1 = ... = D_n$ implies $D = D_1 = ... = D_n$, so $D_i$ cannot really be interpreted as the deposits of bank $i$. This is important since the opportunity cost of a given amount of composite deposits $D$, assuming that all banks charge the same spread $s$, is $nDs$. Thus, an increase in the number of banks with the same amount of deposits would increase the cost of deposit holdings without any increase in the household's utility, leading to a downward bias in the demand for deposits. Given that the key DSS's regression is about the effect of changes in the policy rate on equilibrium deposits for different degrees of banks' market power, this feature has consequences for understanding their empirical results.

For this reason, in the analysis of the oligopoly model in Section 4, I will assume an alternative specification of the composite deposits, namely

$$D = \left( \frac{1}{n} \sum_{i=1}^{n} (nD_i)^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}, \tag{5}$$

where $\eta > 1$. Under this specification, $D_1 = ... = D_n$ implies $D = D_1 + ... + D_n$, so $D_i$ can be interpreted as the deposits of bank $i$.[4] In this case, an increase in the number of banks with the same amount of deposits increases both the cost and the utility of deposit holdings. However, it is important to note that both specifications, (3) and (5), are identical in the case of a monopoly bank analyzed in Section 3.

[4]This specification of the composite deposits is also used by Balloch and Koby (2026).

Given the policy rate $r$ and the deposit spreads $s_1, ..., s_n$ set by the $n$ banks, the representative household maximizes her utility function (1) subject to the constraint (4). The solution to this problem yields a demand for deposits $D_i(s_1, ..., s_n; r)$ of bank $i = 1, ..., n$. Assuming that banks earn the policy rate $r$ on their investments, the profits of bank $i = 1, ..., n$ are

$$\pi_i(s_1, ..., s_n; r) = (r - r_i)D_i(s_1, ..., s_n; r) = s_i D_i(s_1, ..., s_n; r). \tag{6}$$

These payoff functions are used to compute the symmetric *Nash equilibrium spread* $s^*(r)$ set by the banks as a function of the policy rate $r$. Finally, substituting the equilibrium spreads into the household demand for deposits, and using (5), gives the *equilibrium amount of deposits* $D^*(r)$. DSS claim that $D^*(r)$ is decreasing in the policy rate $r$.

In what follows I will examine the validity of this claim under two reasonable assumptions not considered by DSS. The first assumption is that the household's choice of cash and deposits is restricted to satisfy the borrowing constraint

$$M + \sum_{i=1}^{n} D_i \leq W_0. \tag{7}$$

Thus, the household cannot borrow at the policy rate $r$ to overinvest in cash and deposits. The second assumption is that banks cannot pay negative deposit rates, so $r_i \geq 0$ for $i = 1, ..., n$. Thus, deposit spreads have to satisfy $s_i = r - r_i \leq r$ for $i = 1, ..., n$.[5]

To review the results of DSS, it is convenient to start with the simpler case of a monopoly bank ($n = 1$).

# 3 The Monopoly Model

To assess the effect of a change in the monetary policy rate $r$ on the equilibrium amount of deposits of the monopoly bank, one has to determine the equilibrium spread set by the bank, which in turn requires deriving the household's demand for cash $M$ and deposits $D$ as a function of the policy rate $r$ and the deposit spread $s$.

[5]Note that since cash and deposits enter the utility function and are imperfect substitutes, the demand for deposits of bank $i$ would not drop to zero when $r_i < 0$. Thus, $r_i \geq 0$ is an assumption.

I first derive these functions for the case in which there is no borrowing constraint (7). Then, I show that this constraint will be violated for small values of the policy rate $r$, and derive the demands for cash and deposits under this constraint. Finally, I characterize the monopoly bank's optimal choice of spread $s^*$ and the corresponding equilibrium amount of deposits $D^*$ as a function of $r$.

**Proposition 1** *In the absence of the borrowing constraint $M + D \leq W_0$, the household's unconstrained demands for cash and deposits are*

$$\widehat{M}(s;r) = \frac{W_0(1+r)}{r^{\epsilon}\mu^{\epsilon-1}(1+\lambda^{-\rho}\mu^{1-\rho})} \text{ and } \widehat{D}(s;r) = \frac{\delta^{\epsilon}W_0(1+r)}{s^{\epsilon}\mu^{\epsilon-1}(1+\lambda^{-\rho}\mu^{1-\rho})}, \tag{8}$$

*where*

$$\mu = \left(r^{1-\epsilon} + \delta^{\epsilon}s^{1-\epsilon}\right)^{\frac{1}{\epsilon-1}}. \tag{9}$$

The following result shows some useful properties of the unconstrained demands for cash and deposits.

**Proposition 2** *The unconstrained demand for deposits $\widehat{D}(s;r)$ is decreasing in the deposit spread $s$ and increasing in the policy rate $r$. Moreover, $\widehat{M}(s;r) + \widehat{D}(s;r)$ is decreasing in the spread $s$ for $0 < s < r$, and $\lim_{r\to 0}\left[\widehat{M}(r;r) + \widehat{D}(r;r)\right] = \infty$.*

According to this proposition, higher spreads lead to a lower demand for deposits while higher policy rates lead to an outward shift in the demand for deposits. The proposition also implies that, for a given policy rate $r > 0$, there is (at most) a single value of the spread $s$ such that for lower values of the spread the constraint $M + D \leq W_0$ will be binding. Finally, the proposition implies that for small values of the policy rate, and for any spread $0 \leq s \leq r$ set by the monopoly bank, the borrowing constraint $M + D \leq W_0$ will be binding. The intuition is straightforward: if cash and deposits yield valuable liquidity services and (in the limit) pay the same return as bonds, the household would want to short an infinite amount of bonds to invest the proceeds in the liquid assets.[6]

To complete the analysis of the monopoly model I next analyze the case where the household's choice of cash and deposits is restricted to satisfy the constraint $M + D \leq W_0$.

[6]This point was noted by Sá and Jorge (2019), but they did not formally analyze the model with a nonnegative restriction on bond holdings.

I start by considering a situation in which the household can only invest in cash and deposits, so $M + D = W_0$. In this case her final wealth is

$$W = M + D(1 + r_1) = W_0 + Dr_1,$$

where $r_1 = r - s$ denotes the deposit rate set by the monopoly bank 1. Hence, the problem of the household becomes

$$\max_D \left[ (W_0 + Dr_1)^{\frac{\rho-1}{\rho}} + \lambda \left( (W_0 - D)^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}. \tag{10}$$

I can now prove the following result.

**Proposition 3** *When the household can only invest in cash and deposits, her constrained demands for cash and deposits are*

$$\overline{M}(s; r) = W_0 - \overline{D}(s; r) \text{ and } \overline{D}(s; r) = \overline{D}(r_1),$$

*where* $\overline{D}(r_1)$ *is a solution to the first-order condition*

$$(W_0 + Dr_1)^{-\frac{1}{\rho}} r_1 = \lambda \left( M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\rho-\epsilon}{\rho(\epsilon-1)}} \left( M^{-\frac{1}{\epsilon}} - \delta D^{-\frac{1}{\epsilon}} \right), \tag{11}$$

*with* $r_1 = r - s$ *and* $M = W_0 - D$. *Moreover* $\overline{D}'(r_1) > 0$ *if*

$$r_1 < \frac{\rho}{1 - \rho}. \tag{12}$$

The first-order condition (11) implies that when $r_1 = 0$, that is when the deposit rate paid by the monopoly bank equals zero, the solution must satisfy $\overline{M}^{-\frac{1}{\epsilon}} = \delta \overline{D}^{-\frac{1}{\epsilon}}$, which implies

$$\frac{\overline{D}}{\overline{M}} = \delta^{\epsilon}. \tag{13}$$

Thus, when $r_1 = 0$ the ratio of deposits to cash will be greater than 1 if and only if the parameter $\delta$ of the liquidity services function (2) is greater than 1. Similarly, for $r_1 > 0$, it must be the case that $\overline{M}^{-\frac{1}{\epsilon}} > \delta \overline{D}^{-\frac{1}{\epsilon}}$, which implies $\overline{D}/\overline{M} > \delta^{\epsilon}$, so the household increases the ratio of deposits to cash relative to the case where $r_1 = 0$. The proposition also states that a sufficient condition for the demand for deposits to be increasing in the deposit rate $r_1$

is that $r_1$ is below the upper bound in (12). Since $r_1 = r - s \leq r$, then a sufficient condition for the constrained demand for deposits $\overline{D}(s;r)$ to be decreasing in the spread $s$ is that

$$s < r \leq \frac{\rho}{1-\rho}. \tag{14}$$

I can now turn to the characterization of the monopoly bank's optimal choice of spread $s^*$ for any given level of the policy rate $r$, which requires specifying the household's demand for deposits $D(s;r)$. By Proposition 2, for any $r$ there is (at most) a single value of the spread $s$ such that for lower values of the spread the constraint $M + D \leq W_0$ will be binding, in which case $D(s;r) = \overline{D}(s;r)$, where $\overline{D}(s;r)$ is the constrained demand derived in Proposition 3; otherwise, we have $D(s;r) = \widehat{D}(s;r)$, where $\widehat{D}(s;r)$ is the unconstrained demand derived in Proposition 1. From here it follows that the household's demand for deposits is given by

$$D(s;r) = \min\left\{\overline{D}(s;r), \widehat{D}(s;r)\right\}. \tag{15}$$

By Proposition 1, $\widehat{D}(s;r)$ is decreasing in the spread $s$, while by Proposition 3, $\overline{D}(s;r)$ is decreasing in the spread $s$ when condition (14) is satisfied. Hence, under this weak condition,[7] the household's demand for deposits $D(s;r)$ will be decreasing in the spread $s$. It will also be continuous, since both $\widehat{D}(s;r)$ and $\overline{D}(s;r)$ are continuous, but in general it will not be differentiable at the point where $\widehat{D}(s;r)$ and $\overline{D}(s;r)$ intersect.

Substituting (15) into the bank's profit function (6) for $n = 1$ gives the profit maximizing spread

$$s^*(r) = \arg\max_{0 \leq s \leq r} [sD(s;r)], \tag{16}$$

which implies the following equilibrium amount of deposits

$$D^*(r) = D(s^*(r);r).$$

Clearly, for $r > 0$ the solution to the bank's problem (16) satisfies $s^*(r) = r - r_1^* > 0$, where $r_1^*$ denotes the corresponding equilibrium deposit rate. Then, $r_1^* < r$ implies that the equilibrium deposit rate is characterized by a mark-down relative to the policy rate $r$.

[7] For example, for $\rho = 0.5$ the sufficient condition in (14) is that policy rate is below 100%.

However, if there is a zero lower bound on deposit rates, there could be a range of (low) values of the policy rate for which $s^*(r) = r - r_1^* = r$ and the equilibrium deposit rate $r_1^*$ will be zero.

By the proof of Proposition 2, for low values of the policy rate $r$, the unconstrained demand for deposits becomes unbounded, in which case the constraint $M + D \leq W_0$ cannot be exactly binding, that is

$$D^*(r) = \overline{D}(s^*(r); r) < \widehat{D}(s^*(r); r).$$

This leads to the following result.

**Proposition 4** *When the constraint $M + D \leq W_0$ is not exactly binding, the equilibrium amount of deposits $D^*(r)$ is either flat, when the deposit rate is at the zero lower bound, or increasing in the policy rate $r$, otherwise.*

The intuition for this result is that, in the range where the constraint $M + D \leq W_0$ is not exactly binding, the demand for deposits only depends on the deposit rate $r_1$ set by the monopoly bank and does not depend on the policy rate $r$.[8] Then, when the bank is not at the deposit zero lower bound, an increase in the policy rate $r$ leads to an increase in the deposit rate $r_1$, which in turn makes deposits more attractive than cash, so the equilibrium amount of deposits $D^*(r)$ goes up.

In contrast, when the policy rate is sufficiently high, so the constraint $M + D \leq W_0$ is not binding, the demand for deposits depends on both the deposit spread $s$ and the policy rate $r$, since the household invests part of her wealth in bonds that yield the policy rate. Then, an increase in the policy rate has an ambiguous effect on the equilibrium amount of deposits $D^*$. To see this, consider the household's budget constraint (4) rewritten as

$$Mr + Ds + W = W_0(1 + r).$$

An increase in the policy rate $r$ increases the "price" of cash $r$ and the "price" of deposits $s$ (since $s$ is generally increasing in $r$), so there is a *substitution effect* that reduces the demand

[8] Note that the constraint $M+D \leq W_0$ is exactly binding when the bank chooses a spread at the kink where the convex unconstrained demand for deposits $\widehat{D}(s; r)$ equals the concave constrained demand for deposits $\overline{D}(s; r)$. In this case, one cannot assess the effect of changes in the policy rate by simply differentiating the constrained demand.

for cash and deposits. At the same time, the increase in $r$ produces an *income effect* that increases the demand for cash and deposits, so the final effect is in general ambiguous.

Summing up, I have shown that in the monopoly case, for low values of the policy rate the household will always invest her entire initial wealth in cash and deposits, in which case the equilibrium amount of deposits will be first flat and then increasing in the policy rate. For higher values of the policy rate for which the borrowing constraint is not binding, the effect is ambiguous, and depends on the choice of parameter values. This choice will be discussed in the following section, in the context of the analysis of the oligopoly model.

# 4 The Oligopoly Model

I next consider the oligopoly model in which $n > 1$ banks indexed by $i = 1, 2, ..., n$ compete in the deposit market by setting spreads $s_i$ between the policy rate $r$ and their deposit rate $r_i$. As in the case of the monopoly model, I start with the case in which there is no borrowing constraint.

**Proposition 5** *In the absence of the borrowing constraint* (7)*, the household's unconstrained demands for cash and deposits of any bank $i$ are*

$$\widehat{M}(s_1, ..., s_n; r) = \frac{W_0(1+r)}{r^{\epsilon}\mu^{\epsilon-1}(1+\lambda^{-\rho}\mu^{1-\rho})} \tag{17}$$

*and*

$$\widehat{D}_i(s_1, ..., s_n; r) = s_i^{-\eta}\left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{\epsilon-\eta}{\eta-1}} \frac{\delta^{\epsilon} W_0(1+r)}{n\mu^{\epsilon-1}(1+\lambda^{-\rho}\mu^{1-\rho})}, \tag{18}$$

*where*

$$\mu = \left[r^{1-\epsilon} + \delta^{\epsilon}\left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{\epsilon-1}{\eta-1}}\right]^{\frac{1}{\epsilon-1}}. \tag{19}$$

In a symmetric Nash equilibrium where all the banks set the same spread $s$, (17) and (18) imply that

$$\widehat{M}(s, ..., s; r) = \widehat{M}(s; r) \text{ and } \sum_{i=1}^{n} \widehat{D}_i(s, ..., s; r) = \widehat{D}(s; r),$$

where $\widehat{M}(s; r)$ and $\widehat{D}(s; r)$ are defined in Proposition 1, and $\mu$ in (19) is the same as $\mu$ in (9). From here it follows that, when focussing on symmetric equilibria, Proposition 2 also applies

to the oligopoly model. Thus, for low values of the policy rate $r$ the borrowing constraint (7) will be binding.

Moreover, since Proposition 2 states that $\widehat{M}(s;r) + \widehat{D}(s;r)$ is decreasing in the spread $s$, it follows that $\widehat{M}(s;r) + \widehat{D}(s;r) \geq \widehat{M}(r;r) + \widehat{D}(r;r)$, so a sufficient condition for the borrowing constraint (7) to be binding in a symmetric equilibrium is that

$$\widehat{M}(r;r) + \widehat{D}(r;r) = \frac{W_0(1+r)}{r + r^{\rho}\lambda^{-\rho}(1+\delta^{\epsilon})^{\frac{1-\rho}{\epsilon-1}}} \geq W_0,$$

which simplifies to

$$\rho \geq \frac{\ln(1+\delta^{\epsilon})}{(\epsilon-1)(\ln\lambda - \ln r) + \ln(1+\delta^{\epsilon})} \text{ and } \ln\lambda > \ln r - \frac{\ln(1+\delta^{\epsilon})}{\epsilon-1} \tag{20}$$

Thus, the borrowing constraint is more likely to be binding for high values of the parameter $\lambda$ that captures the utility of liquidity services relative to final wealth and of the parameter $\rho$ that captures the elasticity of substitution between liquidity services and final wealth, and for low values of the policy rate $r$.

As in the case of monopoly, I next consider a situation in which the household can only invest in cash and deposits, in which case her final wealth is

$$W = M + \textstyle\sum_{i=1}^{n} D_i(1+r_i) = W_0 + \sum_{i=1}^{n} D_i r_i.$$

Hence, the problem of the household becomes

$$\max_{D_1,\ldots,D_n} \left[ \left(W_0 + \textstyle\sum_{i=1}^{n} D_i r_i\right)^{\frac{\rho-1}{\rho}} + \lambda \left( \left(W_0 - \sum_{i=1}^{n} D_i\right)^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \tag{21}$$

where $D$ is given by (5).

**Proposition 6** *When the household can only invest in cash and deposits, her constrained demands for cash and deposits of any bank $i$ when it pays a deposit rate $r_i$ and the other $n-1$ banks pay a deposit rate $r_{-i}$ are*

$$\overline{M}(s_i, s_{-i}; r) = W_0 - \overline{D}_i(s_i, s_{-i}; r) - (n-1)\overline{D}_{-i}(s_i, s_{-i}; r),$$

*where $\overline{D}_i(s_i, s_{-i}; r) = \overline{D}_i(r_i, r_{-i})$ and $\overline{D}_{-i}(s_i, s_{-i}; r) = \overline{D}_{-i}(r_i, r_{-i})$ are a solution to the first-order conditions*

$$(W_0 + D_i r_i + (n-1)D_{-i}r_{-i})^{-\frac{1}{\rho}} r_i = \lambda \left(M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\rho-\epsilon}{\rho(\epsilon-1)}} \left(M^{-\frac{1}{\epsilon}} - \delta D^{\frac{\epsilon-\eta}{\epsilon\eta}} (nD_i)^{-\frac{1}{\eta}}\right), \quad (22)$$

$$(W_0 + D_i r_i + (n-1)D_{-i}r_{-i})^{-\frac{1}{\rho}} r_{-i} = \lambda \left(M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\rho-\epsilon}{\rho(\epsilon-1)}} \left(M^{-\frac{1}{\epsilon}} - \delta D^{\frac{\epsilon-\eta}{\epsilon\eta}} (nD_{-i})^{-\frac{1}{\eta}}\right), \quad (23)$$

*with*

$$D = \left(\frac{1}{n}(nD_i)^{\frac{\eta-1}{\eta}} + \frac{n-1}{n}(nD_{-i})^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}},$$

$r_i = r - s_i$, $r_{-i} = r - s_{-i}$, *and* $M = W_0 - D_i - (n-1)D_{-i}$,

Note that dividing (22) by (23) gives

$$\frac{r_i}{r_{-i}} = \frac{M^{-\frac{1}{\epsilon}} - \delta D^{\frac{\epsilon-\eta}{\epsilon\eta}} (nD_i)^{-\frac{1}{\eta}}}{M^{-\frac{1}{\epsilon}} - \delta D^{\frac{\epsilon-\eta}{\epsilon\eta}} (nD_{-i})^{-\frac{1}{\eta}}}.$$

Hence, $r_i > r_{-i}$ implies $(nD_i)^{-\frac{1}{\eta}} < (nD_{-i})^{-\frac{1}{\eta}}$, which in turn implies $D_i > D_{-i}$. Thus, if bank $i$ pays a higher deposit rate than the other $n-1$ banks, it will get a higher amount of deposits.

Also, note that when all banks pay a zero deposit rate, (22) implies

$$\overline{M}^{-\frac{1}{\epsilon}} = \delta \overline{D}^{\frac{\epsilon-\eta}{\epsilon\eta}} \overline{D}^{-\frac{1}{\eta}} = \delta \overline{D}^{-\frac{1}{\epsilon}},$$

so the ratio $\overline{D}/\overline{M}$ of deposits to cash equals $\delta^\epsilon$, the same result (13) as in the monopoly model.

I can now turn to the characterization of the symmetric Nash equilibrium spread $s^*(r)$ set by the banks as a function of the policy rate $r$. As in the case of the monopoly model, the demand for deposits of any bank $i$ has two possible regimes, namely one in which the

borrowing constraint (7) is not binding, where the demand is given in Proposition 5, and one in which the constraint is binding, where the demand is characterized in Proposition 6.

The *symmetric Nash equilibrium spread* $s^*(r)$ is defined by the condition that the best response of any bank $i$ to the spread $s^*(r)$ set by the other $n-1$ banks is $s^*(r)$. To compute the best response function, write the profits (6) of bank $i$ as

$$\pi_i(s_i,s_{-i};r) = s_i D_i(s_i,s_{-i};r),$$

where

$$D_i(s_i,s_{-i};r) = \min\left\{\widehat{D}_i(s_i,s_{-i};r), \overline{D}_i(s_i,s_{-i};r)\right\},$$

$\widehat{D}_i(s_i,s_{-i};r)$ is the unconstrained demand (18) for the case where bank $i$ sets a spread $s_i$ and the other $n-1$ banks set a spread $s_{-i}$, and $\overline{D}_i(s_i,s_{-i};r)$ is the constrained demand for the case where bank $i$ sets a spread $s_i$ and the other $n-1$ banks set a spread $s_{-i}$ characterized in Proposition 6. Then, the symmetric Nash equilibrium spread satisfies

$$s^*(r) = \arg\max_{0\leq s_i\leq r} \pi_i(s_i,s^*(r);r),$$

and the corresponding equilibrium amount of deposits is

$$D^*(r) = nD_i(s^*(r),s^*(r);r).$$

I am now ready to present the main result of this paper, showing that the equilibrium amount of deposits $D^*(r)$ is either flat or increasing in the policy rate $r$ for a wide range of parameter values.

The model has six parameters. In the utility function (1) there is parameter $\lambda > 0$ that captures the utility of liquidity services relative to final wealth and parameter $0 < \rho < 1$ that captures the elasticity of substitution between liquidity services and final wealth; in the liquidity services function (2) there is parameter $\delta > 0$ that captures the liquidity services of deposits relative to cash and parameter $\epsilon > 1$ that captures the elasticity of substitution between deposits and cash; and in the composite deposits (5) there is the elasticity of substitution $\eta > 1$ between the deposits of the $n$ banks.

To set the deposits to cash ratio (13) for low values of the policy rate, I use data from the Financial Accounts of the US for the last quarter of 2015, that is just before the year in which the Federal Reserve started to tighten monetary policy after seven years of interest rates at the zero lower bound. According to this data, the households' checkable deposits and currency (the empirical counterpart of $M$) were \$ 1,197.7 bn, while households' total time and savings deposits (the empirical counterpart of $D$) were \$ 7,977.5 bn. For such low policy rate it is reasonable to assume that the borrowing constraint (7) was binding and that the deposit rates were at the zero lower bound. Hence, Proposition 6 implies

$$\frac{\overline{D}}{\overline{M}} = \delta^{\epsilon} = 6.66. \tag{24}$$

Next, following Balloch and Koby (2026), I assume that $\epsilon < \eta$, since the deposits of the different banks are arguably closer substitutes than deposits and cash. In particular, I will assume that $\epsilon = 4$ and $\eta = 8$, which then yields $\delta = 6.66^{1/4} \simeq 1.61$.

With regard to the two parameters of the household's utility function (1), Figure 1 plots the sufficient condition (20) with the utility of liquidity services relative to final wealth $\lambda$ in the horizontal axis and the elasticity of substitution between liquidity services and final wealth $\rho$ in the vertical axis, using the value of $\delta^{\epsilon}$ in (24) and $\epsilon = 4$, and for two values of the policy rate, namely $r = 2.5\%$ and $r = 5\%$.[9] The results show that there is a wide range of parameter values (those above the curves) for which the borrowing constraint (7) will be binding. Moreover, since (20) is only a sufficient condition, the constraint will also be binding for parameter values below the curves. Finally, note that the lower the policy rate the wider the set of parameter values for which the borrowing constraint will be binding.

With regard to the number of banks, I focus the discussion on two particular values of $n$, namely $n = 2$ and $n = 5$, which correspond to the values of the mean Herfindahl index (HHI) corresponding to high HHI (0.49) and low HHI (0.20) counties in Panel A of Table 1 in DSS.[10]

[9] These values roughly correspond to the peaks of the effective Federal Funds rate in 2019 (before the Covid loosening) and 2023 (after the Covid tightening).

[10] Recall that the Herfindahl index for a market with $n$ identical banks is HHI $= 1/n$.

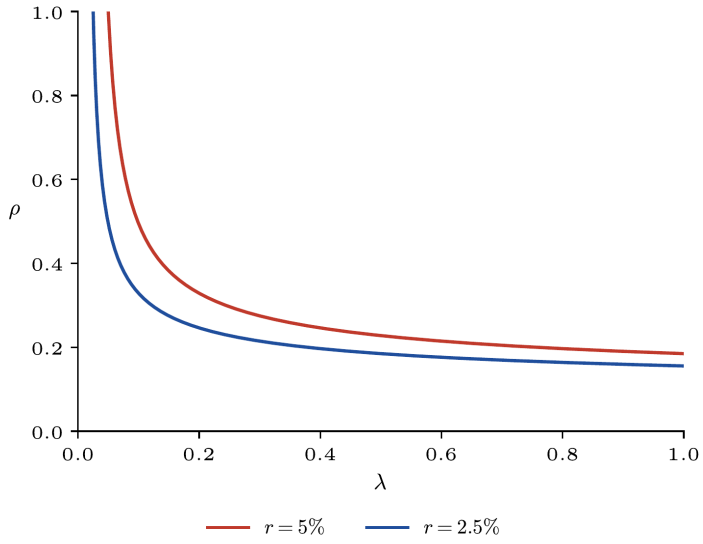



**Figure 1. Sufficient condition for a binding borrowing constraint**

This figure plots the sufficient condition (20) for a binding borrowing constraint, with parameter $\lambda$ in the horizontal axis and parameter $\rho$ in the vertical axis. In the region above the red (blue) line the constraint is binding for a policy rate of 5% (2.5%).

Figure 2 plots the equilibrium amount of deposits $D^*(r)$ in the oligopoly model with $n = 2$ and $n = 5$ banks for values of the policy rate that range from $r = 0$ to $r = 20\%$, and different combinations of parameters $\lambda$ and $\rho$, which capture, respectively, the utility of liquidity services relative to final wealth and the elasticity of substitution between final wealth and liquidity services. Final wealth $W_0$ is normalized to 1. To cover a wide range of these parameters, I take $\lambda = 0.2$, 0.5, and 0.8, and $\rho = 0.2$, 0.5, and 0.8. The pattern that emerges from this figure is clear. For high values of the elasticity of substitution $\rho$ equilibrium deposits $D^*(r)$ are initially flat, corresponding to the deposit rate being at the zero lower bound, and then increasing in the policy rate $r$.[11] For low values of the elasticity of substitution $\rho$ the flat region tends to disappear and equilibrium deposits $D^*(r)$ are increasing

[11] Note that in all panels $D^*(0) = 0.87$. This is explained by the fact that when the policy rate tends to zero, the borrowing constraint is binding and the equilibrium deposit rate is at the zero lower bound, in which case $D^*/M^* = \delta^\epsilon = 6.66$. This, together with the constraint $D^* + M^* = 1$, determines $D^* = (1 + \delta^{-\epsilon})^{-1} = 0.87$.

in the policy rate $r$.[12] At the same time, increases in the utility of liquidity services relative to final wealth $\lambda$ move to the right the points at which the zero lower bound on deposit rates ceases to be binding. Finally, increases in the number of banks $n$ lead to an upward shift in equilibrium deposits, except in the region where the zero lower bound on deposit rates is binding.

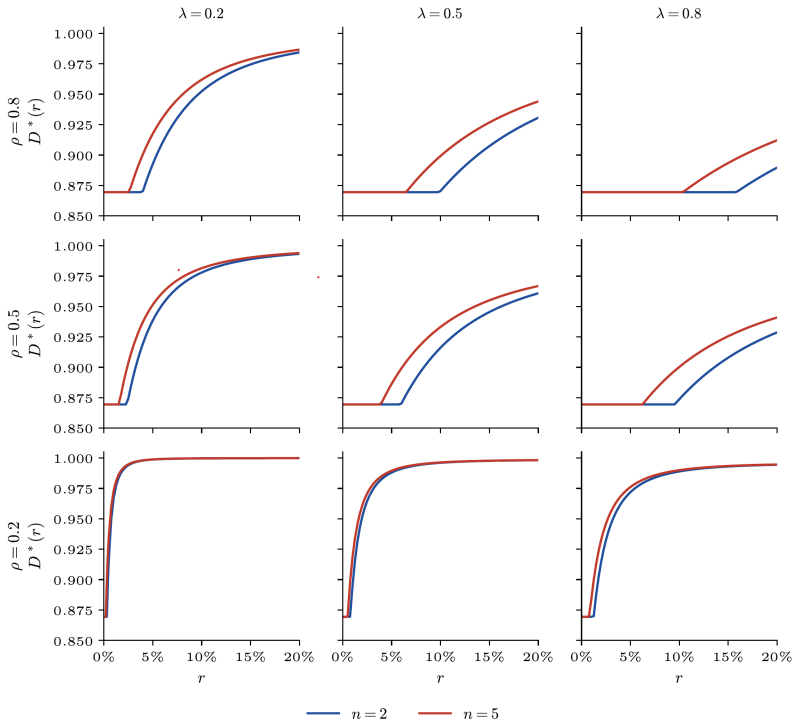



**Figure 2. Equilibrium deposits in the oligopoly model**

This figure shows the equilibrium amount of deposits in the oligopoly model with $n = 2$ and $n = 5$ banks for values of the policy rate $r$ that range from 0% to 20% and different combinations of parameters $\lambda$ (in the horizontal axis) and $\rho$ (in the vertical axis).

Figure 3 plots the equilibrium spreads $s^*(r)$ in the oligopoly model with $n = 2$ and $n = 5$ banks for values of the policy rate that range from $r = 0$ to $r = 20\%$, and the same combinations of parameters $\lambda$ and $\rho$ as in Figure 2. The pattern that emerges from this figure

[12] This is consistent with the observation in footnote 3. DSS's specification of the utility function (1) implies that for low values of $\rho$ the value of $\lambda$ becomes irrelevant.

is consistent with the results in Figure 2. For high values of the elasticity of substitution $\rho$ equilibrium spreads $s^*(r)$ are initially on the $45^o$ line, corresponding to the deposit rate being at the zero lower bound, and then increasing in the policy rate $r$ with a slope smaller than 1, so equilibrium deposit rates $r - s^*(r)$ are positive and increasing in the policy rate $r$. For low values of the elasticity of substitution $\rho$ equilibrium spreads $s^*(r)$ are very small, and banks set equilibrium deposit rates close to the policy rate $r$. At the same time, increases in the utility of liquidity services relative to final wealth $\lambda$ move to the right the points at which the banks start paying positive deposit rates. Finally, increases in the number of banks $n$ reduce equilibrium spreads except in the region where the zero lower bound on deposit rates is binding.

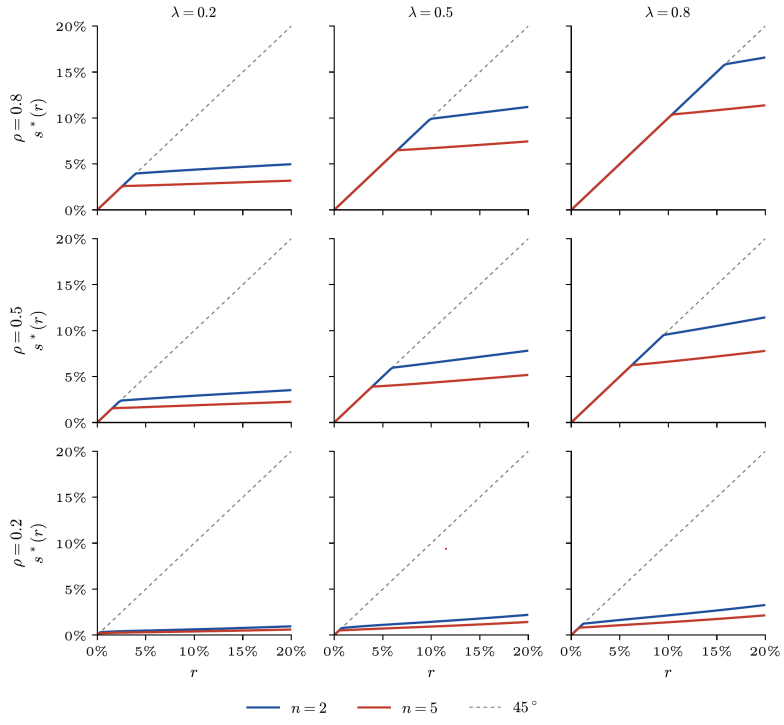



**Figure 3. Equilibrium spreads in the oligopoly model**

This figure shows the equilibrium spreads in the oligopoly model with $n = 2$ and $n = 5$ banks for values of the policy rate $r$ that range from 0% to 20% and different combinations of parameters $\lambda$ (in the horizontal axis) and $\rho$ (in the vertical axis).

The intuition for these results is as follows. On the one hand, increases in parameter $\lambda$ of the utility function (1), which captures the utility of liquidity services relative to final wealth, increase (ceteris paribus) the demand for liquidity. Banks would want to take advantage of this effect by increasing spreads. Thus, as shown in Figures 2 and 3, the region where the zero lower bound on deposit rates is binding becomes larger, and in the region where this bound is not binding equilibrium spreads are higher and equilibrium deposits are lower. On the other hand, one can show that increases in parameter $\rho$ of the utility function (1), which captures the elasticity of substitution between liquidity services and final wealth, reduce (ceteris paribus) the elasticity of the demand for deposits with respect to the deposit rate. Banks would want to take advantage of this effect by increasing spreads. Thus, as in the case of increases in parameter $\lambda$, the region where the zero lower bound on deposit rates is binding becomes larger, and in the region where this bound is not binding equilibrium spreads are higher and equilibrium deposits are lower.

I can now turn to discuss the effect of a change in the number $n$ of banks on the relationship between the policy rate and equilibrium spreads and deposits. Starting with the latter, the panels in Figure 2 show that equilibrium deposits are first flat and then increasing in the policy rate, with the flat region being larger for high market power (low $n$). Thus, increasing the number of banks either has no effect or induces a discrete increase of the slope of the relationship between the policy rate and equilibrium deposits.[13] As for spreads, the panels in Figure 3 show that equilibrium spreads move along the $45^o$ line (corresponding to a binding zero lower bound of deposit rates) and then have a lower slope, with the $45^o$ region being larger for high market power (low $n$). Thus, increasing the number of banks either has no effect or induces a discrete decrease of the slope of the relationship between the policy rate and equilibrium spreads.

The conclusion that follows from these results is that *DSS's theoretical model does not yield predictions that are consistent with a novel "deposits channel" for the transmission*

[13] Note that the effect on the slope changes sign for high values of the policy rate, because deposits have an upper bound given by the household's initial wealth. Note also that these high rates are outside the range observed in the recent past.

*of monetary policy*: in the relevant range, increases in the policy rate do not lead to a reduction in bank deposits. In addition, *the predictions of the model are consistent with the empirical results in DSS's regressions*: spreads are more sensitive and deposits are generally less sensitive to changes in the policy rate when banks' market power is high than when it is low.

# 5 Discussion

This section discusses the role of the two assumptions not considered by DSS, namely that the household cannot borrow at the policy rate to overinvest in cash and deposits and that banks cannot pay negative deposit rates. The discussion will be conducted using the monopoly model ($n = 1$), but the results are similar for the oligopoly model.

Proposition 1 shows that in the absence of the borrowing constraint $M + D \leq W_0$, the household's demand for deposits is given by $\widehat{D}(s; r)$ in (8). Faced with this demand function, the monopoly bank chooses the spread

$$\widetilde{s}(r) = \arg\max_{0 \leq s} [s\widehat{D}(s; r)]$$

for the case where the deposit rate is not restricted to be nonnegative, and

$$\widehat{s}(r) = \arg\max_{0 \leq s \leq r} [s\widehat{D}(s; r)]$$

for the case where there is a zero lower bound on deposit rates. The corresponding equilibrium amounts of deposits are $\widetilde{D}(r) = D(\widetilde{s}(r); r)$ and $\widehat{D}(r) = D(\widehat{s}(r); r)$. Finally, when there is a borrowing constraint but no lower bound on deposit rates, the monopoly bank chooses the spread

$$s^+(r) = \arg\max_{0 \leq s} [sD(s; r)],$$

where $D(s; r)$ is the demand for deposits given by (15). The corresponding equilibrium amount of deposits is $D^+(r) = D(s^+(r); r)$.

Panel A of Figure 4 plots equilibrium deposits and Panel B equilibrium spreads corresponding to these three cases for the parameter values used in the previous section and

$\lambda = \rho = 0.5$. The results show that in the absence of the borrowing constraint the zero lower bound on deposit rates is almost irrelevant: the monopoly bank would set a spread just above (for low rates) or just below (for higher rates) the policy rate even when it could set a spread above the policy rate. This is represented by the green lines in Figure 4. As noted above, in the limit when the policy rate approaches zero, the household shorts an infinite amount of bonds and the equilibrium amount of deposits tends to infinity.

The results also show that when there is a borrowing constraint but no lower bound on deposit rates the monopoly bank sets very negative deposit rates. This is represented by the blue lines in Figure 4. In this case, as the policy rate goes up, equilibrium spreads move closer to the $45^o$ line, so equilibrium deposit rates increase. This leads to a shift from cash to deposits, leading to an increase in the equilibrium amount of deposits.

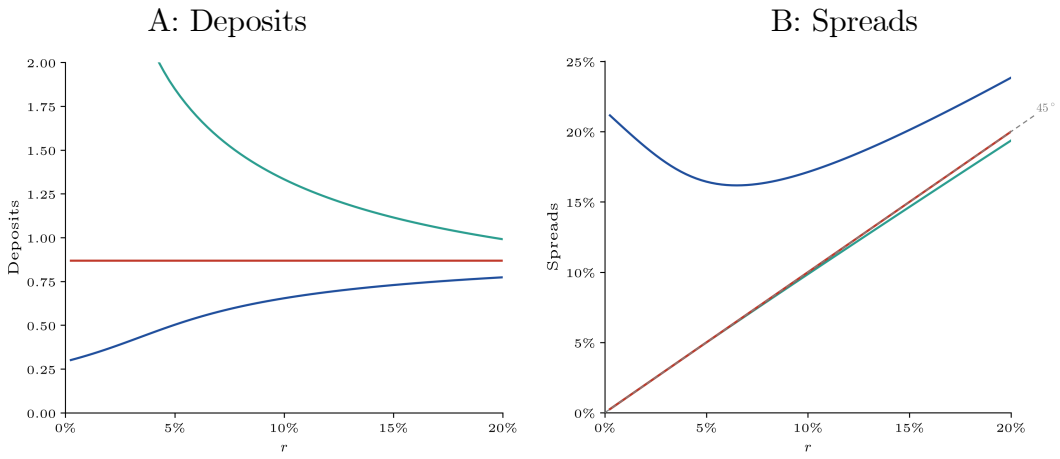



**Figure 4. Equilibrium deposits and spreads without the borrowing constraint and/or the zero lower bound on deposit rates**

This figure shows the equilibrium amount of deposits (panel A) and spreads (panel B) in the monopoly model, for values of the policy rate $r$ that range from 0% to 20%. The green lines correspond to the absence of a borrowing constraint, the blue lines to the absence of a zero lower bound on deposit rates, and the red lines to the benchmark case where both constraints are present.

Finally, the red lines in Figure 4 show equilibrium spreads and deposits for the benchmark case where there is a borrowing constraint and a zero lower bound on deposit rates.

Compared to the oligopoly case shown in the middle panel of Figures 2 and 3 (corresponding to $\lambda = \rho = 0.5$), the monopoly bank sets a spread equal to the policy rate, so the equilibrium amount of deposits does not vary with the policy rate.

Summing up, these results show that in the absence of the borrowing constraint, an increase in the policy rate leads to a reduction in the equilibrium amount of deposits, with or without a zero lower bound on deposit rates, so DSS's results hold true. The problem is that this requires that, for low policy rates, the household borrows large amounts (and in the limit unbounded) at the policy rate, a most implausible result. The results also show that, with a borrowing constraint and no zero lower bound on deposit rates, an increase in the policy rate leads to an increase in equilibrium amount of deposits, a result that contradicts DSS's claim, but which is based on banks paying implausibly large negative deposit rates.

# 6 Conclusion

This paper has reviewed the claim in Drechsler, Savov, and Schnabl (2017) that the transmission of monetary policy should be understood from the liability side of banks' balance sheets. In particular, they argue that there is a "deposits channel" whereby increases in the policy rate widen deposit rate spreads, leading to deposit outflows that reduce banks' lending capacity. I have shown that, adding two reasonable assumptions to their theoretical model of imperfect competition in a local banking market, the relationship between the policy rate and the equilibrium amount of deposits is in general either flat or increasing in the relevant range.

I would like to conclude with a comment on DSS's approach. They look at the effect of monetary policy on bank lending through the lens of deposit taking. In this approach, the characteristics of the loan market take a back seat. It is true that "deposits are a special source of funding for banks, one that it is not perfectly substitutable with wholesale funding." But it is also true that if the focus of the analysis is on bank lending, characteristics such as market power and risk-taking in lending should have a prominent role.

# Appendix

**Proof of Proposition 1** To derive the household's demand for cash and deposits of the monopoly bank for a policy rate $r$ and a deposit spread $s$ let

$$X = Mr + Ds \tag{25}$$

denote the opportunity cost of the liquidity held by the household. The optimal way to allocate $X$ between cash $M$ and deposits $D$ is obtained by solving

$$\max_{M,D} \left( M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}$$

subject to (25). The first-order conditions that characterize the solution to this problem are

$$\left( M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{1}{\epsilon-1}} M^{-\frac{1}{\epsilon}} = \mu r, \tag{26}$$

$$\left( M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{1}{\epsilon-1}} \delta D^{-\frac{1}{\epsilon}} = \mu s, \tag{27}$$

where $\mu$ denotes the Lagrange multiplier associated with the constraint. Dividing (26) by (27) gives

$$\left( \frac{D}{M} \right)^{\frac{1}{\epsilon}} = \frac{\delta r}{s}. \tag{28}$$

Substituting (28) into (26) and solving for the Lagrange multiplier gives (9). Solving for $D$ in (28) and substituting the result into (25) and solving for $M$ in (28) and substituting the result into (25) then gives

$$M = \frac{X}{r^{\epsilon} \mu^{\epsilon-1}} \ and \ D = \frac{\delta^{\epsilon} X}{s^{\epsilon} \mu^{\epsilon-1}}. \tag{29}$$

Substituting (29) into the liquidity services function (2) implies

$$L = \frac{X}{\mu^{\epsilon-1}} \left( r^{1-\epsilon} + \delta^{\epsilon} s^{1-\epsilon} \right)^{\frac{\epsilon}{\epsilon-1}} = \mu X.$$

Hence, the household's maximization problem becomes

$$\max_{X} \left[ (W_0(1+r) - X)^{\frac{\rho-1}{\rho}} + \lambda (\mu X)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}. \tag{30}$$

The first-order condition that characterizes the solution to this problem is

$$(W_0(1+r) - X)^{-\frac{1}{\rho}} = \lambda \mu^{\frac{\rho-1}{\rho}} X^{-\frac{1}{\rho}},$$

which implies

$$X = \frac{W_0(1+r)}{1+\lambda^{-\rho}\mu^{1-\rho}}. \tag{31}$$

Substituting this result into (29) gives (8). □

**Proof of Proposition 2** To show that $\widehat{D}(s;r)$ is decreasing in the deposit spread $s$ note that the numerator of $\widehat{D}(s;r)$ does not depend on $s$ and the denominator can be decomposed in the following manner

$$s^{\epsilon}\mu^{\epsilon-1}(1+\lambda^{-\rho}\mu^{1-\rho}) = s^{\epsilon}\mu^{\epsilon-1} + \lambda^{-\rho}s^{\epsilon}\mu^{\epsilon-\rho},$$

with

$$s^{\epsilon}\mu^{\epsilon-1} = s^{\epsilon}\left(r^{1-\epsilon}+\delta^{\epsilon}s^{1-\epsilon}\right) = s\left[\left(\frac{s}{r}\right)^{\epsilon-1}+\delta^{\epsilon}\right]$$

and

$$s^{\epsilon}\mu^{\epsilon-\rho} = s^{\epsilon}\left(r^{1-\epsilon}+\delta^{\epsilon}s^{1-\epsilon}\right)^{\frac{\epsilon-\rho}{\epsilon-1}} = s^{\rho}\left[\left(\frac{s}{r}\right)^{\epsilon-1}+\delta^{\epsilon}\right]^{\frac{\epsilon-\rho}{\epsilon-1}}$$

Then, $0<\rho<1<\epsilon$ implies that the denominator is increasing in $s$. To show that $\widehat{D}(s;r)$ is increasing in the policy rate $r$ note that the numerator of $\widehat{D}(s;r)$ is increasing in $r$ and, by our previous expressions, the denominator is decreasing in $r$.

To show that $\widehat{M}(s;r)+\widehat{D}(s;r)$ is decreasing in the spread $s$ note that by the proof of Proposition 1 we have

$$L = \mu X = \frac{W_0(1+r)}{\mu^{-1}+\lambda^{-\rho}\mu^{-\rho}}.$$

Since $\mu$ is decreasing in $s$, this implies $\partial L/\partial s<0$. But then, using the liquidity services function (2) we have

$$\frac{\partial L}{\partial s} = L^{\frac{1}{\epsilon}}\left(\widehat{M}^{-\frac{1}{\epsilon}}\frac{\partial \widehat{M}}{\partial s}+\delta\widehat{D}^{-\frac{1}{\epsilon}}\frac{\partial \widehat{D}}{\partial s}\right)<0,$$

which, using (8), $\partial\widehat{D}/\partial s<0$, and the fact that $s\leq r$, implies

$$\frac{\partial \widehat{M}}{\partial s} < -\delta\left(\frac{\widehat{M}}{\widehat{D}}\right)^{\frac{1}{\epsilon}}\frac{\partial \widehat{D}}{\partial s} = -\frac{s}{r}\frac{\partial \widehat{D}}{\partial s} \leq -\frac{\partial \widehat{D}}{\partial s},$$

which gives the result.

Finally, to prove that $\lim_{r\to 0}\left[\widehat{M}(r;r)+\widehat{D}(r;r)\right]=\infty$, note that the previous expressions of the denominator of $\widehat{D}(s;r)$ show that $\lim_{r\to 0}\widehat{D}(r;r)=\infty$. Since $\widehat{M}(r;r)$ is always positive, this completes the proof of the proposition. □

**Proof of Proposition 3** Differentiating the household's objective function (10) with respect to $D$ gives the first-order condition (11). Differentiating this condition implies

$$\overline{D}'(r_1)=-\frac{\frac{\partial}{\partial r_1}\left[(W_0+Dr_1)^{-\frac{1}{\rho}}r_1\right]}{\frac{\partial}{\partial D}\left[(W_0+Dr_1)^{-\frac{1}{\rho}}r_1+\lambda\left(M^{\frac{\epsilon-1}{\epsilon}}+\delta D^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\rho-\epsilon}{\rho(\epsilon-1)}}\left(\delta D^{-\frac{1}{\epsilon}}-M^{-\frac{1}{\epsilon}}\right)\right]}>0$$

if and only if the numerator is positive (since the denominator is negative by the second order-condition). But

$$\frac{\partial}{\partial r_1}\left[(W_0+Dr_1)^{-\frac{1}{\rho}}r_1\right]=(W_0+Dr_1)^{-\frac{1}{\rho}}\left[1-\frac{Dr_1}{\rho(W_0+Dr_1)}\right]>0$$

if and only if

$$r_1<\frac{\rho W_0}{(1-\rho)\overline{D}(r_1)}.$$

Then, $W_0>\overline{D}(r_1)$ implies the result.

**Proof of Proposition 4** By Proposition 3, when the constraint $M+D\leq W_0$ is not exactly binding, the demand for deposits is $\overline{D}(s;r)=\overline{D}(r_1)$, that is only depends on the deposit rate $r_1$ set by the monopoly bank. Then, the first-order condition that characterizes an interior solution to the bank's maximization problem is

$$(r-r_1)\overline{D}'(r_1)-\overline{D}(r_1)=0,$$

which implies

$$\overline{D}'(r_1)=\frac{\overline{D}(r_1)}{r-r_1}>0.$$

Differentiating the first-order condition, and assuming that the second-order condition is satisfied, then gives

$$\frac{dr_1}{dr}=-\frac{\overline{D}'(r_1)}{\frac{\partial}{\partial r_1}\left[(r-r_1)\overline{D}'(r_1)-\overline{D}(r_1)\right]}>0,$$

which implies

$$\frac{dD^*}{dr} = \overline{D}'(r_1)\frac{dr_1}{dr} > 0. \ \square$$

**Proof of Proposition 5** To derive the household's demand for cash and deposits of the $n$ banks for a policy rate $r$ and set of spreads $s_1, ..., s_n$ let

$$X = Mr + \textstyle\sum_{i=1}^{n} D_i s_i. \tag{32}$$

denote the opportunity cost of the liquidity held by the household. Substituting (5) into (2), it follows that the optimal way to allocate $X$ between cash $M$ and deposits $D_1, ..., D_n$ is obtained by solving

$$\max_{M, D_1, ..., D_n} \left[ M^{\frac{\epsilon-1}{\epsilon}} + \delta \left( \frac{1}{n} \textstyle\sum_{i=1}^{n} (nD_i)^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta(\epsilon-1)}{(\eta-1)\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}$$

subject to (32). The first-order conditions that characterize the solution to this problem are

$$\left( M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{1}{\epsilon-1}} M^{-\frac{1}{\epsilon}} = \mu r, \tag{33}$$

$$\left( M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{1}{\epsilon-1}} \delta D^{-\frac{1}{\epsilon}} \left( \frac{nD_i}{D} \right)^{-\frac{1}{\eta}} = \mu s_i, \tag{34}$$

where $\mu$ denotes the Lagrange multiplier associated with the constraint. To solve for $\mu$, first note that by (34) we have

$$D_i = D_1 \left( \frac{s_1}{s_i} \right)^{\eta},$$

which by the definition (5) of $D$ implies

$$D = \left( \frac{1}{n} \textstyle\sum_{i=1}^{n} (nD_i)^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} = nD_1 s_1^{\eta} \left( \frac{1}{n} \textstyle\sum_{i=1}^{n} s_i^{1-\eta} \right)^{\frac{\eta}{\eta-1}}.$$

From here it follows that

$$D_i s_i^{\eta} = D_1 s_1^{\eta} = \frac{D}{n} \left( \frac{1}{n} \textstyle\sum_{i=1}^{n} s_i^{1-\eta} \right)^{-\frac{\eta}{\eta-1}}. \tag{35}$$

Now, dividing (33) by (34) gives

$$\left( \frac{D}{M} \right)^{\frac{1}{\epsilon}} \left( \frac{nD_i}{D} \right)^{\frac{1}{\eta}} = \delta \frac{r}{s_i},$$

which using (35) implies

$$\left(\frac{D}{M}\right)^{\frac{1}{\epsilon}} = \delta r \left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{1}{\eta-1}}. \tag{36}$$

Using this result together with (33) gives

$$\left[1+\delta\left(\frac{D}{M}\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{1}{\epsilon-1}} = \left[1+\delta\left(\delta r\left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{1}{\eta-1}}\right)^{\epsilon-1}\right]^{\frac{1}{\epsilon-1}} = \mu r,$$

which implies (19).

To solve for $D_i$ use (35) and (36) to get

$$D_i s_i = s_i^{1-\eta}\frac{D}{n}\left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{-\frac{\eta}{\eta-1}} = \frac{1}{n}s_i^{1-\eta}M(\delta r)^{\epsilon}\left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{\epsilon-\eta}{\eta-1}}, \tag{37}$$

which implies

$$\sum_{i=1}^{n} D_i s_i = M(\delta r)^{\epsilon}\left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{\epsilon-1}{\eta-1}}.$$

Substituting this result into (32) and using (19) gives

$$X = Mr + \sum_{i=1}^{n} D_i s_i = Mr^{\epsilon}\left[r^{1-\epsilon} + \delta^{\epsilon}\left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{\epsilon-1}{\eta-1}}\right] = Mr^{\epsilon}\mu^{\epsilon-1},$$

which implies

$$M = \frac{X}{r^{\epsilon}\mu^{\epsilon-1}}. \tag{38}$$

Substituting this result into (37) and solving for $D_i$ gives

$$nD_i = s_i^{-\eta}\left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{\epsilon-\eta}{\eta-1}}\frac{\delta^{\epsilon}X}{\mu^{\epsilon-1}}. \tag{39}$$

Hence, (5) implies

$$D = \left(\frac{1}{n}\sum_{i=1}^{n}(nD_i)^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}} = \left(\frac{1}{n}\sum_{i=1}^{n} s_i^{1-\eta}\right)^{\frac{\epsilon}{\eta-1}}\frac{\delta^{\epsilon}X}{\mu^{\epsilon-1}}. \tag{40}$$

Substituting (38) and (40) into (2) gives

$$L = \left(M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}} = \mu X.$$

Substituting this result into the household's utility function (1) yields the same maximization problem (30) as in the case of the monopoly bank, whose solution is given by (31). Finally, substituting this result into (38) and (39) implies (17) and (18), as required. □

**Proof of Proposition 6** Differentiating the household's objective function (21) with respect to $D_i$ gives the first-order conditions

$$(W_0 + \sum_{i=1}^{n} D_i r_i)^{-\frac{1}{\rho}} r_i = \lambda (M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}})^{\frac{\rho-\epsilon}{\rho(\epsilon-1)}} \left( M^{-\frac{1}{\epsilon}} - \delta D^{\frac{\epsilon-\eta}{\epsilon\eta}} (nD_i)^{-\frac{1}{\eta}} \right),$$

for $i = 1, ..., n$, where $M = W_0 - \sum_{i=1}^{n} D_i$. Particularizing these conditions for the case where bank $i$ pays a deposit rate $r_i$ and the other $n-1$ banks pay a deposit rate $r_{-i}$ implies the result. □

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