A Model of Retail Banking and the Deposits Channel of Monetary Policy*

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Abstract

We develop a dynamic, search-theoretic model of bank deposits markets where relationships are bilateral, the demand for liquid assets is microfounded, and consumers are privately informed about their liquidity needs. As the policy rate rises, the deposit spread widens, and aggregate deposits shrink, in accordance with the deposits channel documented in Drechsler et al. (2017). We show that the deposit outflow originates from consumers with low liquidity needs. As banks become more informed about consumers' types (e.g., through big data), their market power increases but transmission weakens. As entry costs are reduced (e.g., through online banking), market power shrinks and transmission weakens.

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1 Introduction

The role of banks in the transmission mechanism of monetary policy is a debated question.[1] A recent study by Drechsler et al. (2017) argues that bank market power in the deposits market is pivotal and provides evidence that monetary policy affects the real economy through the supply of deposits — a so-called *deposits channel*. The evidence, which we review in Section 1.1, includes the following observations. First, the deposit spread, defined as the difference between the federal funds rate and interest rates on deposits, is positive and increases with the policy rate. Second, the growth rate of bank deposits and the change in the policy rate are negatively correlated. Moreover, as the federal funds rate rises, the flow of deposits out of the banking system is larger in concentrated markets. Last, following an increase in the policy rate, banks with higher market power in deposits markets reduce their lending by more relative to other banks.

In order to explain the evidence, Drechsler et al. (2017) propose a static model of monopolistic competition among banks where cash and bank deposits enter a CES utility function.[2] While the model generates some useful intuition on how the deposits channel might operate, it takes liquidity services, the imperfect substitutability of bank deposits, and the resulting market power of banks as primitives. Instead, the purpose of our paper is to provide theoretical foundations for bank market power and the deposits channel of monetary policy from first principles. The main components of our theory include a microfounded demand for liquid assets, a role for banks in the provision of such assets, and an explicit description of the creation of contractual relations in a dynamic, decentralized deposits market. The demand for liquid assets comes from households who lack commitment and are subject to idiosyncratic spending shocks, in the spirit of the New Monetarist literature surveyed in Lagos et al. (2017). Banks issue liabilities that serve as means of payments and that have a lower user cost than cash. Relationships between consumers and banks are bilateral and the terms of the deposit contracts are determined through negotiations

[1] The literature has identified different channels through which monetary policy can affect the real economy, a subset of them involving banks. For an overview of this literature, see, e.g., Ireland (2010).

[2] Drechsler et al. (2021) use a similar model to show it is optimal to use maturity transformation to hedge interest-rate risk. Related contributions on the role of liquid deposits for the transmission mechanism of monetary policy include Wang (2018) and Di Tella and Kurlat (2021).

under private information.

We use our model to study how informational frictions and market structure matter for each component of the deposits channel, i.e., passthrough to deposit rate and spread, effects on individual and aggregate deposits, changes in output. We address the following questions. Is bank market power necessary and/or sufficient for the transmission mechanism to operate? How does monetary policy affect the distribution of deposits? Does the origin of bank market power (e.g., consumer search and switching costs, banks' ability to price discriminate) matter for transmission? Relatedly, how do FinTech advances, such as mobile banking and Big Data, affect the transmission mechanism of monetary policy?

A first contribution of our model is to explain the bank deposit spread as an intermediation premium in over-the-counter banking markets. The determinants of the deposit spread include the policy rate, banks' bargaining power, and market concentration (or dilution) as captured by the number of banks per consumer. As the policy rate increases, the deposit spread widens, provided that banks have some bargaining power. The passthrough is positive because the outside option of the banked consumer, which is to hold her liquid wealth in the form of non-interest-bearing cash while searching for an alternative bank, becomes less valuable as the opportunity cost of cash increases.

When banks have complete information about consumers' liquidity needs, the existence of a deposit spread passthrough is inconsequential for individual deposits: the deposit size is invariant to monetary policy. So, bank market power is not sufficient for the deposits channel to operate. If consumers have heterogeneous liquidity needs and their preferences are private information, then monetary policy does affect the supply of deposits. Indeed, under private information, banks engage in second-degree price discrimination by offering a menu of incentive-compatible deposit contracts. The optimal menu has a two-tier structure. For low-liquidity-needs consumers, participation constraints bind and pricing is linear. For those contracts, the deposit spread rises and deposits shrink as the policy rate increases. For large-liquidity-needs consumers, pricing is nonlinear, participation constraints are slack, and deposit sizes do not respond to the policy rate.

So, a new implication from our theory is that monetary policy has a stronger effect on the lower percentiles of the distribution of deposits. In a calibrated version of our model, bank market power (i.e., bank bargaining power and search frictions) has to be large in order to be consistent with the size of the passthrough and the interest-rate elasticity of aggregate deposits observed in the data.

We generalize the model by allowing for multiple deposit categories with different rates of return and degrees of liquidity. As the policy rate increases, consumers substitute away from the most liquid deposits into higher-return but less liquid ones. This substitution effect and the bank-market-power effect described earlier work in opposite directions. As a result, the relationship between less-liquid bank deposits and the policy rate is nonmonotone, i.e., bank deposits increase at low interest rates and decrease when the policy rate is above a threshold. We endogenize the liquidity of deposits and show it depends on policy, which allow us to explain how financial innovations (i.e., efforts to enhance the liquidity of high-return deposits) can arise from policy changes and affect the strength of the deposits channel.

Last, we emphasize the importance of identifying the origin of banks' market power (e.g., entry costs versus informational rents) to assess its effects on the transmission of monetary policy. We make this point in the context of FinTech advances. We show that vanishing barriers to entry improve consumers' outside options and reduce banks' market power, which promotes the accumulation of deposits by households but weakens the transmission mechanism. Another important dimension of FinTech is Big Data that allows banks to acquire information about consumers' financial needs. More informed banks gain market power by being better at price discrimination, which weakens the strength of the deposits channel. We endogenize information acquisition and show it depends on monetary policy, thereby providing another example of the needs for microfoundations for both liquidity and market power.

1.1 Empirical evidence

We now review the main evidence on the deposits channel of monetary policy and banks' market power provided by Drechsler et al. (2017).[3] We organize this evidence as a list of observations that will guide our modeling choices in the rest of the paper.

Observation #1a: The deposit spread passthrough is positive. There is a positive passthrough from the federal funds rate, to the deposit spread defined as the difference between the policy rate and the interest rate on bank deposits. A 100 bps increase in the Federal funds rate leads to an increase in the deposit spread by 54 bps according to Drechsler et al. (2017).

Observation #1b: The deposit spread passthrough is higher for more liquid deposits. Drechsler et al. (2017) distinguish three categories of deposits ranked by their liquidity: checking accounts are the most liquid; savings accounts; and, time deposits are the least liquid. As illustrated in Figure 1, the passthrough increases from 0.238 for small time deposits, to 0.415 for savings deposit, and 0.875 for checkable deposits.[4]

[INSERT FIGURE 1]

Observation #1c: The deposit spread passthrough is state-dependent. Wang (2018) documents that the deposit rate passthrough (one minus the deposit spread passthrough) is lower when the interest rate is lower. For checking and savings deposits, a 100 bps increase of the policy rate raises the deposit rate passthrough by about 0.3% percentage point at a 8-month time horizon.

Observation #2a: The growth rate of aggregate deposits is strongly negatively correlated with changes in the federal funds rate. Drechsler et al. (2017) find that the correlation between the growth rate of aggregate deposits and the year-over-year change in the

[3] Additional evidence on banks' market power in the US deposits markets is provided by Hannan and Berger (1991), Neumark and Sharpe (1992), Degryse and Ongena (2008). Begenau and Stafford (2022) challenge the evidence of the deposits channel by pointing out that Drechsler et al. (2017) exclude all branches whose deposit rates are determined by a centralized rate setting policy. Once these branches are included, then there is no reliable relation between deposit rate pass-through and market concentration.

[4] These findings are similar to that of Figure 1 in Drechsler et al. (2017). Our data has been formatted to match various vintages of Call reports using the standard procedure in Kashyap and Stein (2000). We thank Russell Wong for providing us with this data. See Appendix D for details of the data source.

federal funds rate is -0.49. These correlations are -0.28 and -0.55 for checkable and saving deposits, respectively. See the top and middle panels of Figure 2. Drechsler et al. (2017) also estimate the semi-elasticity of deposits with respect to deposit spreads and conclude that a 100 bps increase in the federal funds rate generates a 323 bps contraction in deposits.

Observation #2b. The growth rate of less-liquid deposits is positively correlated with the change in the federal funds rate. The correlation between the growth rate of deposits and the change in the federal funds rate is negative for checkable and savings deposits (top and middle panels of Figure 2), but positive, equal to 0.30, for small time deposits (bottom panel).

[INSERT FIGURE 2]

Observation #3a: Deposit rates and market concentration are negatively correlated. Berger and Hannan (1989) are the first to establish a relationship between local market concentration and the interest rates offered by banks for retail deposits. They found that banks in the most concentrated local markets pay deposit rates that are 25 to 100 basis points less than those paid in the least concentrated markets.

Observation #3b: The deposit spread passthrough increases with market power. Drechsler et al. (2017, Section 4) show that the deposit spread passthrough increases with market concentration, measured according to the Herfindahl–Hirschman Index (HHI), by about 12 percent from low to high concentration counties. They also consider an alternative measure of bank market power, namely the lack of financial sophistication of consumers proxied by age, income, and education. Following an increase in the policy rate, banks in counties with an older population, lower median household income, and less college education increase deposit spreads by more than banks in other counties.

Observation #4: The correlation between deposit growth and changes in the federal funds rate is more negative in more concentrated markets. Drechsler et al. (2017, Section 4) show that deposit growth is more sensitive to changes in the federal funds rate in more concentrated counties. Following a 100 bps increase in the Fed funds rate, deposits flow out by

38 bps more in high-concentration counties than low-concentration counties.[5] Other proxies for market power (age, income, and education) have a similar effect as market concentration.

We add an observation that is useful to interpret a new testable implication of our model.

Observation #5: The strength of the deposits channel decreases with household income. Drechsler et al. (2017, Table 5) document a weaker transmission mechanism in counties where median household income is larger: the deposit spread and growth react less to a change in the federal funds rate.

Table 1 recapitulates the empirical observations related to the deposits channel of monetary policy and gives a preview of the predictions of three versions of our model (bargaining under complete information, posting under private information, bargaining under private information).[6] In order to account for all the observations, we will need private information and bargaining powers by agents on both sides of the market.

[INSERT TABLE 1]

1.2 Literature

Within the New Monetarist literature, different assumptions have been made regarding bank competition.[7] Versions with perfectly competitive banks include Williamson (2012), Keister and Sanches (2022), and Andolfatto et al. (2020), among others. New-Monetarist models where banks have market power include Rocheteau et al. (2018) and Bethune et al. (2021).[8] The market structure is similar to our model in that contracts between entrepreneurs and banks are bilateral

[5] Li et al. (2019) elaborate on the findings of Drechsler et al. (2017) and show that market power in the deposits market matters not only for prices and quantities (interest rate and supply of deposits) but for other terms of bank contracts such the maturity of the loans that banks offer.

[6] While we focus on the evidence regarding the deposits market, Drechsler et al. (2017) establishes a link between the contraction in deposits and the contraction in lending. They show that following an increase in the policy rate, banks that collect deposits in more concentrated markets reduce their lending more relative to other banks. Schaffer and Segev (2021) provide a critical reappraisal of these results. We extend our model in Appendix of our working paper to account for the lending part of the transmission mechanism.

[7] Vives (2016) provides a discussion about the trade-offs between competition and stability in banking.

[8] Applications of this model include Silva (2019), Jackson and Madison (2021) and Liang (2021). Similarly, Lagos and Zhang (2022) formalize banks as securities dealers in the market for consumer credit and emphasize the role of sellers' option to settle transactions with money as a mechanism to restrain banks' market power.

and relationships take time to form.[9] These models focus on lending channels (for businesses or consumers) whereas our focus is on the deposits market. Our foundations for bank market power differ in that consumers' outside options include the possibility to keep searching for alternative banks. As a result, our model delivers perfect competition at the limit when the speed of search goes to infinity. Finally, while the literature above assumes that banks have complete knowledge of their consumers' characteristics, we make consumers' liquidity needs private information. Our bargaining game under private information is related to Inderst (2001) but we adopt a different protocol and assume a continuum of consumer types.

Alternative industrial organization approaches to imperfect competition in the deposits market are reviewed in Chapter 3 of Freixas and Rochet (2008) and have been recently applied to the study of central bank digital currencies. Andolfatto et al. (2020) adopts the model of a monopoly bank, as in Klein (1971) and Monti et al. (1972) while Chiu et al. (2022) and Dong et al. (2021) formalize bank market power as the outcome of Cournot competition.[10] These approaches raise the thorny issue of the choice of the appropriate strategic variables to describe competition among banks.[11] Under our approach, competition is in terms of menus of deposit contracts that specify both prices and quantities or, alternatively, the utility that these contracts provide to consumers. Relative to Bertrand competition, perfect competition is only obtained at the limit when search costs vanish. The determination of deposit spreads in our model is analogous to the determination of bid-ask spreads in the model of over-the-counter markets of Duffie et al. (2005) and Lagos and Rocheteau (2009).

Gu et al. (2013) depart from the equilibrium approach and adopt mechanism design to ex-

[9] Alternative formulations of the banking sector with search and bargaining frictions include Wasmer and Weil (2004) and Petrosky-Nadeau and Wasmer (2017).

[10] Chiu et al. (2022) develop in their appendix a version of their model in the spirit of Burdett and Judd (1983) where competition is in terms of the deposit rate.

[11] According to Freixas and Rochet (2008):

> "The (generalized) Monti-Klein model (...) suffers from the same criticisms as the Cournot model from which it is adapted. In particular, as emphasized originally by Bertrand, prices (here rates) may be more appropriate strategic variables for describing firms' (banks') behavior. As is well know, however, price competition a la Bertrand may go too far, since (1) existence of an equilibrium is not guaranteed, and (2) as soon as two firms are present, perfect competition is obtained."

plain the emergence of banks in an economy with limited commitment. Gu et al. (2020) study how banks' limited ability to commit to return consumers' deposits can generate endogenous instability. In contrast to these papers, we assume banks can commit and focus instead on the optimal design of deposit contracts under consumer heterogeneity and private information within an extensive-form bargaining game.

The heterogenous needs for liquid assets among consumers is formalized as in Lagos and Rocheteau (2005). The banks' mechanism design problem is set up according to the methodology in Mussa and Rosen (1978), Maskin and Riley (1984) and Jullien (2000). Faig and Jerez (2005), Ennis (2008), and Bajaj and Mangin (2020) introduced liquidity constraints into a similar mechanism design problem with directed search, undirected search, and consumer search under multilateral matching, respectively. Williamson (1987) also studies asymmetric information in banking contracts but using a costly monitoring approach.

2 Environment

Time, agents, and goods Time is continuous and indexed by $t \in \mathbb{R}_+$.[12] The economy is composed of two types of agents: a unit measure of consumers/producers (thereafter called consumers) and a large measure of bankers. Bankers are infinitely lived while consumers die at rate $\delta > 0$ and are replaced by new consumers upon death. There are two perishable goods, $y \in \mathbb{R}_+$ and $c \in \mathbb{R}$. Good c is taken as the numéraire.

Preferences and technologies Consumers' preferences over good c and y are given by:

$$\mathbb{E}\left[\int_0^T e^{-\rho t} dC(t) + \sum_{n=1}^{+\infty} e^{-\rho t_n} \varepsilon u\left[y(t_n)\right] \mathbb{I}_{\{t_n \leq T\}}\right], \tag{1}$$

where $\rho > 0$ is the rate of time preference and T is the time horizon of the consumer, which is exponentially distributed with mean $1/\delta$. The function $C(t)$ is the cumulative net consumption of the numéraire good. Negative consumption is interpreted as production, i.e., consumers have the technology to produce the numéraire at unit cost. Consumption and production can take

[12] Our environment of a monetary economy in continuous time is closely related to that in Choi and Rocheteau (2021b).

place in flows, $dC(t) = c(t)dt$, or in discrete quantities, $C(t^+) - C(t^-) \neq 0$.

The second term in (1) represents the preferences over good y. At random times, $\{t_n\}_{n=1}^{+\infty}$, the agent has the desire to consume good y, where $\{t_n\}_{n=1}^{+\infty}$ follows a Poisson process with arrival rate, $\sigma > 0$. The utility of consumption is $\varepsilon u(y)$ where $u(y)$ satisfies $u' > 0$, $u'' < 0$, $u'(0) = +\infty$ and where $\varepsilon \in \mathbb{R}_+$ is consumer-specific and is private information. Throughout, we adopt the functional form $u(y) = y^{1-a}/(1-a)$ with $a > 0$. The cumulative distribution of ε across consumers is $\Upsilon(\varepsilon)$ with density $\gamma(\varepsilon)$ and support $[0, \bar{\varepsilon}]$. We assume that $1 - \Upsilon(\varepsilon)$ is log-concave, which implies that $\gamma(\varepsilon)/[1 - \Upsilon(\varepsilon)]$ is increasing with ε. The technology to produce good y is linear, i.e., one unit of numéraire can be turned into one unit of good y. This technology can be operated by consumers. We denote y_ε^* such that $\varepsilon u'(y_\varepsilon^*) = 1$.

Bankers only value the numéraire and are risk neutral. Their preferences are given by

$$\mathbb{E}\left[\int_0^{+\infty} e^{-\rho t} dC(t)\right].$$

Markets and money Both goods are traded in competitive spot markets opened around the clock. Consumers who are hungry for good y cannot produce to finance their consumption. Moreover, consumers lack commitment and are not trusted to repay their debts. These frictions create a need for a means of payment for good y.

There is a quantity M_t of fiat money – a perfectly divisible and durable object that is intrinsically useless – growing at a constant rate $\pi \geq -\rho$. The revenue from money creation finances unproductive government consumption. Throughout our analysis, we identify the policy rate with the opportunity cost of holding a non-interest-bearing asset, such as fiat money or reserves, i.e., $i = \rho + \pi$.[13]

Bank deposits Alternative means of payment are provided by bankers in the form of deposits. Bankers have the technology to invest the funds they receive from consumers at some real interest rate r_b and can commit to return these funds on demand. In the Appendix of our working paper, Choi and Rocheteau (2021a), we endogenize r_b by formalizing the lending market where entre-

[13] It can also be interpreted as the interest rate on a risk-free bond that cannot be used to finance consumption of good y, e.g., because these bonds would take a small amount of time to be sold.

preneurs with investment opportunities search for bank loans, and the interbank market where banks trade funds competitively. In Section 5, we introduce bank deposits that are imperfectly liquid.

Deposits market Consumers form long-term relationships with bankers. A banker can only manage the account of a single consumer.[14] The overall supply of deposits is determined by the free entry of bankers in the deposit market where the flow entry cost is $\kappa > 0$ (in utils or numéraire). In Drechsler et al. (2021), this cost is interpreted as the cost for the bank to operate a deposit franchise. At the start of their lives, consumers are unbanked and search for a long-term relationship with a bank. Each unbanked consumer meets an unmatched banker at Poisson rate $\alpha(\tau)$ where τ is the measure of unmatched bankers per unbanked consumer, $\alpha' > 0$, and $\alpha'' < 0$. A banker meets a potential consumer at rate $\alpha(\tau)/\tau$.

Search frictions provide a tractable way to formalize imperfect competition in the market for deposit contracts. They capture the limited awareness of consumers of the banks in their area and the time to gather information about retail banking products and offers.[15] The frictions can be made arbitrarily small.

We assume that only unmatched consumers can search for a bank. Once such a relationship is formed, at rate α, consumers remain with their bank for the rest of their lives. (One can interpret the δ-shock as a separation for exogenous reasons such as, e.g., a change in location.) In the Appendix of our working paper, we introduce bank-to-bank transitions.

[14] This assumption is similar to the one-firm-one-job assumption in the labor market of Pissarides (2000).

[15] Abrams (2019) argues that bank market power is exacerbated by consumers' limited consideration of banks. Honka et al. (2017) report that the average consumer considers 6.8 banks among the 24 banks that populate the average metropolitan statistical area. According to the authors: "*A consumer searches among the banks he is aware of. Searching for information is costly for the consumer since it takes time and effort to contact financial institutions and is not viewed as pleasant by most consumers.*" Similarly, according to WSJ: "*Why haven't savers moved more of their money? Opening a new bank account is time consuming [...] Some customers aren't aware of how much money they could make by switching, he said, and others just don't care.* "

3 Equilibrium of the deposits market

A steady-state equilibrium is composed of: HJB equations for consumers; a menu of deposit contracts determined as the outcome of a non-cooperative bargaining game; an optimal entry decision by banks; and an invariant distribution of banked and unbanked consumers.

3.1 Hamilton-Jacobi-Bellman equations

We start by writing the HJB equations of consumers in a steady-state monetary equilibrium where the real rate of return of money is constant and equal to $-\pi$.

Unbanked consumers We denote $\mathcal{V}^u(m;\varepsilon)$ the value function of an unbanked consumer with m real balances and preference type ε. From the linearity of preferences with respect to c, the value function is linear in wealth, $\mathcal{V}^u(m;\varepsilon) = m + V^u(\varepsilon)$ (see Choi and Rocheteau, 2021b), where the intercept, $V^u(\varepsilon)$, solves the HJB equation:

$$\rho V^u(\varepsilon) = U(\varepsilon; i) + \alpha(\tau)\left[V^b(\varepsilon) - V^u(\varepsilon)\right] - \delta V^u(\varepsilon), \tag{2}$$

where $i \equiv \rho + \pi$ and

$$U(\varepsilon; i) \equiv \max_{0 \leq y \leq m} \left\{-im + \sigma\left[\varepsilon u(y) - y\right]\right\}. \tag{3}$$

According to (3) the unbanked consumer chooses her real balances, m, in order to maximize the expected surplus from trade, $\sigma\left[\varepsilon u(y) - y\right]$, net of the cost of holding real balances, im. The maximization is subject to the feasibility constraint according to which the payment cannot be larger than her real balances, $y \leq m$, where we have used that the price of good y is one (since it is produced from the numéraire at unit cost). The surplus from production is zero and is omitted from the HJB equations. At Poisson rate, $\alpha(\tau)$, the consumer finds a banker with whom to enter into a demand deposit contract. At Poisson rate, δ, the consumer depletes her wealth and dies, which generates a capital loss equal to V^u.

From (3), $m = y$ for all $i > 0$, i.e., when the cost of holding money is positive, the consumer does not accumulate more real balances than she intends to spend. From the first-order condition of (3), the optimal choice of real balances of an unbanked consumer is such that

$$\varepsilon u'\left[m(\varepsilon)\right] = 1 + \frac{i}{\sigma}, \quad \text{for all } \varepsilon \in [0, \bar{\varepsilon}]\,. \tag{4}$$

It equalizes the consumer's marginal utility to the unit price augmented by the expected cost of holding money, i/σ. From (4), $m(\varepsilon)$ increases with ε. Hence, ε is a measure of the liquidity needs of the consumer.

Banked consumers We now turn to a consumer of type ε under a stationary demand deposit contract. The contract specifies a pair, $[d(\varepsilon), \phi(\varepsilon)]$, where $d(\varepsilon)$ is the amount deposited at the bank expressed in terms of the numéraire and $\phi(\varepsilon)$ is the flow banking fee also expressed in the numéraire. The consumer pays $\phi(\varepsilon)$ to the banker in order to access its investment technology. The value function of the banked consumer, $\mathcal{V}^b$, is defined taking the pair $[d(\varepsilon), \phi(\varepsilon)]$ as given. This value function is linear in total wealth, $\mathcal{V}^b(m;\varepsilon) = m + d(\varepsilon) + V^b(\varepsilon)$, where $V^b(\varepsilon)$ solves:

$$\rho V^b(\varepsilon) = \max_{y \leq m + d(\varepsilon),\, m \geq 0} \left\{ -\phi\left(\varepsilon\right) - im - s_b d(\varepsilon) + \sigma\left[\varepsilon u\left(y\right) - y\right]\right\} - \delta V^b(\varepsilon), \tag{5}$$

where $s_b \equiv \rho - r_b$ is the opportunity cost of investing into banks' assets. The consumer can supplement bank deposits by holding m real balances at the opportunity cost i. As before, since the consumer is not trusted to repay her debt, consumption cannot exceed her holdings of liquid assets, $m + d(\varepsilon)$.

3.2 Demand deposit contracts

We now characterize the menu of deposit contracts, $\{[\phi(\varepsilon), d(\varepsilon)]\}$, as the outcome of a bargaining game between the bank and the consumer under one-sided private information.

The bargaining game The game has two rounds. In the first round, the bank offers a menu of contracts to the consumer. The consumer can either select a contract in the menu or reject the offer altogether. In the second round, if the offer is rejected, then the consumer has the possibility to make a take-it-or-leave-it counteroffer with probability $1 - \theta$. The concept of equilibrium is perfect Bayesian, i.e., strategies are sequentially rational and beliefs are updated according to Bayes' rule whenever possible. In our game, belief updating occurs if the consumer rejects the bank's offer to make a counteroffer, but in this case the bank's belief about the consumer type is irrelevant since ε does not affect the bank's payoff, ϕ, directly. As we will show later in Section 4.1, under complete information, this game generates the same outcome as the generalized Nash solution with banks' bargaining power equal to θ.

Subgame where the consumer makes an offer If the consumer makes an offer in the second round of the game, she sets $\phi(\varepsilon) = 0$ so that the bank is indifferent between accepting the offer or not. The lifetime expected utility of the consumer is $\hat{V}^b(\varepsilon)$, solution to

$$(\rho + \delta)\,\hat{V}^b(\varepsilon) = U(\varepsilon; s_b) \equiv \max_{0 \le y \le d} \left\{-s_b d + \sigma\left[\varepsilon u(y) - y\right]\right\}. \tag{6}$$

Her instantaneous payoff, $U(\varepsilon; s_b)$, is the payoff from investing in banks' assets at the spread s_b.

The screening problem of the bank At the start of the bargaining game, the banker offers a menu of contracts (or a direct revelation mechanism), $\{[\phi(\varepsilon), d(\varepsilon)]\}$, where each contract specifies banking fees and deposit size as a function of ε. The consumer selects the contract in the menu corresponding to her type. We define the flow value of a contract as $\nu(\varepsilon) = (\rho + \delta)V^b(\varepsilon)$, i.e.,

$$\nu(\varepsilon) = \max_{m \ge 0} \left\{-\phi\left(\varepsilon\right) - im - s_b d\left(\varepsilon\right) + \sigma\left\{\varepsilon u\left[d\left(\varepsilon\right) + m\right] - d\left(\varepsilon\right) - m\right\}\right\}, \quad \text{for all } \varepsilon \in [0, \bar{\varepsilon}]. \tag{7}$$

It is the expected surplus of the consumer net of fee paid to the bank and the cost of holding real balances and deposits. We conjecture that $d\left(\varepsilon\right) + m \le y^*$.

The menu of contracts offered by the bank is subject to participation and incentive-compatibility constraints. We start with the consumers' participation constraints. The consumer of type ε accepts the bank's offer, $[\phi(\varepsilon), d(\varepsilon)]$, if

$$V^b(\varepsilon) \ge \theta V^u(\varepsilon) + (1 - \theta)\hat{V}^b(\varepsilon). \tag{8}$$

The value of accepting the offer, on the left side of (8), is larger than the expected value of rejecting it, on the right side of (8). If the bank's offer is rejected, then the consumer is either unbanked, with probability θ, or he has the opportunity to make a take-it-or-leave-it offer to the bank with probability $1 - \theta$.

Lemma 1 ***(Participation constraints.)*** *The participation constraint of a type-ε consumer, (8), holds if and only if*

$$\nu(\varepsilon) \geq \underline{\nu}(\varepsilon) \equiv \theta \left[\frac{(\rho+\delta)\, U(\varepsilon; i) + \alpha \nu^*(\varepsilon)}{\rho + \delta + \alpha} \right] + (1-\theta) U(\varepsilon; s_b), \tag{9}$$

where $\nu^*(\varepsilon)$ is the flow utility of a banked consumer in equilibrium.

The expected value of the consumer of rejecting an offer is represented by the right side of (9). It is the weighted sum of the reservation utility of the consumer, denoted by the large bracketed term, and the utility when the consumer makes a take-it-or-leave-it offer, $U(\varepsilon; s_b)$.

We now turn to the incentive-compatibility constraints,

$$\nu(\varepsilon) = \max_{\varepsilon', m, y \leq m + d(\varepsilon')} \left\{ -\phi\left(\varepsilon'\right) - im - s_b d\left(\varepsilon'\right) + \sigma\left[\varepsilon u\left(y\right) - y\right] \right\} \quad \forall \varepsilon \in [0, \bar{\varepsilon}]. \tag{10}$$

The incentive-compatibility constraint, (10), requires that a type-ε consumer weakly prefers $[\phi(\varepsilon), d(\varepsilon)]$ to any other contract in the menu offered by the banker taking into account that she can supplement bank deposits with real money balances. Applying the Envelope Theorem to (10) and Lemma 2, the incentive-compatibility constraint takes the form of

$$\nu'(\varepsilon) = \sigma u\left[d(\varepsilon) + m(\varepsilon)\right] \quad \text{for all } \varepsilon \in [0, \bar{\varepsilon}]. \tag{11}$$

The problem of the banker consists in maximizing the expected fee, $\Phi \equiv \int \phi(\varepsilon) d\Upsilon(\varepsilon)$, subject to the participation and incentive-compatibility constraints above. We transform the banker's problem into an optimal control problem where the state variable is the consumer's flow utility, $\nu(\varepsilon)$, and the control variable is the deposit size, $d(\varepsilon)$. If we replace $\phi(\varepsilon)$ with its expression coming from (7) in the objective of the bank, the bank's optimal control problem takes the form:

$$\Phi \equiv \max_{\{(\nu(\varepsilon), d(\varepsilon))\}} \int_0^{\bar{\varepsilon}} \overbrace{\left\{ -\nu(\varepsilon) - (s_b + \sigma) d(\varepsilon) + \sigma \varepsilon u\left[d(\varepsilon) + m(\varepsilon)\right] \right\}}^{=\phi(\varepsilon)} d\Upsilon(\varepsilon) \tag{12}$$

$$\text{s.t.} \quad \nu'(\varepsilon) = \sigma u\left[d(\varepsilon) + m(\varepsilon)\right], \quad \forall \varepsilon \in [0, \tilde{\varepsilon}] \tag{13}$$

$$\nu(\varepsilon) \geq \underline{\nu}(\varepsilon), \quad \forall \varepsilon \in [0, \tilde{\varepsilon}] \tag{14}$$

where $m(\varepsilon)$ is the optimal amount of money that banked consumers carry, given the contract $[d(\varepsilon), \phi(\varepsilon)]$. We establish first that consumers hold no money under any optimal deposit contract.

Lemma 2 ***(Optimal money holdings of banked consumers.)*** *Any optimal menu of de-*

posits contracts must serve all consumers and must be such that $m(\varepsilon) = 0$ *for all* ε*, i.e.,*

$$\sigma\varepsilon u'\left[d(\varepsilon)\right] \leq i + \sigma \quad \textit{for all } \varepsilon \in \left[0, \bar{\varepsilon}\right]. \tag{15}$$

The logic of Lemma 2 is as follows. Suppose there are consumers who accumulate cash in addition to their deposits. A profitable deviation for the banker consists in raising the deposit size it offers without paying any additional interest to the consumer. The consumer is indifferent while banks' profits increase.

Proposition 1 ***(Optimal banking contract under private information.)*** *Let* $u(y) = y^{1-a}/(1-a)$*. The solution to the banker's problem, (12)-(14), in a symmetric equilibrium is given by:*

$$d(\varepsilon) = \left[\frac{\varepsilon\sigma}{\bar{s}(i, s_b, \theta, \alpha) + \sigma}\right]^{1/a} \quad \textit{for } \varepsilon < \tilde{\varepsilon} \tag{16}$$

$$d(\varepsilon) = \left\{\varepsilon - \left[\frac{1 - \Upsilon(\varepsilon)}{\gamma(\varepsilon)}\right]\right\}^{1/a} \left(1 + \frac{s_b}{\sigma}\right)^{-1/a} \quad \textit{for } \varepsilon \geq \tilde{\varepsilon} \tag{17}$$

where

$$\bar{s}(i, s_b, \theta, \alpha) \equiv \sigma \left\{ \left[\frac{(1-\theta)(\rho + \delta + \alpha)\left(\frac{\sigma}{s_b + \sigma}\right)^{\frac{(1-a)}{a}} + \theta(\rho + \delta)\left(\frac{\sigma}{i + \sigma}\right)^{\frac{(1-a)}{a}}}{(1-\theta)(\rho + \delta + \alpha) + \theta(\rho + \delta)} \right]^{-\frac{a}{1-a}} - 1 \right\} \tag{18}$$

and $\tilde{\varepsilon} \in (0, \bar{\varepsilon})$ *is the unique solution to*

$$\frac{1 - \Upsilon(\tilde{\varepsilon})}{\gamma(\tilde{\varepsilon})} = \tilde{\varepsilon}\left(\frac{\bar{s} - s_b}{\bar{s} + \sigma}\right). \tag{19}$$

The bank's flow profits are

$$\phi(\varepsilon) = d(\varepsilon)\left(\bar{s} - s_b\right) \quad \textit{for } \varepsilon \in (0, \tilde{\varepsilon}) \tag{20}$$

$$\phi(\varepsilon) = -\underline{\nu}(\tilde{\varepsilon}) - \sigma \int_{\tilde{\varepsilon}}^{\varepsilon} u\left[d(x)\right] dx - (s_b + \sigma) d(\varepsilon) + \sigma\varepsilon u\left[d(\varepsilon)\right] \quad \textit{for } \varepsilon \geq \tilde{\varepsilon}. \tag{21}$$

In the next section, we interpret in details the menu of deposit contracts offered by the bank. For now, we just mention that it is divided into two tiers. Above a threshold, $\tilde{\varepsilon}$, the consumer participation constraint, (14), is slack whereas below $\tilde{\varepsilon}$ it is binding. When it is binding, the pricing of deposits in (20) is linear, where $\bar{s}$ is the largest spread the consumer is willing to accept.[16] According to (18), $\bar{s}$ is between s_b and i and depends on market structure and bargaining powers. From (20), the consumer rebates the difference between $\bar{s}$ and s_b to the bank. Given this linear pricing scheme, the deposits in (16) solve $\varepsilon u'\left[d(\varepsilon)\right] = 1 + \bar{s}/\sigma$.

When the participation constraint is slack, the demand for deposits, (17), resembles the demand for real money balances where the valuation, ε, is replaced with the *virtual valuation*, $\tau(\varepsilon) \equiv \varepsilon - \left[1 - \Upsilon(\varepsilon)\right]/\gamma(\varepsilon)$, and the nominal interest rate, i, is replaced with the bank's spread, s_b. So deposits in the upper tier are distorted due to the incentive-compatibility constraints but are not affected by i. The pricing of deposits in (21) is nonlinear in ε and can be interpreted as follows. The last two terms correspond to the consumer's net utility from accessing the bank's investment technology. Under complete information, if the consumer had no outside option, it is what the bank would charge the consumer. The first term is the outside option of the consumer while the second term is informational rent due to ε being private information to the consumer.

Deposit spread We define the nominal deposit rate associated with the deposit contract, $[d(\varepsilon), \phi(\varepsilon)]$, as

$$\hat{\imath}_d(\varepsilon) = r_b + \pi - \frac{\phi(\varepsilon)}{d(\varepsilon)} = i - s_b - \frac{\phi(\varepsilon)}{d(\varepsilon)}. \tag{22}$$

It is the nominal interest rate on banks' assets, $i_b = r_b + \pi$, reduced by the payment made to the bank per unit deposited, ϕ/d. The deposit spread is the difference between i and $\hat{\imath}_d$, i.e.,

$$\hat{s}_d(\varepsilon) \equiv i - \hat{\imath}_d(\varepsilon) = s_b + \frac{\phi(\varepsilon)}{d(\varepsilon)}. \tag{23}$$

The deposit spread is equal to the bank spread, $s_b \equiv i - i_b$, augmented by an intermediation premium, ϕ/d. From (20), when consumers' participation constraints bind, $\hat{s}_d(\varepsilon) = \bar{s}$.

3.3 Free entry and the share of banked consumers

We close the model with the free-entry condition for bankers. In an active equilibrium, the flow entry cost, κ, is equal to the rate at which a bank meets a consumer, $\alpha(\tau)/\tau$, times the expected discounted profits generated by a deposit contract, $\Phi/(\rho + \delta)$, i.e.,

[16] In the Appendix of our working paper, we restrict the contract space by imposing linear pricing. We show that if the bargaining power θ is sufficiently small, then banks' optimal choice is to offer a spread equal to $\bar{s}$.

$$\kappa = \frac{\alpha(\tau)}{\tau}\frac{\Phi}{\rho+\delta}. \tag{24}$$

From (24) the measure of bankers per consumer in the deposits market, τ, increases with the expected profits generated by the deposit contracts.

At a steady state, the flow of consumers who acquire a demand deposit contract is equal to the flow of banked consumers who exit the market, i.e., $\alpha(\tau)n^u = \delta n^b$. Solving for n^b:

$$n^b = \frac{\alpha(\tau)}{\delta+\alpha(\tau)}. \tag{25}$$

The measure of n^b rises in τ. We now define an equilibrium of the deposits market.

Definition 1 *An equilibrium is a list of: (i) Value functions, $V^u(\varepsilon)$ and $V^b(\varepsilon)$, that solve (2) and (5); (iii) Banks' profits, Φ, solution to (12); (ii) A menu of deposit contracts, $\{[\phi(\varepsilon), d(\varepsilon)]\}$, that solves (16)-(17) and (20)-(21); (iv) Market tightness, τ, solution to (24); (v) Share of banked consumers, n^b, solution to (25).*

4 Anatomy of the deposits channel

The objective of this section is to disentangle the different components of the deposits channel by considering special cases of our model.

4.1 The deposit spread passthrough

We start by analyzing the deposit spread passthrough in a complete-information version of our model with a unit mass of consumers at $\varepsilon = 1$.

Proposition 2 ***(Deposit contract under complete information.)*** *Consider the limit when all consumers have $\varepsilon = 1$. The solution to the bargaining problem when $\varepsilon = 1$ gives*

$$u'(d) = 1 + \frac{s_b}{\sigma}, \tag{26}$$

and splits that surplus according to the players' bargaining power, which gives

$$\phi = \frac{\theta\,(\rho+\delta)}{\rho+\delta+\alpha\,(1-\theta)}\left[U(1;s_b) - U(1;i)\right]. \tag{27}$$

The deposit spread is

$$\hat{s}_d = s_b + \frac{\theta\left(\rho+\delta\right)\left[U(1;s_b)-U(1;i)\right]}{\left[\rho+\delta+\alpha(\tau)\left(1-\theta\right)\right]u'^{-1}\left(1+\frac{s_b}{\sigma}\right)}. \tag{28}$$

The terms of the deposit contract, (d, ϕ), coincide with the generalized Nash solution to the bargaining problem between the bank and the consumer where the bank's bargaining power is θ. The deposit size maximizes the joint surplus, $V^b(1) - V^u(1) + \Pi$, while the fee divides the surplus according to the bank's and consumer's bargaining powers. From (26), d is the deposit size that the consumer would choose if she had direct access to the bank's investment technology. It increases with r_b (or decreases with s_b), but it is independent of α, θ, and i. From (27), ϕ is a fraction of the consumer's gains, $U(1; s_b) - U(1; i)$, that increases with the banker's bargaining power (θ), but decreases with the speed at which the consumer can find another banker (α).

We now reduce an equilibrium to a pair $(\hat{s}_d, \tau)$ representing the two measures of market power in the deposits market, namely, deposit spread and market tightness.[17] The deposit spread is given by (28). Market tightness is obtained by substituting $\Phi = (\hat{s}_d - s_b)d$ into the free-entry condition, (24), i.e.,

$$\kappa = \frac{\alpha(\tau)}{\tau}\frac{(\hat{s}_d - s_b)d}{\rho+\delta}. \tag{29}$$

We represent the two equilibrium conditions, (28) and (29), in the left panel of Figure 3. The bank entry curve, (29), is upward sloping: as the deposit spread increases, bank profits rise, which leads to more entry. The deposit spread curve, (28), is downward sloping: as market tightness increases, consumers' outside options improve, which drives the deposit spread down. An increase in the policy rate shifts the deposit spread curve upward, which leads to both a higher spread and higher market tightness. In the right panel of Figure 3, we represent the relationship between aggregate deposits, $D = n^b d$, and market tightness.

[INSERT FIGURE 3]

Proposition 3 ***(Deposits channel under complete information.)*** *Suppose $i > s_b$ and consumers are homogenous with $\varepsilon = 1$. If $\theta > 0$, then there exists a unique equilibrium with*

[17] The notion of market power in Drechsler et al. (2017) is market concentration as measured by the Herfindahl-Hirschman Index (HHI). In the case of homogeneous banks, HHI is equal to market share, which is simply $d/(n^b d) = 1/n^b$. It is inversely related to τ.

$\tau > 0$. In any active equilibrium, $i_d < \pi + r_b$.

1. ***Monetary policy and deposit spread**. The deposit spread passthrough is given by*

$$\frac{\partial \hat{s}_d}{\partial i} = \theta \frac{(\rho+\delta)\left[1-\eta(\tau)\right]}{(\rho+\delta)\left[1-\eta(\tau)\right]+(1-\theta)\,\alpha(\tau)} \frac{u'^{-1}\left(1+\frac{i}{\sigma}\right)}{u'^{-1}\left(1+\frac{s_b}{\sigma}\right)} > 0. \tag{30}$$

   Moreover, $\partial \hat{s}_d/\partial \theta > 0$ and $\partial \hat{s}_d/\partial \kappa > 0$.

2. ***Deposit spread and market concentration.** Suppose deposit markets differ in bank entry costs. Then there is a positive correlation between deposit spread, $\hat{s}_d$, and market concentration, $1/\tau$. Moreover, if $\alpha(\tau) = \alpha_0 \tau^\eta$ with $\eta \in (0,1)$, then the deposit spread passthrough, $\partial \hat{s}_d/\partial i$, is higher in a more concentrated market.*

3. ***Transmission to deposits**. Individual deposits (d) are independent of i, but aggregate deposits ($n^b d$) increase with i.*

Proposition 3 provides implications of our model that can be compared to the evidence on the deposits channel reviewed in Section 1.1. First, our model generates a positive passthrough from the policy rate to the deposit spread whenever $\theta > 0$. From (30) the size of the passthrough depends on market structure (e.g., matching technology and bargaining powers), and policy. These predictions are consistent with Observation 1 in Table 1. Second, a change in i has no effect on d. Individual deposits are at their efficient level, which only depends on s_b. Aggregate deposits, however, increase with i because banks have incentives to spend more resources to attract unbanked consumers whose outside options worsen. This prediction contradicts Observation 2a. Third, if two markets differ by their entry costs, then the market with the highest entry costs will have a higher concentration of bankers ($1/\tau$) and a larger deposit spread. This prediction is consistent with Observation 3 where a local market is interpreted as a county. In summary, under complete information, our model explains the deposit spread passthrough and its relation to market power, but it fails to explain for the contraction of deposits as i increases.

4.2 Transmission to deposits

We re-introduce consumer heterogeneity and private information but assume banks have all the bargaining power, $\theta = 1$. The model has a simple recursive structure whereby the terms of the deposit contracts can be solved independently from market tightness. From (18), the maximum deposit spread consumers are willing to accept is $\bar{s}(i, s_b, \theta, \alpha) = i$, which is independent of θ and α. From (16) and (17), deposits are given by:

$$u'[d(\varepsilon)] = \frac{i+\sigma}{\varepsilon\sigma} \quad \text{for all } \varepsilon < \tilde{\varepsilon} \tag{31}$$

$$u'[d(\varepsilon)] = \left\{\varepsilon - \left[\frac{1-\Upsilon(\varepsilon)}{\gamma(\varepsilon)}\right]\right\}^{-1}\left(1+\frac{s_b}{\sigma}\right) \quad \text{for all } \varepsilon \geq \tilde{\varepsilon}. \tag{32}$$

Consumers with low spending needs, $\varepsilon \leq \tilde{\varepsilon}$, deposit $d(\varepsilon) = m(\varepsilon)$, the real balances they hold when they are unbanked as defined in (4). Bankers do not pay interest on such deposits, $\hat{\imath}_d(\varepsilon) = 0$. Consumers with high spending needs, $\varepsilon > \tilde{\varepsilon}$, deposit more than the cash they hold when unbanked, $d(\varepsilon) > m(\varepsilon)$, and are offered a positive interest on their deposits, $\hat{\imath}_d(\varepsilon) > 0$. However, they hold less deposits than under complete information except for the highest type, $\varepsilon = \bar{\varepsilon}$.

In the top left panel of Figure 4, the red dashed curve, $d^{CI}(\varepsilon)$, is the complete-information deposit schedule given by $\varepsilon u'[d(\varepsilon)] = 1 + s_b/\sigma$. The blue dashed curve, $m(\varepsilon)$, is the schedule for real balances of unbanked consumers given by $\varepsilon u'[m(\varepsilon)] = 1 + i/\sigma$. The private-information schedule, denoted $d^{PI}(\varepsilon)$ and represented by a plain purple curve, is located between $d^{CI}(\varepsilon)$ and $m(\varepsilon)$. It coincides with m for low ε and it reaches d^{CI} at $\varepsilon = \bar{\varepsilon}$. An increase i shifts m downward (light blue dashed curve), and hence it shifts deposits downward for low ε but it does not affect deposits for large ε (light purple dashed curve).

[INSERT FIGURE 4]

In order to describe the effects of monetary policy on aggregate variables, we define the average real balances of unbanked consumers, $\mathrm{M} \equiv \int_0^{\bar{\varepsilon}} m(\varepsilon) d\Upsilon(\varepsilon)$, and the average deposit per banked consumer, $\mathrm{D} \equiv \int_0^{\bar{\varepsilon}} d(\varepsilon) d\Upsilon(\varepsilon)$. We also define the average spread across deposit contracts, $\widehat{s}_d$, and aggregate production, Y, as:

$$\widehat{s}_d \equiv \int_0^{\bar{\varepsilon}} \hat{s}_d(\varepsilon) \frac{d(\varepsilon)}{\mathrm{D}} d\Upsilon(\varepsilon), \tag{33}$$

$$Y \equiv \sigma\left(n^u \mathrm{M} + n^b \mathrm{D}\right). \tag{34}$$

The spread in (33) is an average of all spreads across consumers weighted by deposit sizes. Aggregate output in (34) is equal to the frequency of consumption opportunities multiplied by the average liquidity of consumers.

Proposition 4 ***(The deposits channel under price-discriminating monopolies.)*** *Assume $\theta = 1$. An increase in i leads to:*

1. *A decrease in individual deposits, $d(\varepsilon)$, for all $\varepsilon < \tilde{\varepsilon}$, and a decrease in the average deposit per banked consumer, D, with*

$$\mathrm{D}'(i) = \int_0^{\tilde{\varepsilon}(i)} \frac{1}{\sigma \varepsilon u''\left[d(\varepsilon)\right]} d\Upsilon(\varepsilon) < 0. \tag{35}$$

2. *An increase in the measure of banked consumers, $\partial n^b / \partial i > 0$.*

3. *A decrease in aggregate deposits, $D = n^b \mathrm{D}$, if δ is small.*

4. *An increase in individual deposit spreads equal to:*

$$\frac{\partial \hat{s}_d(\varepsilon)}{\partial i} = 1 - \left(\frac{d(\varepsilon) - d(\tilde{\varepsilon})}{d(\varepsilon)}\right) \mathbb{I}_{\{\varepsilon > \tilde{\varepsilon}\}} \in (0, 1] \tag{36}$$

   An increase in the average deposit spread, $\partial \widehat{s}_d / \partial i > 0$.

5. *A decrease in aggregate output, Y, if δ is small.*

Our model explains the following observations from Section 1.1. First, there is a positive passthrough from i to the deposit spread, $\hat{s}_d(\varepsilon) = i - \hat{\imath}_d(\varepsilon)$. For low ε, the deposit spread increases one-to-one with i, i.e., deposit rates stay at zero. For high ε, the passthrough is below one.

Second, an increase in i leads to a reduction in consumers' deposits. The bottom left panel of Figure 4 illustrates this result for different values for ε, where $\varepsilon_2 < \varepsilon_1 < \bar{\varepsilon}$. If $i < s_b$, then there is no role for bank deposits and $d(\varepsilon) = 0$ for all ε. As i reaches s_b, all consumers are indifferent between money and deposits, hence $d(\varepsilon) = m(\varepsilon)$. As i increases above s_b, deposits start decreasing except for ε in the neighborhood of $\bar{\varepsilon}$. If ε is not too low, e.g., ε_1 in the bottom panels, above some value $\tilde{\varepsilon}_\infty$, then $d(\varepsilon)$ remains constant once i passes a threshold. Otherwise, if $\varepsilon < \tilde{\varepsilon}_\infty$, e.g., ε_2 in Figure 4, $d(\varepsilon)$ keeps decreasing. In the right panel, we plot $\tilde{\varepsilon}$ as a function of i. It is equal to $\bar{\varepsilon}$ when $i = s_b$, it decreases as i increases, and it approaches a lower bound, $\tilde{\varepsilon}_\infty$, as i goes to $+\infty$.[18]

A testable implication of our model is that the deposit outflow following an increase in the policy rate is concentrated on deposits at the bottom of the distribution. We illustrate this implication with a numerical example in Figure 5.[19] In the left panel, we plot the probability density of $\log[d(\varepsilon)]$ among banked consumers under two different policy rates. The density function jumps down as the banking contract moves from the lower tier to the upper tier (see the online appendix for the details). In the right panel, we illustrate how various percentiles of the distribution change with i.

While there is no data on individual deposits to test these predictions directly, they are consistent with the observation from Drechsler et al. (2017, Table 5) according to which the strength of the deposits channel weakens with household income.[20] Indeed, households with higher ε can be interpreted as higher income households since they work more to finance a larger consumption. Hence, our model predicts that changes in the policy rate have a stronger effect on the deposit spread and deposit sizes of low-income households.

[INSERT FIGURE 5]

Finally, monetary policy affects aggregate output, Y, as follows. As i increases, consumers with small ε carry less money and deposits, and thus their consumption of good y falls. But there are more banked consumers, which tends to increase total payments and production. The first effect dominates when δ is small, i.e., Y falls in i, because most consumers are already banked.

4.3 Banks' market power and the strength of the deposits channel

When $\theta = 1$, the terms of the deposit contracts are independent of α. To allow the growth rate of deposits after a change in i to depend on market concentration, we now consider the case where

[18] The threshold, $\tilde{\varepsilon}_\infty > 0$, solves $[1 - \Upsilon(\tilde{\varepsilon}_\infty)] / \gamma(\tilde{\varepsilon}_\infty) = \tilde{\varepsilon}_\infty$.

[19] We assume ε is exponentially distributed and the parameters are given by Table 2 except $\theta = 1$ and $\sigma = 0.01$. In the left panel we increase i from 0.05 to 0.1.

[20] Drechsler et al. (2017) compare deposit spreads and deposit growth across counties with different income levels. For their finding to be consistent with our model, we need to assume that banks offer the same menu of deposit contracts across counties, which is consistent with uniform pricing, e.g., Begenau and Stafford (2022).

consumers have some bargaining power, $\theta < 1$. We simplify the analysis by assuming $\alpha(\tau) \equiv \alpha$.

Proposition 5 ***(Monetary policy under incomplete information and two-sided bargaining powers.)*** *Suppose $\theta \in (0, 1)$ and $\alpha(\tau) \equiv \alpha$.*

1. ***Deposit spread passthrough and deposits channel.*** *For all ε, $\partial \hat{s}_d(\varepsilon)/\partial i > 0$. For all $\varepsilon < \tilde{\varepsilon}$, $\partial d(\varepsilon)/\partial i < 0$; for all $\varepsilon > \tilde{\varepsilon}$, $\partial d(\varepsilon)/\partial i = 0$. As i increases, $\tilde{\varepsilon}$ decreases.*

2. ***Bank market power and the transmission mechanism.*** *As α increases, $\partial \hat{s}_d(\varepsilon)/\partial i$ decreases (weakly) for all ε. If*

$$a \leq 1 - \theta + \theta \left(\frac{s_b + \sigma}{i + \sigma} \right)^{\frac{1-a}{a}}, \tag{37}$$

then $|\partial d(\varepsilon)/\partial i|$ (weakly) decreases in α for all ε. Otherwise it is (weakly) hump-shaped as α increases from 0 to $+\infty$.

3. ***Deposits channel and aggregate output.*** *As i increases, Y decreases.*

According to Proposition 5, our model with private information and two-sided bargaining powers generates the main observations of the deposits channel reviewed in Section 1.1. The main novelty relative to Proposition 4 is Part 2, according to which as bank market power increases as α falls, the deposit spread passthrough increases and the strength of the transmission to deposits increases if (37) holds. These findings are consistent with Observation 3 and 4 in Table 1.

We now calibrate our model in order to quantify the market power of banks that is consistent with the observed strength of the deposits channel. The distribution of consumer types is given by an exponential distribution with mean 1. The matching technology in the deposits markets is $\alpha(\tau) = \bar{\alpha}$. We set $s_b = 0$. The key parameters to be calibrated are $(\theta, \bar{\alpha}, \sigma, a)$. We choose θ to match the size of the deposit spread passthrough, $\partial \hat{s}_d/\partial i$, and use the measure of unbanked households to calibrate $\bar{\alpha}$. The pair, (σ, a), targets the change of aggregate deposits with respect to i. We normalize the data and the model such that the aggregate deposits $\text{D} = 1$ at $i = 0.05$. The details of the calibration are in an online appendix. We report the calibrated parameters in Table 2. Our calibration results suggest that banks must have substantial bargaining power, $\theta = 0.92$, to generate the transmission mechanism observed in the data.

[INSERT TABLE 2]

We illustrate the empirical observations from Section 1.1 through the lens of our model in Figure 6. In the top row, we plot the average deposit rate, $\hat{\imath}_d \equiv i - \int_0^{\bar{\varepsilon}} \phi(\varepsilon) d\Upsilon(\varepsilon)/\text{D}$, and average deposit spread, $\hat{s}_d \equiv s_b + \int_0^{\bar{\varepsilon}} \phi(\varepsilon) d\Upsilon(\varepsilon)/\text{D}$. Both $\hat{\imath}_d$ and $\hat{s}_d$ rise in i, which reflects the incomplete passthrough from the policy to the deposit rate. As $\bar{\alpha}$ increases, banks' market power falls, and the curve representing the deposit rate shifts upward while the deposit spread shifts downward.

[INSERT FIGURE 6]

In the second row, we plot average bank deposits, D, in the left panel and the deposit levels across consumer types, $d(\varepsilon)$, in the right panel. The relationship between D and i is negative but it flattens out as $\bar{\alpha}$ rises. The effect on aggregate deposits can be sizable. For instance, suppose $i = 10\%$ and the deposits market becomes frictionless, $\bar{\alpha} \to +\infty$. The average deposits per consumer increase by about 50%.

In the bottom row, we plot the deposit spread, $\hat{s}_d(\varepsilon)$, across consumer types in the left panel and the deposit spread passthrough, $\partial \hat{s}_d / \partial i$, as functions of the policy rate for different values of $\bar{\alpha}$ in the right panel. A higher $\bar{\alpha}$ reduces the deposit spread for all consumers. The size of the deposit spread passthrough falls in i and $\bar{\alpha}$, which illustrates its state dependence.

5 Multiple bank deposit types

So far we assumed that banks offer a single category of bank deposits that can be withdrawn instantly and at no cost, i.e., they are as liquid as cash. We now assume that banks offer two types of deposits. Liquid (type-1) deposits, denoted d^1, are invested in non-interest-bearing assets like cash or reserves and can be liquidated on demand. Hence, $s_b^1 = i$. Less-liquid (type-2) deposits, denoted d^2, are invested at rate r_b^2, with $0 < s_b^2 \equiv \rho - r_b^2 < i$, and can be liquidated when demanded with probability $\chi_2 < 1$. For now χ_2 is exogenous but we provide microfoundations later. An equivalent interpretation is that banks only offer imperfectly liquid deposits (d^2) while consumers can hold both cash (d^1) and deposits (d^2).

The flow utility of the banked consumer is now

$$\nu(\varepsilon) = -\phi(\varepsilon) - id^1(\varepsilon) - s_b^2 d^2(\varepsilon) + \sigma(1-\chi_2)\left\{\varepsilon u\left[d^1(\varepsilon)\right] - d^1(\varepsilon)\right\}$$
$$+\sigma\chi_2\left\{\varepsilon u[d^1(\varepsilon)+d^2(\varepsilon)] - d^1(\varepsilon) - d^2(\varepsilon)\right\}. \quad (38)$$

Since i and s_b^2 are strictly positive, the consumer has no incentive to carry excess liquidity, i.e., she will use up her cash and deposits whenever possible. The first term on the right side of (38) is the fee paid to the bank. The second and third terms are the costs of holding type-1 and type-2 deposits, respectively, where the cost is the interest-rate spread relative to an illiquid asset. The last two terms are the consumer's surpluses in the two types of matches. In type-1 matches, consumption is financed with type-1 deposits only, $y^1 = d^1$, whereas in type-2 matches, consumption is financed with both types of deposits, $y^2 = d^1 + d^2$.

5.1 The non-monotone deposits channel

We analyze the case where banks have all the bargaining power, $\theta = 1$. We show in the Appendix of our working paper that the results are robust when $\theta < 1$.

Proposition 6 ***(Imperfectly liquid bank deposits.)*** *Assume θ=1. Suppose there are two types of deposits. Type-1 deposits are perfectly liquid and have the same rate of return as fiat money, $s_b^1 = i$. Type-2 deposits have a higher rate of return, $s_b^2 < i$, but are imperfectly liquid, $\chi_2 < 1$. As i rises from $i = \underline{i} \equiv s_b^2/\chi_2$ to $i = +\infty$, the two types of deposits, $d^1(\varepsilon; i)$ and $d^2(\varepsilon; i)$, are affected as follows: $d^1(\varepsilon; \underline{i}) > d^1(\varepsilon; +\infty) = 0$ $\forall \varepsilon \in [0, \bar{\varepsilon}]$ and $d^2(\varepsilon; \underline{i}) = 0 < d^2(\varepsilon; +\infty) \forall \varepsilon$ where $\tau(\varepsilon)$>0.*

If i is small, i.e., $i < s_b^2/\chi_2$, then the cost of holding money is lower than the liquidity-adjusted cost of holding type-2 deposits. Hence, $d^1(\varepsilon) > 0$ and $d^2(\varepsilon) = 0$. If i is large, $i \to +\infty$, the cost of holding type-1 deposits becomes prohibitive, and hence $d^1(\varepsilon) = 0$ and $d^2(\varepsilon) > 0$ for all types ε with a positive virtual valuation, i.e., $\tau(\varepsilon) > 0$. This result illustrates a *substitution effect* according to which consumers substitute away from type-1 deposits into higher-return deposits as i increases. However, the relationship between d^2 and i does not need to be monotone because there is an opposite *market-power effect* from an increase in i, according to which as the outside options of consumers worsen, banks have incentives to reduce the supply of type-2 deposits.

In Figure 7, we provide a numerical example to illustrate this non-monotonicity. We define average deposits as $\text{D}^2 \equiv \int_0^{\bar{\varepsilon}} d^2(\varepsilon) d\Upsilon(\varepsilon)$ and the average spread on type-2 deposits as

$$\hat{s}_d^2 \equiv \int_0^{\bar{\varepsilon}} \left[s_b^2 + \frac{\phi(\varepsilon)}{d^2(\varepsilon)} \right] \frac{d^2(\varepsilon)}{\text{D}^2} d\Upsilon(\varepsilon).$$

In the right panel that plots D^2, the substitution effect dominates at low interest rates, i.e., average deposits increase with i. For i above a threshold, and provided that χ_2 is not too small, the market-power effect takes over and D^2 decreases with i. Hence, the relationship between partially liquid deposits and the policy rate is nonmonotone. This result is consistent with Observation 2b according to which the growth rate of less-liquid deposits is positively correlated with the change in the policy rate. Finally, the left panel of Figure 7 that plots $\hat{s}_d^2$ shows that the deposit spread passthrough is positive irrespective of whether D^2 rises or falls in i.

[INSERT FIGURE 7]

5.2 Endogenous deposit liquidity

We now illustrate the importance of the Lucas Critique or, equivalently, the Wallace (1998) dictum, when considering the effect of monetary policy on the supply of deposits. We endogenize χ_2 and show it varies with i, thereby affecting the strength, or even the sign, of the deposits channel.

Our approach is in spirit of Lester et al. (2012) where agents can exert effort to raise the acceptability of assets. Banks incur a cost, $\psi(\chi_2)$, e.g., by actively managing the asset portfolio backing deposits, in order to guarantee a degree of liquidity equal to χ_2, where $\psi(0) = \psi'(0) = 0$, $\psi' > 0$, $\psi'' > 0$. We assume $\psi(\chi_2)$ is incurred by the bank when it meets a consumer and designs the menu of deposit contracts. The problem of the bank is:

$$\max_{\chi_2 \in [0,1]} \{-\psi(\chi_2) + \Phi(\chi_2; i)\} \tag{39}$$

where $\Phi(\chi_2; i)$ is the value of the mechanism design problem of the bank, which depends on χ_2.

Proposition 7 ***(Endogenous acceptability of deposits.)*** *The liquidity of type-2 deposits rises from $\chi_2 = 0$ when $i = s_b^2$ to $\chi_2 > 0$ solution to*

$$\psi'(\chi_2) = \sigma \int_{\tilde{\varepsilon}}^{\bar{\varepsilon}} \left[\varepsilon - \frac{1 - \Upsilon(\varepsilon)}{\gamma(\varepsilon)} \right] u\left[d(\varepsilon)\right] - d(\varepsilon) d\Upsilon(\varepsilon) \tag{40}$$

as $i \rightarrow +\infty$.

Proposition 7 shows that the liquidity of type-2 deposits responds to monetary policy. If i is small, then type-2 deposits are not useful and hence banks invest no resources to make them liquid. At the opposite, if i is very large, type-2 deposits become useful and banks design them to be liquid, $\chi_2 > 0$. So, as i increases, consumers substitute away from cash into higher-return deposits and banks invest additional resources to make these deposits more liquid.

[INSERT FIGURE 8]

In the numerical example of Figure 8, the orange lines represent the outcomes (liquidity, spread, deposits) when χ_2 is endogenous.[21] In the left panel, χ_2 rises in i initially and then falls. The non-monotonicity is due to the substitution and market-power effects working in opposite directions. When the substitution effect is strong, for low i, it is optimal to increase χ_2. When the market-power effect outweighs the substitution effect, for i sufficiently large, it becomes optimal to reduce χ_2. In the right panel, type-2 deposits tend to comove with χ_2 as i increases. In the middle panel, the deposit spread is convex in i when the substitution effect dominates and is concave when the market-power effect takes over.

In order to illustrate the importance of endogenizing χ_2, we represent with blue lines the outcomes when χ_2 is constant and equal to the average value obtained in the model with endogenous liquidity. The deposit spread in the middle panel is substantially more non-linear when χ_2 is endogenous. With a constant χ_2, one over-estimates the deposit-spread passthrough at low interest rates and under-estimates it for intermediate interest rates. Similarly, in the right panel, the model with constant χ_2 over-estimates the strength of the deposits channel at low interest rates but under-estimates it for intermediate values for i.

[21] The parameter values are the same as that in Figure 7 and $\psi(\chi_2) = \Psi(\chi_2)^2/2$ where $\Psi = 20000$.

6 Origins of bank market power and the deposits channel

We show in this section that the origins of bank market power, e.g., entry costs or informational rents, can have vastly different implications for how bank market power affects the strength of the deposits channel.

6.1 Entry costs as a source of market power

Barriers to entry, as captured by κ, constitute one source of market power. One aspect of the FinTech revolution is the lowering of entry costs, e.g., online banks can operate without branches and offices in physical locations.[22] In the following proposition, we describe outcomes at the limit when barriers to entry vanish, $\kappa \to 0$.

Proposition 8 ***(Limit as entry costs vanish.)*** *As* $\kappa \to 0$*,* $\tau \to +\infty$*,* $\phi(\varepsilon) \to 0$*,* $\hat{s}_d(\varepsilon) \to s_b$*,* $d(\varepsilon) \to \left[\varepsilon\sigma / (s_b + \sigma)\right]^{1/a}$ *for all* $\varepsilon \leq \bar{\varepsilon}$*.*

At the limit where $\kappa \to 0$, bank concentration in the deposits market goes to zero, $1/\tau \to 0$, leading to a Bertrand competition outcome where consumers can access competing banks almost instantly, $\alpha \to +\infty$, thereby driving banks' profits to zero. The deposit spread converges to s_b and becomes invariant to monetary policy, i.e., the passthrough from i to the deposit rate is one. Similarly, deposit sizes correspond to the ones that consumers would choose if they had direct access to banks' investment technology. As a result, $d(\varepsilon)$ is independent of i, i.e., the deposits channel vanishes. In summary, the loss of market power by banks due to diminishing entry barriers weakens the transmission of monetary policy to deposits.

6.2 Information acquisition as a source of market power

Another important aspect of the Fintech revolution is the ability of financial institutions to collect data about consumers to better assess their liquidity and financial needs. To the extent that information generates more precise price discrimination in the deposit market, it can affect the strength of the channel through which monetary policy affects deposits.

[22] For a review of the FinTech revolution in the banking industry, see OECD (2020).

6.2.1 Exogenous information and the strength of the deposits channel

We formalize this idea by parameterizing the information structure as follows. Suppose there are two categories of meetings between banks and consumers: informed and uninformed meetings. In the former meetings, ε is common-knowledge so that consumers are offered deposit contracts with terms given by Proposition 2 while in the latter consumers who are privately-informed about ε are offered contracts with terms satisfying Proposition 1. Informed meetings occur with probability ω. Average deposits per banked consumer are now $\mathrm{D} = \omega \mathrm{D}^I + (1-\omega)\mathrm{D}^U$ where D^I is the average deposits in informed meetings and D^U is the average deposits in uninformed meetings. As ω increases, a larger share of consumers are offered the complete-information contracts and, since $\mathrm{D}^I > \mathrm{D}^U$, average deposits increase. But since $\left|\partial \mathrm{D}^I / \partial i\right| = 0 < \left|\partial \mathrm{D}^U / \partial i\right|$, average deposits become less sensitive to monetary policy, i.e., the transmission weakens.

In Figure 9, we compare the deposits channel under complete ($\omega = 1$), private ($\omega = 0$), and mixed ($\omega = 0.5$) information.[23] The deposit spread decreases with ω while average deposits, D, increase with ω. The bank profits rise in ω as shown in the right panel, which is consistent with banks having more market power. As i rises, the spread increases regardless of the information structure, but the passthrough is larger when ω is smaller. The transmission of i to deposits in the right panel decreases as ω increases. These findings suggest that as banks become more informed about consumers' preferences, their profits increase but the deposits channel becomes weaker and monetary policy is less effective.

[INSERT FIGURE 9]

6.2.2 Endogenous information and the strength of the deposits channel

By the same Lucas critique we invoked earlier, we now argue that the information structure should be made endogenous as the value of information depends on monetary policy. Suppose that, at the time a match is formed, the bank makes an investment in information that determines the probability ω with which it will be able to learn its consumer type.[24] The cost function

[23] Other parameter values are the same as that in Table 2.

[24] We develop the idea of rent seeking through information acquisition in dynamic, decentralized markets in Choi and Rocheteau (2022).

associated with this investment is $H(\omega)$, where H is increasing and convex. We think of this cost, for instance, as the payment to data brokers to obtain information about consumers. The problem of the bank is then

$$\max_{\omega\in[0,1]} \left\{-H(\omega) + \omega\Phi^I + (1-\omega)\Phi^U\right\}, \tag{41}$$

where Φ^I are expected profits when the bank is informed about ε while Φ^U are expected profits when the bank is uninformed. The optimal information, assuming interiority, is

$$\omega = H^{-1\prime}\left(\Phi^I - \Phi^U\right), \tag{42}$$

where $\Phi^I - \Phi^U$ is the value of information to banks. If $H(\omega) = h\omega$, then $\omega = 1$ if $h < \Phi^I - \Phi^U$, $\omega = 0$ if $h > \Phi^I - \Phi^U$ and $\omega \in [0,1]$ otherwise. In the next proposition, we show that the value of information in equilibrium, and hence ω, depends on the policy rate i.

Proposition 9 ***(Monetary policy and endogenous information acquisition.)*** *Assume $\theta = 1$ and $H(\omega) = h\omega$ where $h \in \mathbb{R}_+$.*

1. ***Low interest rates.*** *There exists $\underline{i} > s_b$ such that $\omega = 0$ and $\partial \mathrm{D}/\partial i < 0$ for all $i \leq \underline{i}$.*

2. ***Large interest rates.*** *There exists $\bar{h} > 0$ and $\bar{\imath} > s_b$ such that if $h < \bar{h}$ and $i > \bar{\imath}$, then $\omega = 1$ and $\partial \mathrm{D}/\partial i = 0$.*

When i is low, the gains from trade generated by deposit contracts are low so that incentives to personalize the pricing of these contracts is also low. Banks choose to remain uninformed and the deposits channel is operative. At the opposite, when i is large, the differential between Φ^I and Φ^U is large so that banks choose to be informed, and the deposits channel becomes ineffective. In summary, an increase in i raises the informational rents that banks capture in the deposits market, which gives banks incentives to seek rents by acquiring information. These rent-seeking efforts ultimately shut down the deposits channel.

[INSERT FIGURE 10]

We illustrate this point with a numerical example in Figure 10 for a quadratic cost of information (so that the choice of ω varies continuously with i).[25] The orange lines represent outcomes

[25] We assume the cost of information is $14700 \times \omega^2/2$. The other parameter values are given in Table 2.

when information is endogenous while the blue dotted lines represent outcomes when ω is fixed at 0.5. The marginal cost of information is chosen such that the average ω is 0.5 as i varies from 0 to 0.15. In the left panel, ω rises with i, as suggested by Proposition 9. In the middle panel, the deposit spread is approximately the same under endogenous or exogenous information. The novel implication is shown in the right panel where average deposits are now a non-monotone function of i. As i rises, banks gain market power through information acquisition and no longer need to distort deposit to price discriminate across consumers. It shows that the deposits channel is critically dependent on the information structure, which itself depends on monetary policy.

7 Conclusion

We constructed a model of retail banking in which banks have market power in deposits markets. We showed that when consumers are heterogenous and have private information about their liquidity needs, a deposits channel emerges according to which an increase in the policy rate widens the deposit spread, and generates a contraction of aggregate deposits. This channel is not uniform across consumers and operates through those at the bottom of the distribution of deposit holdings. Moreover, by allowing for both private information and two-sided bargaining powers, we showed that the spread passthrough and the strength of the deposits channel are higher in more concentrated markets, in according with the evidence in Drechsler et al. (2017).

We used our model to study FinTech innovations in the banking industry that can reduce (e.g., online banking) or exacerbate (e.g., better information about consumers) bank market power. Innovations that reduce bank market power by improving consumers' outside options weaken the transmission mechanism of monetary policy. However, changes that reduce bank market power by limiting their information about consumers, thereby constraining banks' ability to price discriminate, strengthen the transmission mechanism. These results showcase the need to go deeper into our understanding of market power in banking.

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8 Figures and Tables

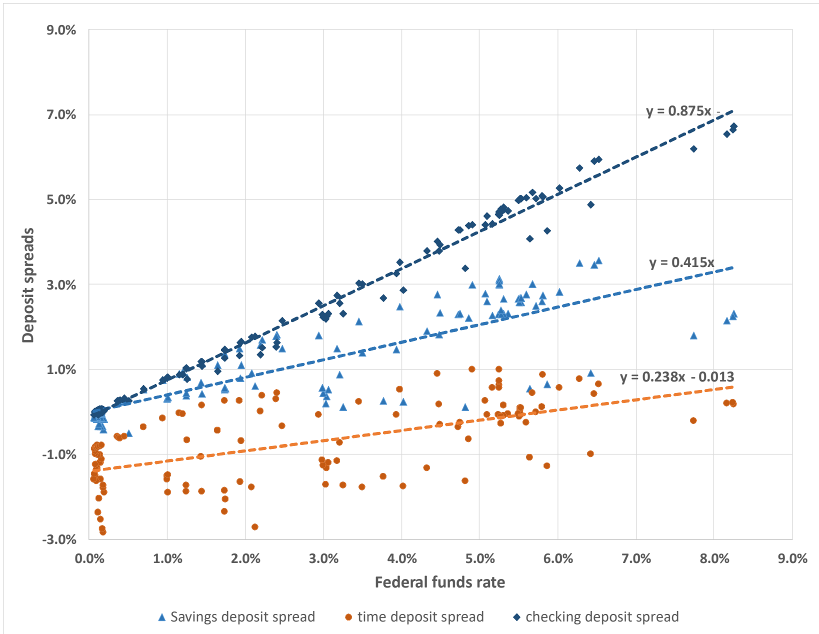

Figure 1: Passthrough from federal funds rate to deposit spreads.

Observations	**Models' predictions**		
	Complete information	*Private Information*	
		Posting	Bargaining
1a. deposit spread passthrough	✓	✓	✓
1b. passthrough across deposits	✓	✓	✓
1c. state-dependent passthrough	✓	✓	✓
2a. aggregate deposits and policy rate	$\times$	✓	✓
2b. disaggregated deposits and policy rate	✓	✓	✓
3a. deposit rate and market power	✓	$\times$	✓
3b. passthrough and market power	✓	$\times$	✓
4. deposits and market power	$\times$	$\times$	✓

Notes: ✓ means the model's prediction matches with data. $\times$ means the opposite.

Table 1: Summary of data and model predictions.

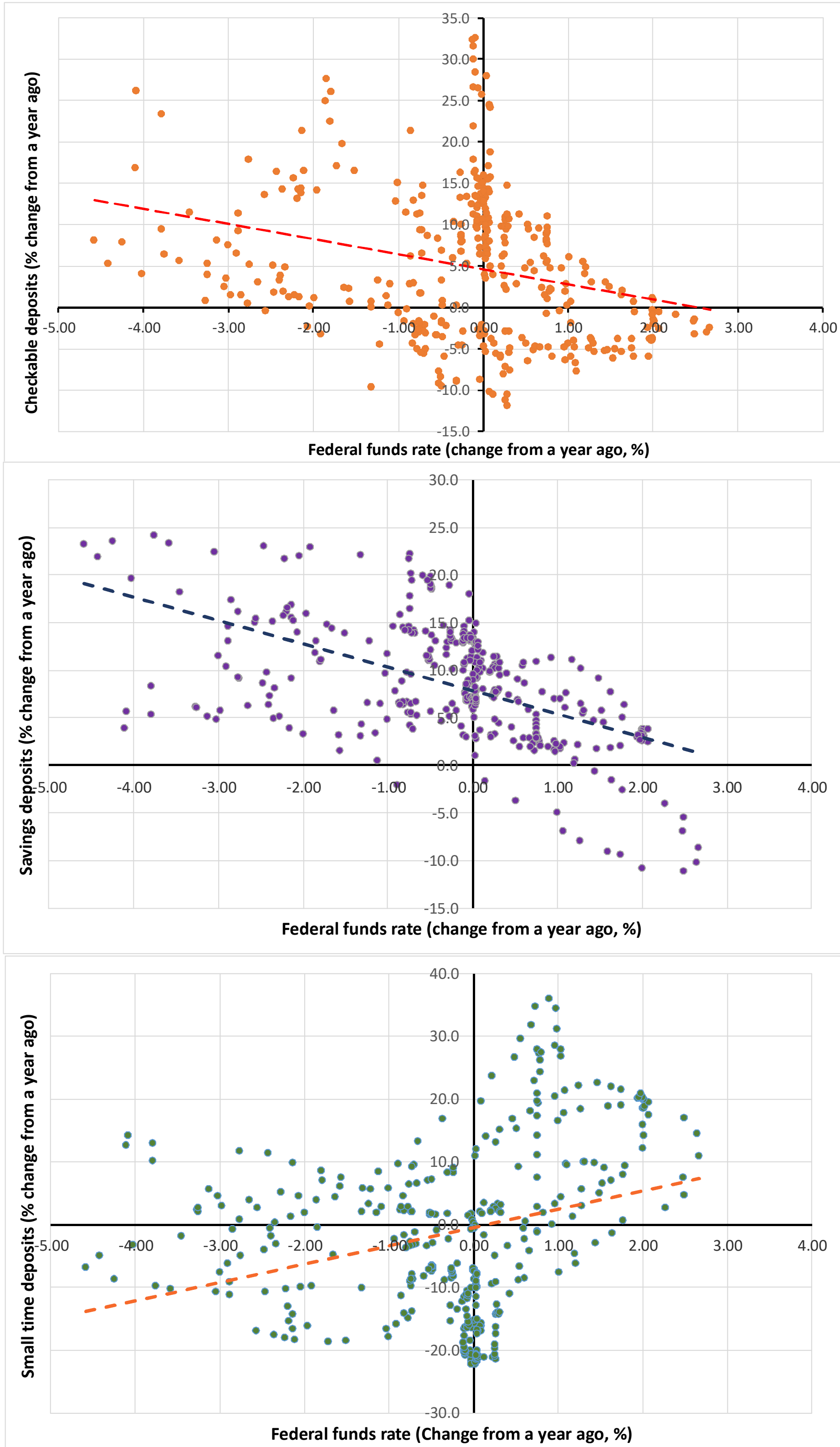

Figure 2: Relation between deposits and federal funds rate. Top: checkable deposits; Middle: savings deposits; Bottom: time deposits. The data on deposits is at monthly frequency from 1990 to 2019, is seasonally adjusted, and is expressed in percentage change from a year ago.

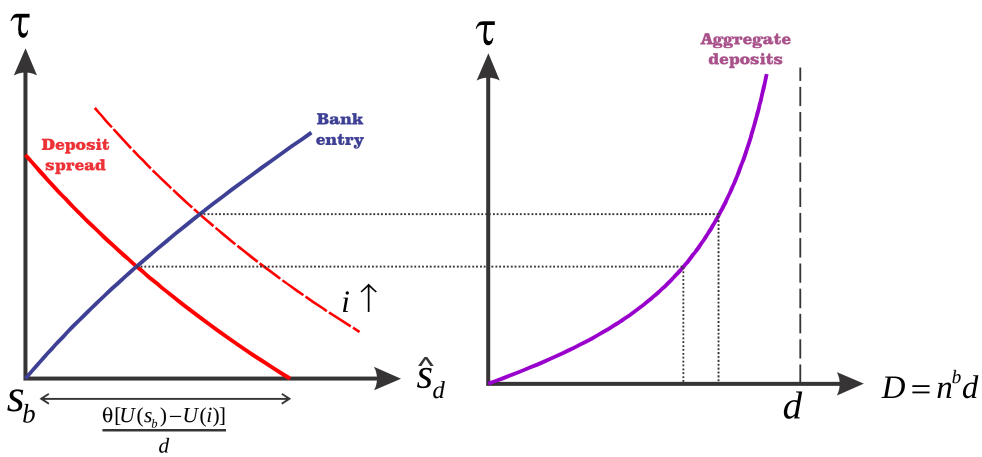

Figure 3: Equilibrium with entry: joint determination of deposit spread and market concentration.

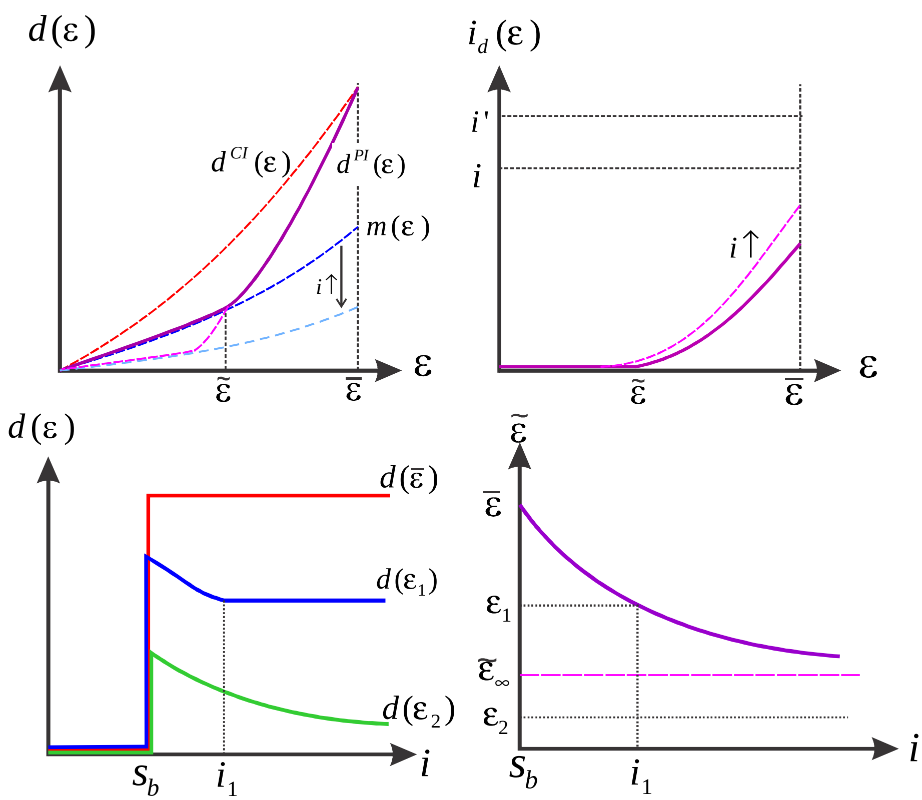

Figure 4: Top panels: Banking contracts under private information. Bottom left panel: Threshold $\tilde{\varepsilon}$ as a function of i. Bottom right panel: Deposits $d(\varepsilon)$ as a function of i

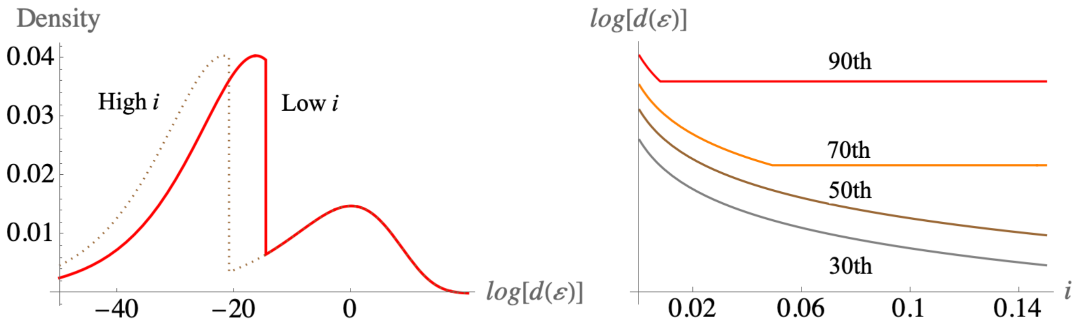

Figure 5: Changes in the distribution of deposits due to an increase in the policy rate

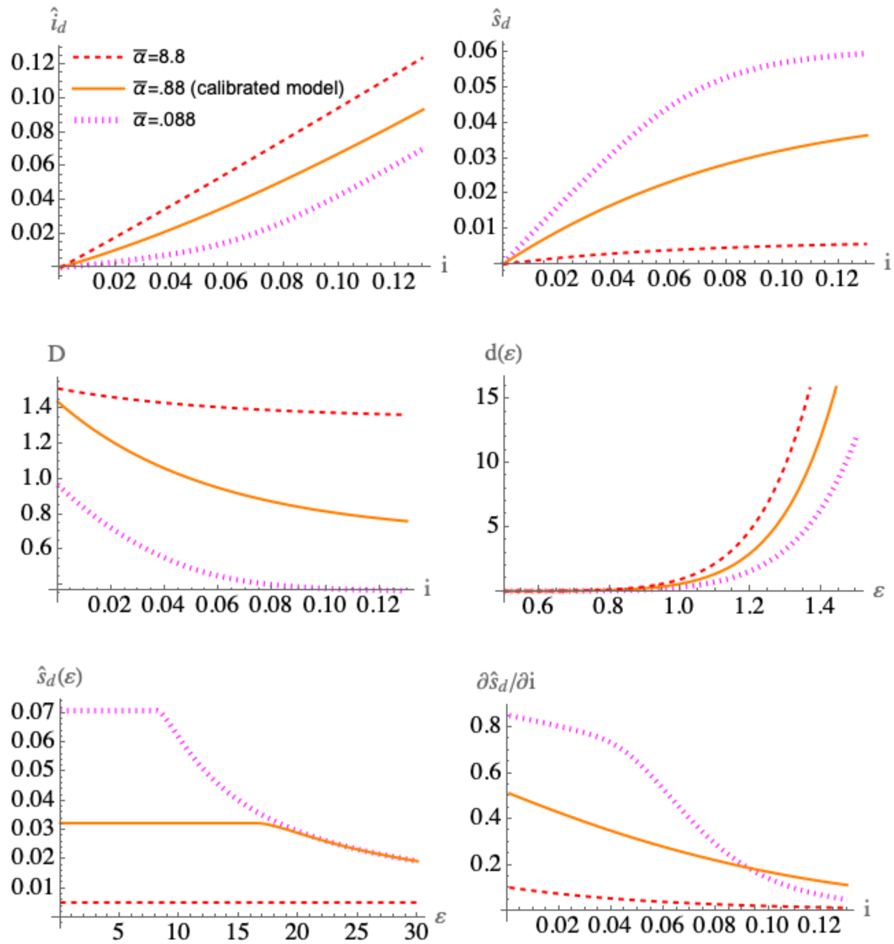

Figure 6: (Top-left) Average interest rate (Top-right) Average spread (Middle-left) Aggregate deposits (Middle-right) Deposits of various agent types (Bottom-left) Spread of various agent types (Bottom-right) Passthrough to the average spread. Orange lines represent the calibrated model. We increase the matching rate by 10 times in the red dashed lines and we reduce that by 10 times in the purple dotted lines.

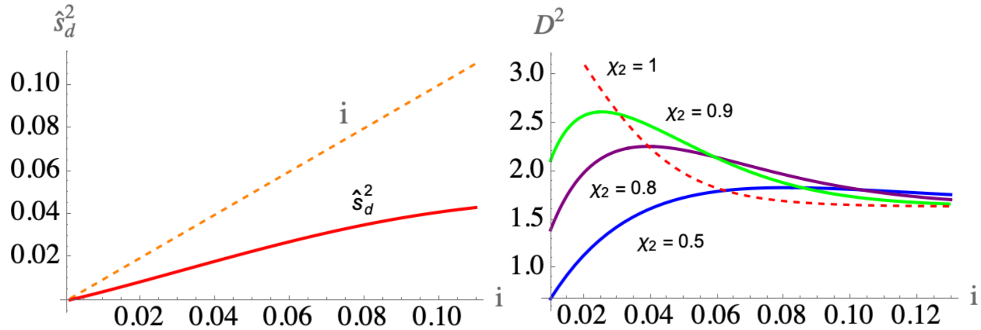

Figure 7: Outcome from second-degree price discrimination with $i = s_d^1$: $u(y) = y^{0.89}/0.89, \rho = 0.04, \sigma = 0.5, s_b^2 = 0, \varepsilon \sim Exp(1)$. In the left panel $\chi_2 = 0.8$.

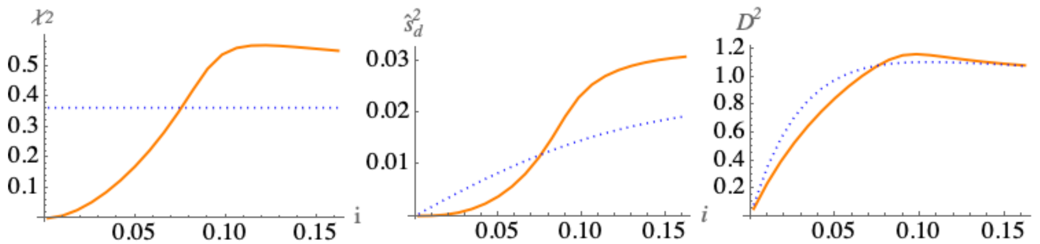

Figure 8: Endogenous acceptability of bank deposits

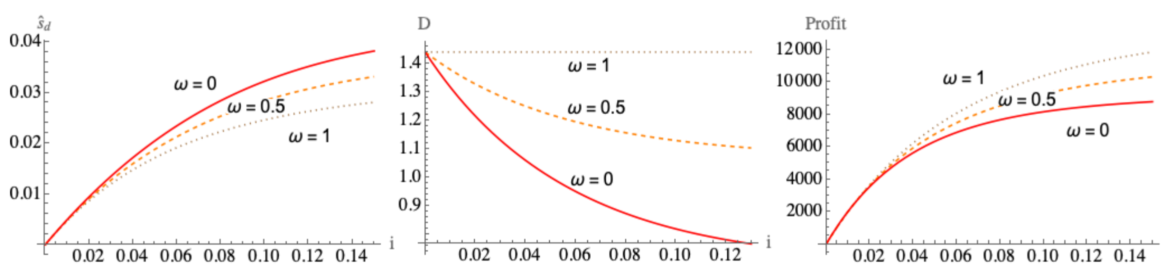

Figure 9: The deposits channel under various information structures.

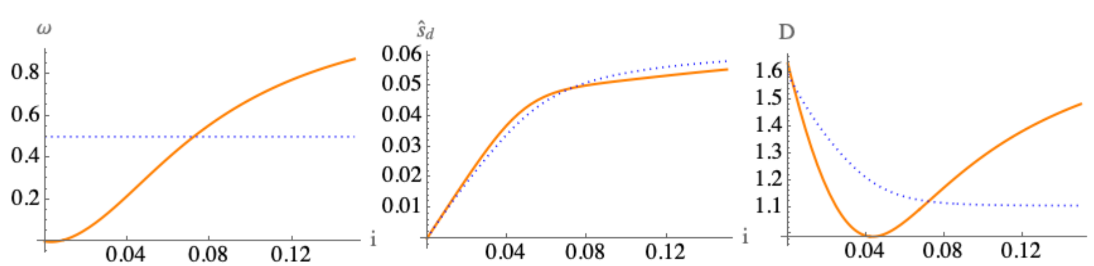

Figure 10: The deposits channel under endogenous information.

Parameter	Description	Targets	Value
ρ	Rate of time preference	Lagos-Wright (2005)	0.04
δ	Consumer's death rate	surveys of bank customers	0.05
s_b	Spread on banks' assets	abundant investment opportunities	0
$\bar{\alpha}$	Matching rate of consumers	fraction of unbanked households	0.88
θ	Bank's bargaining power	deposit spread passthrough	0.92
σ	Poisson rate of consumption shocks	semi-elasticity of deposits	0.5
a	Relative risk aversion	semi-elasticity of deposits	0.11

Table 2: Parameter values of the calibrated model

Supplementary Materials

A Proofs of propositions and lemmas

Proof of Lemma 2. The proof is by contradiction. Suppose there is a subset $\widehat{\mathcal{E}} \subset [0,\bar{\varepsilon}]$ with positive measure such that $m(\varepsilon) > 0$ for all $\varepsilon \in \widehat{\mathcal{E}}$. A deviation from the bank consists in offering alternative contracts, $[\phi'(\varepsilon), d'(\varepsilon)]$, for all $\varepsilon \in \widehat{\mathcal{E}}$ constructed as follows:

$$\begin{aligned} d'(\varepsilon) &= d(\varepsilon) + m(\varepsilon) \\ \phi'(\varepsilon) &= \phi(\varepsilon) + (i - s_b)m(\varepsilon). \end{aligned}$$

By construction consumers in $\widehat{\mathcal{E}}$ are indifferent between $[\phi(\varepsilon), d(\varepsilon)]$ and $[\phi'(\varepsilon), d'(\varepsilon)]$, i.e.,

$$\begin{aligned} &-\phi(\varepsilon) - im(\varepsilon) - s_b d(\varepsilon) + \sigma\left\{\varepsilon u\left[d(\varepsilon) + m(\varepsilon)\right] - d(\varepsilon) - m(\varepsilon)\right\} \\ &= -\phi'(\varepsilon) - s_b d'(\varepsilon) + \sigma\left\{\varepsilon u\left[d'(\varepsilon)\right] - d'(\varepsilon)\right\}. \end{aligned}$$

So, if the IC and IR constraints, (9) and (10), hold for the original contracts, $[\phi(\varepsilon), d(\varepsilon)]$, then they also hold for the new contracts, $[\phi'(\varepsilon), d'(\varepsilon)]$. Finally, since $m(\varepsilon) > 0$ for all $\varepsilon \in \widehat{\mathcal{E}}$, $\phi'(\varepsilon) > \phi(\varepsilon)$ for all $\varepsilon \in \widehat{\mathcal{E}}$. Hence, the deviation is profitable and $m(\varepsilon)$ cannot be positive for a positive measure of consumers. ■

Proof of Lemma 1. We multiply both sides of (8) by $\rho + \delta$ and we use (2), (5) and (6), to reexpress the consumer's participation constraint as:

$$\nu(\varepsilon) \geq \theta\left[U(\varepsilon; i) + \alpha\Delta V(\varepsilon)\right] + (1-\theta)U(\varepsilon; s_b), \tag{43}$$

where $\Delta V(\varepsilon) \equiv V^b(\varepsilon) - V^u(\varepsilon)$. The utility of the contract must be larger than a weighted average of the reservation utility of the consumer, $U(\varepsilon; i) + \alpha\Delta V(\varepsilon)$, and the complete-information utility when the consumer has all the bargaining power, $U(\varepsilon; s_b)$. From (2) and (5), the difference $\Delta V(\varepsilon) \equiv V^b(\varepsilon) - V^u(\varepsilon)$ can be written as

$$(\rho + \delta)\,\Delta V(\varepsilon) = \nu^*(\varepsilon) - U(\varepsilon; i) - \alpha\Delta V(\varepsilon),$$

where $\nu^*(\varepsilon)$ is the flow surplus of a type-ε banked consumer in a symmetric equilibrium. Solving for $\Delta V(\varepsilon)$,

$$\Delta V(\varepsilon) = \frac{\nu^*(\varepsilon) - U(\varepsilon; i)}{(\rho + \delta + \alpha)}.$$

Substituting this expression into the participation constraint (43),

$$\nu(\varepsilon) \geq \theta \left[U(\varepsilon; i) + \alpha \frac{\nu^*(\varepsilon) - U(\varepsilon; i)}{(\rho + \delta + \alpha)} \right] + (1 - \theta) U(\varepsilon; s_b),$$

which is equivalent to (9). ■

Proof of Proposition 1. The Hamiltonian of the bank's problem (12) is:

$$\begin{aligned} H(\nu, d, \mu, \xi, \varepsilon) \equiv & \left[-\nu(\varepsilon) - (s_b + \sigma) d + \sigma \varepsilon u(d) \right] \gamma(\varepsilon) + \mu \sigma u(d) \\ & + \xi(\varepsilon) \left[\nu(\varepsilon) - \underline{\nu}(\varepsilon) \right], \end{aligned}$$

where $\mu(\varepsilon)$ is the costate variable, and $\xi(\varepsilon)$ is the Lagrange multiplier associated with the participation constraint. From the Maximum Principle, necessary conditions for an optimum are:

$$[\varepsilon \gamma(\varepsilon) + \mu(\varepsilon)] \sigma u' [d(\varepsilon)] = (s_b + \sigma) \gamma(\varepsilon) \tag{44}$$

$$\mu'(\varepsilon) = \gamma(\varepsilon) - \xi(\varepsilon), \tag{45}$$

with the complementary slackness conditions,

$$\mu(0)\nu(0) = \mu(\bar{\varepsilon})\nu(\bar{\varepsilon}) = 0.$$

We conjecture that there is $\tilde{\varepsilon} > 0$ such that $\nu(\varepsilon) \geq \underline{\nu}(\varepsilon)$ binds for all $\varepsilon < \tilde{\varepsilon}$. We will show that such an $\tilde{\varepsilon} \in (0, \bar{\varepsilon})$ exists and is unique.

Part 1. IR constraints bind for $\varepsilon < \tilde{\varepsilon}$. If the participation constraint binds over some non-empty open interval, then $\nu(\varepsilon) = \underline{\nu}(\varepsilon)$ and from (9),

$$\nu'(\varepsilon) = \sigma u [d(\varepsilon)] = \theta \left[\frac{(\rho + \delta) U'(\varepsilon; i) + \alpha \nu^{*\prime}(\varepsilon)}{\rho + \delta + \alpha} \right] + (1 - \theta) U'(\varepsilon; s_b). \tag{46}$$

Using that $\nu(\varepsilon) = \nu^*(\varepsilon)$ in a symmetric equilibrium and $\nu(\varepsilon) = \underline{\nu}(\varepsilon)$, one can use (9) to derive

$$\nu^*(\varepsilon) = \frac{(1-\theta)(\rho+\delta+\alpha)U(\varepsilon; s_b) + \theta(\rho+\delta)U(\varepsilon; i)}{(1-\theta)(\rho+\delta+\alpha) + \theta(\rho+\delta)}.$$

Using this formula for $\nu^*(\varepsilon)$, we can rewrite (46) as

$$\nu'(\varepsilon) = \sigma u\left[d(\varepsilon)\right] = \frac{(1-\theta)(\rho+\delta+\alpha)U'(\varepsilon; s_b) + \theta(\rho+\delta)U'(\varepsilon; i)}{(1-\theta)(\rho+\delta+\alpha) + \theta(\rho+\delta)}.$$

Moreover, $\partial U(\varepsilon; i)/\partial\varepsilon = \sigma u\left[m(\varepsilon)\right]$ and $\partial U(\varepsilon; s_b)/\partial\varepsilon = \sigma u\left[d^s(\varepsilon)\right]$, where $m(\varepsilon)$ and $d^s(\varepsilon)$ solve

$$\begin{aligned} \sigma\varepsilon u'\left[m(\varepsilon)\right] &= i + \sigma \\ \sigma\varepsilon u'\left[d^s(\varepsilon)\right] &= s^b + \sigma. \end{aligned}$$

So $m(\varepsilon)$ are the real balances of an unbanked consumer while $d^s(\varepsilon)$ represents the complete-information level of deposits. Hence:

$$\omega\left\{u'\left[d(\varepsilon)\right]\right\} = \frac{(1-\theta)(\rho+\delta+\alpha)\omega\left(\frac{s^b+\sigma}{\sigma\varepsilon}\right) + \theta(\rho+\delta)\omega\left(\frac{i+\sigma}{\sigma\varepsilon}\right)}{(1-\theta)(\rho+\delta+\alpha) + \theta(\rho+\delta)},$$

where $\omega(x) \equiv u \circ u'^{-1}$. If the utility function is CRRA, $u(y) = y^{1-a}/(1-a)$, then $\omega(x) = x^{-(1-a)/a}/(1-a)$ and

$$\varepsilon u'\left[d(\varepsilon)\right] = \varepsilon\left[d(\varepsilon)\right]^{-a} = \frac{\left[(1-\theta)(\rho+\delta+\alpha) + \theta(\rho+\delta)\right]^{\frac{a}{1-a}}}{\left[(1-\theta)(\rho+\delta+\alpha)\left(\frac{\sigma}{s^b+\sigma}\right)^{\frac{(1-a)}{a}} + \theta(\rho+\delta)\left(\frac{\sigma}{i+\sigma}\right)^{\frac{(1-a)}{a}}\right]^{\frac{a}{1-a}}}.$$

Hence, the deposit levels are:

$$d(\varepsilon) = \varepsilon^{\frac{1}{a}}\left[\frac{(1-\theta)(\rho+\delta+\alpha)\left(\frac{\sigma}{s^b+\sigma}\right)^{\frac{(1-a)}{a}} + \theta(\rho+\delta)\left(\frac{\sigma}{i+\sigma}\right)^{\frac{(1-a)}{a}}}{(1-\theta)(\rho+\delta+\alpha) + \theta(\rho+\delta)}\right]^{\frac{1}{1-a}}, \tag{47}$$

which corresponds to (16).

By the definition of $\bar{s}$ in (18), we can rewrite $d(\varepsilon) = [\sigma\varepsilon/(\bar{s}+\sigma)]^{1/a}$ and $\varepsilon u'\left[d(\varepsilon)\right] = \bar{s}/\sigma + 1$. By the definition of $\phi(\varepsilon)$ and the IC condition,

$$\phi'(\varepsilon) = \left\{-(s_b+\sigma) + \sigma\varepsilon u'\left[d(\varepsilon)\right]\right\} d'(\varepsilon).$$

Since $\varepsilon u'\left[d(\varepsilon)\right]$ is independent of ε and $d(0)=0$, the fee, $\phi(\varepsilon)$, is

$$\phi(\varepsilon) = d(\varepsilon)\left(\bar{s} - s_b\right), \quad \text{for all } \varepsilon < \tilde{\varepsilon}.$$

From (44) that the closed-form solution for the costate variable is:

$$\begin{aligned}
\mu(\varepsilon) &= \varepsilon\gamma(\varepsilon)\left[\frac{s_b+\sigma}{\sigma\varepsilon u'\left[d(\varepsilon)\right]} - 1\right] \\
&= \varepsilon\gamma(\varepsilon)\left\{\left[\frac{(1-\theta)(\rho+\delta+\alpha)+\theta(\rho+\delta)\left(\frac{s^b+\sigma}{i+\sigma}\right)^{\frac{(1-a)}{a}}}{(1-\theta)\left(\rho+\delta+\alpha\right)+\theta(\rho+\delta)}\right]^{\frac{a}{1-a}} - 1\right\} \\
&= -\varepsilon\gamma(\varepsilon)\left(\frac{\bar{s}-s_b}{\bar{s}+\sigma}\right)
\end{aligned} \tag{48}$$

for all $\varepsilon \in (0, \tilde{\varepsilon})$.

Part 2. IR constraints are slack for $\varepsilon \geq \tilde{\varepsilon}$. Hence, $\xi(\varepsilon) = 0$ for all $\varepsilon > \tilde{\varepsilon}$. It follows from (45) and (48):

$$\mu(\varepsilon) = \mu(\tilde{\varepsilon}) + \Upsilon(\varepsilon) - \Upsilon(\tilde{\varepsilon}), \quad \text{for all } \varepsilon \geq \tilde{\varepsilon}. \tag{49}$$

Provided $\nu(\bar{\varepsilon}) > 0$, the optimality condition for a free end-point problem is $\mu(\bar{\varepsilon}) = 0$, which, from (48), gives

$$\frac{1-\Upsilon(\tilde{\varepsilon})}{\gamma(\tilde{\varepsilon})} = \tilde{\varepsilon}\left(\frac{\bar{s}-s_b}{\bar{s}+\sigma}\right), \tag{50}$$

which corresponds to (19). The right side of (50) is increasing in $\tilde{\varepsilon}$ while the left side is decreasing in $\tilde{\varepsilon}$ due to the log-concavity of $1-\Upsilon$. Moreover, the left side is greater than the right side at

$\tilde{\varepsilon} = 0$ and it is smaller at $\tilde{\varepsilon} = \bar{\varepsilon}$. Hence, there is a unique $\tilde{\varepsilon} \in (0, \bar{\varepsilon})$ solution to (50).

By (44) and $\mu(\varepsilon) = -1 + \Upsilon(\varepsilon)$, the deposits $d(\varepsilon)$ solves

$$u'\left[d(\varepsilon)\right] = \left\{\varepsilon - \left[\frac{1 - \Upsilon(\varepsilon)}{\gamma(\varepsilon)}\right]\right\}^{-1}\left(1 + \frac{s_b}{\sigma}\right) \quad \text{for all } \varepsilon \geq \tilde{\varepsilon}.$$

Using that u is CRRA,

$$d(\varepsilon) = \left\{\varepsilon - \left[\frac{1 - \Upsilon(\varepsilon)}{\gamma(\varepsilon)}\right]\right\}^{1/a}\left(1 + \frac{s_b}{\sigma}\right)^{-1/a} \quad \text{for all } \varepsilon \geq \tilde{\varepsilon},$$

which corresponds to (17).

For $\varepsilon \leq \tilde{\varepsilon}$, the value of the state variable, $\nu(\varepsilon)$, is equal to $\underline{\nu}(\varepsilon)$ by Lemma 1. Therefore by integrating over the IC constraint (13),

$$\nu(\varepsilon) = \underline{\nu}(\tilde{\varepsilon}) + \sigma \int_{\tilde{\varepsilon}}^{\varepsilon} u\left[d(x)\right] dx \quad \text{for all } \varepsilon \geq \tilde{\varepsilon}. \tag{51}$$

Using this expression and the definition of the fees we can reexpress $\phi(\varepsilon)$ by (21) for $\varepsilon \geq \tilde{\varepsilon}$.

Part 3. Sufficiency. We now check the Mangasarian sufficiency conditions. Given our solution for μ, the Hamiltonian function, $H(\nu, d, \mu, \xi, \varepsilon)$, is jointly concave in (ν, d). To see this, note that H is additively separable in ν and d. It is linear in ν (hence, concave); and, provided that $\mu(\varepsilon) + \varepsilon\gamma(\varepsilon) \geq 0$, which holds from (48) and (49), it is concave in d due to the strict concavity of $u(d)$. Finally, the terminal conditions, $\mu(0)\nu(0) = 0$ and $\mu(\bar{\varepsilon})\nu(\bar{\varepsilon}) = 0$, hold since $\nu(0) = 0$ and $\mu(\bar{\varepsilon}) = 0$.

Part 4. Uniqueness. Finally, we argue that our conjecture about the two-tier structure of the menu of contracts is the only way to construct a solution. At $\varepsilon = 0$, the consumer can never get any surplus from monetary trades. Since $\phi_0 \geq 0$, $\nu(0) \leq 0$. But the IR constraint $\nu(0) \geq U(0; \bar{s}) = 0$ must hold, hence $\nu(0) = 0$. Suppose next that as ε rises above 0, the menu of contracts transitions into an nonempty interval, $[\tilde{\varepsilon}, \tilde{\tilde{\varepsilon}}]$, where $\tilde{\tilde{\varepsilon}} < \bar{\varepsilon}$ and IR is slack in the interior of the interval but binds at the end points of the interval. By the proof logic of Part 2,

$d(\varepsilon) > m(\varepsilon)$, for $\varepsilon \in (\tilde{\varepsilon}, \tilde{\tilde{\varepsilon}}]$. Hence by (51),

$$\nu(\varepsilon) = U(\tilde{\varepsilon}; \bar{s}) + \sigma \int_{\tilde{\varepsilon}}^{\varepsilon} u\left[d(x)\right] dx > U(\varepsilon; \bar{s})$$

for $\varepsilon \in (\tilde{\varepsilon}, \tilde{\tilde{\varepsilon}}]$ and the IR constraint cannot bind at $\tilde{\tilde{\varepsilon}}$, leading to a contradiction. Therefore, once the IR becomes slack at $\tilde{\varepsilon}$, it must stay slack for all larger ε. ■

Proof of Proposition 2. Consider a sequence of distributions, $\{\Upsilon_n\}_{n=1}^{+\infty}$, such that $\gamma_1(0) = 0$, $\int_0^{\bar{\varepsilon}} \varepsilon d\Upsilon_1(\varepsilon) = 1$, and

$$\Upsilon_n(\varepsilon) = \Upsilon_1\left[n(\varepsilon - 1) + 1\right] \text{ for all } n > 1.$$

As $n \to +\infty$, almost all consumers have a preference type arbitrarily close to $\varepsilon = 1$. We formalize the limit to complete information as follows. Consider a distribution $\Upsilon_1(\varepsilon)$ with mean 1 and support $[0, \bar{\varepsilon}]$ and Υ_1 satisfies the assumption for the menu of deposits contracts to be fully separating and $\gamma_1(0) = 0$. We consider a sequence of distributions obtained from Υ_1 as follows:

$$\Upsilon_n(\varepsilon) = \Upsilon_1\left[n(\varepsilon - 1) + 1\right].$$

The support of Υ_n is $[1 - 1/n, 1 + (\bar{\varepsilon} - 1)/n]$. The variance of the distribution has been scaled down by a factor of $1/n^2$. As $n \to +\infty$,

$$\Upsilon_n(1 + \varsigma) - \Upsilon_n(1 - \varsigma) = \Upsilon_1\left(n\varsigma + 1\right) - \Upsilon_1\left(1 - \varsigma n\right) \to 1,$$

the mass of consumers is concentrated at $\varepsilon = 1$.

We argue that when n is sufficiently large, $\tilde{\varepsilon}_n \in (1 - 1/n, 1)$. Consider the definition of $\tilde{\varepsilon}_n$ by (19):

$$\frac{1 - \Upsilon_1\left[n(\tilde{\varepsilon}_n - 1) + 1\right]}{n\gamma_1\left[n(\tilde{\varepsilon}_n - 1) + 1\right]} = \tilde{\varepsilon}_n\left(\frac{\bar{s} - s}{\bar{s} + \sigma}\right)$$

where the left side falls and the right side rises in $\tilde{\varepsilon}_n$. Since $\gamma_1(0) = 0$, the solution of $\tilde{\varepsilon}_n$ always exceeds the lower support, $1 - 1/n$. When n is sufficiently large,

$$\frac{1 - \Upsilon_1(1)}{n\gamma_1(1)} < \frac{\bar{s} - s}{\bar{s} + \sigma},$$

and the cutoff $\tilde{\varepsilon}_n$ is strictly smaller than 1. Thus the deposits are characterized by (17) at $\varepsilon = 1$. At the limit $n \to +\infty$, the virtual valuation at $\varepsilon = 1$ is

$$1 - \frac{1 - \Upsilon_1(1)}{n\gamma_1(1)} \to 1.$$

So the deposit sizes solves $u'[d(1)] = 1 + s_b/\sigma$.

Since $\tilde{\varepsilon}_n \in (1 - 1/n, 1)$, it converges to 1 as $n \to +\infty$. Therefore, the participation constraint binds for consumers of type $\varepsilon = 1$. Then by (21) the fee is given by

$$\phi(1) = -\underline{\nu}(1) - (s_b + \sigma)d(1) + \sigma\varepsilon u[d(1)].$$

Substitute $\underline{\nu}(1)$ by its expression given by (9), i.e.,

$$\underline{\nu}(1) = \frac{(1-\theta)(\rho+\delta+\alpha)U(1;s_b) + \theta(\rho+\delta)U(1;i)}{(1-\theta)(\rho+\delta+\alpha) + \theta(\rho+\delta)},$$

we obtain

$$\begin{aligned}\phi(1) &= U(1;s_b) - \frac{(1-\theta)(\rho+\delta+\alpha)U(1;s_b) + \theta(\rho+\delta)U(1;i)}{(1-\theta)(\rho+\delta+\alpha) + \theta(\rho+\delta)} \\ &= \frac{\theta(\rho+\delta)}{(1-\theta)(\rho+\delta+\alpha) + \theta(\rho+\delta)}\left[U(1;s_b) - U(1;i)\right].\end{aligned}$$

We obtain the closed-form expression for the deposit spread, (28), by substituting ϕ by its expression given by (27) and d by its expression from (26), i.e., $d = u'^{-1}(1 + s_b/\sigma)$, into (23). ■

Proof of Proposition 3. **Existence and uniqueness of equilibrium**. Define the following function:

$$\Gamma(\tau) \equiv \alpha(\tau)\,(1-\theta)\,\kappa - \frac{\alpha(\tau)}{\tau}\theta\,[U(\rho - r_b) - U(i)] + (\rho+\delta)\kappa.$$

A solution to (29) is such that $\Gamma(\tau) = 0$. By the properties of $\alpha(\tau)$, the function $\Gamma(\tau)$ is strictly increasing with $\Gamma(0) = -\infty$ if $U(\rho - r_b) > U(i)$ and $\Gamma(0) > 0$ if $U(\rho - r_b) \leq U(i)$. Moreover, $\Gamma(+\infty) = +\infty$. So, there exists a positive solution to $\Gamma(\tau) = 0$ if and only if $U(\rho - r_b) > U(i)$, i.e., $\rho - r_b < i$. Using that $i = \rho + \pi$, the condition for existence can be reexpressed as $\pi + r_b > 0$. From the monotonicity of Γ, equilibrium is unique. From (22) and the fact that $\phi > 0$ in any active equilibrium it follows that $i_d < \pi + r_b$.

Parts 1 and 2. In equilibrium the value of τ, n^b, m and d and given by $\Gamma(\tau) = 0$, (25), (4) and (26), respectively. Comparative statics are summarized in the following table:

exogenous→ endogenous↓	r_b	i	θ	κ	δ
τ	+	+	+	−	−
n^b	+	+	+	−	−
m	0	−	0	0	0
d	+	0	0	0	0

From (29),

$$\frac{\partial \tau}{\partial i} = \left\{(\rho+\delta)\kappa\frac{[1-\eta(\tau)]}{\alpha(\tau)} + (1-\theta)\,\kappa\right\}^{-1}\theta m > 0,$$

where $\eta(\tau) \equiv \tau\alpha'(\tau)/\alpha(\tau)$.

If we substitute the free entry condition, that $\kappa = [\alpha(\tau)/\tau]\,\phi/(\rho+\delta)$, and (27) into (28) we can obtain an alternative expression of the deposit spread that does not depend directly on θ and i, i.e.,

$$\hat{s}_d = s_b + (\rho+\delta)\,\frac{\kappa\tau}{\alpha(\tau)d}. \tag{52}$$

According to this formulation, $\hat{s}_d$ and τ are positively correlated. Since τ is an increasing function of i, it follows immediately that the deposit spread increases with the policy rate.

From (52),

$$\frac{\partial \hat{s}_d}{\partial i} = (\rho + \delta) \frac{\kappa}{d} \frac{[1 - \eta(\tau)]}{\alpha(\tau)} \frac{\partial \tau}{\partial i}.$$

Hence, substituting $\partial \tau / \partial i$ in the expression above we obtain (30). In order to establish $\partial \hat{s}_d / \partial \theta > 0$ and $\partial \hat{s}_d / \partial \kappa > 0$, we use (52). The result $\partial \hat{s}_d / \partial \theta > 0$ follows from the fact that $\hat{s}_d$ increases with τ and $\partial \tau / \partial \theta > 0$. From (29),

$$\frac{\tau \kappa}{\alpha(\tau)} = \frac{\theta [U(s_b) - U(i)]}{(\rho + \delta) + \alpha(\tau)(1 - \theta)}.$$

Hence, the deposit spread can be rewritten as:

$$\hat{s}_d = s_b + \frac{(\rho + \delta)}{d} \frac{\theta [U(s_b) - U(i)]}{(\rho + \delta) + \alpha(\tau)(1 - \theta)}.$$

Using that $\partial \tau / \partial \kappa < 0$, it follows that $\partial \hat{s}_d / \partial \kappa > 0$.

From (30), if $\alpha(\tau) = \alpha_0 \tau^\eta$, then

$$\frac{\partial \hat{s}_d}{\partial i} = \theta \frac{(\rho + \delta)(1 - \eta)}{(\rho + \delta)(1 - \eta) + (1 - \theta) \alpha_0 \tau^\eta} \frac{u'^{-1}\left(1 + \frac{i}{\sigma}\right)}{u'^{-1}\left(1 + \frac{s_b}{\sigma}\right)},$$

which is decreasing in τ, i.e., the passthrough is larger in more concentrated markets.

Part 3. Since d is independent of i and n^b rises in i as shown above, the aggregate deposits, $n^b d$, increase with i. ■

Lemma 3 *The deposit rate is $\hat{i}_d(\varepsilon) = 0$ for all $\varepsilon < \tilde{\varepsilon}$ and it rises in ε for $\varepsilon \geq \tilde{\varepsilon}$.*

Proof. By (22) and Proposition 1, for $\varepsilon \geq \tilde{\varepsilon}$ the deposit rate is

$$\hat{i}_d(\varepsilon) = i - \left(\sigma \frac{\{\varepsilon u [d(\varepsilon)] - d(\varepsilon)\} - \int_0^\varepsilon u [d(x)] \, dx}{d(\varepsilon)} \right).$$

To prove the claim, we will show the expression in the large parenthesis falls in ε for $\varepsilon \geq \tilde{\varepsilon}$. Since $d'(\varepsilon) > 0$ by Proposition 1, the derivative of this expression is proportional to

$$\begin{aligned}\frac{\partial}{\partial \varepsilon}\left(\frac{\{\varepsilon u\left[d(\varepsilon)\right] - d(\varepsilon)\} - \int_0^{\varepsilon} u\left[d(x)\right] dx}{d(\varepsilon)}\right) &\propto \varepsilon u'\left[d(\varepsilon)\right] d(\varepsilon) - \varepsilon u\left[d(\varepsilon)\right] + \int_0^{\varepsilon} u\left[d(x)\right] dx \\ &= \varepsilon u'\left[d(\varepsilon)\right] d(\varepsilon) - (1 + s_b/\sigma) d(\varepsilon) - \phi(\varepsilon)/\sigma\end{aligned}$$

where the second line uses (21). By (20) and (31) the last expression is 0 at $\varepsilon = \tilde{\varepsilon}$. We argue that this expression falls in ε:

$$\begin{aligned}\frac{\partial}{\partial \varepsilon}\left\{\left[\varepsilon u'\left[d(\varepsilon)\right] - (1 + \frac{s_b}{\sigma})\right] d(\varepsilon) - \frac{\phi(\varepsilon)}{\sigma}\right\} &= d(\varepsilon)\frac{\partial\left[\varepsilon u'\left[d(\varepsilon)\right] - (1 + s_b/\sigma)\right]}{\partial \varepsilon} \\ &+ d'(\varepsilon)\left\{\varepsilon u'\left[d(\varepsilon)\right] - \left(1 + \frac{s_b}{\sigma}\right)\right\} - \frac{\phi'(\varepsilon)}{\sigma} \\ &= d(\varepsilon)\frac{\partial}{\partial \varepsilon}\left[\frac{1 - \Upsilon(\tilde{\varepsilon})}{\gamma(\tilde{\varepsilon})} u'\left[d(\varepsilon)\right]\right] < 0,\end{aligned}$$

where the second line uses (32) and

$$\phi'(\varepsilon) = \{-(s_b + \sigma) + \sigma \varepsilon u'\left[d(\varepsilon)\right]\} d'(\varepsilon) \quad \text{for all } \varepsilon \geq \tilde{\varepsilon}, \tag{53}$$

which is implied by (21). The inequality is true by the log-concavity of $1 - \Upsilon$, $d'(\varepsilon) > 0$ and the concavity of u. ■

Proof of Proposition 4. Part 1. The derivative, (35), follows directly from

$$d(i) \equiv \int_0^{\bar{\varepsilon}} d(\varepsilon) d\Upsilon(\varepsilon) = \int_0^{\tilde{\varepsilon}(i)} u'^{-1}\left(\frac{i + \sigma}{\varepsilon \sigma}\right) d\Upsilon(\varepsilon) + \int_{\tilde{\varepsilon}(i)}^{\bar{\varepsilon}} u'^{-1}\left[\frac{\gamma(\varepsilon)}{\varepsilon \gamma(\varepsilon) - 1 + \Upsilon(\varepsilon)}\left(1 + \frac{s_b}{\sigma}\right)\right] d\Upsilon(\varepsilon).$$

Parts 2 and 3. We differentiate $n^b = \alpha(\tau)/\left[\delta + \alpha(\tau)\right]$ to obtain:

$$\frac{\partial n^b}{\partial i} = \frac{\alpha'(\tau)\delta}{\left[\delta + \alpha(\tau)\right]^2}\frac{\partial \tau}{\partial i},$$

where, from (24),

$$\frac{\partial\tau}{\partial i} = \frac{\alpha(\tau)}{[1-\eta(\tau)]\,(\rho+\delta)\,\kappa}\frac{\partial\Phi}{\partial i},$$

with $\eta(\tau) \equiv \tau\alpha'(\tau)/\alpha(\tau)$ and, from (20)-(21),

$$\frac{\partial\Phi}{\partial i} = \int_0^{\tilde{\varepsilon}} d(\varepsilon)d\Upsilon(\varepsilon) + d(\tilde{\varepsilon})\left[1-\Upsilon(\tilde{\varepsilon})\right].$$

So

$$\frac{\partial n^b/n^b}{\partial i} = \frac{\eta(\tau)\delta n^b}{[1-\eta(\tau)]\,\alpha(\tau)\Phi}\left\{\int_0^{\tilde{\varepsilon}} d(\varepsilon)d\Upsilon(\varepsilon) + d(\tilde{\varepsilon})\left[1-\Upsilon(\tilde{\varepsilon})\right]\right\} > 0.$$

As $\delta \to 0$, $\partial\Phi/\partial i$ is unaffected, $\partial\tau/\partial i < +\infty$, and hence $\partial n^b/\partial i \to 0$. Hence, from (35), there is a threshold for δ below which

$$\frac{\partial(n^b d)}{\partial i} = \frac{\partial n^b}{\partial i}d + n^b\frac{\partial d}{\partial i} < 0.$$

Part 4. The deposit spread is

$$\hat{s}_d(\varepsilon) = s_b + \frac{\phi(\varepsilon)}{d(\varepsilon)} = i\mathbb{I}_{\{\varepsilon\leq\tilde{\varepsilon}\}} + \left(\sigma\frac{\{\varepsilon u\left[d(\varepsilon)\right] - d(\varepsilon)\} - \int_0^{\varepsilon} u\left[d(x)\right]dx}{d(\varepsilon)}\right)\mathbb{I}_{\{\varepsilon>\tilde{\varepsilon}\}}. \qquad (54)$$

To obtain (36), note that

$$\sigma\int_0^{\varepsilon} u\left[d(x)\right]dx = U(\tilde{\varepsilon};i) + \sigma\int_{\tilde{\varepsilon}}^{\varepsilon} u\left[d(x)\right]dx.$$

The derivative of the right side with respect to i is $-d(\tilde{\varepsilon})$. The average spread is

$$\widehat{s}_d = s_b + \int_0^{\overline{\varepsilon}} \frac{\phi(\varepsilon)\gamma(\varepsilon)}{d(i)}d\varepsilon.$$

Using that $\phi(\varepsilon)$ is increasing in i and D is decreasing in i, it follows that $\partial\widehat{s}_d/\partial i > 0$.

Part 5. We re-use the result according to which as $\delta \to 0$, $n^b \to 1$ and $\partial n^b/\partial i \to 0$. Since $\mathrm{D}'(i) < 0$, it follows that $\partial Y/\partial i < 0$. ■

Proof of Proposition 5. Part 1. From (16)-(17) and (20)-(21), the spread passthrough is given by:

$$\begin{aligned}\frac{\partial \hat{s}_d(\varepsilon)}{\partial i} &= \frac{(\bar{s}/\sigma+1)^{\frac{1}{a}}}{(i+\sigma)} \frac{\theta(\rho+\delta)}{a\left[(1-\theta)\left(\rho+\delta+\alpha\right)+\theta(\rho+\delta)\right]}\left(\frac{\sigma}{i+\sigma}\right)^{\frac{1+a}{a}} > 0 \ \text{ for all } \varepsilon < \tilde{\varepsilon} \\ &= \frac{\theta(\rho+\delta)m(\varepsilon)}{d(\varepsilon)\left[(1-\theta)\left(\rho+\delta+\alpha\right)+\theta(\rho+\delta)\right]} > 0 \quad \text{for all } \varepsilon \geq \tilde{\varepsilon}.\end{aligned}$$

The effects of the policy rate on deposits are given by:

$$\begin{aligned}\frac{\partial d(\varepsilon)}{\partial i} &= \frac{-\varepsilon^{1/a}\left(\frac{\sigma}{\bar{s}+\sigma}\right)\theta(\rho+\delta)}{a(i+\sigma)\left[(1-\theta)\left(\rho+\delta+\alpha\right)+\theta(\rho+\delta)\right]}\left(\frac{\sigma}{i+\sigma}\right)^{\frac{1-a}{a}} < 0 \quad \text{for all } \varepsilon < \tilde{\varepsilon} \\ &= 0 \text{ otherwise.}\end{aligned}$$

The cutoff $\tilde{\varepsilon}$ falls in i by (19), the log-concavity of $1-\Upsilon(\varepsilon)$ and the fact that $\bar{s}$ rises in i.

Part 2. Using that $\bar{s}$ is decreasing in α, it follows immediately that $\partial \hat{s}_d(\varepsilon)/\partial i$ decreases in α for all $\varepsilon \in [0, \bar{\varepsilon}]$. Next, we compute:

$$\begin{aligned}\frac{\partial \ln|\partial d(\varepsilon)/\partial i|}{\partial \alpha} &= \frac{a(1-\theta)}{1-a}\left[(1-\theta)(\rho+\delta+\alpha)+\theta(\rho+\delta)\left(\frac{s^b+\sigma}{i+\sigma}\right)^{\frac{(1-a)}{a}}\right]^{-1} \\ &\quad -\frac{1-\theta}{1-a}\left[(1-\theta)\left(\rho+\delta+\alpha\right)+\theta(\rho+\delta)\right]^{-1} \\ &\propto a - \frac{(1-\theta)(\rho+\delta+\alpha)+\theta(\rho+\delta)\left(\frac{s^b+\sigma}{i+\sigma}\right)^{\frac{(1-a)}{a}}}{(1-\theta)\left(\rho+\delta+\alpha\right)+\theta(\rho+\delta)}.\end{aligned}$$

The right side strictly falls in α and it is negative when $\alpha \to +\infty$. When $\alpha = 0$, the right side is negative if and only if (37) holds. Therefore if (37) holds, then $|\partial d(\varepsilon)/\partial i|$ falls in α and otherwise it is hump-shaped in α for $\alpha \in (0, +\infty)$.

Part 3. Using that α is independent of i, it follows that $\partial n^u/\partial i = \partial n^b/\partial i = 0$. Since $\partial m(\varepsilon)/\partial i < 0$ for all ε, $\partial d(\varepsilon)/\partial i < 0$ for all $\varepsilon < \tilde{\varepsilon}$, and $\partial d(\varepsilon)/\partial i = 0$ for all $\varepsilon > \tilde{\varepsilon}$, both M and D decrease with i. Hence, $\partial Y/\partial i < 0$. ■

Proof of Proposition 6.

The proof uses Proposition 14 in our working paper, Choi and Rocheteau (2021a) (CR), which characterizes the optimal contract with two general deposit categories under posting and private information. Proposition 6 concerns the limit when $s_b^1 \to i$.

From (148) in CR, $\tilde{\varepsilon} \to \bar{\varepsilon}$ at the limit $s_b^1 \to i$. Then the solution of (d^1, ℓ) is given by (151)-(152) in Proposition 14:

$$\left\{\varpi(\varepsilon)\chi_1\sigma d^1 - \left(i - s_b^2 + \sigma\chi_1\right)\left(d^1\right)^{1+a}\right\}\chi_2 = \left\{\varpi(\varepsilon)\sigma\chi_2\ell - \left(s_b^2 + \sigma\chi_2\right)(\ell)^{1+a}\right\}\chi_1, \quad (55)$$

$$\sigma\chi_1\varepsilon\left(d^1\right)^{-a} + \sigma\chi_2\varepsilon(\ell)^{-a} = i + \sigma. \quad (56)$$

Part 1: At $i = s_b^2/\chi_2$, by (55), $\ell = d^1$ and thus $d^2 = 0$. Given $\ell = d^1$, the value of d^1 is given by (56).

Part 2: As i rises, the curves labelled FOCs in Figure 17 in CR, representing (55), shift up and the threshold $\tilde{d}^1$ falls by (161) in CR. The curve ICM, representing (56), shifts downward in i. Hence d^1 falls in i. As $i \uparrow +\infty$, the threshold $\tilde{d}^1 \to 0$ in the left panel. Moreover, the slope of FOCs explodes to $+\infty$ in both panels. By (56), the curve ICM becomes an L-shape curve that asymptote to $+\infty$ when $d^1 = 0$ and equals to 0 for all $d^1 > 0$. Hence, $d^1 \to 0$ as $i \uparrow +\infty$. If $\varpi(\varepsilon) > 0$, then (55) is represented by FOCs in the left panel and $\ell \to \tilde{\ell}$ where $\tilde{\ell}$ is given by (160) in CR; otherwise (55) corresponds to FOCs in the right panel and $\ell \to 0$. ■

Proof of Proposition 7. From Proposition 6, if $i = s_b^2$, then $d^2(\varepsilon) = 0$ for all $\chi_2 \in [0,1]$ and since banks can only make profits when type-2 deposits are demanded, $\Phi(\chi_2; i) = 0$. It follows that $\chi_2 = 0$ for $i = s_b^2$. Suppose next that $i \to +\infty$. Then, $d^1(\varepsilon) = 0$. From (19), $[1 - \Upsilon(\tilde{\varepsilon})]/\gamma(\tilde{\varepsilon}) = \tilde{\varepsilon}$. Summing across fees, (21), the expected profits of the bank are

$$\Phi(\chi_2; +\infty) = \int_{\tilde{\varepsilon}}^{\bar{\varepsilon}} \sigma\chi_2\left[\varepsilon - \frac{1 - \Upsilon(\varepsilon)}{\gamma(\varepsilon)}\right] u\left[d(\varepsilon)\right] - (s_b + \sigma\chi_2)d(\varepsilon)d\Upsilon(\varepsilon).$$

Taking the first-order condition of (39), the optimal liquidity of deposits solves (40). Since the right side of (40) is positive and $\psi'(0) = 0$, it follows that $\chi_2 > 0$. ■

Proof of Proposition 8. We establish that $\tau \to +\infty$. The proof is by contradiction. Suppose $\tau < +\infty$. Then, $\alpha(\tau) < +\infty$. From (18), $\bar{s} > s_b$. Hence, $\phi(\varepsilon) = d(\varepsilon)(\bar{s} - s_b) > 0$ for all ε, which implies $\Phi > 0$. Since $\tau < +\infty$ implies $\alpha(\tau)/\tau > 0$, from (24),

$$\kappa = \frac{\alpha(\tau)}{\tau}\frac{\Phi}{\rho+\delta} > 0,$$

which gives a contraction with $\kappa \to 0$. So, $\tau = +\infty$ and $\alpha(\tau) = +\infty$. From (18), $\bar{s} = s_b$, and, from (19), $\bar{s} - s_b = 0$ implies $\tilde{\varepsilon} = \bar{\varepsilon}$. It follows that $\phi(\varepsilon) = 0$ for all $\varepsilon \le \bar{\varepsilon}$. From (23), $\hat{s}_d(\varepsilon) = s_b$ for all $\varepsilon \le \bar{\varepsilon}$. From (16), $d(\varepsilon) = [\varepsilon\sigma/(s_b+\sigma)]^{1/a}$ for $\varepsilon \le \bar{\varepsilon}$. ■

Proof of Proposition 9. When $i = s_b$, consumers do not use bank deposits. Thus banks earn no profit, i.e. $\Phi^I = \Phi^U = 0$ and choose $\omega = 0$. By continuity, there is a $\underline{i} > s_b$ such that $\Phi^I - \Phi^U < h$ for all $i \le \underline{i}$. It follows that $\omega = 0$ for all $i \le \underline{i}$. Since all banks are uninformed, the economy is the same as that characterized by Proposition 4. Hence $\partial d/\partial i < 0$ by (35).

When $i \to +\infty$, consumers do not use money. Their outside option during a meeting, $\underline{\nu}(\varepsilon,\omega)$, is given by

$$\underline{\nu}(\varepsilon,\omega) = \frac{\alpha}{\rho+\delta+\alpha}[\omega\underline{\nu}(\varepsilon,\omega) + (1-\omega)\nu^*(\varepsilon,\omega)], \tag{57}$$

where ω is the information choice by banks in a symmetric equilibrium. In an informed meeting, the consumer gets no surplus and thus only receives a payoff of $\underline{\nu}(\varepsilon,\omega)$. In an uninformed meeting, the payoff for the consumer is denoted by $\nu^*(\varepsilon,\omega)$.

We argue that the consumer's payoff, $\nu^*(\varepsilon,\omega)$, and fees at an uninformed bank are independent of ω. In an uninformed meeting, the bank will offer an optimal contract as characterized by Proposition 1 with $i = \infty$ and the consumers' matching rate is $\alpha(1-\omega)$. Therefore, by (19), the cutoff $\tilde{\varepsilon}$ solves

$$\frac{1-\Upsilon(\tilde{\varepsilon})}{\gamma(\tilde{\varepsilon})} = \tilde{\varepsilon}, \tag{58}$$

which implies $\tilde{\varepsilon}$ does not depend on ω. Since the participation constraint for a type $\tilde{\varepsilon}$ consumer binds, $\nu^*(\varepsilon,\omega) = \underline{\nu}(\varepsilon,\omega)$ at $\varepsilon = \tilde{\varepsilon}$ and both equal 0 by (57). Since $\nu^*(\tilde{\varepsilon},\omega)$ and $d(\varepsilon)$ are independent of ω for $\varepsilon \ge \tilde{\varepsilon}$ by (17), so is $\nu^*(\varepsilon,\omega)$ for $\varepsilon \ge \tilde{\varepsilon}$.

The fee for $\varepsilon < \tilde{\varepsilon}$ is 0 because $d^u(\varepsilon) = m(\varepsilon) = 0$. For $\varepsilon \geq \tilde{\varepsilon}$, the fee is

$$\phi^U(\varepsilon) = -\sigma \int_{\tilde{\varepsilon}}^{\varepsilon} u\left[d(x)\right] dx - (s_b + \sigma) d(\varepsilon) + \sigma \varepsilon u\left[d(\varepsilon)\right].$$

The expected fee of an uninformed bank is $\Phi^{\mathrm{U}} = \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} \phi^U(\varepsilon) d\Upsilon(\varepsilon)$, which is independent of ω.

Given $\nu^*(\varepsilon, \omega)$ is independent of ω, we can rewrite (57) as

$$\underline{\nu}(\varepsilon, \omega) = \frac{\alpha(1-\omega)\nu^*(\varepsilon)}{\rho + \delta + \alpha(1-\omega)}, \tag{59}$$

which falls in ω. In an informed meeting, given the free entry assumption, the bank is willing to trade as long as the trade surplus is positive. An informed bank offers an efficient contract and extracts all surpluses. Hence the fee is

$$\phi^I(\varepsilon, \omega) = U(\varepsilon, s_b) - \underline{\nu}(\varepsilon, \omega).$$

The expected fee of an informed bank is $\Phi^{\mathrm{I}}(\omega) = \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} \phi^I(\varepsilon, \omega) d\Upsilon(\varepsilon)$. Since $\underline{\nu}(\varepsilon, \omega)$ falls in ω, $\Phi^{\mathrm{I}}(\omega)$ rises in ω.

In equilibrium, the banks choose $\omega = 1$ if $h < \Phi^{\mathrm{I}}(\omega) - \Phi^{\mathrm{U}}$. Since $\Phi^{\mathrm{I}}(\omega) - \Phi^{\mathrm{U}}$ rises in ω and $\Phi^{\mathrm{I}}(0) - \Phi^{\mathrm{U}} > 0$, an individual bank will choose $\omega = 1$ in any equilibrium if $h < \bar{h} \equiv \Phi^{\mathrm{I}}(0) - \Phi^{\mathrm{U}}$. In other words $\lim_{i \to +\infty} \Phi^{\mathrm{I}} - \Phi^{\mathrm{U}} \geq \bar{h}$. Therefore, given any $h < \bar{h}$, by continuity, there exists $\bar{\imath}$ such that if $i > \bar{\imath}$ then $\Phi^{\mathrm{I}} - \Phi^{\mathrm{U}} > h$ and $\omega = 1$. Since all banks are informed, the quantity of deposits is at the efficient level and does not depend on i. ■

B Details of the calibrated example

In this section we provide more details regarding our calibration procedure. The unit of time is a year and the rate of time preference is $\rho = 0.04$ as in Lagos and Wright (2005).[26] The utility function is $u(y) = y^{1-a}/(1-a)$ with $a \in (0,1)$. The distribution of consumer types is given by an exponential distribution with mean 1. We interpret δ as the rate at which a consumer gets separated from her bank and set $\delta = 0.05$. This number is consistent with the J.D. Power 2019 U.S. Retail Banking Satisfaction Study according to which 4% of customers switched banks in the past year and a survey conducted by Bankrate reporting that the average U.S. adult has used the same primary checking account for about 16 years. We set the spread on banks' assets to $s_b = 0$. The average Federal fund rate in the sample is $i = 0.05$. The matching technology in the deposits markets is linear in the measure of consumers, so $\alpha(\tau) = \bar{\alpha}$.

The remaining parameters to be calibrated are $(\theta, \bar{\alpha}, \sigma, a)$. We use the measure of unbanked households to calibrate $\bar{\alpha}$. According to the FDIC Survey of Household Use of Banking and Financial Services in 2019, 5.4% of U.S. households were unbanked, which implies $\bar{\alpha} = 0.88$.[27] We choose θ to match the size of the deposit spread passthrough, $\partial \hat{s}_d / \partial i$. Drechsler et al. (2017) documents that a 100 bps increase in the policy rate leads to an average increase in the deposit spread by 54 bps, i.e., $\partial \hat{s}_d / \partial i = 0.54$. The pair, (σ, a), targets the change of aggregate deposits with respect to i. The curvature of the utility function, $a = 0.11$, is in the ballpark of the values that have been estimated in the literature (see, e.g., Craig and Rocheteau, 2008), and it is consistent with estimates from models with competitive goods markets, as in, e.g., Rocheteau and Wright (2009). The frequency of consumption opportunities, $\sigma = 0.5$, can be interpreted as the product of two parameters: the actual arrival rate of idiosyncratic consumption opportunities and a scaling parameter of the consumer surplus. So, consumption opportunities can arrive frequently, but the surplus they generate must be small.

[26] In our continuous time model, the choice of the unit of time imposes a constraint on arrival rates of matching or consumption opportunities.

[27] Alternatively, we could choose $(\theta, \bar{\alpha})$ to target the spread and passthrough. But θ and $\bar{\alpha}$ cannot be separately identified because, by Proposition 1, $(\theta, \bar{\alpha})$ affect the banking contract only via $\underline{i}(i, s_b, \theta, \bar{\alpha})$ and, by (18), the relationship between $\underline{i}$ and i remains unchanged as long as $(\rho + \delta + \bar{\alpha})(1-\theta)/\theta$ is unchanged.

Drechsler et al. (2017) report that a 100 bps increase in the policy rate induces on average a 323 bps contraction in deposits. i.e., $(\partial D/\partial i)\,/D = -3.23$.[28] We illustrate the model fit in Figure 11.

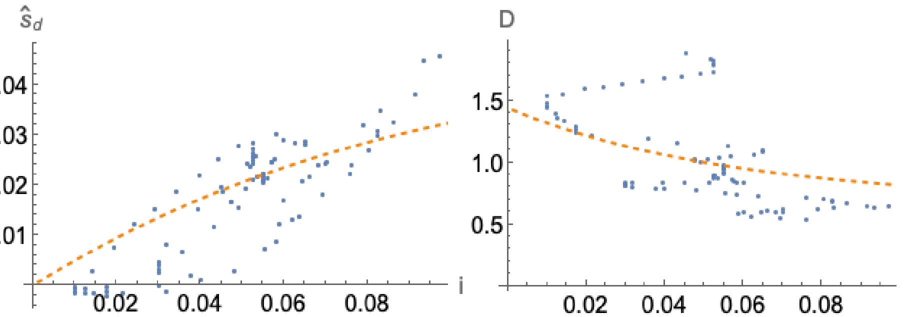

Figure 11: Fit of the calibrated model (Left) Average deposit spread (Right) Aggregate deposits

[28] The data on core deposits and deposit rate are taken from Drechsler et al. (2017) and range from 1986 to 2007 at quarterly frequency. Core deposits are the sum of checking, savings, and small time deposits and amount to 9.3 trillion or 79% of bank liabilities in 2014. Figure 1 and 2 in Drechsler et al. (2017) use deposit and spread data from 1986 to 2013, we drop the data after 2008 because the spread became negative due to a financial crisis.

C Formula for the distribution of deposits

Now we derive the probability density function illustrated in Figure 5. Let G and g be the cumulative distribution function and probability density function of $\log[d(\varepsilon)]$ among banked consumers, respectively. Then

$$G(x) = P\{x > \log[d(\varepsilon)]\} = P[e^x > d(\varepsilon)] = \Upsilon[d^{-1}(e^x)],$$

and the density g is given by

$$g(x) = G'(x) = \frac{e^x \gamma[d^{-1}(e^x)]}{d'[d^{-1}(e^x)]}.$$

Suppose ε is exponentially distributed with parameter λ. By Proposition 1, the inverse of the deposit is

$$\begin{aligned} d^{-1}(z) &= z^a[\bar{s}(i, s_b, \theta, \alpha) + \sigma]/\sigma \quad \text{for } z < d(\tilde{\varepsilon}) \\ d^{-1}(z) &= z^a \left(1 + \frac{s_b}{\sigma}\right) + 1/\lambda \quad \text{for } z \geq d(\tilde{\varepsilon}). \end{aligned}$$

The derivative $d'(\varepsilon)$ is given by

$$\begin{aligned} d'(\varepsilon) &= \frac{\varepsilon^{\frac{1}{a}-1}}{a} \left[\frac{\sigma}{\bar{s}(i, s_b, \theta, \alpha) + \sigma}\right]^{1/a} \quad \text{for } \varepsilon < \tilde{\varepsilon} \\ d'(\varepsilon) &= \frac{1}{a}(\varepsilon - 1/\lambda)^{\frac{1}{a}-1} \left(1 + \frac{s_b}{\sigma}\right)^{-1/a} \quad \text{for } \varepsilon \geq \tilde{\varepsilon}. \end{aligned}$$

The derivative $d'(\varepsilon)$ jumps up at $\varepsilon = \tilde{\varepsilon}$ because

$$\lim_{\varepsilon \uparrow \tilde{\varepsilon}} d'(\varepsilon) = \frac{d(\tilde{\varepsilon})}{a\tilde{\varepsilon}}$$

and

$$\lim_{\varepsilon \downarrow \tilde{\varepsilon}} d'(\varepsilon) = \frac{d(\tilde{\varepsilon})}{a(\tilde{\varepsilon} - 1/\lambda)}.$$

Therefore, the density $g(x)$ jumps down at $x = \log[d(\tilde{\varepsilon})]$.

D Data appendix

We now explain the data we use for our empirical evidence and calibration. In Figure 1 we use monthly data from Call Reports from 1990 Q1 to 2020 Q4. Figure 2 uses data from the Federal Reserve Economic Data (Link: https://fred.stlouisfed.org). For calibrating (σ, a) in our model, we use the time series data of deposit rate, Federal funds rate and core deposits from Drechsler et al. (2017), which is quarterly time series data from 1986-2013.