The Dynamics of Deposit Flightiness and its Impact on Financial Stability*

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Abstract

We find that the flightiness of depositors displays pronounced fluctuations over time, reaching unprecedentedly high levels after the Covid-19 crisis. Elevated deposit flightiness coincides with expansions in central bank reserves and low interest rate environments. We rationalize these trends based on heterogeneity in investors' convenience value for deposits. In our dynamic model, investors in the banking system value the convenience benefits of deposits more than those that choose to invest in non-banks. Following deposit inflows from outside investors, e.g., due to QE's reserve expansions, the marginal depositor in the banking system becomes more rate-sensitive and the risk of panic runs increases. Our findings imply that the risk of panic runs triggered by policy rate hikes is amplified when the Fed's balance sheet size is larger, highlighting a novel linkage between conventional and unconventional monetary policy.

1 Introduction

Deposits are a fundamental building block of the banking system. While stable deposits allow banks to engage in liquidity transformation and invest in long-term assets, flighty deposits can be destabilizing. They can trigger panic runs through the liquidation of illiquid assets Diamond and Dybvig (1983) and through lowering the franchise value of banks (Drechsler, Savov, Schnabl and Wang, 2023, Granja, Jiang, Matvos, Piskorski and Seru, 2024, Haddad, Hartman-Glaser and Muir, 2023). Despite the importance of deposit flightiness for financial stability, there has been no systematic analysis of its variation over time. Existing work has mostly focused on cross-sectional differences in deposit flightiness, e.g., wholesale deposits are more flighty than retail deposits, uninsured deposits are more flighty than insured deposits, etc. Nevertheless, cross-sectional comparisons of deposit flightiness do not inform us about how flighty aggregate deposits in the banking system are at a given point in time, how aggregate deposit flightiness evolves over time, and what the drivers of the deposit flightiness dynamics are.

In this paper, we analyze the magnitude, determinants, and implications of variations in the aggregate deposit flightiness over time. Empirically, we document that deposit flightiness displays pronounced fluctuations from 2000 to 2023. We find that large increases of deposit flightiness coincide with low interest rate environments and expansions in the Federal Reserve's balance sheet size. In particular, the large injection of bank reserves in the aftermath of the Covid-19 crisis elevated deposit flightiness to unprecedentedly high levels before the start of the rate hike cycle in early 2022.

We develop a model to rationalize the dynamics of deposit flightiness. Our model features heterogeneity in investors' convenience value for deposits. Investors who values deposit convenience less are more sensitive to deposit rates. At the same time, investors who value deposit convenience less are also more likely to exit the banking system and switch to non-banks. This is why variations in the sensitivity of deposit flows to deposit rates capture variations in deposit flightiness.

Importantly, our model shows that heterogeneity in investors' convenience value coupled with a fixed cost of moving funds between bank deposits and non-banks causes the marginal depositor in the banking system to be time-varying and path-dependent. At any given point in time, those remaining in the banking system value the convenience of bank deposits more than those that invest in non-banks. Thus, following large deposit inflows from outside investors, the marginal depositor in the banking system values deposit convenience less, is more sensitive to deposit rates, and is flightier in leaving the banking system. This is why aggregate deposit flightiness increases following the influx of deposits induced by QE's reserve expansions and low interest rate environments.

Our findings have two important implications. First, for a given monetary policy rate hike, the expected deposit outflow and increase in run risk are larger when it has been proceeded by QE, as QE attracts inflows and introduces flightier deposits into the banking system. Reducing the size of the Fed's balance sheet before embarking on rate hikes may alleviate these risks. We thereby pinpoint a novel linkage between conventional and unconventional monetary policy through the depositor base.

Second, the speed of rate hikes matters. Compared to a drastic one-off rate hike, smaller steps of rate hikes allow depositors to gradually flow out of the banking system so that the remaining depositors are the ones that value banks' convenience service more. Hence, depositor run risk is smaller with a slower speed of rate hikes. This result sheds light on how the path of monetary policy implementation affects the stability of the banking system.

We begin our analysis by examining fluctuations in aggregate deposit flightiness over time. Informed by the model, our proxy for the flightiness of depositors in the banking sector is how responsive they are to higher deposit rates. To isolate the sensitivity of deposit flows to deposit rates, we instrument for deposit rates using per unit asset fixed costs and salary expense, following the industrial organization literature. We then estimate the sensitivity of bank-level deposit flows to bank-level instrumented deposit rates using rolling window regressions and analyze how the regression coefficients evolve over time.

Our estimated deposit flow sensitivities display pronounced variation in the time series. As shown in Figure 1, they remained at low levels before 2008, became increasingly positive after the 2008 financial crisis, and then fell back again around 2015. In the more recent period, deposit flow sensitivities have become even larger in magnitude with a sharp rise in early 2020, reaching historical highs before the rate hike cycle started in early 2022.

We observe that deposit flow sensitivities are elevated not only following cuts in the monetary policy rate but also following expansions in unconventional monetary policy that inject central bank reserves into the banking system. In particular, after extensive rounds of Fed stimulus in response to the Covid-19 crisis, deposits became more sensitive to rate changes than ever ahead of the 2022 rate hike cycle. We argue that these observed patterns in flow sensitivities arise because investors who switch to bank deposits from other kinds of investments value the convenience of bank deposits less and are more sensitive to rates than those investors who are already invested in bank deposits in the first place. As our model will show, when more rate-sensitive investors enter the banking system during periods of deposit inflows, such as those induced by QE's reserve expansions, the aggregate depositor base becomes flightier, amplifying the risk of bank runs.

Although our proposed channel applies generally to the aggregate deposit base, we further shed light on the characteristics of the deposits that make up the aggregate deposit inflows in our sample period. Using regulatory data from the Federal Reserve, we find that relative to retail deposits, deposits by non-financial corporates experienced both a disproportionate growth following the Covid-19 reserve expansions as well as a disproportionate decline in the 2022 rate hike cycle. We also find that these fluctuations are especially pronounced for corporate deposits in non-operational accounts compared to operational accounts. The rise and fall in the proportion of corporate deposits is consistent with the observed variation in aggregate deposit flightiness given that corporate depositors are more volatile than retail depositors.

We further corroborate the variation in deposit flightiness using novel transaction-level data covering bank accounts at more than 1400 U.S. depository institutions. Among others, we observe, for each user, transactions between checking and savings accounts at different banks as well as transactions between bank accounts and investment accounts. In other words, this dataset allows us to uncover the movement of funds between banks and between banks and non-bank investment options at the depositor level.

In the cross-section of depositors, we find that the sensitivity of a depositor's flows between banks is positively correlated with the sensitivity of her flows between banks and investment options. Therefore, depositors who are more active in switching between banks are also more likely to withdraw their deposits from the banking system to outside investments. Further, the time-series variation in bank-to-bank flow sensitivities estimated using depositor-level data also closely aligns with the variation in deposit flow sensitivities estimated using bank-level data.

To rationalize the observed variation in deposit flightiness and to shed light on the implications for financial fragility, we develop a dynamic multi-bank model in which banks fund illiquid long-term projects with one-period deposits. Investors derive utility from the convenience of deposits and perceive deposits across different banks as imperfect substitutes. Crucially, the relative importance of this convenience feature varies among investors, influencing their trade-off between convenience and returns. We demonstrate that investors who place a higher value on deposit convenience exhibit lower sensitivity to deposit rates. An investor's valuation of deposit convenience, which, in turn, determines the likelihood of the investor exiting the banking system for a given interest rate spread, i.e., flightiness. Investors who value the convenience benefit of deposits less are more likely to leave the banking system, i.e., more flighty. Finally, we assume investors bear a switching cost for moving money in and out of banks, generating sluggishness in the adjustment of the depositor base.

In each period, given the deposit rate offered by banks, investors choose whether to hold deposits or to invest in an outside option without convenience, such as MMFs or Treasuries. Hence, in any given period, investors who value deposit convenience more stay in banks, while investors who value deposit convenience less invest in the outside option.

On banks' asset side, in each period, the projects mature with a certain probability and produce cash flows that are driven by the fundamentals of that period. If there are deposit outflows at a bank, it has to sell a fraction of its illiquid asset. The asset is illiquid in the sense that aggressive fire-sales are associated with heavy liquidity discounts. Specifically, banks incur a discount from selling the asset when the fraction of assets sold in a given period is above a certain threshold. Such liquidation schedule can be rationalized by a cash-in-the-market constraint or slow-moving capital. The costly liquidation region gives rise to strategic complementarity among investors and leads to potential bank runs.

Each bank chooses its deposit rate to maximize equity value in each period, internalizing the effect of deposit rates on flows. In addition to interest rates, deposit flows also depend on the previous depositor base due to the switching cost. We assume banks have common fundamentals and focus on symmetric equilibrium. This implies that banks offer the same deposit rates in equilibrium and have the same default probabilities. In equilibrium, banks offer higher deposit rates when the depositor base is flightier and when asset fundamentals are stronger. As the fundamental deteriorates, banks offer lower deposit rates, leading to deposit outflows and asset liquidation. Eventually, as fundamentals fall below an endogenous threshold, banks can no longer retain enough depositors. Run-driven outflows ensue and banks fail.

One key prediction from our model is that the expected outflow and run probability in a given period are decreasing in how much the existing marginal depositor values the convenience service that the banking sector provides. When the marginal depositor in the banking system does not value deposit convenience as much, banks face larger failure risks. As a result, all other depositors are more likely to take their money out and the probability of runs increases. Furthermore, because of the switching cost of moving funds, the depositor base exhibits stickiness, and the marginal depositor type in a given period depends on the path of fundamentals.

We then calibrate the model to investigate the financial stability impact of conventional and unconventional monetary policy, highlighting their interdependency through the depositor base. We interpret conventional monetary policy rate hikes as the outside option relative to bank deposits becoming more attractive. With respect to a given policy rate hike, the increase in bank-run probability is more significant when the existing marginal depositor is flightier. This is the case following QE,

which introduces a large amount of reserves and deposits into the banking system. As long as not all newly added reserves are costless to liquidate, the influx of investors with a lower convenience need and the sluggish adjustment of the depositor base imply that a rate hike following QE poses a higher financial stability risk than without prior QE implementation.[1] Our estimates show that the increase in bank default risk from a 2% rate hike in 2022Q1 would be significantly reduced absent the QE-induced deposit expansions following the Covid-19 crisis.

Finally, our model sheds light on the effects of more drastic versus more gradual rate hikes. Specifically, we compare a rate hike of 2% in one period with a more gradual rate hike of 1% in two consecutive periods. In the former case, the existing marginal depositor in the banking system before any rate hike does not value convenience as much and is relatively flightier, which leads to large outflows and high run probability in response to the rate increase. In the latter case, the bank can adjust its depositor base in a more contained way in the first period, given the smaller rate cut. Then, at the end of the first period, the remaining marginal depositor in the bank is not as flighty as when the rate is further increased. In other words, smaller steps of rate hikes allow the bank sector to adjust its depositor base in a more managed way without risking too much outflows in a single period that could trigger costly asset liquidations. As depositors flow out gradually, the remaining depositors value the convenience service of banks more and run risk is reduced.

Taken together, our model predictions can rationalize the variation in aggregate deposit flightiness we uncovered from the data. They also highlight the importance of understanding how various monetary policy measures influence deposit flightiness. In particular, we pinpoint an important linkage between conventional and unconventional monetary policies through the depositor base. This linkage implies that rate hikes are more destabilizing when the central bank's balance sheet size is large and when rate hikes are drastic. Reducing the supply of reserves through QT ahead of rate hikes or implementing rate hikes more gradually may help to alleviate the financial fragility concerns induced by monetary policy.

1.1 Literature Review

Our model on dynamic depositor composition and run risk contributes to the literature on bank fragility. Deposit-funded banks transforming illiquid assets are subject to coordination failure, e.g., Diamond and Dybvig (1983) and Goldstein and Pauzner (2005). More recently, Drechsler, Savov,

[1] Although reserves are perfectly liquid and safe assets in theory, banks demand reserves to satisfy a range of regulatory constraints (Copeland et al., 2021, Afonso et al., 2022, Acharya et al., 2023, Lopez-Salido and Vissing-Jorgensen, 2023). These constraints make it costly for banks to reduce their reserve holdings beyond a certain level.

Schnabl and Wang (2023), Granja, Jiang, Matvos, Piskorski and Seru (2024) and Haddad, Hartman-Glaser and Muir (2023) show that panic runs may also be driven by the "illiquidity" of banks' deposit franchise value. Gertler and Kiyotaki (2015) focus on endogenous liquidation prices in a macro banking model with runs, while He and Xiong (2012) analyze the coordination failure of depositors making rollover decisions across periods. Our notion of runs is dynamic like He and Xiong (2012) and He and Li (2024), but we further allow depositors to differ in their value for payment convenience. Few papers have considered the effect of investor heterogeneity on the risk of panic runs. Dávila and Goldstein (2023) and Mitkov (2020) allow differences in endowments and focus on the determination of optimal deposit insurance and governments' policy response in crisis times, respectively. Iyer et al. (2016) empirically show that depositor behavior depends on various factors, including deposit insurance, account age, and transaction frequency. Egan, Hortaçsu and Matvos (2017) and Jiang, Matvos, Piskorski and Seru (2023) further shed light on the effect of uninsured versus insured depositors in driving run risk. Begenau, Elenev and Landvoigt (2025) develop a model of heterogeneous banks to analze the financial stability risks of banks' uninsured deposit funding share and interest rate risk exposure. We allow for a novel source of heterogeneity in terms of investors' value for convenience and show that run risk is driven by the marginal investor in the banking system. Importantly, we focus on the endogenous variation of the aggregate depositor base over time.

Our findings also relate to the unintended consequences of QE. Diamond, Jiang and Ma (2023) show that reserve injections from QE may crowd out lending from bank balance sheets. Acharya and Rajan (2022) show that reserve injections expand bank deposits, but a subsequent shrinkage in reserves may not symmetrically reduce deposit claims, and banks may also hoard excess reserves during liquidity stress. Acharya, Chauhan, Rajan and Steffen (2023) empirically show that banks that took up more reserves during QE expanded their credit lines and demandable uninsured deposits by more but did not proportionally reduce these claims during QT, which renders them more vulnerable to liquidity shocks. Similarly, Darst et al. (2025) argue that banks adjust credit supply and manage liquidity risk following QE. Finally, Lopez-Salido and Vissing-Jorgensen (2023) develop a framework for understanding banks' demand for reserves to estimate when QT would lead to heightened interest rate volatility, while Afonso et al. (2022) also estimate banks' reserve demand and show when reserves are ample versus scarce. We highlight another important side effect of the deposit expansions from QE is that they add to and amplify the flightiness of the depositor base because of investor heterogeneity. Importantly, we show that run risk is heightened with respect to subsequent rate hikes, which uncovers an important linkage between conventional and unconventional monetary policy.

Further, our results relate to the literature on depositors' sensitivity to interest rates and the passthrough of monetary policy. Drechsler, Savov and Schnabl (2017) show that the response of

deposit flows to monetary policy shocks depends on bank market power, which varies across regions with different degrees of deposit concentration. More recently, d'Avernas, Eisfeldt, Huang, Stanton and Wallace (2023) show that depositors at large banks are less sensitive to interest rates and more attracted to the better liquidity services that large banks offer. Erel, Liebersohn, Yannelis and Earnest (2023) and Koont, Santos and Zingales (2023) show that depositors at digital banks are more sensitive to interest rates. Lu, Song and Zeng (2024) show that depositors are more alert with better payment technology. Zhang, Muir and Kundu (2024) analyze the emergence of high-rate and low-rate banks, while Gelman and MacKinlay (2024) find that banks with unsought deposit inflows have higher losses during monetary tightening. While investors' sensitivity to deposit rates is also the key economic variable in our paper, we shed light on how it varies for investors inside the banking sector over time, rather than focusing on its cross-sectional variation across banks. More closely related to us is Xiao (2020) and Wang, Whited, Wu and Xiao (2022), who follow the industrial organization literature to allow for heterogeneous investor preferences to rationalize the transmission of monetary policy to shadow banks and banks, respectively. Our findings are consistent with these results. We contribute by empirically estimating the aggregate variation in investors' rate sensitivity over time and analyzing its effect on banking sector fragility. Our results also have important implications for how the speed of rate hikes influences run risk.

Finally, in analyzing the dynamics of depositor flows and bank liquidity management, our paper also relates to dynamic banking models. Jermann and Xiang (2023) study endogenous deposit maturity as depositors trade off liquidity needs and default risks, highlighting the risk of dilution. Bolton, Li, Wang and Yang (2023) investigate both the liability and asset side management in which banks have imperfect control over their deposits. Hugonnier and Morellec (2017) study the effects of liquidity and leverage requirements on banks' financing decisions and insolvency risk.[2] In our dynamic model, banks set deposit rates optimally taking into account the switching cost that depositors face when moving money in and out of the bank. We leverage the model to study the time variation of the aggregate depositor base.

2 Data

Our empirical findings are based on several sources of data.

[2]More generally, several macro models with a banking sector focus on quantifying the effects of banking regulations in a dynamic general equilibrium model (e.g., Van den Heuvel 2008, De Nicolò et al. 2014, Begenau 2020). Jermann and Quadrini (2012) document the cyclicality of financial flows and develop a dynamic model to study the impacts of financial shocks. Finally, existing work highlights bank equity as an important state variable (e.g., Gertler and Kiyotaki 2010, He and Krishnamurthy 2013, Brunnermeier and Sannikov 2014, Rampini and Viswanathan 2018).

Call Report Data We use Call Reports data to obtain quarterly bank-level characteristics including deposit volumes and deposit rates. We calculate deposit rates by dividing deposit expense by the volume of deposits.

Deposit Data by Counterparty and Account Type We are the first to use regulatory data from the Complex Institution Liquidity Monitoring Report (FR2052) to shed light on the amount of deposits held by different counterparties using different types of deposit accounts. This data allows us to break down bank-level deposits by retail versus corporate depositors. Monthly data is reported by banks with more than $100 billion in assets, while the daily data is reported by 11 systemically important institutions. Deposits by counterparty type are available from 2018 through 2023. Deposits by account type are available from 2018 through 2021 because of a change in variable definitions in 2022.

Depositor-level Data We obtain transaction-level data of bank accounts for more than 1,400 U.S. depository institutions from a leading financial data processor from 2015 to 2022. This dataset provides, for each de-identified user, transactions between checking and savings accounts at different banks as well as transactions between bank accounts and investment accounts. In Appendix B, we provide further details on how we identify flows between banks and between banks and investment options from the data.

Aggregate Data We obtain aggregate data, including the Fed funds rate and the volume of outstanding reserves on bank balance sheets from FRED.

3 Stylized Facts

3.1 Bank-level Deposit Flow Sensitivity over Time

We first measure how deposit flow sensitivity varies over time using bank-level data. To isolate the response of deposit flows to deposit rate shocks, we instrument deposit rates using supply-side instruments from the industrial organization literature. Specifically, we follow Xiao (2020) in using fixed costs and salary expenses over total assets as instruments. The assumption is that changes in a bank's per unit fixed costs and salary expenses affect its deposit rates through the cost of producing deposits rather than depositors' demand for deposits. Indeed, the first stage regression shows that increases in fixed costs and salary expenses are associated with lower deposit rates (see Table 6).

We then use the instrumented deposit rates for bank j in quarter t, $\widehat{DepRate}_{jt}$, to estimate the rolling window regression:

$$Flow_{jt} = \beta_y \widehat{DepRate}_{jt} + TimeFE_t + \epsilon_{jt}, \tag{3.1}$$

where $Flow_{jt}$ is the deposit flow of bank j in quarter t. β_y indicates the sensitivity of bank-level deposit flows to bank-level deposit rates in rolling window y. A positive flow sensitivity β_y indicates that the deposit base has become more rate-sensitive than before, whereby deposits are more disproportionately attracted to banks offering higher deposit rates. The inclusion of time effects implies that β_y captures the sensitivity of deposit flows between banks.[3] We estimate flow sensitivities using an 8-quarter rolling window for banks that exist for four periods or more.[4] Standard errors are clustered at the bank level.

The estimated flow sensitivities in Figure 1a display significant fluctuations over time. They remained close to zero before 2008, became increasingly positive after the 2008 financial crisis and then fell back again around 2015. In the more recent period, fluctuations in deposit flow sensitivities have become even more pronounced with a sharp rise in early 2020 to reach historical highs in 2022Q, when a 1% increase in deposit rates at a given bank induced a 10.1% larger deposit flow from other banks.

Our estimated deposit flow sensitivities comove with the monetary policy cycle: they are more positive following rate cuts and in low-interest-rate environments (see Figure 1b). This finding is consistent with the transmission of monetary policy to banks (Drechsler et al., 2017) and shadow banks (Xiao, 2020). Low interest rates lower the opportunity cost of holding deposits relative to outside investment options like MMFs, which is why rate cuts and low interest rates draw deposits into the banking sector. We argue that the investors who switch from outside options to bank deposits have a lower convenience value for deposits than investors who always remain in the banking system. The convenience value, e.g., from the payment function of deposits, makes depositors less sensitive to the deposit rate. As a result, the influx of deposits renders the resulting depositor base inside the banking system more sensitive to deposit rates.

We note that fluctuations in deposit flow sensitivities are not explained by conventional monetary policy alone. They also coincide with cycles of unconventional monetary policy that inject central bank reserves into the banking system. In particular, flow sensitivities become more positive when reserves held on bank balance sheets are increasing, following QE, and become less positive when

[3] For further details regarding this specification, please refer to Appendix A.

[4] In theory, the specification can also be run quarter by quarter, but the rolling window helps to reduce the effect of seasonal fluctuations in deposit flows and improve statistical power.

reserves held on bank balance sheets are shrinking, following QT (Figure 2a). As Acharya and Rajan (2022) and Acharya et al. (2023) point out, increases in reserves on the asset side of bank balance sheets are accompanied by increases in deposits on the liability side. We argue that the investors drawn into banks through QE's reserve expansions value convenience less than the average depositor in the banking system. This is because, by revealed preferences, investors outside of the banking system should be less convenience-seeking than those who chose to be in the banking system in the first place.[5] As our model will show, the aggregate depositor base becomes more flighty when more rate-sensitive investors enter the banking system during periods of deposit inflows, such as those induced by QE's reserve expansions.

Indeed, Figure 2b shows that our estimated flow sensitivities are positively correlated with aggregate inflows to the banking system. To show this relationship more formally, we estimate

$$Flow_{jt} = \beta_1 \widehat{DepRate}_{jt} + \beta_2 \widehat{DepRate_{jt} \cdot AggFlow_t} + TimeFE_t + FE_j + Controls + \epsilon_{jt}, \quad (3.2)$$

where $AggFlow_t$ is the one-year cumulative deposit flow in quarter t, and the independent variables, $\widehat{DepRate}_{jt}$ and $\widehat{DepRate_{jt} \cdot AggFlow_t}$, are instrumented with the same fixed cost and salary expense instruments as in Equation 3.1. In addition to time fixed effects, we further control for the ratio of insured deposits, bank equity, and non-deposit liabilities in select specifications. From the estimation results in Table 1, we see that deposit flows indeed become more sensitive to deposit rates when there have been large aggregate inflows into the banking system.

One concern is that our results may be mechanically driven by changes in the ratio of demandable deposits. As pointed out by Supera (2021), there has been a secular decline in the fraction of time deposits over time. This trend may have contributed to the rise in overall deposit flightiness because there are more restrictions on withdrawing time deposits compared to demandable deposits. Nevertheless, when we estimate flow sensitivities within savings deposits, the same trends remain (Figure 3), suggesting that our findings are not mechanically driven by the shift from time to savings deposits.

Another possibility may be that the variation in flow sensitivities is driven by the fraction of uninsured deposits. Uninsured depositors are more flighty than insured depositors, and banks with more uninsured deposits are more prone to runs (Egan et al., 2017). The time-series variation of flow sensitivities for the aggregate banking sector, however, does not match the cyclical variation in

[5]Note that sellers of QE-eligible securities may not be the ultimate holders of deposits. For example, if a hedge fund sells a Treasury to the Fed via banks and then buys another security using the proceeds, the seller of that security becomes the ultimate holder of the bank deposit. However, even if these ultimate holders of bank deposits are not the original institutional investors, our channel goes through by revealed preferences, as these new deposit-holders must have been more rate-sensitive than existing depositors in the banking system.

aggregate uninsured deposits over time (Figure 4a). Controlling for the fraction of uninsured deposits at the bank level also has a limited impact on the overall trends in flow sensitivities over time (Figure 4b).[6]

Finally, one may worry whether other bank characteristics could be confounding our estimation despite the use of instruments. To this end, we control for indicators of banks' branch density and service quality using assets per branch, number of employees per branch, and salary per employee. We further control for banks' fundamentals using return on assets as a proxy following cite.[7] The results in Figure 5 closely resemble the benchmark results in Figure 1a.

So far, our estimates capture how deposit flows respond to deposit rates over time. In our model, we will show that a more rate-sensitive depositor base amplifies the risk of panic-driven runs so that fluctuations in deposit flow sensitivity imply that banks' run risk also varies over time.

3.2 Deposit Flows by Counterparty and Account Type

Our proposed mechanism is general and not limited to any particular type of deposits. That is, investors that remain in banks should always value bank convenience by more and be less rate-sensitive than investors outside of the banking system, both in aggregate and for any given deposit type. Nevertheless, it is valuable to understand how different types of deposits fluctuates over time and how they relate to the variation in aggregate deposit flow sensitivities.

We provide the first evidence on which types of depositors hold what kind of accounts for large U.S. banks. This information is required to be reported monthly for banks with assets above $100 billion and daily for 11 of the largest banks as part of the Federal Reserve's Complex Institution Liquidity Monitoring Report. These banks make up the bulk ot total bank assets in the U.S. at 74% and 55% in 2023Q4, respectively.

In Figure 6a, we first plot the total monthly deposits by counterparty type from 2018 through 2023. We observe that the three largest counterparty types are retail, non-financial corporate, and non-bank financial institutions, and that they all experienced a significant uptick in deposits in early 2020. For easier comparison, we normalize the level of deposits for each counterparty type by their values in January 2020 and plot the normalized graph in Figure 6b. Figure 6b shows that corporate

[6] Unfortunately, we cannot estimate flow sensitivities within uninsured and insured deposits because deposit expenses are not separately available for each category.

[7] A more direct proxy for banks' fundamental risk would be banks CDS spreads. However, CDS spreads are only available for a very smalll number of bank holding companies.

deposits grew by more than 60% from the beginning of 2022 to the end of 2021 before contracting by 20% relative to the baseline in the 2022 rate hike cycle. The initial growth and subsequent decline in corporate deposits was much more pronounced than for retail and small business deposits, which provides the first evidence that corporate deposits have higher volatility.[8]

In Table 2, we examine the volatility of deposits held by different counterparties more closely. Panel A shows bank-level deposit volatility calculated as the standard deviation of each bank's monthly deposits by counterparty type over the sample period, divided by their corresponding mean. We observe that at the 25^{th}, 50^{th}, and 75^{th} percentile, retail and small business deposits are less volatile than deposits by non-financial corporates, non-bank financial institutions, and other banks. This pattern is mirrored in the aggregate volatility of Panel B, which is calculated as the rolling standard deviation of the aggregate monthly deposits by counterparty type over 4-month windows, divided by the corresponding rolling mean. Similar trends are also evident from deposit volatility at a daily frequency (Panels C and D). This higher volatility of corporate deposits implies that the disproportionate growth of corporate deposits starting in March 2020 (Figure 6b) increased the flightiness of the aggregate depositor base over the same period.

Similarly, we examine the volatility of deposits by account type in Table 3 and observe that deposits in non-operational accounts are more volatile than deposits in operational accounts. This pattern may arise because firms' operations involve more regular cash transfers, while investment decisions using excess cash in non-operational accounts fluctuates by more. Further, deposits in transactional accounts are more volatile than deposits in non-transactional accounts, which is consistent with retail depositors using transactional deposits to meet liquidity shocks and non-transactional deposits as a stable store of value.[9] At the same time, Figures 7a and 7b show that deposits in non-operational accounts grew by more than deposits in operational accounts from the start of 2020 to the end of 2021, while deposits in transactional accounts grew by more than deposits in non-transactional accounts in the same period.[10] This disproportionate growth in the more volatile non-operational deposits for firms and transactional deposits for retail may have contributed to the rise of deposit flow sensitivity leading up to the 2022 rate hike cycle.

[8] We also observe that deposits at non-bank financial institutions experienced a sharp and short-lived rise in March 2020 before falling back to relatively stable values. This pattern may be explained by liquidity-providing non-banks, like MMFs and mutual funds, setting aside cash reserves in anticipation of redemption during the dash-for-cash episode in March 2020.

[9] The split between operational and non-operational accounts applies only to corporate deposits. The split between transactional and non-transactional accounts only apply to retail and small businesses accounts.

[10] Note that the sample of the account type data ends at the end of 2021 rather than 2023 because of a change in variable definition in 2022.

3.3 Depositor-level Flow Sensitivities in the Cross-section

In Section 3.1, our bank-level estimates of deposit flow sensitivities have been based on deposit flows between banks. One concern is whether this bank-to-bank flow sensitivity is informative about investors' tendency to switch between banks and non-banks as well. To verify, we use transaction-level data that allows us to uncover the movement of funds between banks and between banks and outside investment options at the depositor level. We provide further details about the data in Appendix B.

First, we show that there exists significant heterogeneity in both bank-to-bank and bank-to-non-bank deposit sensitivity across depositors. We proxy for deposit sensitivity using three measures: (1) the proportion of months in which a depositor had flows; (2) the standard deviation of flows scaled by total payment flows; (3) the sensitivity of deposit flows. We evaluate each of these three measures separately for flows between banks and flows between banks and non-banks.

To compute the third measure, we first sort depositors into 100 bins based on their standard deviation of deposit flows between banks. We then estimate bank to bank flow sensitivity for each bin b: For each bank account j of depositor i in month m, we calculate $BankFlow_{ijm}$ as the net volume of deposits transferred from other bank accounts of depositor i in the same month normalized by the total account balance of depositor i. We calculate deposit rates $DepRate_{ijm}$ by dividing interest income by account balance. Then, we estimate how deposit flows between banks respond to deposit rates:

$$BankFlow_{ijbm} = \gamma_b DepRate_{ijbm} + FE_{ib} + Controls_{jbm} + \epsilon_{ijbm}, \tag{3.3}$$

where FE_{ib} is a depositor fixed effect and and control variables include indicator variables for various time-varying account-level characteristics, including the presence of overdraft fees, ATMs, and fast payment services like Zelle. The assumption is that after controlling for these qualitative characteristics, we can interpret γ_b as the sensitivity of bank-to-bank deposit flows to deposit rates for bin b.

To capture the sensitivity of deposit flows between banks, we then re-estimate equation 3.3 replacing bank-to-bank flows $BankFlow_{ijbm}$ with outside investment-to-bank flows $NonBankFlow_{ijbm}$ and deposit rates $DepRate_{ijbm}$ with deposit spreads $DepSpread_{ijbm}$, where deposit spreads are defined relative to the Fed funds rate.

From the summary statistics in Table 4, we observe significant heterogeneity in depositors' sensitivity to move funds between banks and between banks and non-banks. The median depositor transfers funds between banks in 1.06% of months, while the 75^{th} percentile depositor transfers funds between banks in 5.32% of months (Table 4). Similarly, the median depositor transfers funds in and

out of the banking sector in 2.13% of months, while the 75^{th} percentile depositor does so in 14.89% of months. Further, some depositors display much more variation in their deposit flows between banks and between banks and non-banks as a proportion of total deposit flows. Finally, rate sensitivities of deposit flows between banks and between banks and non-banks varies in the cross section as well.

Most importantly, we find that depositors who switch funds more readily between banks are also more active in moving deposits between banks and non-banks. In Figure 8, we show binned scatter plots of depositor-level flightiness in flows between banks versus flows between banks and non-banks. Across all three measures, Figure 8 displays a clear positive relationship between the two dimensions of deposit sensitivity. These results imply that depositors that are more sensitive in substituting between banks are also more sensitive in substituting between banks and non-banks.

3.4 Depositor-Level Flow Sensitivities over Time

Having examined cross-sectional variation in depositors' flightiness, we proceed to examine how the sensitivity of bank-to-bank deposit flows evolves over time in the depositor-level data as a verification of our baseline estimates using bank-level data in Section 3.1.

We estimate how deposit flows between banks respond to deposit rates for a given depositor similar as in Equation 3.3 and repeat the estimation for each month m using the full sample:

$$BankFlow_{ijm} = \gamma_m DepRate_{ijm} + FE_{im} + Controls_{jkm} + \epsilon_{jkm}. \tag{3.4}$$

where FE_{im} is a depositor fixed effect and the control variables are the same as before. γ_m in then the depositor-level sensitivity of bank-to-bank deposit flows to deposit rates in month m.

We plot the 12-month moving average of γ_m in Figure 9. Observe that depositor-level deposit flow sensitivity falls from 2016 to early 2020, rises from early 2020 onward before declining again in early 2020. Note that this pattern closely resembles of the bank-level deposit flow sensitivity in Section 3.1, which corroborates the dynamics of aggregate depositor sensitivity over time. It is also aligned with the pattern of aggregate deposit inflows bringing in more rate-sensitive depositors into the banking system.

4 Model

Our empirical facts provide strong support that investors indeed have heterogeneous flow sensitivity. To rationalize the time-varying depositor flow-sensitivity and investigate its financial stability implications, we incorporate investor heterogeneity into a dynamic banking model with run risks (He and Xiong, 2012). The key novelty of our model is to endogenize the investor base in the banking system over time and show how it drives bank vulnerability. We start by presenting the model setup in Section 4.1 and the value functions in Section 4.2. We then derive the equilibrium run conditions and agents' optimal strategies in Section 4.3.

4.1 Setup

Investors There is measure one of continuum of investors who are infinitely lived. Each investor has one dollar available for investment, and can choose to either deposit the money with banks or invest in an outside option, such as MMFs or Treasuries. The outside option has value R. Importantly, investors are heterogeneous in how much they value the convenience feature of deposits. Such convenience benefits can be motivated by the payment function that is unique to deposits and can vary across investors depending on their payment needs. For investor i, the convenience value she derives from holding deposits is

$$\theta_i \left(\sum_{j=1}^{N} d_{i,j}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{4.1}$$

where $d_{i,j}$ is the amount of deposit that investor i holds at bank j. Deposits at different banks are imperfect substitutes because of the differentiated services offered by banks. The coefficient σ is the elasticity of substitution, capturing the degree of deposit differentiation across banks. The coefficient θ_i controls how much the investor values the convenience benefit of deposits relative to financial returns. For a given investor i, θ_i is known and fixed over time. The value of θ_i varies across investors — capturing the heterogeneity in how much weight investors place on the convenience benefit of deposits. We denote the cumulative density function (CDF) of θ_i as $H(\cdot)$, and $G(\theta) \equiv 1 - H(\theta)$. We will later show how θ_i determines investor i's sensitivity to rates and her flightiness in withdrawing from the banking system.

Furthermore, investors face switching cost $f > 0$ whenever they move money in and out of the banking system, similar to the marginal withdrawal cost in Jermann and Xiang (2023) and switching

cost in Haddad et al. (2023). Such cost is homogeneous across investors and generates sluggishness in depositor base. All investors are risk neutral with discount rate β. We assume no shorting is allowed. As a result, each investor either invests everything in bank deposits or the outside option.

Banks There are $N \geq 1$ banks in the economy. Banks offer one-period deposits to investors in order to fund long-term illiquid projects. The equity holders of banks are long-lived with discount rate $\beta \in (0, 1)$. To study the liquidity problem faced by banks, we assume that equity holders have no endowment and cannot issue equity at any point in time.

On the asset side, banks invest in projects that mature with probability λ each period. The project generates no cash-flow before maturity. If the project matures at the end of period t, it produces cash-flow $y_t \geq 0$ per unit of asset and the game ends. y_t is i.i.d. across periods and is drawn from the CDF $F(\cdot)$. Even though the event of maturity is realized at the end of period t, all agents observe a signal about the value of y_t at the beginning of period t. The signal of y_t serves as a coordinating signal among investors. This asset could be interpreted as long-term loans made by banks, whose cash flow is mostly generated upon maturity and the fundamentals of the loan varies overtime.[11]

Modeling bank-run problems with bank competition is notoriously difficult. In order to simplify the problem of bank competition, we assume that banks are symmetric, i.e. their asset side returns are homogeneous. This allows us to later characterize the dynamic investor base in a tractable way.

Next, we describe how banks adjust their balance sheet when there are deposit flows. When there are deposit inflows, banks use the influx of money to scale up their projects at per-unit cost 1. When there are deposit outflows, banks need to liquidate their assets to meet the outflows. Banks assets are illiquid in the sense that aggressive fire sales in a given period are associated with heavy discounts. Specifically, in a given period, if the asset sold is more than a fraction ϕ of the total asset, each unit is sold at $L(y) < 1$. Otherwise, each unit of asset can be sold frictionlessly at price 1. This liquidation schedule can be motivated by cash-in-the-market constraints or slow moving capital (Mitchell et al., 2007, Duffie, 2010). We assume the liquidation value is piece-wise linear in y,

$$L(y) = \min(\alpha_0 + \alpha_1 y, 1). \tag{4.2}$$

As we will show later, this liquidity discount will eventually give rise to strategic complementarity among investors.

[11] We can relax the i.i.d. assumption of y_t and also allow intermediate cash flows being generated before the project matures. Since they do not change the key mechanisms, we present the simplest case. In the calibration, we extend the model to the case when y_t follows an AR(1) process.

For each dollar of deposit, bank j promises payment $r_{j,t}$ if the asset side matures in period t; otherwise investors get face value 1 at the end of the period. Since investors are risk-neutral, this is equivalent to an expected interest rate payment of $\lambda(r_{j,t} - 1)$. We refer to $r_{j,t}$ as the deposit rate paid by bank j. Because the project generates no intermediate cash flows before maturity, banks can only pay interests when the projects mature. Because the equity holder of the banks have no endowment, the promised deposit rate to the investors $r_{j,t}$ has to be weakly smaller than the cash flow generated from the asset side y_t, i.e.

$$r_t \leq y_t \tag{4.3}$$

This is effectively a liquidity constraint, limiting how much interest payment can be promised to retain depositors.

Banks profit from the spread between the asset side returns and the deposit rates paid to investors. Bank equity holders are risk-neutral and choose the deposit rate optimally each period to maximize the expected equity value, internalizing the effect of deposit rate on flows, taking the depositor base in the banking system as given.

Timing At the beginning of each period, all agents observe the same signal about the value of y_t, which is the fundamental cash flow *if* the banks' projects mature this period. This serves as a coordination signal for the investors. Then, the banks choose deposit rates $r_{j,t}$, which investors take as given to decide whether and where to hold deposits. The banks scale up or sell their assets depending on the deposit flows. Finally, whether the projects mature or not is realized at the end of the period. If the projects mature, cash is paid out and the economy ends; otherwise, the economy continues to the next period.

4.2 Value Functions

Investors For investor i, her value from holding bank deposits in period t is denoted as $D(\{r_{j,t}\}, \theta_i, \Theta_t)$, where $r_{j,t}$ is the promised rate on bank j's deposits, θ_i is her own convenience value from holding deposits and Θ_t is the set of investors in the banking system in period t. As we will see later in Section

4.3, banks' default probabilities depend on the set of existing depositors.[12]

$$D(\{r_{j,t}\},\theta_i,\Theta_t) = \max_{\{d_{i,j,t}\geq 0\}} \underbrace{\theta_i \left(\sum_{j=1}^{N} d_{i,j,t}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}}_{\text{convenience benefit}} + \underbrace{\lambda \sum_j r_{j,t} d_{i,j,t}}_{\text{expected (gross) interest payment}} \tag{4.4}$$

$$+ (1-\lambda)\beta \mathbb{E}[(1-\mathbf{1}_{def,t+1}) \underbrace{\max\{D(\{r_{j,t+1}\},\theta_i,\Theta_{t+1}), R-f\}}_{\text{Continuation value if no bank default}} + \mathbf{1}_{def,t+1} L(y_{t+1})] \tag{4.5}$$

$$s.t. \quad \sum_j d_{i,j,t} = 1 \tag{4.6}$$

where $d_{i,j,t}$ is the amount of deposits that investor i holds at bank j in period t. The first term in Equation 4.4 is the convenience value that investor i derives from holding deposits, and the second term is the gross interest payment that the investor expects to receive. Investors with higher θ_i derive higher value from holding deposits. Equation 4.5 is the continuation value if the projects do not mature in this period. The indicator function $\mathbf{1}_{def,t+1}$ equals 1 if and only if the banks experience a run and default in period $t+1$. It is a function of the fundamental realization y_{t+1} as well as the set of existing depositors Θ_t. Because of symmetry, in equilibrium, the default risks of the banks are perfectly correlated. If the banks default in the next period, then the investor gets the liquidation value $L(y_{t+1})$. If the banks do not default, the investor chooses between staying in the banking sector to obtain $D(\{r_{j,t+1}\},\theta_i,\Theta_{t+1})$ and moving out of the banking sector to earn $R-f$.

Investors take the deposit rates offered and the default probability as given and allocate money across banks to maximize their value, subject to the constraint that the total deposits sum to one. To gain insights into how θ_i is directly related to the deposit rate sensitivity, let us consider depositor's optimization problem, which yields the following relationship between the deposit demand at bank j_1 and bank j_2,

$$\lambda(r_{j_1,t} - r_{j_2,t}) = -\theta_i \left(\sum_{j=1}^{N} d_{i,j,t}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{1}{\sigma-1}} \left(d_{j_1}^{-\frac{1}{\sigma}} - d_{j_2}^{-\frac{1}{\sigma}}\right) \tag{4.7}$$

Equation 4.7 shows that $1/\theta_i$ controls investor i's sensitivity to deposit rates when allocating deposits across banks. Investors with smaller θ_i value convenience benefit less, and hence are more sensitive to deposit rates. From the banks' perspective, deposit rate sensitivity is proportional to the average

[12] To simplify expositions, here we only show the depositor value when banks survive, which is the relevant case up until default happens.

$1/\theta_i$ for the set of investors who are in the banking system. As the depositor base changes overtime, the rate sensitivity of deposits in the banking system evolves as well.

Each period, investors compare their values from holding deposits with their outside option. If investor i already holds deposits in period $t-1$, then she will continue to hold deposits if and only if the value of holding deposits exceeds the value of the outside option less the switching cost,

$$D(\{r_{j,t}\}, \theta_i, \Theta_t) \geq R - f. \tag{4.8}$$

If investor i did not hold deposits in period $t-1$, then she will hold bank deposits in period t if and only if the value of holding deposits minus the switching cost exceeds the outside option value,

$$D(\{r_{j,t}\}, \theta_i, \Theta_t) - f \geq R. \tag{4.9}$$

Equation 4.4 implies that, investors with higher θ_i derive greater benefit from holding deposits and are therefore more inclined to remain in the banking system, all else equal. In contrast, those with lower θ_i are more likely to withdraw deposits from the banking system, all else equal, so that an individual investor's convenience value naturally captures her "flightiness." Below, we will show formally that the marginal depositor's θ determines the probability of a panic-driven bank run.

The switching cost f creates a discontinuity in investors' value function, and an inaction region of deposit rates in which the investor does not move her money. As a result, the depositor base is sticky over time and the previous period's depositor base becomes an important state variable for deposit rates, flows and default risks. This also implies that fundamental shocks or policy rate changes can have a long-lasting impact.

Given the value of holding deposits, we can characterize which investors endogenously sort into bank deposits.

Lemma 1. *For a given period t, there exists an endogenous cutoff θ_t, such that investors with $\theta_i \geq \theta_t$ hold deposits, and investors with $\theta_i < \theta_t$ invest in the outside option. In other words,*

$$\Theta_t = \{\theta_i : \theta_i \geq \theta_t\}. \tag{4.10}$$

Lemma 1 highlights an important intuition: investors who value the convenience benefit of deposits more sort into the bank, while investors who value the convenience benefit less invest in the outside option. The marginal depositor θ_t is indifferent between bank deposits and the outside option so her θ_t is a sufficient statistic for the depositor base. A smaller θ_t implies there are more deposits

in banks and the marginal depositor has a smaller convenience value. From now on, we denote the deposit value of investor i as $D(\{r_{j,t}\}, \theta_i, \theta_t)$.

Another implication of Lemma 1 is that when the bank receives deposit inflows, the incoming depositors necessarily have lower convenience values than the incumbents. As the volume of inflows increases, the convenience value of the marginal depositor declines, making that depositor more prone to exit the banking system. Conversely, during deposit outflows, the marginal depositor's convenience value increases, reducing her propensity to withdraw funds thereafter. Hence, our model establishes a tight link between deposit-flow dynamics and shifts in the characteristics of the depositor base.

Banks We denote bank j's value function as $V(y_t, r_{j,t}, \theta_t)$, where y_t is the fundamental cash flow in period t, $r_{j,t}$ is the interest paid to depositors, and θ_t is the marginal depositor in the banking system. Conditional on not experiencing a run, the banker's equity value is

$$V(y_t, r_{j,t}, \theta_t) = \lambda(y_t - r_{j,t})D_{j,t} + (1-\lambda)\beta\mathbb{E}[(1 - \mathbf{1}_{def,t+1})V^*(y_{t+1}, \theta_{t+1})], \tag{4.11}$$

where $D_{j,t}$ is the amount of deposits in the bank. If the project matures, the banker earns $y_t - r_{j,t}$ per unit of deposit. If the project does not mature and the bank does not experience a run, the banker gets the continuation value $V^*(y_{t+1}, \theta_{t+1})$, which is a function of next period's fundamentals y_{t+1} and next period marginal depositor θ_t.

When the bank does not face a run, its equity holder's problem is to choose a deposit rate $r_{j,t}$ — taking as given the rates set by other banks and the aggregate depositor base θ_t — to maximize its value function $V(y_t, r_{j,t}, \theta_t)$, subject to the liquidity constraint in Equation 4.3. However, if outflows become too large, the bank may be forced to liquidate a substantial portion of its assets at steep discounts, potentially triggering a depositor run. In that case, the bank fails and its value drops to zero.

Throughout the analysis, we focus on symmetric equilibrium where all banks adopt the same equilibrium strategy. Hence, when there is no confusion, we collapse the equilibrium deposit rates offered $\{r^*_{j,t}\}$ to simply r^*_t.

Evolution of Depositor Base Due to the switching cost f of moving money in and out of the banking system, the depositor base is sticky over time. Specifically, if there is inflow into the banking system, it must mean that the marginal depositor is willing to pay the fixed cost f to move money into the banks; alternatively, if there is outflow, it must mean the marginal depositor is indifferent between

staying in the banking system and receiving the outside option minus the fixed cost. Finally, there is an inaction region when there is no flow.

$$\begin{cases} D(\{r_{j,t}\}, \theta_t, \theta_t) = R - f & \text{if} \quad \theta_t > \theta_{t-1} \\ D(\{r_{j,t}\}, \theta_t, \theta_t) \in (R - f, R + f) & \text{if} \quad \theta_t = \theta_{t-1} \\ D(\{r_{j,t}\}, \theta_t, \theta_t) = R + f & \text{if} \quad \theta_t < \theta_{t-1} \end{cases} \tag{4.12}$$

As the above equation shows, the current period marginal depositor θ_t depends on the previous period depositor base θ_{t-1} and current period interest rates offered.

Connection with the Empirical Results Before characterizing the equilibrium outcomes, we provide a quick mapping between our model setting and our stylized facts in Section 3. First, recall that the deposit flow sensitivities in Figure 2b reflect changes in the sensitivity of deposits to rate differentials. In the model, the rate sensitivity of deposits across banks is determined by the average investor's rate sensitivity within the banking system. Hence, positive deposit flow-sensitivity estimates imply that this underlying average rate sensitivity has increased.[13] Further, as Lemma 1 shows, changes in rate sensitivity are driven by changes in the marginal depositor's flightiness θ_t, which in turn is closely linked to aggregate deposit flows—a relationship we confirm empirically in Table 1. Our empirical estimates therefore map observed changes in aggregate flows directly into corresponding movements in θ_t, thereby linking the model's theoretical mechanism with our empirical findings.

4.3 Equilibrium Analysis

In this section, we first characterize when banks experience runs and defaults. We then proceed to solve for banks' optimal strategy and the deposit flows in equilibrium. We find that the risk of panic run increases not only when fundamentals are poor but also when the previous period's marginal depositor is flightier.

4.3.1 Bank Runs

When a bank sells less than ϕ fraction of its asset, there is no liquidation discount. Hence a bank can always sell the necessary amount of assets to meet outflows. However, when outflows exceed ϕ,

[13] Since our model is stationary, these predicted changes should be interpreted relative to a long-run trend, which may itself reflect digitization or other structural shifts in the economy.

the bank needs to sell more assets for each unit of deposit outflow due to fire-sale discounts. This incurred discount in turn makes remaining investors more likely to leave as well. We show that when the liquidity discount is large, i.e., α_0 and α_1 are small, the bank experiences a run if it cannot retain more than $(1-\phi)$ fraction of its investors.

Since in equilibrium banks are symmetric and have the same amount of deposits, each bank's deposit flow is perfectly correlated with the aggregate flow. To characterize the aggregate flow, we define $\bar{\theta}_t$ as the "critical" depositor in period t, in the sense that if the depositor with convenience benefit $\bar{\theta}_t$ leaves, then the banking sector experiences more than ϕ fraction of outflows and the banks need to liquidate more than ϕ fraction of assets, incurring high liquidation losses, i.e.,

$$\underbrace{G(\theta_{t-1}) - G(\bar{\theta}_t)}_{\text{flow}} = \phi G(\theta_{t-1}). \tag{4.13}$$

Banks can potentially reduce outflows by increasing the deposit rate paid to investors. However, such deposit rate is bounded above by the asset side payoff y_t. When y_t is low, banks may not be able to pay the deposit rate necessary to retain a critical mass of investors. As we show in Lemma 2, when y_t falls below an endogenous threshold, all depositors choose to leave, triggering a bank run. Under symmetric equilibrium, we can write the depositor's value function as $D(r_t^*, \theta_i, \theta_t)$, given all the banks will offer the same deposit rate r_t^*.

Lemma 2. *When α_0 and α_1 are small, a bank experiences a run in period t when $y_t < y^*(\theta_{t-1})$, where θ_{t-1} is the previous period's marginal depositor in the banking sector. The run threshold $y^*(\theta_{t-1})$ is defined implicitly by,*

$$D(y^*(\theta_{t-1}), \bar{\theta}_t(\theta_{t-1}), \bar{\theta}_t(\theta_{t-1})) = R - f, \tag{4.14}$$

where $\bar{\theta}_t$ is defined in Equation 4.13.

Lemma 2 shows that when the liquidation discount is large, all investors choose to leave the bank if the critical depositor $\bar{\theta}_t$ chooses to leave, due to the strategic complementarity from the liquidation costs. Hence, whether banks can survive depends on whether they can offer a high enough deposit rate to convince the critical depositor to stay. When y_t is smaller than the threshold $y^*(\theta_{t-1})$, the critical investor $\bar{\theta}_t$ leaves even when banks set the highest deposit rate possible $r_{j,t} = y_t$. In this case, all investors leave, triggering a bank run. When y_t is above this threshold, then banks can set a high enough deposit rate to retain enough investors.

Similar to He and Xiong (2012), the run threshold y^* is endogenously pinned down by the inter-temporal strategic complementarity among investors making rollover decisions in different periods: if future investors are more likely to run, current investors require a higher deposit rate, raising the run threshold and the run probability.[14]

Although bank runs caused by liquidity discounts have been studied extensively in the literature, a novel feature of our model is that the run probability is closely tied to the types of existing depositors in the banking system, which are endogenous and time-varying. Proposition 1 characterizes how the existing depositor base affects the equilibrium run probability.

Proposition 1. *The critical depositor $\bar{\theta}_t$ in period t is increasing in the previous period's marginal depositor's θ_{t-1}. The run threshold $y^*(\theta_{t-1})$ and a bank's run probability is decreasing in θ_{t-1}.*

Proposition 1 formally shows that the flightiness of the marginal depositor θ_{t-1} determines the risk of panic runs. When the previous period's marginal depositor is flightier (with lower θ_{t-1}), then the critical depositor in the current period is also flightier. This implies that, all else equal, a bank needs to pay higher interest rates in order to convince depositors to stay. Consequently, there is a higher run threshold and larger run probability in equilibrium.

Furthermore, Proposition 1 also highlights how a given investors' value of deposits depends on other types of investors in the banking system. If the marginal depositor is flightier, this increases future run probability and lowers the value of bank deposits for *all* investors in the current period.

Having characterized the run condition, we can rewrite bank j's problem as the following,

$$V^*(y_t, \theta_t) = \max_{r_{j,t}} \quad V(y_t, r_{j,t}, \theta_t) \tag{4.15}$$

$$s.t. \quad r_{j,t} \leq y_t \tag{4.16}$$

$$D_{j,t} \geq (1-\phi) D_{j,t-1} \tag{4.17}$$

where the demand curve faced by the individual bank $D_{j,t} \equiv \int_{\theta_i \geq \theta_t} d_{i,j,t}$ depends on the deposit rates offered by other banks as well as the aggregate depositor base. When constraint (4.16) and (4.17) cannot be both satisfied, the bank fails.

Bank's Liquidity Management So far, we have abstracted away from banks' asset side adjustment to illustrate the main mechanism. One concern is that as deposit inflows increase the flightiness of the

[14] Because of strategic complementarity, a bad run equilibrium always exists in our model in any given period. However, a good equilibrium only exists when the fundamental cash flow is above the endogenous run threshold y^*. We assume that a good equilibrium is selected whenever it exists.

marginal depositor, banks may want to disproportionately purchase liquid assets over illiquid assets, which would create an offsetting effect on run risk. To this end, we extend the model to allow banks' portfolio composition to vary with the flightiness of the marginal depositor and discuss the conditions under which our baseline result in Proposition 1 goes through. Specifically, we allow the fraction of liquid assets $\phi(\theta_t)$ to be a function of the marginal depositor flightiness θ_t. One could think of this function as the outcome of banks' optimal portfolio choice problem given the banking sector's depositor base. Here we model it in a reduced form way, where we assume that the chosen fraction of liquid asset is higher when the marginal depositor becomes flightier, i.e., $\phi'(\theta_t) < 0$. We then have the following corollary

Corollary 1. *When α_0 and α_1 are small, the run threshold $y^*(\theta_{t-1})$ and the bank's run probability decreases with θ_{t-1} if*

$$\frac{G'(\theta_{t-1})}{G(\theta_{t-1})} < \frac{\phi'(\theta_{t-1})}{1-\phi(\theta_{t-1})}. \tag{4.18}$$

To understand Corollary 1, consider the relationship between the critical depositor $\bar{\theta}_t$ and the previous period marginal depositor θ_{t-1}. As before, the critical depositor is defined as the depositor whose departure would force banks into selling illiquid assets and incur liquidation discounts. The marginal depositor influences banks' default probabilities by affecting who the critical depositor is. Different from before, ϕ now varies with θ_{t-1}, which changes the relationship between the critical depositor and the marginal depositor. Specifically, $\bar{\theta}_t$ is now defined by

$$G(\theta_{t-1}) - G(\bar{\theta}_t) = \phi(\theta_{t-1})G(\theta_{t-1}). \tag{4.19}$$

When ϕ is fixed, $\bar{\theta}_t$ is always increasing in θ_{t-1} — as the marginal depositor becomes flightier, the critical depositor also becomes flightier, which means banks need to promise higher deposit rates to convince investors to stay in the banking system. However, if banks can increase the fraction of liquid asset ϕ as the marginal depositor becomes flightier, i.e., $\phi' < 0$, the relationship between the flightiness of the critical depositor and that of the marginal depositor is weakened. Condition (4.18) compares the adjustment in liquid assets scaled by the existing fraction of illiquid assets $|\frac{\phi'(\theta_{t-1})}{1-\phi(\theta_{t-1})}|$ and the amount of deposit flow $|\frac{G'(\theta_{t-1})}{G(\theta_{t-1})}|$ scaled by existing depositor base.[15] When the two terms are exactly equal, it implies all deposit inflows are invested in the liquid asset. As a result, the adjustment in asset composition fully offsets the change in the depositor base, and the critical depositor flightiness does not vary with the marginal depositor flightiness at all. Outside of this extreme case, Corollary 1

[15]Note that $\phi' < 0$ and $G' < 0$.

states that our results go through as long as the indirect effect from adjusting ϕ does not fully offset the direct effect from the change in the depositor base.

4.3.2 Deposit Rates and Flows

To determine the endogenous depositor base in the banking system, we solve for banks' optimal policy function and its implication for deposit flows. In general, the marginal depositor in period t, θ_t, is determined by the previous period's marginal depositor θ_{t-1} and current period fundamentals y_t.

Suppose a bank does not face a run, its problem is to maximize equity value given the deposit demand function and the flow constraint in Eq. (4.17). Denote the Lagrangian Multiplier in front of the flow constraint Eq. (4.17) as ι. Bank j's first order condition with respect to its deposit rate $r_{j,t}$ is

$$-\lambda D_{j,t} + \left[\lambda(y_t - r_{j,t}) + \iota + (1-\lambda)\beta \frac{\partial \mathbb{E}[(1-\mathbf{1}_{def})V^*]}{\partial D_{j,t}}\right] \int_{\theta_t} \frac{\partial d_{i,j,t}}{\partial r_{j,t}} dF(\theta) = 0 \tag{4.20}$$

The first term captures the additional interest expense if the deposit rate is higher, while the second term captures the benefit of the additional deposits that a higher rate would attract. Finally, if the flow constraint is binding, the bank needs to set a higher rate than otherwise to avoid large-scale asset sales and bank runs. Note that an individual bank takes the aggregate depositor base, characterized by θ_t, as given, but internalizes the effect of deposit rates on flows between banks.

Furthermore, because of the switching cost f, the deposit flow implied by the equilibrium deposit rate is characterized by different regions in Proposition 2.

Proposition 2. *For a given θ_{t-1}, there exists an outflow threshold $y_{out}(\theta_{t-1})$, defined by Equation D.25, and an inflow threshold $y_{in}(\theta_{t-1})$, defined by Equation D.26, such that*

1. *For $y_t \in [y^*(\theta_{t-1}), y_{out}(\theta_{t-1}))$, $\theta_t^* = \min\{\theta_1(y_t), \bar{\theta}_t\}$, where $\theta_1(y_t)$ is defined by Equation D.27. In this case, $\theta_t^* > \theta_{t-1}$ and the bank has deposit outflows.*
2. *For $y_t \in [y_{out}(\theta_{t-1}), y_{in}(\theta_{t-1})]$, $\theta_t^* = \theta_{t-1}$. There is no deposit flow.*
3. *For $y_t > y_{in}(\theta_{t-1})$, $\theta_t^* = \theta_2(y_t)$, where $\theta_2(y_t)$ is defined in Equation D.28. In this case, $\theta_t^* < \theta_{t-1}$ and the bank has deposit inflows.*

Proposition 2 provides a complete characterization of the banking sector's marginal depositor under different scenarios. In the first case when the fundamentals are weak, banks do not want to

invest much. Hence banks set low deposit rates, which lead to moderate degree of deposit outflows. However, the outflows cannot be too large or else banks risk selling large amounts of assets that incur liquidation discounts. When y_t is very low, the flow constraint starts to bind, in which case banks are forced to set a higher deposit rate than the unconstrained level to reduce the outflows. When y_t is below y^*, banks cannot keep the critical depositor and experience runs, as explained in Section 4.3.1. In the second case, y_t is in an intermediate region with no flow at all. This inaction region exists because of the switching cost. Finally, in the third case, y_t is so high that banks want to make more investments by attracting more deposits. Competition among banks leads to high deposit rates, which convince outside investors to pay the switching cost and move money into banks. This only occurs when the fundamentals are above the inflow threshold $y_{in}(\theta_{t-1})$.

Therefore, our model endogenously links the flightiness of the current deposit base with the fundamentals on the asset side and the previous period depositor base. Intuitively, the marginal benefit of deposits is larger when the fundamentals are stronger. Hence, when y_t is larger, banks set higher rates, which attract flightier depositors. Furthermore, the depositor base is sticky due to the switching cost, which is why the marginal depositor's flightiness tends to be positively correlated across periods. Figure 10a provides a numerical illustration of the equilibrium strategy for two different levels of θ_{t-1}.

Having characterized the bank's optimal policy function, we next discuss how the magnitude of deposit flows depends on the fundamentals and the previous period's marginal depositor. The details are presented in Corollary 2.

Corollary 2. *For a given θ_{t-1}, θ^* is decreasing in y_t. The net deposit flow in period t, $G(\theta^*(y_t, \theta_{t-1})) - G(\theta_{t-1})$, is weakly increasing in y_t and θ_{t-1}.*

Figure 10b provides a numerical illustration of the equilibrium deposit flows. The banking sector's net inflow increases with y_t because banks set higher deposit rates when the fundamentals are stronger. Furthermore, banks are more likely to attract inflows when the previous period's depositor base is smaller and less flighty. As a result, the net inflow is increasing in θ_{t-1}.

Our model highlights that the deposit flow is an important object to keep track of for banking sector fragility. Given Lemma 1, whenever we see deposit inflows from the outside, the marginal depositor in the banking system becomes flightier, and whenever we see outflows, the marginal depositor becomes less flighty. Furthermore, the marginal deposit type affects the run probability directly, as shown in Proposition 1. Hence, the endogenous determination of flows characterized in Corollary 2 governs the evolution of financial fragility risks over time.

5 Implications for Monetary Policy and Financial Stability

In this section, we study the joint effect of conventional and unconventional monetary policy on financial stability considering a heterogeneous and path-dependent depositor base.

We interpret conventional monetary policy as changing the value of the outside option R, since the returns of short-term assets held by money market funds are mostly determined by the policy rate (Drechsler et al., 2017, Xiao, 2020).

We interpret unconventional monetary policy as an inflow of investors into the banking system. This mapping follows Acharya and Rajan (2022) and Acharya et al. (2023), who point out that reserve injections from QE expanded the depositor base.

We first extend and calibrate the model in Section. In Section 5.2, we show that the impact of rate hikes on financial fragility is larger after QE, which points to a novel interaction effect between conventional and unconventional monetary policy. Further, we evaluate how the speed of rate hikes matters for financial stability in Section 5.3.

5.1 Model Calibration

We calibrate the model to match the size-weighted average of all U.S. banks. Unless otherwise mentioned, we use the call report data in Section 2 and average over the sample period from 2000Q1 to 2019Q4, before the latest round of QE. We take each period in the model to be one year and use annualized returns and interest rates. We summarize the empirical targets and moments in Table 5a and Table 5b . The calibrated parameter values are shown in Table 5c. In the remainder of this subsection, we discuss our calibration approach and intuition.

First, on the asset aside, we relax the model assumption that y_t is i.i.d. across periods. Instead, we extend the model to let y_t follow an AR(1) process, with mean μ and auto-correlation coefficient $\rho < 1$.

$$y_t - \mu = \rho(y_{t-1} - \mu) + \epsilon_t \qquad \epsilon_t \sim N(0, \sigma_y^2), \tag{5.1}$$

where ϵ_t is the shock in period t and is i.i.d. across periods. We run an AR(1) regression using the gross return on assets from just the interest income, and we set ρ to the AR(1) coefficient from the regression. Furthermore, we set the expected project maturity $1/\lambda$ to the average bank asset maturity in the data.

For the liquidation value function, $L(y) = \min(\alpha_0 + \alpha_1 y, 1)$, we set $\alpha_0 = 0$ and match $1 - \alpha_1$ to the weighted average discount of bank assets. We follow Bai et al. (2018) to use the New York Fed's repo haircut data as liquidation discounts for Treasuries, agency securities, corporate bonds, municipal bonds, asset-backed securities, and mortgage-backed securities. For the cost of liquidating loans, we apply the estimate in Chernenko and Sunderam (2020) that loans are 4.8 times as illiquid as corporate bonds. For the liquid asset fraction, ϕ, we match the amount of "ample" reserves that can be liquidated without costs.

We follow the literature (e.g., He and Krishnamurthy 2019 among others) and set the time discount rate to 2%, i.e. $\beta = 0.98$. We set the outside option value R to $1 + \overline{FFR}$ where $\overline{FFR}$ is the average Fed funds rate in our sample period.

To calibrate the remaining parameters, we simulate model moments to match their empirical counterparts. We assume the convenience value of investors θ_i follows an exponential distribution, i.e., $H(\theta) = 1 - e^{-\gamma\theta}$. We jointly estimate the rate parameter γ, switching cost f, the elasticity of substitution σ, the average asset return μ and the volatility of the shock process in Equation 5.1 to match the correlation between aggregate deposit flow and deposit spreads, the aggregate deposit flow volatility, the median deposit rate, the average asset return conditional on survival, and the median default probability in the data. We use the correlation between the aggregate deposit flow and the average deposit spread to infer the parameter γ.[16] The default probabilities are obtained from the average bank CDS spreads. We simulate the model for 10,000 periods, discard the first 500 periods to reduce the impact of the initial starting point, and calculate the same moments using model-simulated data.[17]

5.2 Counterfactual: Interaction Effect between QE and Rate Hikes

In this exercise, we would like to understand how the effect of policy rate hikes on run risk interacts with QE. When the monetary policy rate is increased, the return that investors can earn from switching to the outside options, R, increases, leading to deposit outflows and raising the probability of bank runs. At the same time, reserve injections from unconventional monetary policy trigger an influx of deposits (Acharya et al., 2023, Lopez-Salido and Vissing-Jorgensen, 2023). By revealed preferences, these incoming investors value the convenience benefit of deposits less compared to existing depositors (Lemma 1), so the marginal depositor becomes flightier after the implementation of QE, i.e., θ_{t-1}

[16] While bank-to-bank rate sensitivity depends solely on the level of the marginal depositor's θ_t at each date, the sensitivity of flows between the banking sector and outside investments is governed by the full distribution of θ.

[17] If the simulated fundamental value in a given period is below the run threshold in that period, we replace it with the value at the run threshold.

decreases. Therefore, we expect the same rate hike to cause a larger jump in run risk and outflows following a larger amount of QE.

First, we show that run risk is more sensitive to rate hikes when the marginal depositor has a lower convenience value i.e., when θ_{t-1} is lower. We demonstrate this result by analyzing the impact of an unexpected 2% rate hike at the end of 2022Q1, which marks the start of the Federal Reserve's most recent rate hike cycle. This increases the value of the outside option by 2%. We set the starting point of the fundamental value y to match the asset return in 2022Q1 and estimate the increase in run risk with different convenience values of the existing marginal depositor currently in the banking system.

Figure 11a shows that the increase in bank default probability for this 2% rate hike is increasing in the flightiness of the marginal depositor. When the marginal depositor in the banking sector values convenience by less, all investors expect banks to fail with higher probability in the future. Hence, investors are more likely to withdraw their deposits in the current period when the outside option becomes more attractive, leading to a larger jump in default risk.

We then ask how much QE in the aftermath of the Covid-19 crisis raised the risk from subsequent rate hikes by drawing in less convenience-seeking investors into the banking system. Of course, deposit expansions from QE are initially backed by an increase in reserves on the asset side of bank balance sheets. Although reserves are perfectly liquid and safe assets in theory, banks have substantial demand for reserves to satisfy a range of regulatory constraints (Copeland et al., 2021, Afonso et al., 2022, Acharya et al., 2023, Lopez-Salido and Vissing-Jorgensen, 2023). These constraints render it costly for banks to reduce their reserve holdings beyond a certain level. That is why a substantial portion of bank reserves are costly to liquidate in practice. Unless the entire increase in reserves is completely costless to sell, the amplification effect of a flightier deposit base on run risk remains, as shown in Corollary 1. Furthermore, the equilibrium distribution of reserves across banks also varies, where some banks may absorb a disproportionate amount of deposit expansion relative to their reserve holdings. The increase in run risk would be larger at these banks.

To quantify the interaction effect of conventional and unconventional monetary policy, we compare the effect of a 2% rate hike with and without QE. In the baseline, we set the convenience value of the marginal depositor equal to the simulation results. The reserve expansion in QE attracts new deposits (Acharya et al., 2023), which increases the average deposit rate sensitivity. With QE, we adjust the marginal depositor in the model such that the change in the deposit rate sensitivity matches with the cumulative flow sensitivity estimated between 2020Q1 to 2022Q1 in Figure 1a. From Figure 11b, we see that when the 2% rate hike follows QE, there is a 182 bps increase in bank default probability.

In comparison, if the same 2% rate hike were implemented absent of QE, the increase in bank default probability would be reduced by almost 50% to 94 bps.

Our results indicate that the financial stability risk of rate hikes crucially hinges on the flightiness of the depositor base, which is in turn affected by the amount of deposit inflows from QE. Our results also imply that unconventional monetary policy has long-lasting implications for the financial stability impact of conventional monetary policy. Hiking interest rates when central bank balance sheets are inflated by QE bears higher financial stability risk than otherwise. However, these risks may be alleviated from tapering QE or conducting QT before embarking on a rate hike cycle so that flightier investors can be drained from the banking system ahead of time.

5.3 Counterfactual: Speed of Rate Hikes

We further shed light on how the speed of rate hikes affects run risk. The baseline case is a drastic rate hike of 2% in the first period (and stays at 2% in the subsequent period). In the counterfactual, we allow the same 2% to occur over two period with a gradual rate hike. That is, policy rates unexpectedly increase by 1% in the first period, and then again by 1% in the second period.

Figure 12 shows the changes in default risk under QE in both cases. We observe that the default probability increases more in the drastic rate hike case than in the gradual rate hike case. The gradual rate hike is more stabilizing because the small rate increase in the first period gives the banking sector time to adjust its depositor base, allowing the flightiest investors to leave. Since the rate increase is small, the banks are able to manage this mild outflow by selling a small fraction of assets without incurring heavy liquidation discounts. As a result, the run risk is small. In the second period, when the rate is eventually increased by 2%, the depositors remaining in the banking system are those who value convenience benefits more than those at the beginning of the cycle, and are less likely to leave for any given outside option value. Hence, the default probability in the second period is also relatively small. In contrast, the drastic rate hike occurs when the marginal depositor has a low convenience value and is more inclined to withdraw, which increases the risk of large outflows in the same period that trigger costly asset liquidations.

We note that these results arise from the interaction between depositor heterogeneity and the asset liquidation schedule. For the former, the speed of rate hikes would not matter if depositors are homogeneous because the critical depositor remains the same even regardless of how the banking sector adjusts its depositor base. For the latter, we let the banks sell ϕ fraction of assets in each period without discount, so spreading out asset sales over two periods is less likely to trigger costly

liquidation. Essentially, what we need is that the long-run elasticity in the asset market is larger than the short-run elasticity, which is supported by theories such as slow moving capital. Empirically, in many markets, the long-run demand is more elastic than the short-run demand (Duffie, 2010).

To summarize our two counterfactuals, the effect of policy rate hikes on bank stability crucially depends on who is in the banking system. Raising policy rates is more destabilizing when the existing depositor base is flightier. QE draws deposits into banks that render the marginal depositor more flighty. At the same time, drastic rate hikes do not allow for a gradual adjustment of the marginal depositor to a less flighty type. That is why drastic rate hikes following large amounts of reserve injections, like the rate hike cycle that started in 2022Q1, can be especially destabilizing for the banking system.

6 Conclusion

In this paper, we analyzed the magnitude, determinants, and implications of variations in the aggregate deposit flightiness over time. We show that deposit flightiness displays pronounced fluctuations over time. Large increases in deposit flightiness coincide with low interest rate environments and expansions in the Federal Reserve's balance sheet size. In particular, the large injection of central bank reserves in the aftermath of the Covid-19 crisis elevated deposit flightiness to unprecedentedly high levels before the start of the rate hike cycle in early 2022.

We rationalize the variation in deposit flightiness based on heterogeneity in investors' convenience value for deposits. With a fixed cost of moving deposits, the marginal depositor in the banking system is time-varying and path-dependent. At any given point in time, those remaining in the banking system value the convenience of bank deposits by more than those that invest in outside options. Following large deposit inflows from outside investors, the marginal depositor in the banking system values convenience less, and the aggregate depositor base becomes flightier. This is why aggregate deposit flightiness increases following the influx of deposits induced by QE's reserve expansions and low interest rate environments.

Our findings have far-reaching policy implications. First, for a given monetary policy rate hike, the expected deposit outflow and increase in run risk are larger following large-scale QE programs, which introduce flightier deposits into the banking system. In contrast, reducing the size of the Fed's balance sheet before embarking on rate hikes may alleviate these risks. Going forward, this linkage between the financial fragility risk of monetary policy and the size of the central bank's balance sheet is especially relevant as central banks navigate monetary policy in ample reserve environments.

The second implication is that more drastic rate hikes amplify the increase in run risk. Relative to drastic one-off rate hikes, smaller steps of rate hikes allow depositors to gradually flow out the banking system so that the remaining depositors are the ones that value banks' convenience service more. Hence, deposit run risk is smaller with a slower speed of rate hikes. This result sheds light on how the path of monetary policy implementation affects the stability of the banking system.

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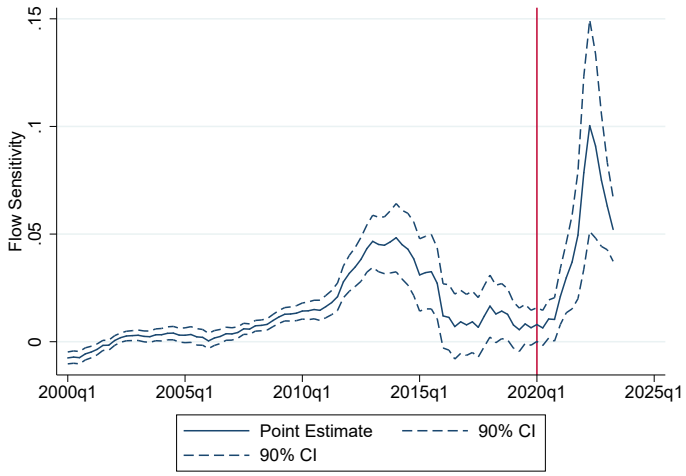
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7 Figures and Tables

Figure 1: Deposit Flow Sensitivity and Monetary Policy

Panel (a) shows deposit flow sensitivities over time. Deposit flow sensitivities are obtained from regressing bank-level deposit flows on instrumented bank-level interest rates (%) as described in Equation 3.1. The vertical red line corresponds to 2020Q1. Panel (b) shows deposit flow sensitivities and the Fed funds rate over time. Standard errors are clustered at the bank level.

(a) Deposit Flow Sensitivity



(b) Deposit Flow Sensitivity and Monetary Policy

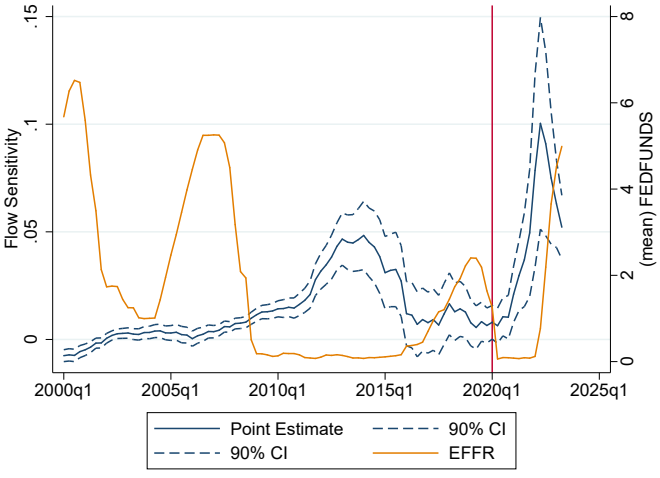
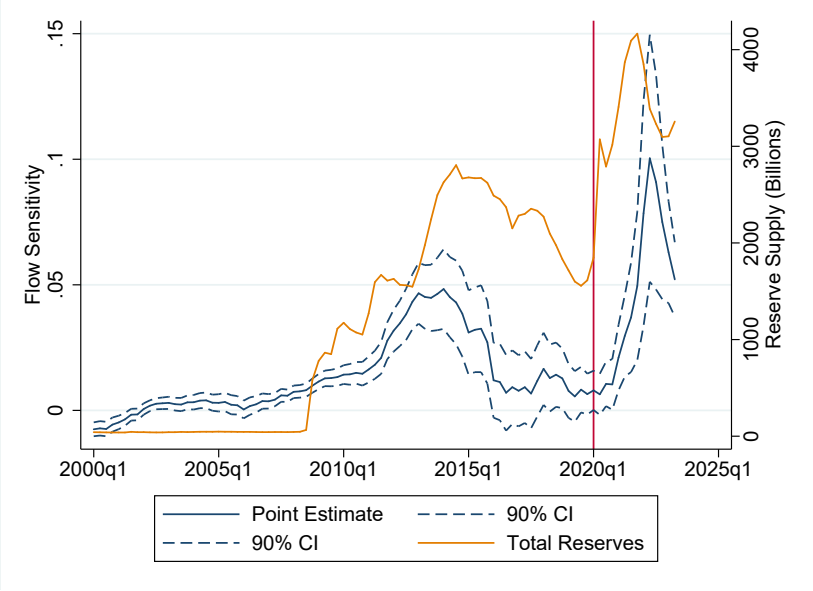


Figure 2: Deposit Flow Sensitivity, Deposit Flow, and Reserve Supply

Panel (a) shows deposit flow sensitivities and the supply of reserves over time. Deposit flow sensitivities are obtained from regressing bank-level deposit flows on instrumented bank-level interest rates (%) as described in Equation 3.1. Reserve supply is the total volume of outstanding reserves on bank balance sheets. The vertical red line corresponds to 2020Q1. Panel (b) shows deposit flow sensitivities and agregate deposit flows over time. Aggregate deposit flows are calculated as 8-quarter cumulative flows. Standard errors are clustered at the bank level.

(a) Deposit Flow Sensitivity and Reserve Supply



(b) Deposit Flow Sensitivity and Aggregate Deposit Flow

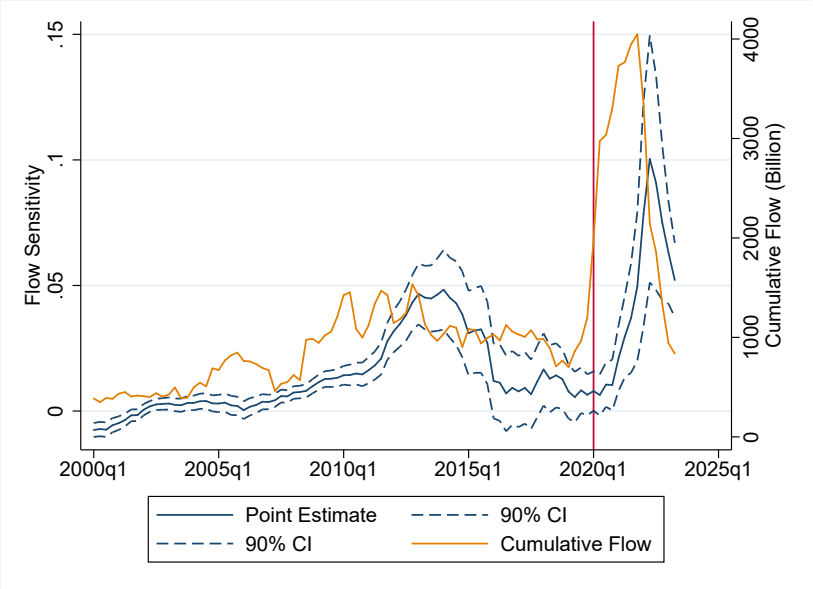


Figure 3: Savings Deposit Flow Sensitivity

This figure shows savings deposit flow sensitivities. Savings deposit flow sensitivities are obtained from regressing bank-level savings deposit flows on instrumented bank-level interest rates (%) as described in Equation 3.1. The vertical red line corresponds to 2020Q1. Standard errors are clustered at the bank level.

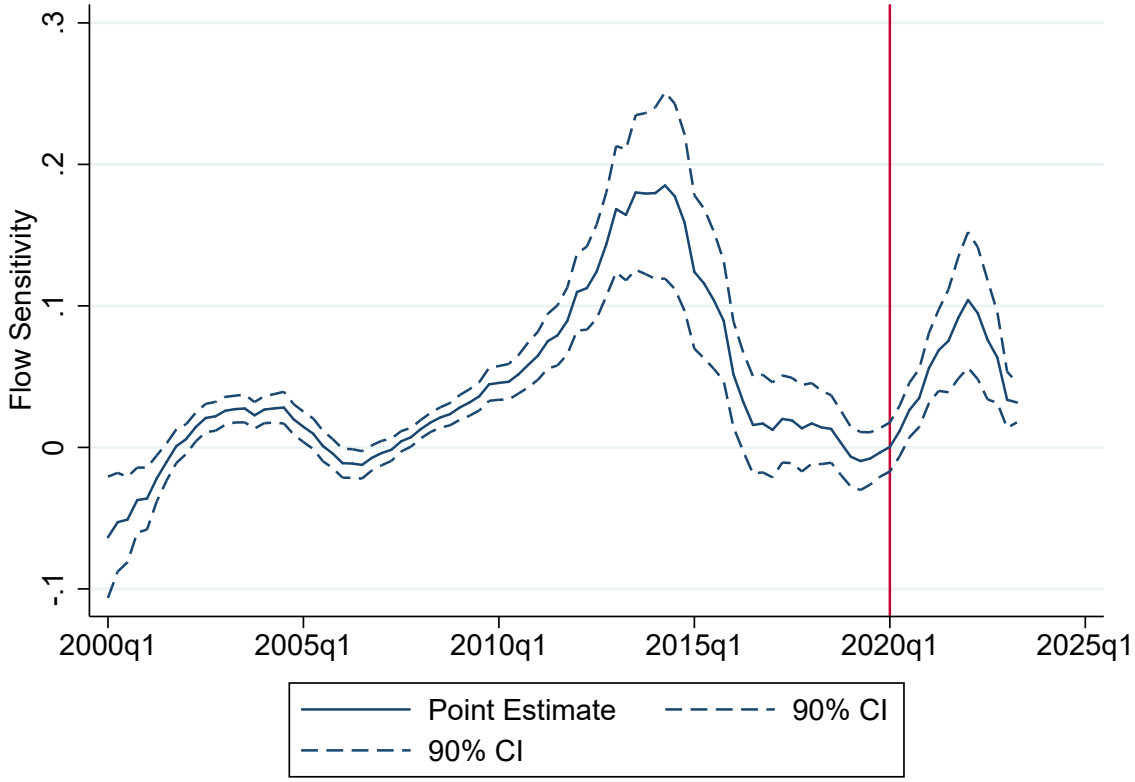
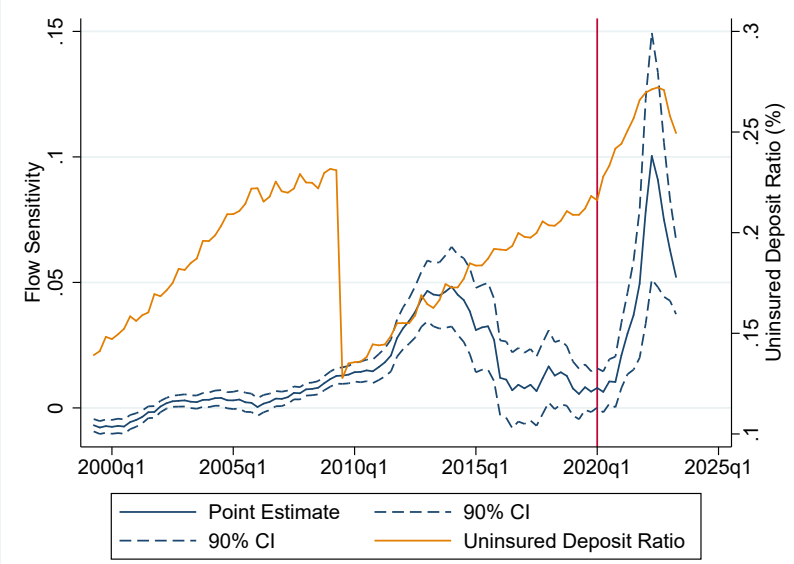


Figure 4: Deposit Flow Sensitivity and the Ratio of Uninsured Deposits

Panel (a) shows deposit flow sensitivities and the aggregate ratio of uninsured deposits over time. Deposit flow sensitivities are obtained from regressing bank-level deposit flows on instrumented bank-level interest rates (%) as described in Equation 3.1. Panel (b) shows deposit flow sensitivities controlling for the ratio of uninsured deposits at the bank level. eposit flow sensitivities are obtained from regressing bank-level deposit flows on instrumented bank-level interest rates (%) as described in Equation 3.1 and controlling for the level of uninsured deposits. The vertical red line corresponds to 2020Q1. Standard errors are clustered at the bank level.

(a) Deposit Flow Sensitivity and the Aggregate Ratio of Uninsured Deposits



(b) Deposit Flow Sensitivity controlling for Uninsured Deposits

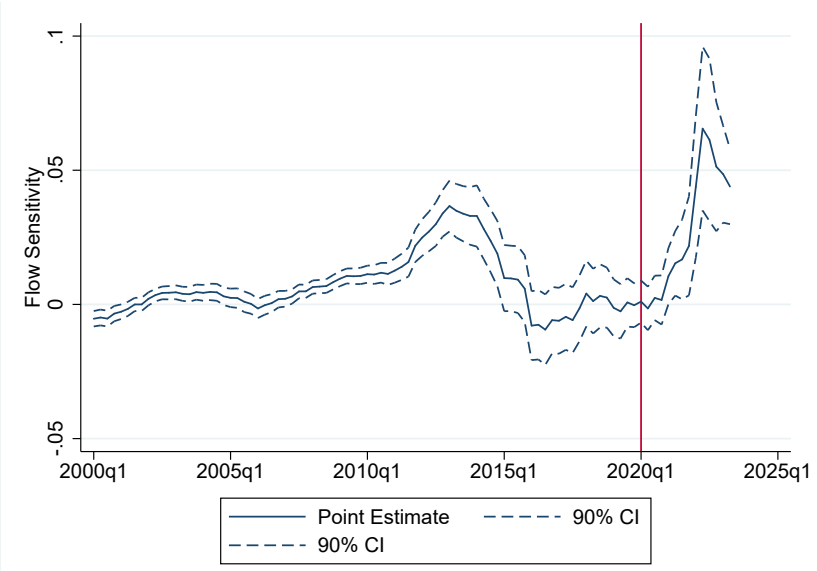


Figure 5: Deposit Flow Sensitivity (Additional Controls)

This figure shows deposit flow sensitivities over time controlling for additional bank characteristics. Deposit flow sensitivities are obtained from regressing bank-level deposit flows on instrumented bank-level interest rates (%) as described in Equation 3.1. Additional controls include banks' return on assets, assets per branch, number of employees per branch, and salaries per employee. The vertical red line corresponds to 2020Q1. The vertical red line corresponds to 2020Q1. Standard errors are clustered at the bank level.

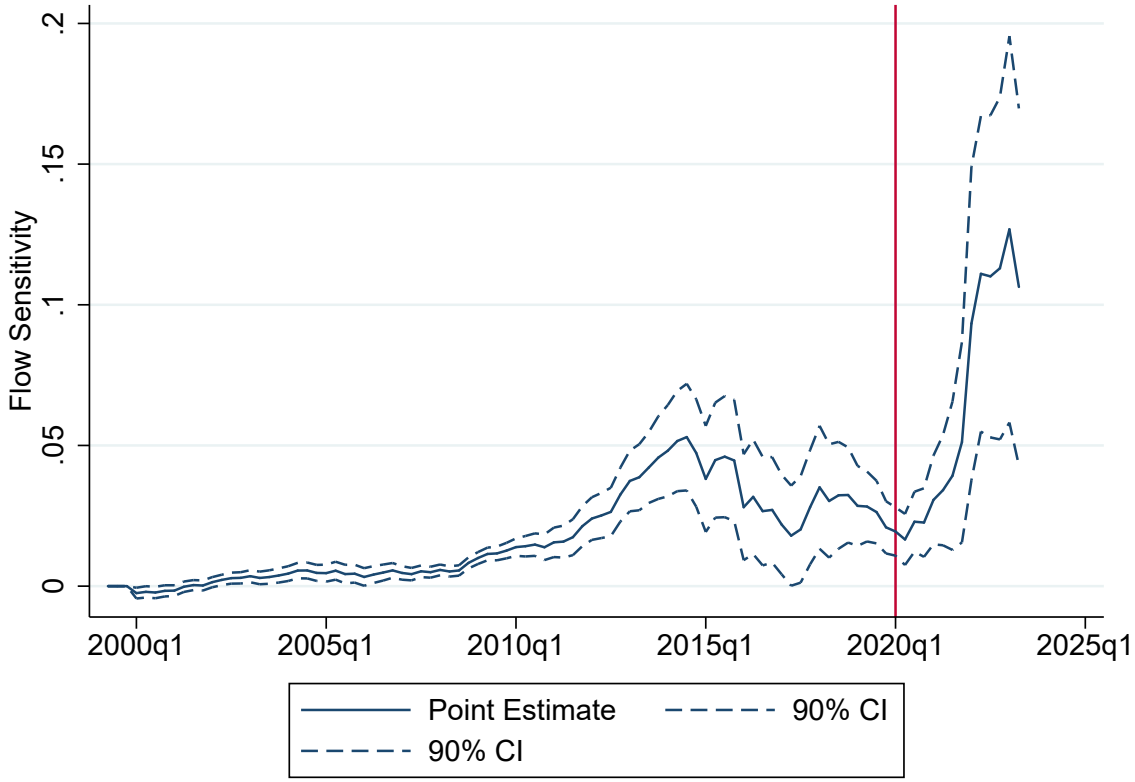
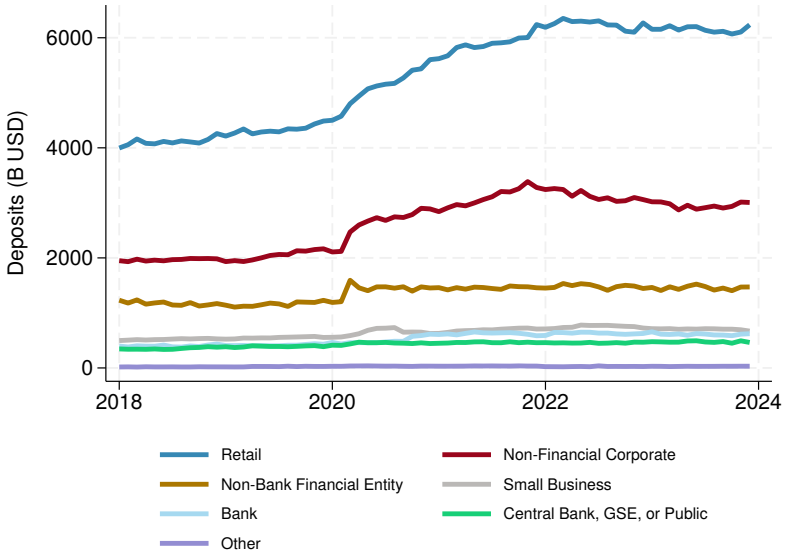


Figure 6: Deposits by Counterparty Type

Panel (a) shows the total volume of deposits by counterparty type. Panel (b) shows the volume of deposits by counterparty type as an index relative to their January 2020 levels. The sample includes banks with assets above $100 billion that filed the corresponding variables in the FR2052 form from 2018 through 2023.

(a) Volume of Deposits ($1 Billion)



(b) Volume of Deposits (Indexed to January 2020)

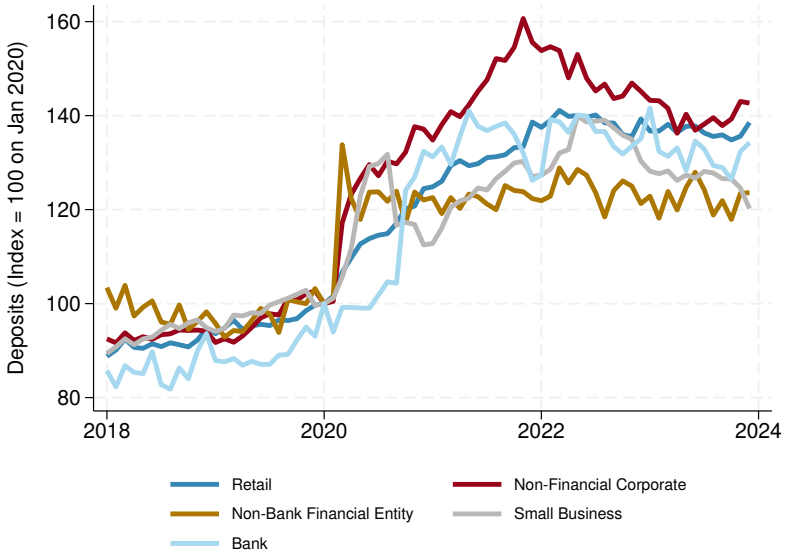
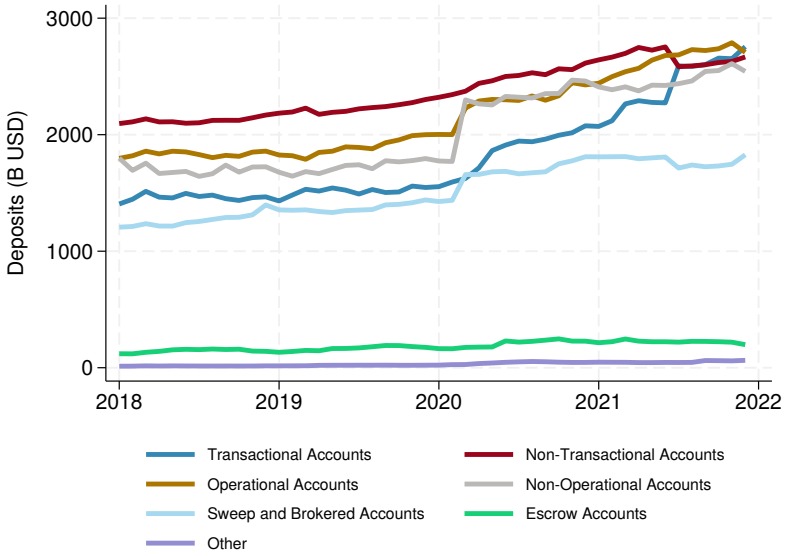


Figure 7: Deposits by Account Type

Panel (a) shows the total volume of deposits by account type. Panel (b) shows the volume of deposits by account type as an index relative to their January 2020 levels. The sample includes banks with assets above $100 billion that filed the corresponding variables in the FR2052 form from 2018 through 2021.

(a) Volume of Deposits ($1 Billion)



(b) Volume of Deposits (Indexed to January 2020)

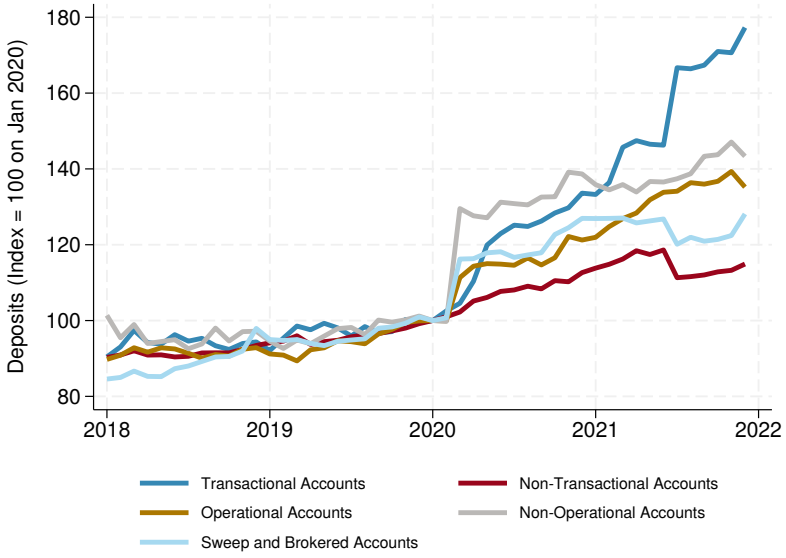
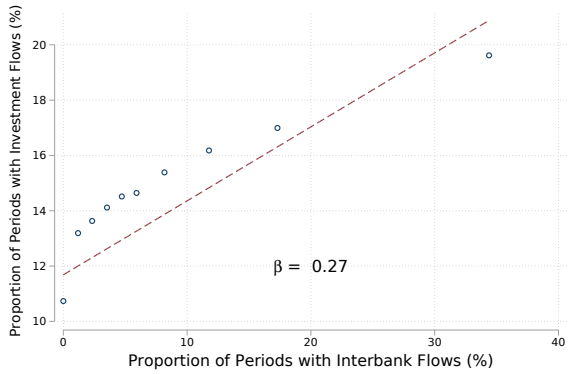


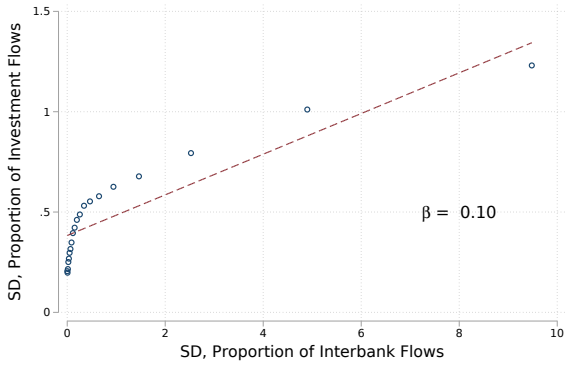
Figure 8: Depositor Flightiness in the Cross-Section

This figure shows binned scatter plots of depositor-level flightiness in moving funds between banks versus in moving funds between banks and outside investments during our sample period from Jan 2015 to Sep 2022. Panel (a) measures flightiness in terms of the proportion of months in which a depositor had flows between banks and between banks and outside investment options. Panel (b) measures flightiness as the standard deviation in flows between banks and between banks and outside investment options scaled by total payment flows. Panels (c) measures flightiness as the rate sensitivity of deposit flows between banks and between banks and outside investment options.

(a) Prop of Months with Flows



(b) Scaled SD of Flows



(c) Flow Sensitivity

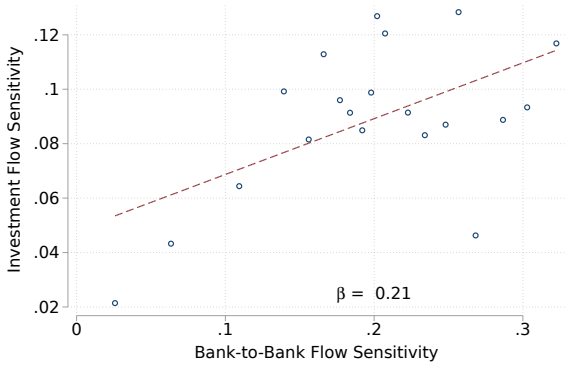


Figure 9: Depositor-Level Deposit Flow Sensitivity

This figure plots depositor-level deposit flow sensitivities between banks. W (panel (a)) and between banks and outside investments (panel (b)). In panel (a), we show the sensitivity of net deposit flows to a depositor's bank account from her other bank accounts with respect to the deposit rate offered by that bank account. In panel (b), we show the sensitivity of net deposit flows to a depositor's bank account from outside investment options with respect to the deposit spread offered by that bank account relative to the Fed funds rate. We run monthly regressions and plot 12-month moving averages of the coefficient on account-level interest rates. In each regression, we include depositor fixed effects and indicator variables for various account characteristics.

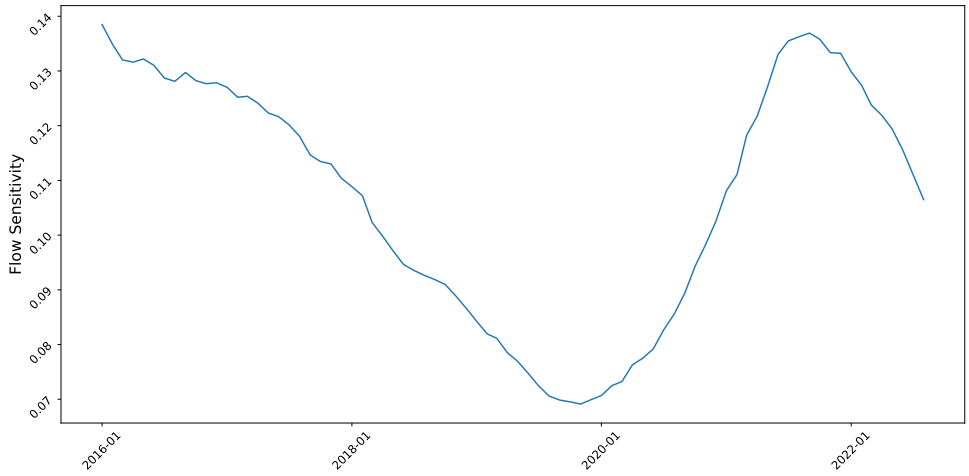
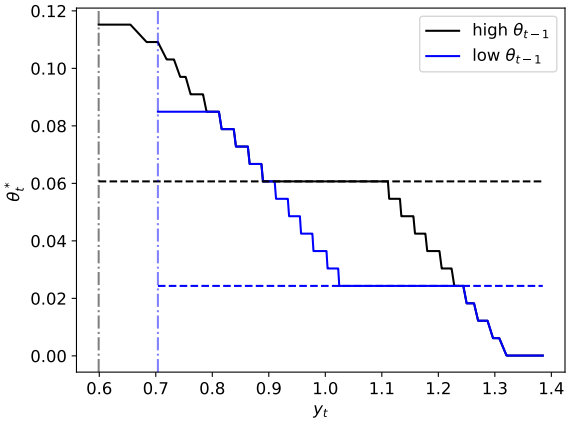


Figure 10: Numerical Illustration of the Equilibrium

Subfigure (a) plots the equilibrium marginal depositor type $\theta^*(y_t, \theta_{t-1})$ against the realized fundamental cash flow y_t. Subfigure (b) shows the net deposit flow under the bank's optimal rate setting policy against realizations of y_t. The black line shows the equilibrium solution for a high $\theta_{t-1} = 0.06$, and the blue line shows the solution for a low $\theta_{t-1} = 0.024$. The vertical line shows the run threshold in the two cases. We assume y is normally distributed with mean 1.02 and volatility 0.15, and θ_i is uniformly distributed in $[0, 0.6]$. For the other parameters, we set $R = 1$, $\lambda = 0.5$, $f = 0.05$, $\phi = 0.1$, $\beta = 0.9$, $\alpha_0 = 0$ and $\alpha_1 = 0.3$.

(a) Equilibrium θ_t^*



(b) Net Deposit Flows

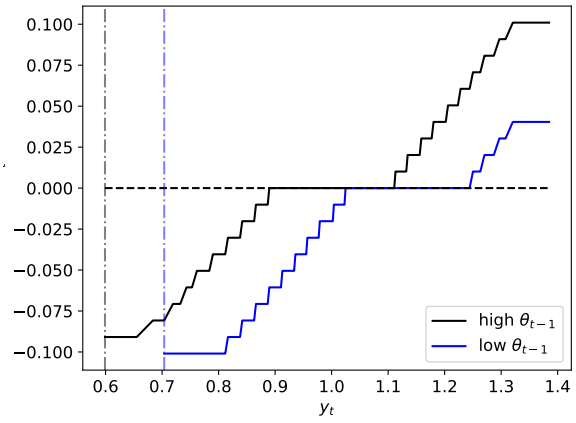
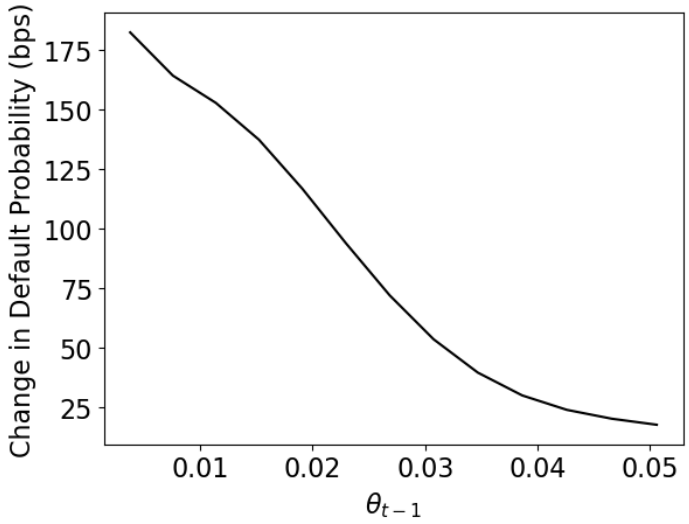


Figure 11: Effect of Rate Hikes on Bank Default Probability

Panel (a) plots the change in bank default probability $F(y^*)$ when the Fed Fund rate increases unexpectedly by 2% in one period, against the marginal depositor type θ_{t-1} at the beginning of the period. We use calibrated parameter values in Table 5c. The fundamental value y before the rate hike is set to match the asset return in 2022Q1. Panel (b) compares the effect on bank default probability for a 2% rate increase in scenarios with and without QE. In the no "QE" case, the starting point of the marginal depositor is equal to the average marginal depositor in the simulation. In the "QE" case, we adjust the starting point of the marginal depositor such that the change in depositor rate sensitivity matches with the cumulative flow sensitivity estimates between 2020Q1 to 2022Q1 in Figure 1a.

(a) Change in Default Probability from a 2% Rate Hike by Marginal Investor Type



(b) Change in Default Probability with and without QE

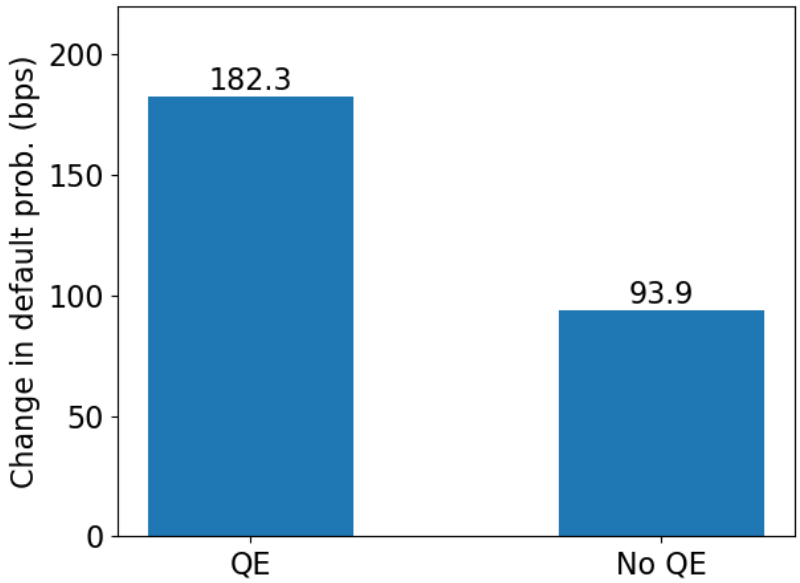


Figure 12: Change in Default Probability from Drastic versus Gradual Rate Hikes

This figure compares the per period change in bank default probability with respect to a 2% rate hike under different scenarios. In the drastic case, the 2% rate increase happens in the first period and stays at 2% in the second period. In the gradual case, the Fed Fund rate first increases unexpectedly by 1% in the first period, and then by another 1% in the second period.

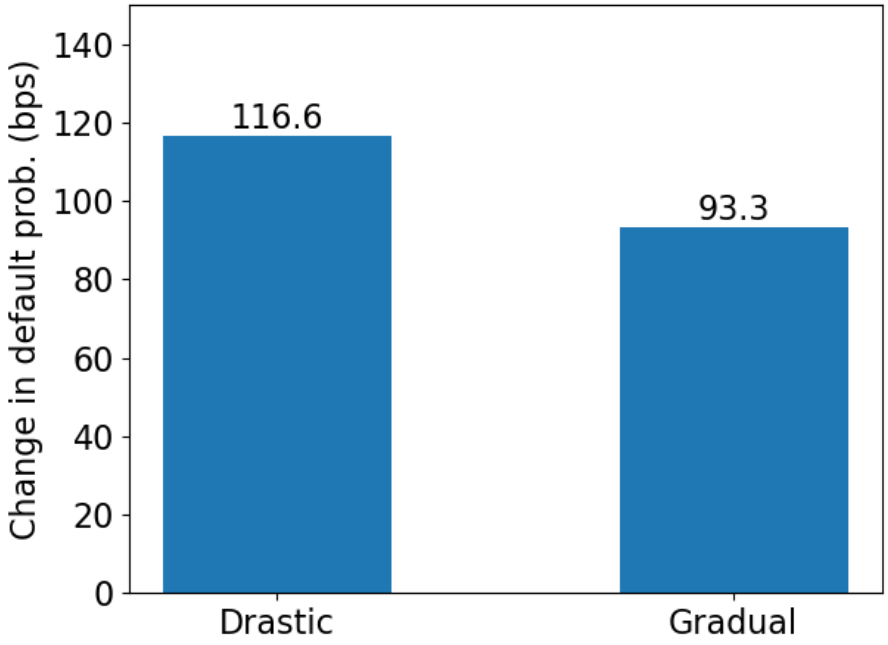


Table 1: Total Deposit Flow Sensitivity

This table shows how the sensitivity of deposit flows vary with aggregate flows to the banking system. The dependent variable, deposit flows, is the bank-level growth in deposits. The key dependent variables are the bank-level deposit rates and the interaction between bank-level deposit rates and the aggregate deposit flows to the banking sector. These variables are instrumented using supply shocks, and the results correspond to the IV estimates. Other control variables include the ratio of insured deposits, the equity ratio, and the non-deposit ratio. Standard errors are clustered at the bank level.

	Total Deposit Flow			
	(1)	(2)	(3)	(4)
Deposit Rate	-0.006***	0.012***	0.003	0.008**
	(0.002)	(0.003)	(0.003)	(0.003)
Deposit Rate × Cum Flow	0.190***	0.249***	0.103***	0.127***
	(0.030)	(0.032)	(0.030)	(0.032)
Insured Ratio			0.061***	0.117***
			(0.001)	(0.003)
Equity Ratio			-0.089***	-0.167***
			(0.004)	(0.009)
Non-Deposit Ratio			-0.038***	-0.076***
			(0.002)	(0.003)
Time FE	Yes	Yes	Yes	Yes
Bank FE	No	Yes	No	Yes
Observations	482334	482334	444246	444246
Adjusted R2	-0.02	-0.10	0.01	0.01

Table 2: Deposit Volatility by Depositor Type

This table shows the volatility of deposits by counterparty type. In Panel A (C), deposit volatility is calculated as the standard deviation of each bank's monthly (daily) deposits by counterparty type over the entire sample period, divided by the mean of the bank's monthly (daily) deposits by that counterparty type over the same period. In Panel B (D), deposit volatility is calculated as the rolling standard deviation of monthly (daily) aggregate deposits by counterparty type over windows of 4 months (60 days), divided by the rolling mean of aggregate monthly (daily) deposits by that counterparty type over the same window. All deposit volatilities are scaled by 100. The sample for Panels A and B includes banks with assets above $100 billion that filed the corresponding monthly variables in the FR2052 form from 2018 through 2023. The sample for Panels C and D includes banks with assets above $100 billion that filed the corresponding daily variables in the FR2052 form from 2018 through 2023.

Counterparty	25 Pctl	Median	75 Pctl
Panel A: Monthly Bank-Level SD			
Retail	14.10	20.07	29.21
Non-Financial Corporate	22.18	27.57	41.17
Non-Bank Financial Entity	18.79	38.00	56.06
Small Business	14.81	19.87	46.84
Bank	25.33	69.82	121.34
Panel B: Monthly Rolling Aggregate SD			
Retail	0.62	1.08	1.72
Non-Financial Corporate	1.04	1.41	2.08
Non-Bank Financial Entity	1.64	2.33	2.65
Small Business	1.03	1.40	2.37
Bank	1.55	2.49	3.44
Panel C: Daily Bank-Level SD			
Retail	17.92	25.44	29.66
Non-Financial Corporate	18.72	31.06	50.46
Non-Bank Financial Entity	17.08	21.79	66.82
Small Business	18.00	23.56	40.26
Bank	19.56	26.63	123.67
Panel D: Daily Rolling Aggregate SD			
Retail	0.50	0.63	0.97
Non-Financial Corporate	0.95	1.20	1.58
Non-Bank Financial Entity	1.77	2.00	2.32
Small Business	0.56	0.78	1.25
Bank	2.27	2.68	3.09

Table 3: Deposit Volatility by Account Type

This table shows the volatility of deposits by account type. In Panel A (C), deposit volatility is calculated as the standard deviation of each bank's monthly (daily) deposits by account type over the entire sample period, divided by the mean of the bank's monthly (daily) deposits in that account type over the same period. In Panel B (D), deposit volatility is calculated as the rolling standard deviation of aggregate monthly (daily) deposits by account type over windows of 4 months (60 days), divided by the rolling mean of aggregate monthly (daily) deposits in that account type over the same window. All deposit volatilities are scaled by 100. The sample for Panels A and B includes banks with assets above $100 billion that filed the corresponding monthly variables in the FR2052 form from 2018 through 2021. The sample for Panels C and D includes banks with assets above $100 billion that filed the corresponding daily variables in the FR2052 form from 2018 through 2021.

Account Type	25 Pctl	Median	75 Pctl
Panel A: Monthly Bank-Level SD			
Transactional Accounts	14.78	19.76	51.00
Non-Transactional Accounts	9.81	12.66	23.98
Operational Accounts	18.27	24.43	38.60
Non-Operational Accounts	19.40	25.07	41.69
Sweep and Brokered Accounts	19.75	28.79	55.44
Panel B: Monthly Rolling Aggregate SD			
Transactional Accounts	1.27	1.57	2.40
Non-Transactional Accounts	0.59	1.00	1.27
Operational Accounts	1.09	1.35	2.20
Non-Operational Accounts	1.17	1.76	2.43
Sweep and Brokered Accounts	0.85	1.61	2.46
Panel C: Daily Bank-Level SD			
Transactional Accounts	22.05	46.59	91.56
Non-Transactional Accounts	14.30	21.28	77.41
Operational Accounts	14.32	21.32	35.51
Non-Operational Accounts	15.16	31.60	69.91
Sweep and Brokered Accounts	14.58	29.48	48.68
Panel D: Daily Rolling Aggregate SD			
Transactional Accounts	0.92	1.13	1.64
Non-Transactional Accounts	0.32	0.58	0.84
Operational Accounts	0.94	1.16	1.52
Non-Operational Accounts	1.35	1.79	2.38
Sweep and Brokered Accounts	0.54	0.78	1.25

Table 4: Statistics on Depositor Flightiness

This table reports summary statistics of different measures of depositor flightiness in moving funds between banks versus in moving funds between banks and outside investments during our sample period from Jan 2015 to Sep 2022. We capture flightiness in terms of the proportion of months in which a depositor had flows between banks and between banks and outside investment options, the standard deviation in flows between banks and between banks and outside investment options scaled by total payment flows, and the rate sensitivity of bank to bank and bank to outside investment option deposit flows.

	Mean	SD	Median	25^{th} Pct	75^{th} Pct
Proportion of Months with Bank to Investment Flows (%)	4.50	8.79	1.06	0.00	5.32
Proportion of Months with Bank to Bank Flows (%)	13.34	23.35	2.13	0.00	14.89
SD (Proportion of Bank to Investment Flows)	0.50	0.84	0.14	0.03	0.59
SD (Proportion of Bank to Bank Flows)	1.12	2.42	0.17	0.04	0.78
Sensitivity of Bank to Investment Flows	0.09	0.05	0.09	0.05	0.12
Sensitivity of Bank to Bank Flows	0.20	0.07	0.20	0.16	0.26

Table 5: Calibration Moments and Estimates

Panel (a) summarizes the empirical moments we target directly. Panel (b) summarizes the empirical moments we target jointly. The moments are size-weighted averages of banks in the U.S. Our sample period is from 2000Q1 to 2019Q4. Panel (c) shows the calibrated parameter values.

(a) Empirical Moments

Parameter	Empirical target	Empirical moments
ρ	Persistence of asset returns	0.806
λ	Average loan maturity	2.845
α_1	Average asset discount	0.204
ϕ	Ample reserve proportion	0.031
R	Average Fed Fund Rate	1.784%
β	Discount rate	0.98

(b) Empirical Moments

Parameter	Empirical target	Empirical moments	Model moments
μ	Average asset return (%)	4.348	4.725
σ	Median deposit rate (bps)	95.410	98.805
σ_y	Median default prob. (bps)	72.302	77.876
γ	Flow-spread correlation	0.258	0.339
f	Flow volatility	1.628	1.496

(c) Parameter Estimates

Parameter	Description	Value
N	Number of banks	25
ρ	Persistence of y_t	0.806
λ	Maturity rate	0.352
α	Liquidity discount	0.796
ϕ	Ample reserve proportion	0.031
R	Value of outside option	1.018
β	Discount rate	0.98
γ	Rate parameter of θ distribution	1.230
μ	Mean of y_t	1.120
σ	Elasticity of substitution	9.684
σ_y	Sd of shock in asset return	0.184
f	Switching cost	0.139

A Estimation of Deposit Flow Sensitivity

In this appendix, we further discuss our estimation of deposit flow sensitivities in Equation 3.1. We first note that the standard specification for estimating deposit rate sensitivity at time t can be written as

$$Log(D_{jt}) = b_t DepRate_{jt} + TimeFE_t + \epsilon_{jt}, \tag{A.1}$$

where $Log(D_{jt})$ is the logged volume of deposits of bank j, $DepRate_{jt}$ is the deposit rate of bank j and b_t captures the sensitivity of bank-level deposits to bank-level deposit rates , i.e., the deposit rate sensitivitity.

To understand changes in deposit rate sensitivity over time, we take the first difference of Equation A.1:

$$Log(D_{jt}) - Log(D_{jt}) = b_t DepRate_{jt} - b_{t-1} DepRate_{jt-t} + TimeFE_t - TimeFE_{t-1} + \epsilon_{jt} - \epsilon_{jt-1}, \tag{A.2}$$

which translates into

$$Flow_{jt} = \Delta b_t DepRate_{jt} + b_{t-1}\Delta r_t + \Delta TimeFE_t + \Delta\epsilon_{jt}. \tag{A.3}$$

We note that Equation A.3 resembles Equation 3.1 with the addition of $b_{t-1}\Delta r_t$. Including or excluding this term should not make a material difference to our estimation if the sticky nature of deposit rate adjustments implies that Δr_t are very small. Indeed, repeating our baseline specification including $b_{t-1}\Delta r_t$, we obtain Figure 13 below, which closely resembles the benchmark result in Figure 1a.

The sensitivity of bank-level deposit flows to bank-level deposit rates estimated from Equation 3.1 can thus be interpreted as the change in deposit rate sensitivity relative to the previous period. A positive sensitivity of bank-level deposit flows to bank-level deposit rates indicates that the deposit base has become more rate-sensitive than before, whereby deposits are more disproportionately attracted to banks offering higher deposit rates. Indeed, directly estimating Eqution A.1 would produce Figure 14. Figure 14 is consistent with the interpretation that rate sensitivity increases by more when flow sensitivities are more positive.

We refer to the sensitivity of bank-level deposit flows to bank-level deposit rates as flow sensitivity.

Figure 13: Deposit Flow Sensitivity (with Deposit Rate Control)

This figure shows deposit flow sensitivities with an additional control of deposit rates. Deposit flow sensitivities are obtained from regressing bank-level deposit flows on instrumented bank-level interest rates (%) as described in Equation A.3. The vertical red line corresponds to 2020Q1. Standard errors are clustered at the bank level.

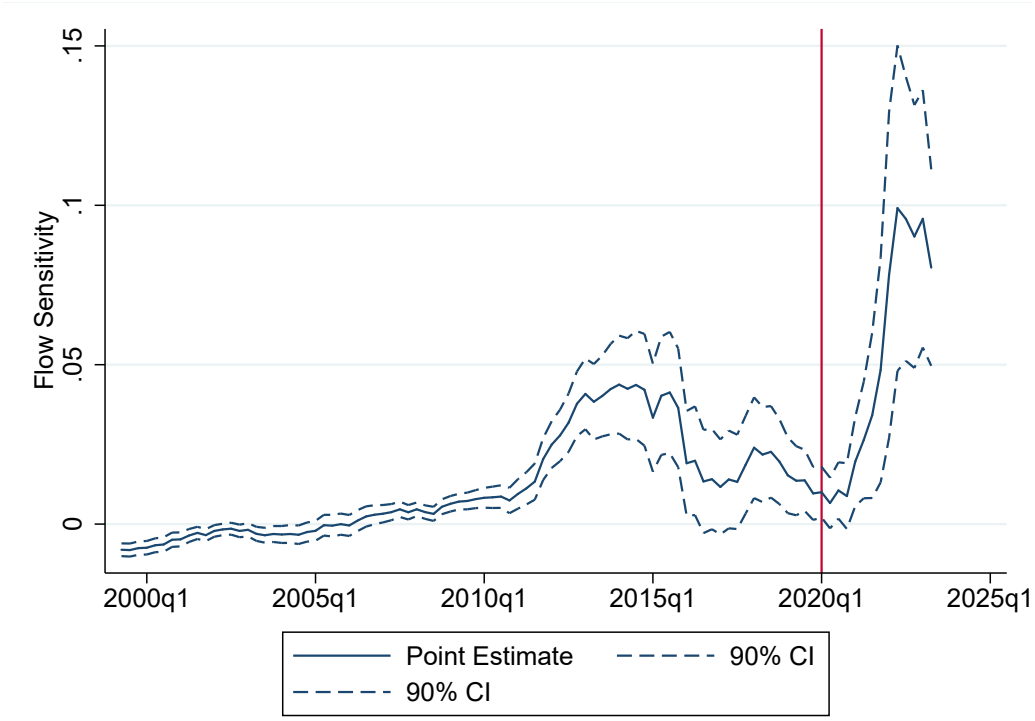
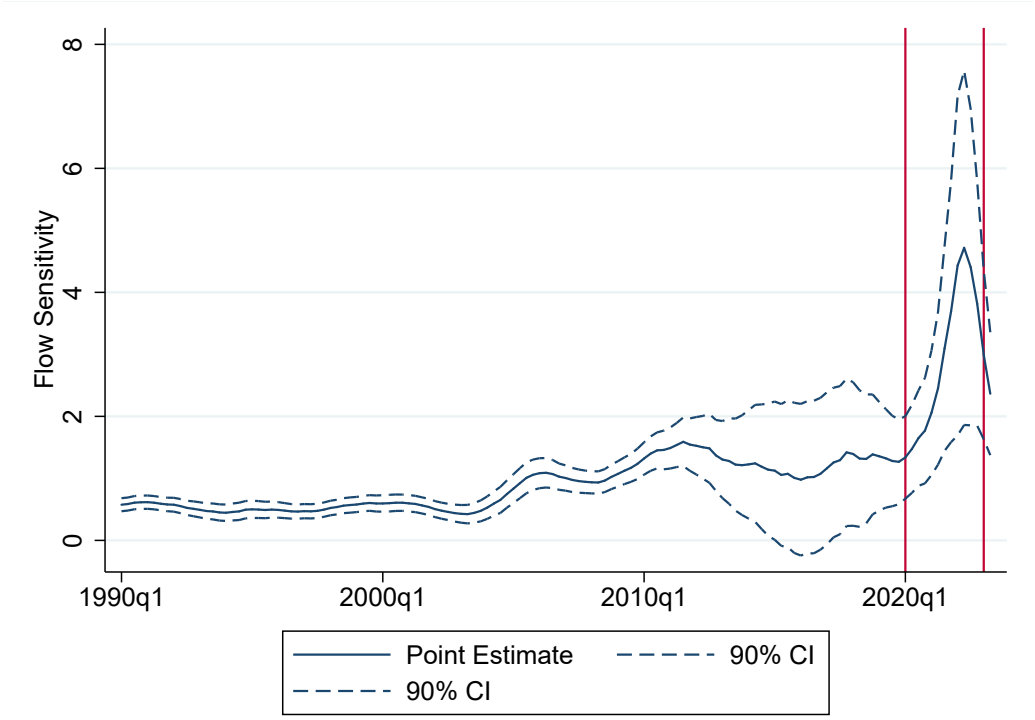


Figure 14: Deposit Rate Sensitivity

This figure shows deposit rate sensitivities, which are obtained from regressing bank-level log deposits on instrumented bank-level interest rates (%) as described in Equation A.1. The vertical red line corresponds to 2020Q1. Standard errors are clustered at the bank level.



B Data Appendix

We use de-identified transaction-level bank account data provided by a prominent financial data processor. This data encompasses records from over 1,400 U.S. banks and credit unions. We observe an identifier for each depositor, which is linked across accounts belonging to the same depositor. Accounts include checking and savings accounts but exclude brokerage and investment accounts. For each withdrawal and deposit transaction, the date, amount, and category of transactions are given. The merchant name and descriptions are also provided with redactions of bank names.

B.1 Sample Selection

Our sample is from January 2015 to September 2022. We start our sample in 2015, when data quality becomes sufficiently reliable. Following Buda et al. (2023), our analysis concentrates on a panel of active users, which have at least ten transactions related to spending, income, or transfers in 32 of the 36 quarters in our sample. This selection criterion helps to ensure that account closures, which go unrecorded, do not skew the data.

Among depositors, we manually identify corporate depositors. First, we include accounts that have outgoing payments labeled as payroll or salary every quarter. Additionally, we include entities that have more than 50 bank accounts and those that include corporate-specific transactions every quarter. We obtain a panel of 5,294 unique corporate depositors and 1.26 million unique household depositors. The larger number of household depositors over corporate depositors is consistent with our conversations with the data provider.

Although our data does not cover the universe of household and corporate depositors, we find that the trend in deposit flows from our data is highly representative of the trends in aggregate deposit flows from public data sources. Figure 16a plots the 12-month moving average of monthly deposit flows for household depositors in our data and the household and non-profit sector from FRED. Figure 16b plots the 12-month moving average of monthly deposit flows for corporate depositors in our data and the non-financial corporate sector from FRED. While the aggregate volumes from our data are smaller than those from FRED, the variations in deposit flows closely track each other for both household and corporate depositors. These results provide suggestive evidence that the depositors in our sample are representative of the population of depositors.

B.2 Classification of Flows between Banks and Investments

We use a multi-step process to identify deposit flows to and from investment options. First, we examine all transactions from bank accounts to brokerages that are classified as securities trading, investments, or retirement-related transactions. We then review thousands of merchant names that represent more than 95% of these transaction volumes to confirm that they are investment-related. This step helps to filter out misclassified investment transactions. Once we have a verified list of brokerages, we manually check the corresponding transaction descriptions to extract relevant keywords. These keywords are in turn used to search through other transaction categories, including bank transfers, check payments, and direct deposits. This method ensures that we capture a comprehensive and accurate list of investment flows across all depositors.

B.3 Classification of Flows between Banks

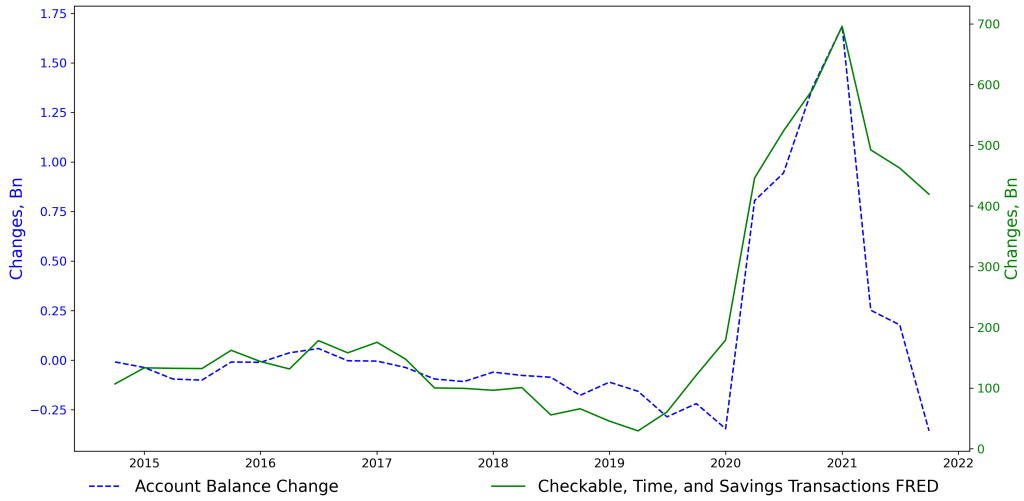
While we can link accounts belonging to the same depositor, the specific banks where these accounts are held remain unknown because bank identifiers for each account and bank names in transfer descriptions are redacted. To identify deposit flows between accounts of the same depositor at different banks, we adopt the methodology in Lu et al. (2024). We track the dollar value of each credit transaction C and each debit transaction D, and designate a transaction as an interbank deposit transfer if it meets the following criteria: first, C and D must originate from different accounts of the same depositor. Second, both C and D must exceed \$50, ensuring we do not capture minor fees or refunds. Third, the absolute difference between D and C, $|D - C|$, must be less than \$50 if D occurs on the next business day after C, and less than \$10 if the time between D and C exceeds one business day. Fourth, the temporal difference between the transactions must not exceed five business days. Additionally, transactions that are initiated and received on the same business day are excluded unless they include a fast payment technology marker including Venmo, PayPal, Cash App, or Zelle. This is because same-day transactions without a fee that are not through fast payment services are mostly across accounts at the same bank.

C Additional Figures and Tables

Figure 16: Account-level Data versus Aggregate Data

This figure compares total deposit flows from our account-level data with aggregate data on deposit flows from FRED. The left-hand axis plots deposit flows from our data, which considers the sum of all incoming and outgoing deposit flows for our sample of account holders. The right-hand axis plots aggregate deposit flows from FRED. Both series are displayed as a 12-month moving average. Panel (a) shows the results for household depositors; panel (b) shows the results for corporate depositors.

(a) Household Depositors



(b) Corporate Depositors

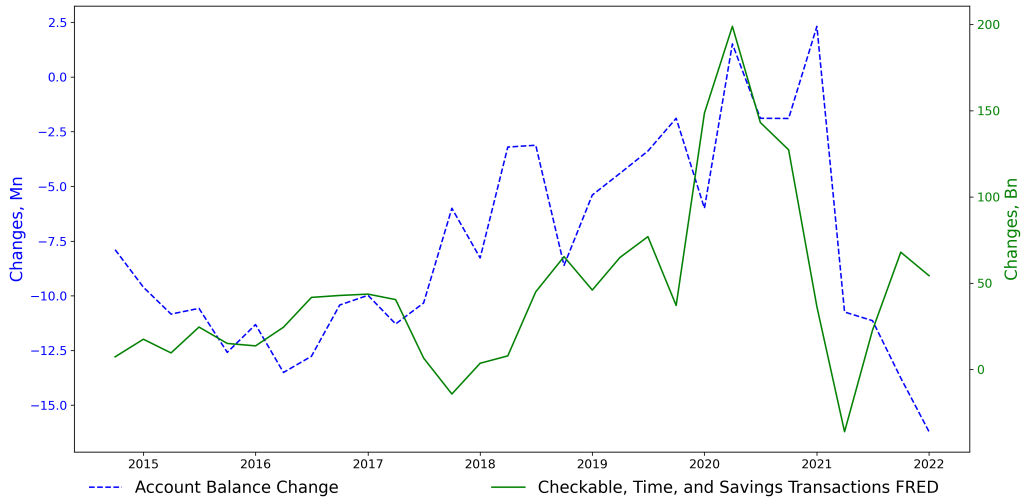
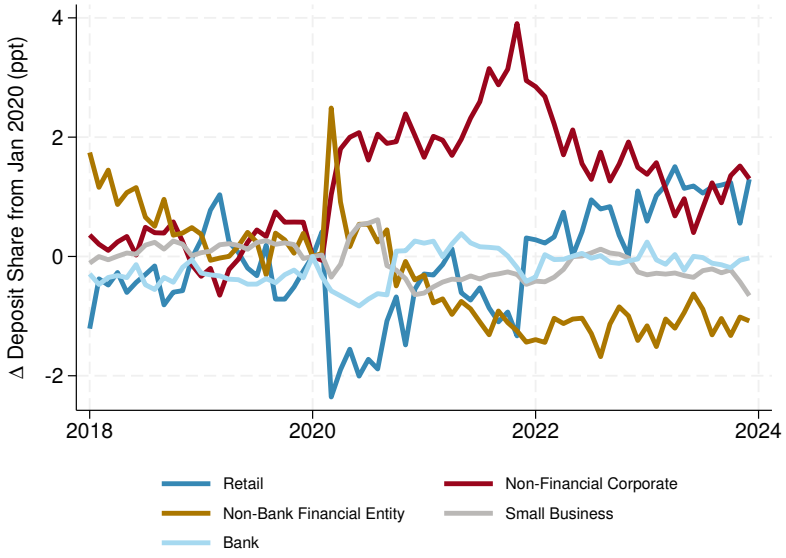


Figure 15: Deposit Composition by Counterparty and Account Type

Panel (a) shows changes in the proportion of deposits by counterparty type relative to January 2020. The sample includes banks with assets above $100 billion that filed the corresponding variables in the FR2052 form from 2018 through 2023. Panel (b) shows changes in the proportion of deposits by account type relative to January 2020. The sample includes banks with assets above $100 billion that filed the corresponding variables in the FR2052 form from 2018 through 2021.

(a) Deposit Composition by Counterparty Type



(b) Deposit Composition by Account Type

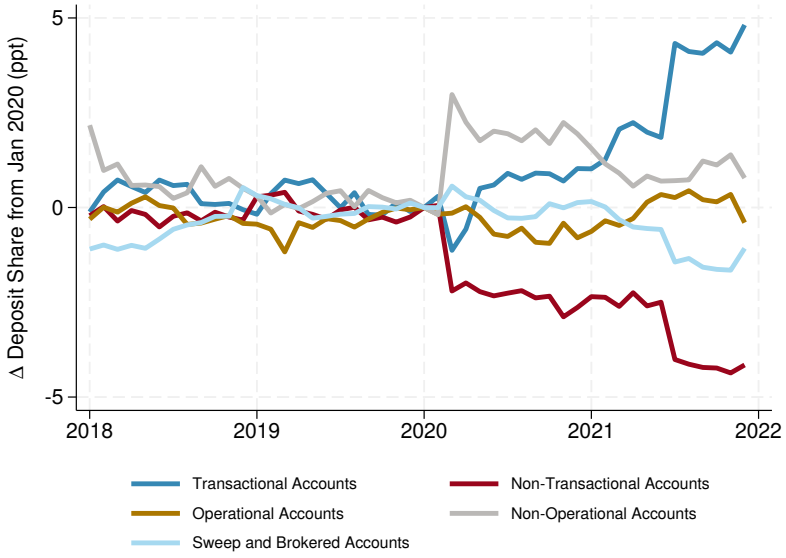


Table 6: First Stage: Effect of Fixed Cost and Salary Expense on Deposit Rates

This table shows how deposit rates are affected fixed costs and salary expenses. Deposit rates are expressed in %. Fixed costs and salary expenses are measured per unit bank asset. Columns (1) and (2) show the results for all deposits; columns (3) and (4) show the results for savings deposits. Standard errors are clustered at the bank level.

	Deposit Rate		Savings Dep Rate	
	(1)	(2)	(3)	(4)
Fixed Cost	-0.292***	-0.161***	-0.130***	-0.041**
	(0.027)	(0.020)	(0.022)	(0.018)
Salary Expense	-0.133***	-0.144***	-0.052***	-0.054***
	(0.012)	(0.008)	(0.008)	(0.006)
Time FE	Yes	Yes	Yes	Yes
Bank FE	No	Yes	No	Yes
Observations	482335	482335	480047	480046
Adjusted R2	0.85	0.93	0.60	0.75

D Derivation and Proofs

D.1 Proof of Lemma 1

Let T^θ be the Bellman operator

$$T^\theta V = \theta \left(\sum_{j=1}^{N} d_{i,j,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} + \lambda \sum_j r_{j,t} d_{i,j} + (1-\lambda)\beta \mathbb{E}[(1 - \mathbf{1}_{def,t+1}) \max\{V, R - f\} + \mathbf{1}_{def,t+1} L(y_{t+1})]$$

Because $(1-\lambda)\beta < 1$, the operator T^θ is β-contraction. So the value iteration converges to a fixed point $D(\theta)$. Furthermore, T^θ is increasing in V, i.e. if $V_1 \geq V_2$, $T^\theta V_1 \geq T^\theta V_2$, and when $d_{i,j,t} \geq 0$, T^θ is increasing in θ, i.e., if $\theta_1 \geq \theta_2$, then $T^{\theta_1} V \geq T^{\theta_2} V$. As a result, the fixed point $D(\theta)$ is non-decreasing in θ. Hence, there exists an equilibrium where the set of investors in the banking system is characterized by a time-varying cutoff θ_t.

D.2 Proof of Lemma 2

To investigate the run condition, we look at the deposit value when the bank is liquidating more than one unit of asset to meet outflows. Denote the asset backing per unit of deposits as a_t. Given the deposits remaining in the bank, $D_{j,t}$, $a_{j,t}$ is determined by the following equation

$$a_{j,t} = \begin{cases} 1 & \text{if} \quad D_{j,t} \geq (1-\phi) D_{j,t-1} \\ \dfrac{(1-\phi)D_{j,t-1} - \frac{(1-\phi)D_{j,t-1} - D_{j,t}}{L(y_t)}}{D_{j,t}} & \text{otherwise} \end{cases} \tag{D.1}$$

On the other hand, given a_t, denote the demand for bank j's deposit as $\tilde{D}_{j,t}$, given the maximum deposit rate that the bank can offer y_t. In other words, the demand for deposit $\tilde{D}_{j,t}$ is a function of the amount of deposit in bank $D_{j,t}$. A stable equilibrium is where $\tilde{D}_{j,t}(D_{j,t})$ crosses the 45 degree line from above, i.e. the slope of the deposit demand $\tilde{D}_{j,t}$ as a function of the deposit volume $D_{j,t}$ is smaller than one. Next we show that when $D_{j,t} < (1-\phi)D_{j,t-1}$, the slope of $\tilde{D}_{j,t}$ as a function of $D_{j,t}$ is larger than 1 when $D_{j,t} > 0$, implying that the only equilibrium that exists in that region is one in which the deposit volume is 0.

From Equation D.1, when $D_{j,t} < (1-\phi)D_{j,t-1}$

$$\frac{\partial a_{j,t}}{\partial D_{j,t}} = \frac{1}{L(y_t)} - 1 \tag{D.2}$$

We can write the depositor value as

$$D = \theta_i \left(\sum_{j=1}^{N} d_{i,j,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} + \lambda \sum_{j' \neq j} r_{j',t} d_{i,j',t} + y_t a_{j,t} d_{i,j,t} + (1-\lambda)\beta \mathbb{E}[D_{cont}] \tag{D.3}$$

where D_{cont} denotes the continuation value in the next period.

For a given investor, demand elasticity for investor i with respect to $a_{j,t}$ is

$$\frac{\partial d_{i,j,t}}{\partial a_{j,t}} = \sigma\lambda \frac{d_{i,j,t}(1-d_{i,j,t})}{\gamma_i - \lambda y_t} y_t > 0 \tag{D.4}$$

where γ_i is the Lagrangian multiplier in front of the budget constraint $\sum d_{i,j,t} = 1$. Under symmetric equilibrium, it is determined by

$$1 = \left(\sum_k \left(\frac{\theta_i}{\gamma_i - \lambda y_t} \right)^{\sigma-1} \right)^{\frac{1}{\sigma-1}} \tag{D.5}$$

Hence the effect of deposit volume on deposit demand is

$$\frac{\partial \tilde{D}_{j,t}}{\partial D_{j,t}} = \int_i \frac{\partial d_{i,j,t}}{\partial a_{j,t}} \left(\frac{1}{L(y_t)} - 1 \right) + \frac{\partial d_{i,j,t}}{\partial D_{j,t}} \tag{D.6}$$

where the second component captures any direct effect of deposit volume on deposit demand through future default probabilities. Notice that when $\alpha_0 \to 0$ and $\alpha_1 \to 0$, we have $\frac{1}{L(y_t)} \to \infty$. Since $\frac{\partial d_{i,j,t}}{\partial a_{j,t}}$ is positive, it implies the slope of $\tilde{D}_{j,t}$ as a function of $D_{j,t}$ is above one. In other words, there is no stable equilibrium in this region except the one in which the deposit volume is zero. Hence, for a bank to avoid a run, it needs to retain at least $(1-\phi)$ fraction of its depositors.

In equilibrium, banks are symmetric and experience the same flows. For banks to retain at least $(1-\phi)$ fraction of its depositors, we must have $\theta_t \leq \bar{\theta}_t$. In other words, we need $D(y_t, \bar{\theta}_t, \bar{\theta}_t) \geq R - f$. Hence, the run threshold is determined by Equation 4.14.

D.3 Proof of Proposition 1

Given that the definition of critical investor in Equation 4.13,

$$G'(\bar{\theta}_t) d\bar{\theta}_t = (1-\phi) G'(\theta_{t-1}) d\theta_{t-1} \tag{D.7}$$

$$\frac{d\bar{\theta}_t}{d\theta_{t-1}} > 0 \tag{D.8}$$

Hence, the critical investor's convenience benefit $\bar{\theta}_t$ is increasing in the previous period marginal depositor's θ_{t-1}.

Furthermore, $D(y, \bar{\theta}_t(\theta_{t-1}), \bar{\theta}_t(\theta_{t-1}))$ is increasing in y^* and $\bar{\theta}_t(\theta_{t-1})$. By the implicit function theorem,

$$\frac{\partial y^*}{\partial \bar{\theta}_t(\theta_{t-1})} = -\frac{\partial D}{\partial \bar{\theta}_t(\theta_{t-1})} \Big/ \frac{\partial D}{\partial y} < 0. \tag{D.9}$$

D.4 Proof of Corollary 1

Similar to before, the run threshold is implicitly defined as

$$D(y^*, \bar{\theta}(\theta_{t-1}), \bar{\theta}(\theta_{t-1})) = R - f \tag{D.10}$$

$$\frac{\partial y^*}{\partial \theta_{t-1}} = \underbrace{-\frac{\partial D}{\partial \bar{\theta}_t(\theta_{t-1})} \Big/ \frac{\partial D}{\partial y}}_{<0} \times \frac{\partial \bar{\theta}}{\partial \theta_{t-1}} \tag{D.11}$$

As long as $\frac{\partial \bar{\theta}}{\partial \theta_{t-1}} > 0$, we have $\frac{\partial y^*}{\partial \theta_{t-1}} < 0$. Fixing everything else, $\frac{\partial y^*}{\partial \theta_{t-1}}$ is decreasing in $\frac{\partial \bar{\theta}}{\partial \theta_{t-1}}$.

From Equation 4.19, we have

$$\frac{\partial \bar{\theta}}{\partial \theta_{t-1}} = \frac{(1-\phi(\theta_{t-1}))G'(\theta_{t-1}) - \phi'(\theta_{t-1})G(\theta_{t-1})}{G'(\tilde{\theta})} \tag{D.12}$$

Under condition (4.18), $\frac{\partial \bar{\theta}}{\partial \theta_{t-1}} > 0$. In other words, the indirect effect from adjustment in ϕ does not offset the direct effect. Consider an extreme case, suppose for all θ_{t-1}, the following condition holds,

$$(1-\phi(\theta_{t-1}))G'(\theta_{t-1}) - \phi'(\theta_{t-1})G(\theta_{t-1}) = 0 \tag{D.13}$$

This implies

$$\frac{G'(\theta_{t-1})}{G(\theta_{t-1})} = \frac{\phi'(\theta_{t-1})}{1-\phi(\theta_{t-1})} \tag{D.14}$$

which means that outside of default, all inflows and outflows only involve adjustment in the liquid assets and the amount of illiquid asset is fixed over time. Under most reasonable liquidity management

problems, when there is inflow, the bank will invest a smaller but non-zero fraction in illiquid assets, satisfying condition (4.18).

D.5 Proof of Proposition 2

Consider the first order condition of an individual bank

$$-\lambda D_{j,t} + \left[\lambda(y_t - r_{j,t}) + \iota + (1-\lambda)\beta \frac{\partial \mathbb{E}[(1-\mathbf{1}_{def})V^*]}{\partial D_{j,t}}\right] \frac{\partial D_{j,t}}{\partial r_{j,t}} = 0 \tag{D.15}$$

where

$$\frac{\partial D_{j,t}}{\partial r_{j,t}} = \int_{\theta_t} \frac{\partial d_{i,j,t}}{\partial r_{j,t}} dH(\theta) \tag{D.16}$$

The demand elasticity for investor i is

$$\frac{\partial d_{i,j,t}}{\partial r_{j,t}} = \sigma\lambda \frac{d_{i,j,t}(1-d_{i,j,t})}{\gamma - \lambda r_{j,t}} \tag{D.17}$$

where γ is the Lagrangian multiplier in front of the budget constraint $\sum d_{i,j,t} = 1$. In equilibrium we have

$$1 = \left(\sum_k \left(\frac{\theta_i}{\gamma - \lambda r_j}\right)^{\sigma-1}\right)^{\frac{1}{\sigma-1}} \tag{D.18}$$

In equilibrium $r_{j,t} = r_t^*$ and $d_{i,j,t} = \frac{1}{N}$. Substituting in $\gamma - \lambda r_j$ into (D.17) we get

$$\frac{\partial d_{i,j,t}}{\partial r_{j,t}} = \sigma\lambda \frac{1/N(1-1/N)}{N^{1/(\sigma-1)}} \frac{1}{\theta_i} \tag{D.19}$$

Hence from the bank's perspective, the deposit rate sensitivity is

$$\frac{\partial D_{j,t}}{\partial r_{j,t}} = \sigma\lambda \frac{1/N(1-1/N)}{N^{1/(\sigma-1)}} \int_{\theta_i \geq \theta_t} \frac{1}{\theta} dH(\theta) \tag{D.20}$$

The deposit semi-elasticity is hence

$$\frac{\partial log D_{j,t}}{\partial r_{j,t}} = \sigma\lambda \frac{1-1/N}{N^{1/(\sigma-1)}} \frac{\int_{\theta_i \geq \theta_t} \frac{1}{\theta} dH(\theta)}{G(\theta_t)} \tag{D.21}$$

Hence Eq. D.15 can be simplified to

$$-\lambda\frac{G(\theta_t)}{N}+[\lambda(y_t-r_t^*)+\iota+(1-\lambda)\beta\frac{\partial\mathbb{E}[(1-\mathbf{1}_{def})V^*]}{\partial D_{j,t}}]\sigma\lambda\frac{1/N(1-1/N)}{N^{1/(\sigma-1)}}\int_{\theta_t}\frac{1}{\theta}dH(\theta)=0 \tag{D.22}$$

Furthermore

$$\mathbb{E}[(1-\mathbf{1}_{def})V^*]=\int_{y^*(\theta_t,D_{j,t})}V^*(y_{t+1},\theta_t,D_{j,t})dH(y_{t+1}) \tag{D.23}$$

$$\frac{\partial\mathbb{E}[(1-\mathbf{1}_{def})V^*]}{\partial D_{j,t}}=-(1-\phi)\int_{y^*(\theta_t,D_{j,t})}\iota_{t+1}dH(y_{t+1})-\frac{(1-\phi)}{\sigma\lambda_y\frac{1/N(1-1/N)}{N^{1/(\sigma-1)}}\int_{\bar{\theta}}\frac{1}{\theta}dH(\theta)}f(y^*)V^*(y^*,\bar{\theta},D_{j,t}) \tag{D.24}$$

We define the unconstrained optimal deposit rate as $\tilde{r}(y_t,\theta_t)$, which solves Equation D.22 when $\iota_t=0$.

When $D(r_t^*,\theta_{t-1},\theta_{t-1})<R-f$, there is outflow and when $D(r_t^*,\theta_{t-1},\theta_{t-1})>R+f$, there is inflow. Hence $y_{in}(\theta_{t-1})$ and $y_{out}(\theta_{t-1})$ are implicitly defined recursively by

$$D(\tilde{r}(y_{out},\theta_{t-1}),\theta_{t-1},\theta_{t-1})=R-f \tag{D.25}$$

$$D(\tilde{r}(y_{in},\theta_{t-1}),\theta_{t-1},\theta_{t-1})=R+f \tag{D.26}$$

When there is unconstrained outflow, the new marginal depositor $\theta_1(y_t)$ is pinned down by

$$D(\tilde{r}(y_t,\theta_1),\theta_1,\theta_1)=R-f \tag{D.27}$$

When there is inflow, the new marginal depositor $\theta_2(y_t)$ is pinned down by

$$D(\tilde{r}(y_t,\theta_2),\theta_2,\theta_2)=R+f \tag{D.28}$$

D.6 Proof of Corollary 2

The equilibrium θ^* is decreasing in y follows from the partition across cases and the fact that $\theta_1(y)$ and $\theta_2(y)$ are decreasing in y. Fixing θ_{t-1}, the net deposit flow is decreasing in θ^*, hence, it is increasing in y.

To investigate the relationship between net flow and the previous period marginal depositor type, consider $\theta_{t-1,1} < \theta_{t-1,2}$. We have

$$y^*(\theta_{t-1,1}) > y^*(\theta_{t-1,2}) \tag{D.29}$$

$$y_{out}(\theta_{t-1,1}) > y_{out}(\theta_{t-1,2}) \tag{D.30}$$

$$y_{in}(\theta_{t-1,1}) > y_{in}(\theta_{t-1,2}) \tag{D.31}$$

We next show that for any y, we have $G(\theta^*(y, \theta_{t-1,1})) - G(\theta_{t-1,1}) \leq G(\theta^*(y, \theta_{t-1,2})) - G(\theta_{t-1,2})$.

When $y \leq y_{out}(\theta_{t-1,2})$, $\theta^*(y, \theta_{t-1,1}) = \theta^*(y, \theta_{t-1,2})$. Hence,

$$G(\theta^*(y, \theta_{t-1,1})) - G(\theta_{t-1,1}) < G(\theta^*(y, \theta_{t-1,2})) - G(\theta_{t-1,2}) \tag{D.32}$$

When $y \in (y_{out}(\theta_{t-1,2}), y_{out}(\theta_{t-1,1})]$,

$$G(\theta^*(y, \theta_{t-1,1})) - G(\theta_{t-1,1}) = 0 \tag{D.33}$$

$$G(\theta^*(y, \theta_{t-1,2})) - G(\theta_{t-1,2}) < 0 \tag{D.34}$$

When $y \in (y_{out}(\theta_{t-1,1}), y_{in}(\theta_{t-1,2})]$, there is no flow in either case, i.e., $G(\theta^*(y, \theta_{t-1,1})) - G(\theta_{t-1,1}) = G(\theta^*(y, \theta_{t-1,2})) - G(\theta_{t-1,2}) = 0$.

When $y \in (y_{in}(\theta_{t-1,2}), y_{in}(\theta_{t-1,1}]$,

$$G(\theta^*(y, \theta_{t-1,1})) - G(\theta_{t-1,1}) > 0 \tag{D.35}$$

$$G(\theta^*(y, \theta_{t-1,2})) - G(\theta_{t-1,2}) = 0 \tag{D.36}$$

Finally, when $y > y_{in}(\theta_{t-1,1}$, $\theta^*(y, \theta_{t-1,1}) = \theta^*(y, \theta_{t-1,2})$ and the condition D.32 holds.