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 low interest rate environments, expansions in central bank reserves, and a disproportionate increase in corporate deposits. Our dynamic model rationalizes these trends based on heterogeneity in investors' convenience value, where those in the banking system value the convenience benefits of deposits more. Following deposit inflows from outside investors, e.g., due to QE's reserve expansions, the marginal depositor 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 rate-insensitive 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 high levels 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 disproportionately drew in corporate deposits and 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 shows that heterogeneity in investors' convenience value for deposits coupled with a fixed cost of moving deposits 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 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 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. One 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, rose 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, 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 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 more flighty.

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.

To corroborate the economic channel at play, we show the existence of and variation in deposit flightiness using granular depositor-level data. We use 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.

We uncover significant heterogeneity in flightiness across depositors and over time that aligns with our bank-level evidence and supports our economic mechanism. In the cross-section, the frequency and standard deviation of a depositor's flows between banks are strongly positively correlated with those of her flows between banks and investment options. In other words, depositors who are more active in moving money between banks are also more likely to withdraw their deposits from the banking system to outside investments. In the time series, we find that depositors' sensitivity of bank-to-bank flows comoves closely with their sensitivity of outside investment-to-bank flows. Both of these sensitivities display significant variation over time, increase following inflows to the banking system, and resemble the pattern in the deposit flow sensitivities that we estimated using bank-level data. Therefore, our depositor-level evidence corroborates the time-series variation in depositor flightiness and is consistent with the influx of deposits driving up the flightiness of the depositor base.

To rationalize the observed variation in deposit flightiness and to shed light on the implications for financial fragility, we develop a dynamic banking model in which banks fund illiquid long-term projects with one-period deposits. Importantly, investors are heterogeneous in how much they value the convenience feature of deposits. In addition, investors bear a switching cost for moving money in and out of the bank. In each period, given the interest rate offered by the bank, 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 the bank, while investors who value deposit convenience less invest in the outside option.

On the bank's asset side, in each period, the project matures with a certain probability and produces cash flows that are driven by the fundamentals of that period. If there are deposit outflows, the bank 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, the bank incurs 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 the potential for bank runs.

The 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. In equilibrium, conditional on the previous depositor base, the bank sets lower interest rates as fundamentals deteriorate, leading to deposit outflows and asset liquidation. Eventually, as fundamentals fall below an endogenous threshold, the bank can no longer retain any depositors. Run-driven outflows ensue, and the bank fails.

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 the bank provides. When the marginal depositor in the bank does not value bank convenience as much, the bank faces a larger failure risk in future periods. As a result, all the 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 paths 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 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 deposit 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 almost reduced by half from 73bps to 40bps, 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 more flighty, 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 when the rate is further increased. In other words, smaller steps of rate hikes allow the bank 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 bank's convenience service more and run risk is reduced. Magnitude wise, a gradual rate hike in 2022Q1 would have increased default probability by 43 bps compared to 73bps by the more drastic 2% rate hike.

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

[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.

implies that rate hikes are more destabilizing when the central bank's balance sheet size is large and when rate hikes are drastic. Going forward, 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, 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. Empirically, Iyer et al. (2016) 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. 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. Related, 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. 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. Related, Zhang, Muir and Kundu (2024) analyze the emergence of high-rate and low-rate banks in the U.S. banking system over the past decade. 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.

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,

[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).

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

One proxy for the flightiness of depositors is how responsive deposit flows between banks are to deposit rates. To isolate the response of deposit flows, 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 i in quarter t, $Dep\hat{R}ate_{it}$, to estimate the rolling window regression:

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

where $Flow_{it}$ is the deposit flow of bank i in quarter t. With the inclusion of time effects, we can interpret β_y as the sensitivity of bank-level deposit flows to bank-level deposit rates in rolling window y. A positive flow sensitivity β_y indicates a more rate-sensitive depositor base than before. For the ease of presentation, we estimate flow sensitivities using an 8-quarter rolling window.[3] Standard errors are clustered at the bank level.

[3] 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.

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 higher 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 raises the average flightiness of depositors inside the banking system, rendering them more sensitive to deposit rates.

Importantly, note that fluctuations in deposit flow sensitivities also coincide with cycles of unconventional monetary policy that inject central bank reserves into the banking system. In particular, flow sensitivities increase when reserves held on bank balance sheets are increasing, following QE, and decrease when 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 not only because sellers of QE-eligible securities to banks tend to be rate-sensitive institutional investors. It is also 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.[4]As our model will show, the aggregate depositor base becomes more flighty when

[4]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.

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

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

where $AggFlow_t$ is the one-year cumulative deposit flow in quarter t, and the independent variables, $\widehat{DepRate}_{it}$ and $\widehat{DepRate_{it} \cdot AggFlow_t}$ are instrumented with the same fixed cost and salary expense instruments as in Equation 3.1. We include time fixed effects and control for the ratio of insured deposits, bank equity, and non-deposit liabilities. 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.

We verify that our results are not purely driven by changes in the ratio of demandable deposits. As pointed out by Supera (2021), there has been a 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 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).[5]

We further check how the variations in deposit flow sensitivities relate to deposit spreads. Figures 12a and 12b show that Fed funds-deposit spreads are negatively correlated with deposit flow sensitivi-

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

ties, which is consistent with our proposed interpretation. When the Fed funds-deposit spread increases, the opportunity cost of holding deposits increases. Only investors that highly value the convenience of bank deposits remain in banks, and these investors have a lower sensitivity with respect to interest rates. Further, when only investors that highly value the convenience of bank deposits remain in banks, banks can afford to set a lower deposit rate relative to the Fed funds rate without losing too many deposits. The observed evolution of deposit spreads is consistent with the deposits channel of monetary policy (Drechsler et al., 2017) and the transmission of monetary policy to shadow banks (Xiao, 2020). It is also related to the notion of deposit betas formalized by Drechsler et al. (2021). Although our focus is not on the passthrough of monetary policy to deposit rates, we discuss time-varying deposit betas in Appendix A.

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 5a, 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 5b. Figure 5b shows that corporate 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.[6]

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 5b) 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.[7] At the same time, Figures 6a and 6b 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.[8] This disproportionate growth in the more volatile non-operational deposits for firms and transactional

[6]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.

[7]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.

[8]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.

deposits for retail depositors contribute further to the rise of deposit flightiness leading up to the 2022 rate hike cycle.

3.3 Depositor-level Deposit Flightiness in the Cross-section

We proceed to show the existence of and variation in deposit flightiness using granular depositor-level data. We provide further details about the data in Appendix B. Essentially, this transaction-level data allows us to uncover the movement of funds between banks and between banks and outside investment options at the depositor level. The data primarily covers household accounts but also includes a small proportion of business accounts so we present results for household and corporate depositors separately. We note that these business accounts are tilted towards small and medium enterprises rather than large firms. Hence, they most likely represent a mixture between the non-financial corporate and small business depositors in Section 3.2.

Our granular data confirms that there exists significant heterogeneity across depositors. Based on corporate depositors' flows between banks, we find that the 25^{th} percentile depositor transfers funds between banks in 13.2% of months, while the 75^{th} percentile depositor transfers funds between banks in 49.5% of months (Table 4). The corresponding probabilities are lower for household depositors at 0.0% and 14.9%, respectively. Also in terms of the number of flows between banks, we find that the 25^{th} percentile corporate depositor moves funds at 0.2 times per month, while the 75^{th} percentile corporate depositor moves funds twice as frequently at 1.3 times per month. Finally, the last row of Table 4) shows that some depositors display much more variation in their deposit flows between banks as a proportion of total deposit flows.

We also observe significant heterogeneity in depositors' sensitivity to move funds between banks and outside investment options. Here, the 25^{th} percentile corporate depositor transfers funds in and out of the banking sector in 1.1% of months, while the 75^{th} percentile depositor does so in 35.1% of months. The corresponding probabilities are again lower for household depositors at 0.0% and 4.3%, respectively. Further, the 25^{th} percentile corporate depositor moves funds in and out of the banking sector 1.2 times per month, while the 75^{th} percentile depositor does so 2.9 times per month. Similarly, we observe that some depositors display much more variation in their deposit flows between banks and outside investment options as a proportion of total deposit flows.

Importantly, depositors who are more flighty in switching funds between banks are also more flighty in moving deposits between banks and outside investments. In Figure 7, we show binned scatter plots of depositor-level flightiness in flows between banks versus flows between banks and outside investments. We proxy for flightiness using three measures: (1) the proportion of months in which a depositor had flows between banks and between banks and outside investment options; (2) the average number of times per month that a depositor has flows between banks and between banks and outside investment options; (3) the standard deviation of flows between banks and between banks and outside investment options scaled by total payment flows. Across all three measures, Figure 7 displays a clear positive relationship between the two dimensions of deposit flightiness for both household and corporate depositors.

These results imply that there is a heterogeneous degree of sensitivity among depositors, which is not only evident in terms of the tendency to move funds between banks but also in and out of the banking sector.

3.4 Depositor-Level Flow Sensitivities over Time

While our bank-level estimates are based on overall changes in deposit volumes, one key advantage of our depositor-level data is that we can distinguish deposit flows between banks from deposit flows between banks and outside investment options. Thus, we proceed to explore how the sensitivity of bank-to-bank deposit flows and the sensitivity of outside investment-to-bank flows evolve over time.

For each bank account k of depositor j in month m, we calculate $BankFlow_{jkm}$ as the net volume of deposits transferred from other bank accounts of depositor j in the same month normalized by the total account balance of depositor j. We calculate deposit rates $DepRate_{jkm}$ by dividing interest income by account balance. Then, for each month m, we estimate how deposit flows between banks respond to deposit rates for a given depositor:

$$BankFlow_{jkm} = \gamma_m DepRate_{jkm} + FE_{jm} + Controls_{jkm} + \epsilon_{jkm}. \tag{3.3}$$

where FE_{jm} is a depositor fixed effect 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_m as 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 8a. Observe that depositor-level bank-to-bank 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 also aligns with the pattern of aggregate deposit flows into the banking system, consistent with deposit inflows bringing more rate-sensitive depositors into the banking system.

If deposit inflows bring more rate-sensitive depositors into the banking system, we would also expect that the sensitivity of depositors' flow between outside investments and banks to increase with aggregate deposit inflows and to follows the same pattern as the sensitivity of bank-to-bank deposit flows. To this end, we re-estimate equation 3.3 replacing bank-to-bank flows $BankFlow_{jkm}$ with outside investment-to-bank flows $NonBankFlow_{jkm}$ and deposit rates $DepRate_{jkm}$ with deposit spreads $DepSpread_{jkm}$, where deposit spreads are defined relative to the Fed funds rate.

We plot the 12-month moving average of the coefficient on $DepSpread_{jkm}$ in Figure 8b. The positive coefficients imply that as deposit rates increase relative to the Fed funds rate, depositors move funds from outside investment options to their bank accounts. Indeed, the sensitivity of these flows varies over time in a very similar way as the sensitivity of bank- to-bank deposit flows at the depositor level and at the bank level. This positive comovement implies that the same depositors who become flightier in moving between banks also become flightier in moving in and out of the banking system, underscoring the importance of understanding the dynamics of the aggregate depositor base over time.

4 Model

To rationalize the time-varying depositor flightiness and investigate its financial stability implications, we consider a dynamic banking model with heterogeneous investors and run risks. 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 a continuum of investors who are infinitely lived with measure one. Each investor has one dollar available for investment, and can choose to either deposit the money with the bank 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, she derives value θ_i each period from holding deposits. This θ_i is known and fixed over time. We denote the cumulative density function (CDF) of θ_i as $H(\cdot)$, and $G(\theta) \equiv 1 - H(\theta)$.

Note that the convenience benefit θ_i is relative to one dollar of expected monetary compensation. In other words, for each unit of convenience benefit, the investor needs to be compensated $1/\theta_i$ units of expected interest payment, i.e., investors with lower θ_i have higher interest rate sensitivity (and are more sensitive to default risks). Hence we refer to investors with low θ_i as flighty investors.

Since we are interested in the aggregate implications of the time-varying depositor base, we model the banking sector as a whole and focus on the heterogeneity in convenience benefit for investors moving between banks and the outside option. To connect this convenience benefit with our empirical estimates in Section 3, we can decompose θ_i as $\theta_i = \tilde{\theta}_i(\mu_b + \mu_j)$, where $\tilde{\theta}_i$ is the weight that investor i puts on the convenience benefit relative to the interest rate, μ_b is the average convenience benefit of bank deposits and μ_j is the bank-j specific convenience benefit. In this case, depositors' rate sensitivity across banks is closely tied to depositors' rate sensitivity between banks and the outside option. This is consistent with our empirical evidence in Section 3.3, which shows that depositors who move money more among banks also move money more between banks and outside investment options, suggesting the two dimensions of rate-sensitivity are positively correlated.

Finally, investors face switching cost $f > 0$ whenever they move money in and out of the bank, 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.

Remark 1. *We will later use the model to analyze the financial stability implications of conventional and unconventional monetary policy. 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. As we will later show, these incoming investors derive smaller convenience benefits from holding deposits compared to existing depositors.

Bank The bank in the economy issues one-period deposits to investors in order to fund long-term illiquid projects. The equity holder of the bank is long-lived with discount rate $\beta \in (0, 1)$. To study the liquidity problem faced by the bank, we assume that she has no endowment and cannot issue equity at any point in time.

On the asset side, the bank invests in a project that matures with probability λ each period. It 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 learn about the value of y_t at the beginning of period t. The value of y_t as a coordinating signal among investors. This asset could be interpreted as a long-term loan made by the bank, whose cash flow is mostly generated upon maturity. The value of the cash flow y_t can be interpreted as the fundamentals of the loan, which affects the repayment received by the bank.[9]

When there is deposit inflow, the bank uses the influx of money to scale up the project at per-unit cost 1. When there is deposit outflow, the bank sells a fraction of the project to meet outflows. The project is 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 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,

$$L(y) = \min(\alpha_0 + \alpha_1 y, 1). \tag{4.1}$$

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

For each dollar of deposit, the bank promises payment r if the asset side matures in this period; otherwise depositors get face value 1 at the end of the period. Since depositors are risk-neutral, this is equivalent to an expected interest rate payment of $\lambda(r - 1)$.[10] Because the project generates no intermediate cash flows before maturity, the bank can only pay interests when the project matures.[11] Because the banker has no endowment, the promised deposit rate to the depositors r_t has to be weakly smaller than the cash flow generated from the project y_t, i.e., $r_t \leq y_t \; \forall t$. This resource constraint limits how much interest payment can be promised to depositors.

The bank profits from the spread between the asset side returns and the interest expenses paid to depositors. She is risk-neutral and chooses the promised payment r_t each period to maximize the expected equity value, internalizing the effect of deposit rate r_t on deposit flows.

[9] 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.

[10] In the subsequent analysis, we refer to r as the deposit rate paid by the bank.

[11] We could alternatively assume that there is a fixed stream of intermediate cash flow being generated, so that the bank can pay interests in all states of the world. This does not change the key economics of the model given that depositors are risk neutral.

Timing At the beginning of each period, all agents learn the value of y_t, which is the fundamental cash flow *if* the project matures this period. Then, the bank chooses deposit rate r_t, which investors take as given to decide whether to hold deposits or invest in the outside option. The bank scales up or sells the asset depending on the flows. Finally, whether the project matures or not is realized. If the project matures, cash is paid out and the game ends; otherwise, the game 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 $D(r_t, \theta_i, \Theta_t)$, where r_t is the promised interest rate on the deposit, θ_i is her own convenience value from holding deposits and Θ_t is the set of investors in the bank in period t. As we will see later, the bank default probability depends on the set of depositors in the bank.[12]

$$D(r_t, \theta_i, \Theta_t) = \underbrace{\theta_i}_{\text{convenience benefit}} + \underbrace{\lambda r}_{\text{expected interest payment}} \tag{4.2}$$

$$+ (1-\lambda)\beta\mathbb{E}[(1 - \mathbf{1}_{def,t+1}) \underbrace{\max\{D(r_{t+1}, \theta_i, \Theta_{t+1}), R - f\}}_{\text{Continuation value if no bank default}} + \mathbf{1}_{def,t+1} L(y_{t+1})] \tag{4.3}$$

The first term in Equation 4.2 is the convenience value that investor i derives from holding deposits, and the second term is the interest payment that the investor expects to receive. Equation 4.3 is the continuation value if the project does not mature in this period. The indicator function $\mathbf{1}_{def,t+1}$ equals 1 if and only if the bank experiences a run and defaults in period $t+1$. If the bank defaults in the next period, then the investor gets the liquidation value $L(y_{t+1})$. If the bank does not default, the investor chooses between staying in the bank to obtain $D(r_{t+1}, \theta_i, \Theta_{t+1})$ and moving out of the bank to earn $R - f$. As we will see in Section 4.3, investor i's deposit value depends on the whole depositor base Θ_t through the probability of bank default in the next period.

[12]To simplify expositions, we only show the depositor value when the bank sells less than ϕ fraction of its assets. This is the relevant case on the equilibrium path. For the general expression of depositor value, see Appendix D.1.

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,

$$D(r_t, \theta_i, \Theta_t) \geq R - f. \tag{4.4}$$

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,

$$D(r_t, \theta_i, \Theta_t) - f \geq R. \tag{4.5}$$

The switching cost f creates a discontinuity in investor's value function, and an inaction region of r_t in which the investor does not move her money. As a result, depositor base is sticky over time and the previous period 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 function of depositors, 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,*

$$\Theta_t = \{\theta_i : \theta_i \geq \theta_t\}. \tag{4.6}$$

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 investor θ_t is indifferent between bank deposits and the outside option so the marginal depositor is a sufficient statistic for the depositor set. A smaller θ_t implies there are more deposits in the bank and the marginal depositor is flightier. From now on, we denote the deposit value of investor i as $D(r_t, \theta_i, \theta_t)$.

Another implication of Lemma 1 is that whenever the bank experiences deposit inflows, the new incoming depositors must be flightier than the existing depositors. As the inflow becomes larger, the marginal depositor becomes flightier. Similarly, when there are outflows, the marginal depositor becomes less flighty. Our model thus suggests a tight link between deposit flows and changes in the depositor base.

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

$$V(y_t, r_t, \theta_t) = \lambda(y_t - r_t)G(\theta_t) + (1-\lambda)\beta\mathbb{E}[(1-\mathbf{1}_{def,t+1})V^*(y_{t+1}, \theta_t)], \tag{4.7}$$

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

The banker's problem is to choose a deposit rate r_t and marginal depositor θ_t to maximize $V(y_t, r_t, \theta_t)$, subject to two constraints: (1) the resource constraint and (2) the marginal depositor must be indifferent between holding deposits or investing in the outside option. That is,

$$V^*(y_t, \theta_{t-1}) = \max_{(r_t, \theta_t)} \quad V(y_t, r_t, \theta_t) \tag{4.8}$$

$$s.t. \quad r_t \leq y_t \tag{4.9}$$

$$\begin{cases} D(r_t, \theta_t, \theta_t) = R - f & \text{if } \theta_t \geq \theta_{t-1} \\ D(r_t, \theta_t, \theta_t) - f = R & \text{if } \theta_t < \theta_{t-1}. \end{cases} \tag{4.10}$$

If the bank does not attract any inflow, that means the marginal investor in period t was already holding deposit in the previous period, i.e. $\theta_t \geq \theta_{t-1}$. In this case, the deposit rate r_t has to be such that the marginal depositor θ_t is indifferent between holding deposits and paying the switching cost to invest in the outside option, which yields net value $R - f$. On the other hand, if the bank attracts inflow, then the marginal investor in period t switched from the outside option to holding bank deposits. In this case, the deposit rate r_t needs to be high enough to compensate the outside investor for her switching cost

f. The state variables for the bank is the current period cash flow y_t and the previous period's marginal depositor θ_{t-1}, due to the fixed switching cost. In the subsequent analysis, we denote the marginal depositor in equilibrium as $\theta^*(y_t, \theta_{t-1})$.

4.3 Equilibrium Analysis

In this section, we first characterize when the bank experiences a run and defaults. We show that the bank experiences a run when outflows exceed ϕ fraction of total deposits. We then proceed to solve for the bank's optimal strategy and the deposit flows in equilibrium. We find that when the fundamental is high and when the previous period's marginal investor is flighty, the current-period marginal depositor is flightier and the bank is more likely to experience net outflows.

4.3.1 Bank Runs

When the bank sells less than ϕ fraction of its asset, there is no liquidation discount. Hence the bank can always sell the necessary amount of assets to meet outflows. However, when outflows exceed ϕ, 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 depositors more likely to leave as well. 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 the bank, then the bank needs to liquidate more than ϕ fraction of assets and incur liquidation costs, i.e.,

$$G(\bar{\theta}_t) = (1-\phi)G(\theta_{t-1}). \tag{4.11}$$

The bank can potentially reduce outflows by increasing the interest rate paid to investors. However, such interest rate is bounded above by the fundamental cash flow y_t. When y_t is low, the bank cannot promise a high enough deposit rate and hence experiences large outflows or even runs. As we show in Lemma 2, when y_t falls below an endogenous threshold, all depositors choose to leave the bank, i.e., the bank experiences a run.

Lemma 2. *When α_0 and α_1 are small, the 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 bank. The run threshold $y^*(\theta_{t-1})$ is* *defined implicitly by,*

$$D(y^*, \bar{\theta}_t(\theta_{t-1}), \bar{\theta}_t(\theta_{t-1})) = R - f, \tag{4.12}$$

where $\bar{\theta}_t$ is defined in Equation 4.11.

Lemma 2 shows that when the liquidation discount is large, all depositors choose to leave the bank if the critical depositor $\bar{\theta}_t$ chooses to leave the bank. The problem of the bank then becomes whether it can 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 the bank even if the bank sets the highest deposit rate possible $r_t = y_t$. In this case, all depositors leave the bank, and a bank run occurs. When y_t is above this threshold, then the bank can set a high enough deposit rate to retain enough depositors.

Furthermore, 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.[13]

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 bank, 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 the bank's run probability is decreasing in θ_{t-1}.*

Proposition 1 states that 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. All else equal, the bank needs to pay higher interest rates in order to convince depositors to stay. This leads to higher run threshold and larger run probability in equilibrium.

[13] 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.

Finally, 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* depositors in the current period.

Bank's Liquidity Management So far, we have abstracted away from the bank's asset side adjustment to illustrate the main mechanism. One concern is that as deposit inflows increase the flightiness of the marginal depositor, the bank 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 the bank's optimal portfolio choice problem given its 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*

$$\frac{G'(\theta_{t-1})}{G(\theta_{t-1})} < \frac{\phi'(\theta_{t-1})}{1 - \phi(\theta_{t-1})}. \tag{4.13}$$

To understand Corollary 1, consider the relationship between the critical depositor flightiness $\bar{\theta}_t$ and the previous period marginal depositor θ_{t-1}. As before, the critical depositor is defined as the depositor whose departure would force the bank into selling illiquid assets and incur liquidation discounts. The marginal depositor influences the bank's default probability by changing 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

$$G(\bar{\theta}_t) = (1 - \phi(\theta_{t-1}))G(\theta_{t-1}). \tag{4.14}$$

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. However, if the bank 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 (4.13) 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.[14] 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. Outside of this extreme case, Corollary 1 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 Flows

To determine the endogenous investor base in the bank, we solve for the bank's 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 y_t.

We can write the bank's problem as targeting a marginal depositor θ_t to maximize equity value subject to the constraint that the deposit rate has to be consistent with the marginal depositor it attracts.[15] We define $\Delta(\theta_t)$ as the difference between the value of the outside option R and marginal depositor θ_t's value of holding deposit, excluding the deposit rate and switching cost, i.e.,

$$\Delta(\theta_t) \equiv R - \theta_t - (1-\lambda)\mathbb{E}[\mathbf{1}_{y_{t+1}\geq y^*(\theta_t)} \max\{D(r^*(y_{t+1},\theta_t),\theta_t,\theta^*_{t+1}(y_{t+1},\theta_t)), R-f\} + (1-\mathbf{1}_{y_{t+1}<y^*(\theta_t)})L(y_{t+1})] \tag{4.15}$$

[14] Note that $\phi' < 0$ and $G' < 0$.
[15] See Appendix D for the expression of deposit rates.

To understand the trade-offs that the bank faces, let us consider the value function when $\theta_t \geq \theta_{t-1}$. The first order condition of V with respect to θ_t is,

$$\frac{\partial V(y_t, \theta_t)}{\partial \theta_t} = (\lambda y_t - \Delta(\theta_t) + f)G'(\theta_t) - \Delta'(\theta_t)G(\theta) + (1-\lambda)\beta \frac{\partial \mathbb{E}[\mathbf{1}_{y_{t+1} \geq y^*(\theta_t)} V^*(y_{t+1}, \theta_t)]}{\partial \theta_t}. \tag{4.16}$$

The first term of Equation 4.16 captures the effect of balance sheet size on the current period profit. The second term captures the change in deposit rate when the bank adjusts its depositor base. The last term in Equation 4.16 captures the effects of the marginal depositor flightiness on future expected profits. The current period marginal depositor flightiness affects bank's continuation value in two ways. First, if the marginal depositor is flightier, then the bank has higher run probability next period, as illustrated in Proposition 1. Second, the current period depositor base also affects the future depositor base through the switching cost.

The existence of switching cost further complicates the analysis because both the level and slope of the value function are different when there are inflows compared to outflows. As a result, we need to consider several different regions. We characterize the bank's optimal policy θ^* under different scenarios 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.24, and an inflow threshold $y_{in}(\theta_{t-1})$, defined by Equation D.25, 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.22. 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.22. In this case, $\theta_t^* < \theta_{t-1}$ and the bank has deposit inflows.*

Proposition 2 provides a complete characterization of the bank's marginal depositor under different scenarios. In the first case when the fundamentals are weak, the bank does not want to invest much. Hence the bank sets a low deposit rate and tolerates moderate degree of deposit outflows. However, the outflows cannot be too large or else the bank risks selling large amounts of assets that incur liquidation discounts. When y_t is very low, the constraint $\theta_t \leq \bar{\theta}_t$ starts to bind, in which case the bank sets a higher deposit rate than the unconstrained level to reduce the outflows, keeping the critical investor $\bar{\theta}_t$ in the bank. When y_t is below y^*, the bank cannot keep the critical depositor and experiences a run, 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. In this case, the deposit rate is set such that the previous marginal depositor is indifferent between keeping deposits or moving money out of the bank.

Finally, in the third case, y_t is so high that the bank wants to attract inflows and increase investments. To attract inflows, the bank needs to increase the deposit rate discontinuously in order to convince outside investors to pay the switching cost and move money into the bank. The bank will only do so when the fundamentals are above the inflow threshold $y_{in}(\theta_{t-1})$. In addition, in contrast to the smooth flow adjustment around the outflow threshold $y_{out}(\theta_{t-1})$, the flow adjustment around the inflow threshold $y_{in}(\theta_{t-1})$ is discontinuous. As y_t increases and crosses over $y_{in}(\theta_{t-1})$, the deposit flow jumps from zero to a positive number.

Therefore, our model endogenously links the flightiness of the marginal depositor with the fundamentals on the asset side and the previous depositor base. Intuitively, the marginal benefit of deposits is larger when the fundamentals are stronger. Hence, when y_t is larger, the bank sets higher rates to attract flightier depositors. Furthermore, the depositor base is sticky due to the switching cost, which is why the marginal depositor's flightiness is positively correlated across periods. Figure 9a 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 9b provides a numerical illustration of the equilibrium deposit flows. The bank's net inflow increases with y_t because the bank sets higher deposit rates when the fundamentals are stronger. Furthermore, the bank is 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 outside of the banking system, the marginal depositor in the bank 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 first extend and calibrate the model in Section 5.1. 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 2023Q2. 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. The calibrated parameter values are shown in Table 5b. 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 $\rho < 1$.

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

where ϵ_t is the shock in period t and is i.i.d. across periods. We back out y_t by setting bank asset returns in the data equal to $\lambda(y_t - 1)$ and bank asset maturity in the data equal to $1/\lambda$. To obtain ρ and μ in Equation 5.1, we run an AR(1) regression using y_t, set ρ to the AR(1) coefficient from the regression, and match μ with the constant (scaled by $1/(1-\rho)$).

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%. The outside option value R is then simply the present value of the average Fed funds rate over our sample period. To calibrate the remaining parameters, we simulate model moments to match their empirical counterparts. We assume a simple uniform distribution, i.e., $\theta_i \sim U[0, \theta^{max}]$, for the convenience value of investors. Then, we jointly estimate the switching cost f, upper bound of convenience value θ^{max}, and the volatility of the shock in Equation 5.1 to match the median deposit rate, deposit flow sensitivity, and median default probability in the data. The deposit flow sensitivity is estimated by regressing aggregate deposit flows on average deposit spreads. 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.

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 depositors 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 depositors 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} 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. To estimate investors' expected persistence of the rate change, we estimate

$$FFR_t = \gamma FFR_{t-1} + \epsilon_{r,t}, \tag{5.2}$$

where FFR_t is the level of the Fed fund rate at time t. Hence, a 2% rate hike increases the value of investors' outside option R by $2\%/(1-\beta\gamma) = 5.86\%$. 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 investor currently in the bank.

Figure 10a shows that the jump in bank default probability for this 2% rate hike is increasing in the flightiness of the marginal depositor. When the marginal depositor in the bank values convenience by less, depositors expect the bank to fail with higher probability in the future. Hence, they 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 depositors. 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 remove, the amplification effect of a flightier deposit base on run risk remains, as shown in Corollary 1.

Specifically, 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 Fed increased reserve supply from \$1.73 trillion in Feb 2020 to \$4.19 trillion in Sep 2021. Acharya et al. (2023) estimate reserves expand deposits one to one. Hence, relative to the \$13.33 trillion of deposits in Feb 2020, QE increased deposits by $(4.19 - 1.73)/13.33 \approx 18.5\%$. Thus, in the QE case, we adjust the convenience value of the marginal depositor by incorporating the 18.5% deposit expansion from QE. From Figure 11, we see that when the 2% rate hike follows QE, there is a 73 bps increase in bank default probability. In comparison, if the same 2% rate hike were implemented without QE, the increase in bank default probability would be almost reduced by half to 40 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 depositor base 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 the same 2% rate hike in one period as in Section 5.2. We allow the same 2% to occur over two period for the counterfactual case 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. Investors' belief about the persistence of each rate hike is the same as before. To eliminate the mechanical effect of cumulative default probability increasing by more over longer horizons, we assume the realization of the fundamental value in the first period is equal to the initial y.

Figure 10b shows how the change in default risk varies with the convenience value of the marginal depositor in both cases. We observe that the default probability increases more in the drastic rate hike case than in the gradual rate hike case for any given θ_{t-1} and that the gap between the two cases widens as θ_{t-1} is lower. For the marginal depositor in the case with QE, where the 2% rate hike triggered a 73 bps increase in default probability, the gradual rate hike would only have increased default probability by 43 bps, as shown in Figure 11.

The gradual rate hike is more stabilizing because the small rate increase in the first period gives the bank time to adjust its depositor base, allowing the flightiest depositors to leave. Since the rate increase is minor, the bank is 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 bank are those who value convenience benefits more than those at the beginning of the first period, 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 bank adjusts its depositor base. For the latter, we let the bank 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. High levels 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 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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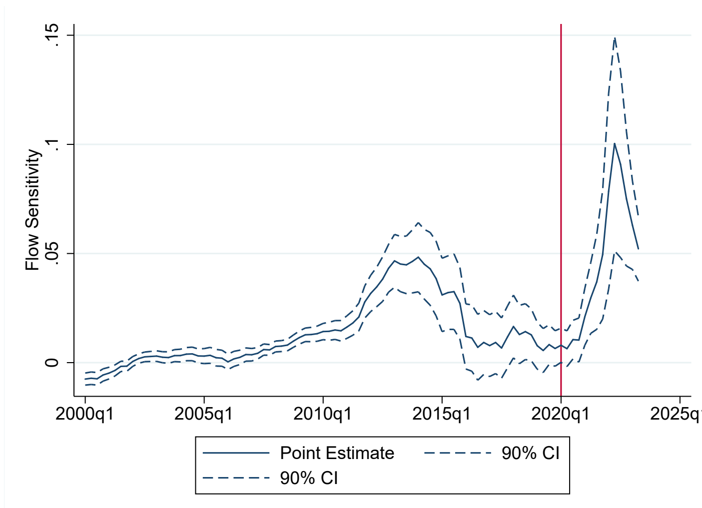
7 Figures and Tables

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

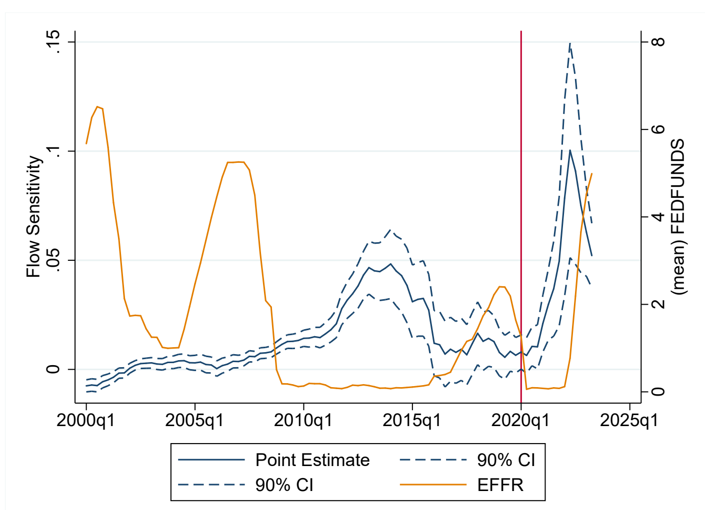
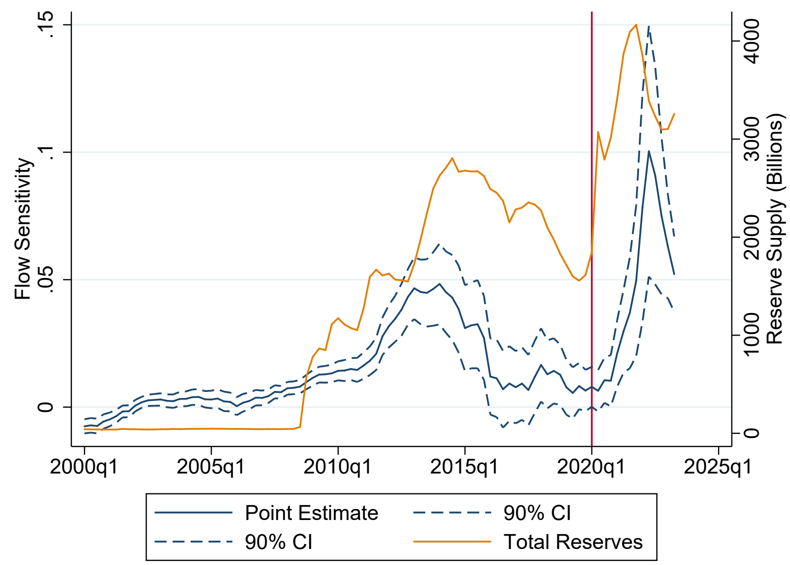


Figure 2: Deposit Flow Sensitivity, Deposit Flow, and Reserve Supply

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

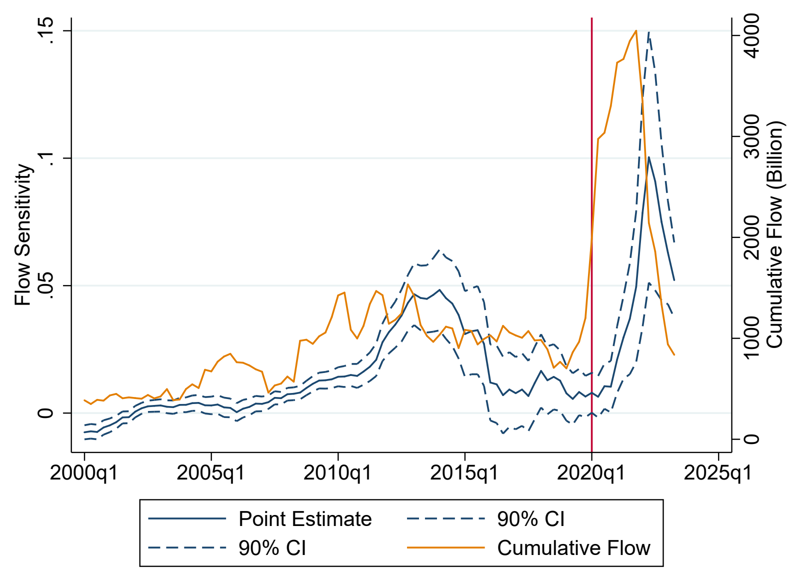


Figure 3: Savings Deposit Flow Sensitivity

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.

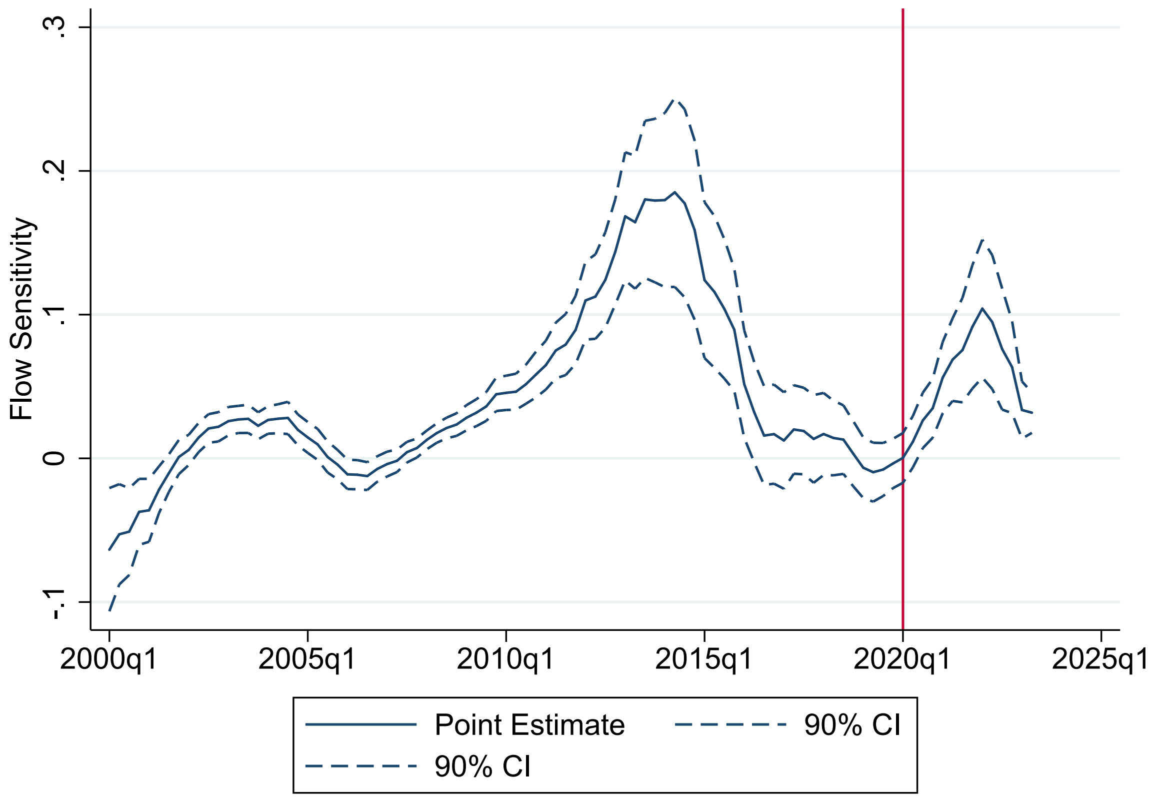
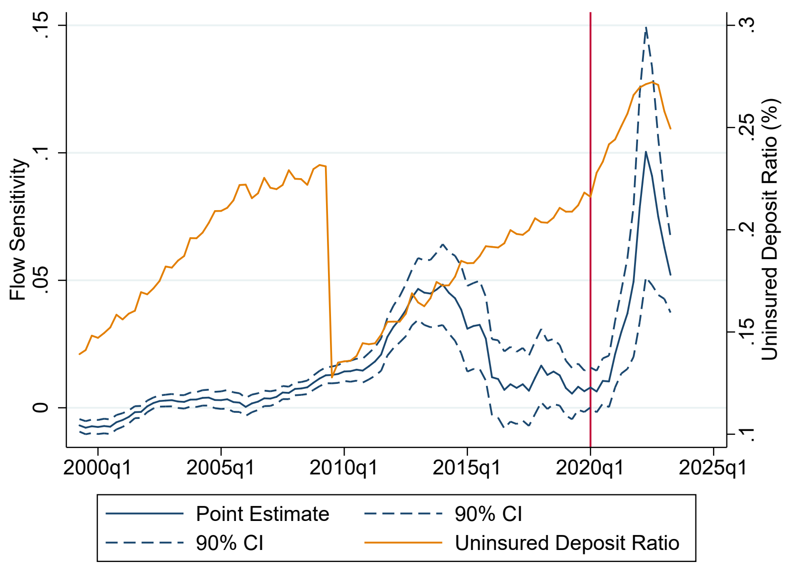


Figure 4: Deposit Flow Sensitivity and the Ratio of Uninsured Deposits

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

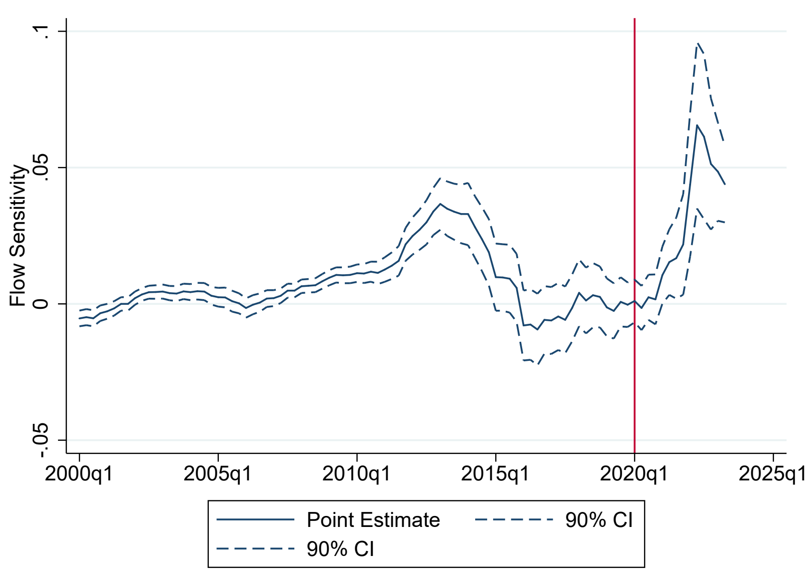
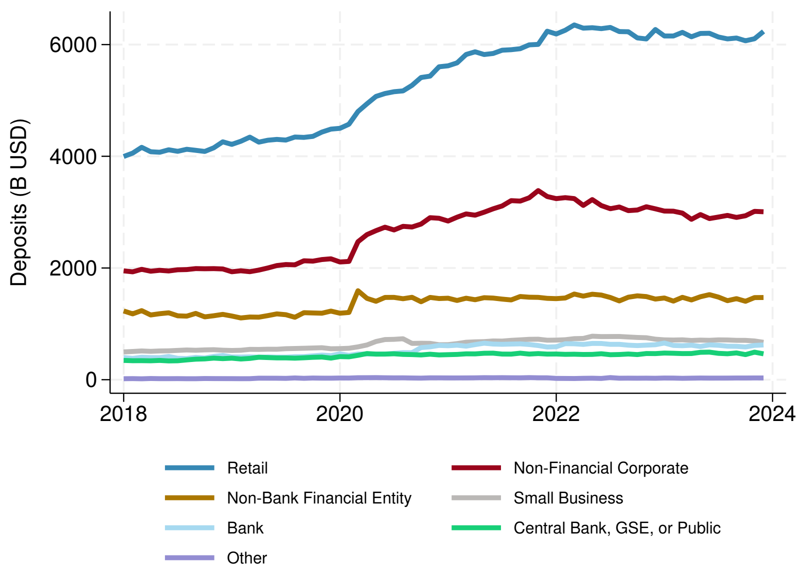


Figure 5: Deposits by Counterparty Type

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)

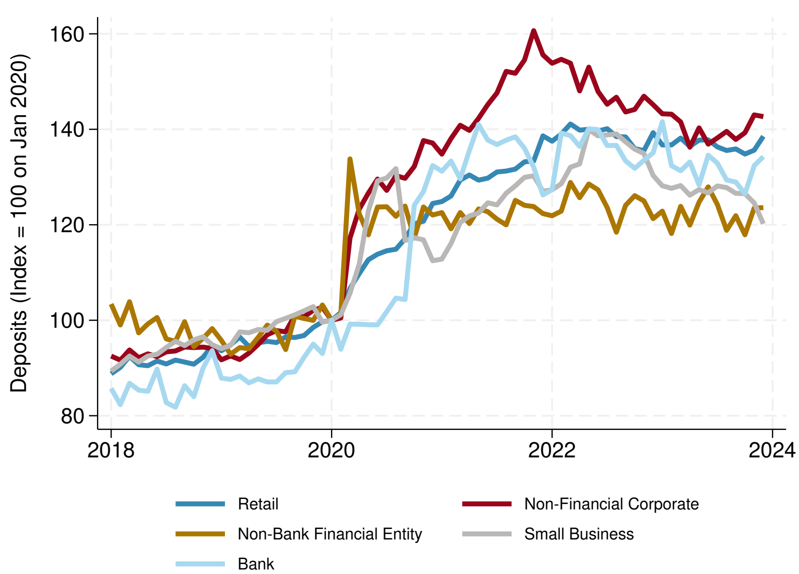
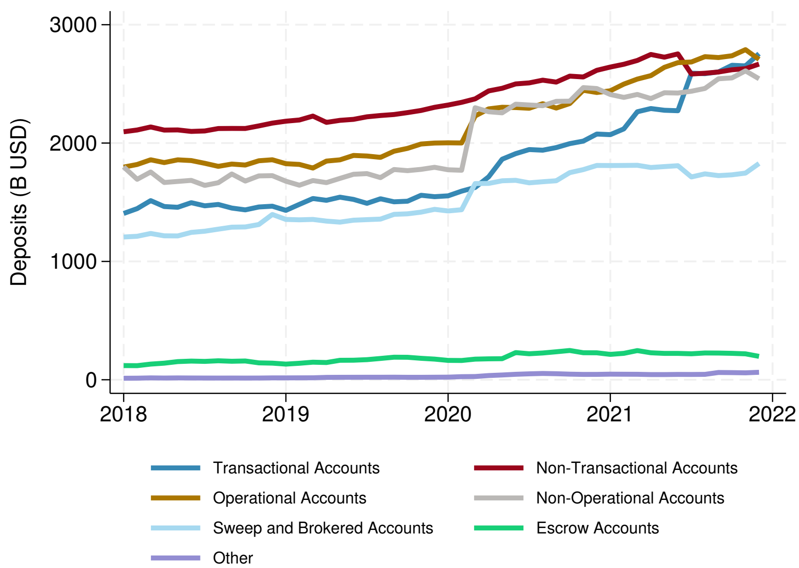


Figure 6: Deposits by Account Type

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)

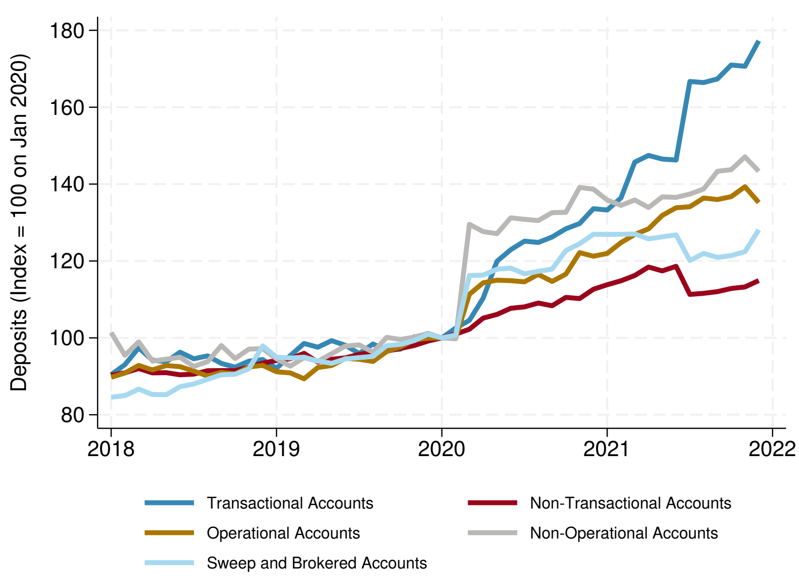
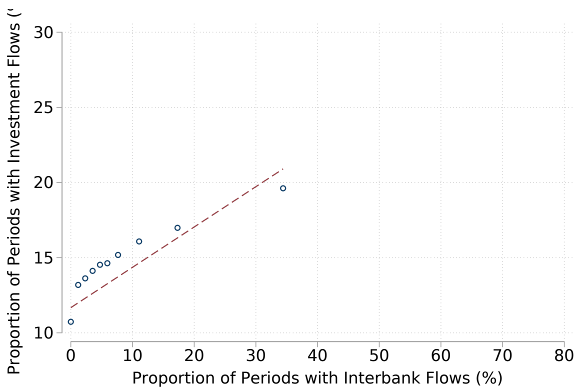


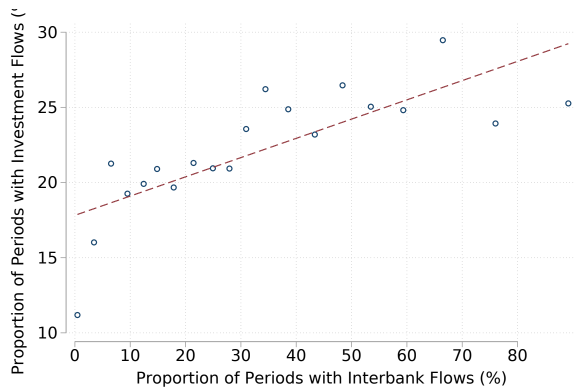
Figure 7: Depositor Flightiness in the Cross-Section

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. Panels (a) and (b) measure flightiness in terms of the proportion of months in which a depositor had flows between banks and between banks and outside investment options. Panels (c) and (d) measure flightiness in terms of the average number of times per month in which a depositor had flows between banks and between banks and outside investment options. Panels (e) and (f) measure flightiness as the standard deviation in flows between banks and between banks and outside investment options scaled by total payment flows. Panels (a), (c), and (e) are based on household depositors; panels (b), (d), and (f) are based on corporate depositors.

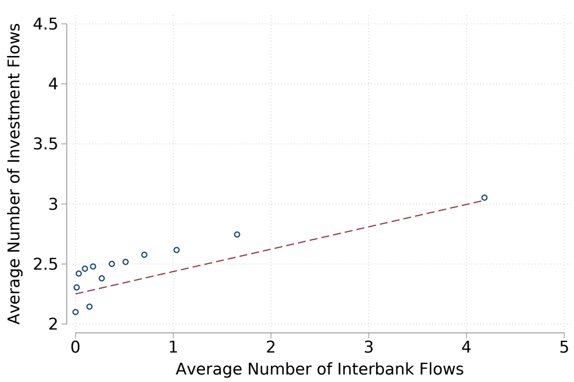
(a) Prop of Months with Flows (Household)



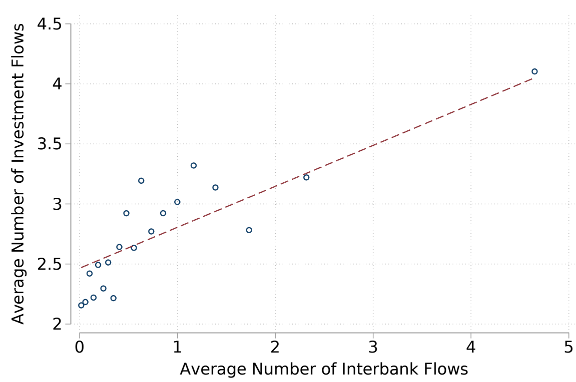
(b) Prop of Months with Flows (Corp)



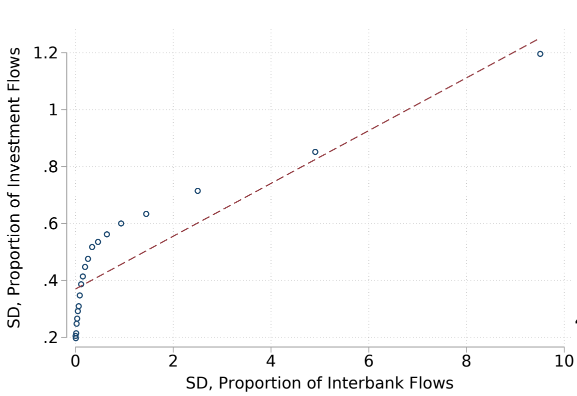
(c) Number of Flows per Month (Household)



(d) Number of Flows per Month (Corp)



(e) Scaled SD of Flows (Household)



(f) Scaled SD of Flows (Corp)

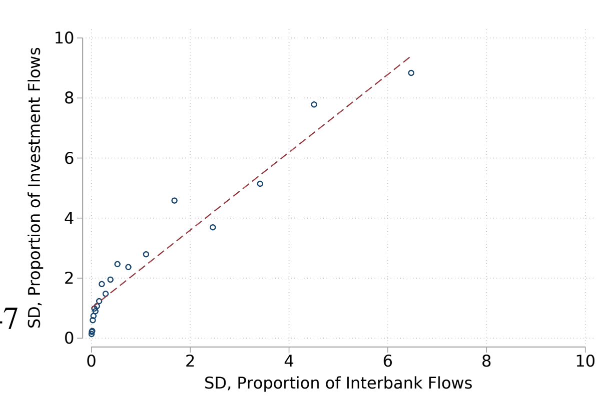
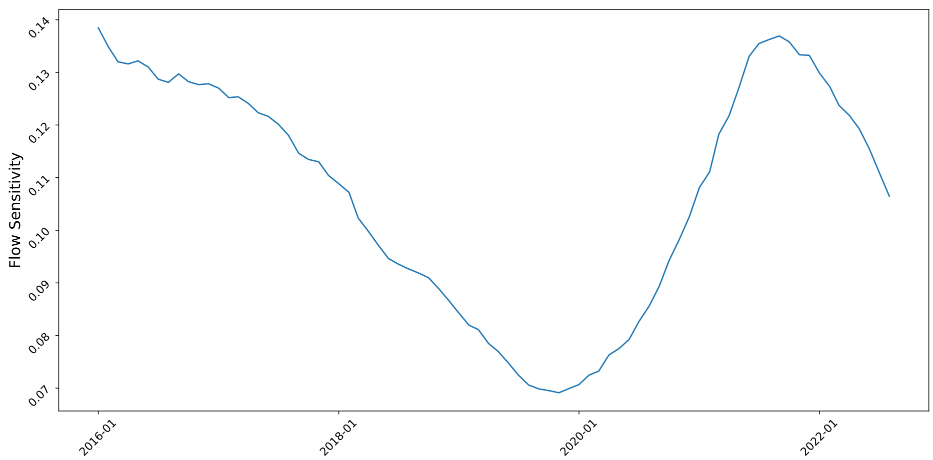


Figure 8: Depositor-Level Deposit Flow Sensitivity

This figure plots depositor-level deposit flow sensitivities between banks (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.

(a) Bank-to-Bank Deposit Flow Sensitivity



(b) Outside-Investment-to-Bank Deposit Flow Sensitivity

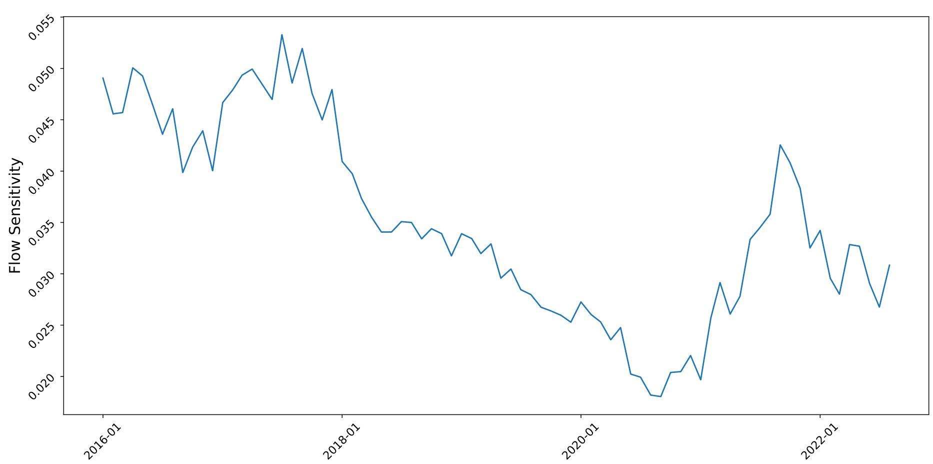
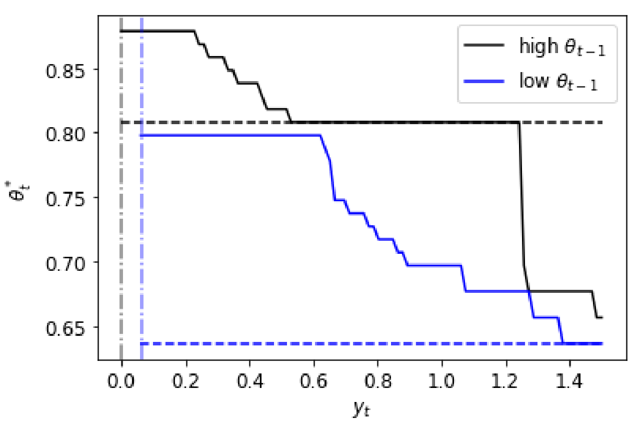


Figure 9: Numerical Illustration of the Equilibrium

Subfigure (a) plots the bank's solution in terms of the marginal depositor type it attracts $\theta^*(y_t, \theta_{t-1})$ 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 $\theta_{t-1} = 0.8$, and the blue line shows the solution for a low $\theta_{t-1} = 0.64$. The vertical line shows the run threshold in the two cases. We assume y is uniformly distributed in $[0, 1.5]$ and θ_i is uniformly distributed in $[0, 1]$. For the other parameters, we set $R = 1.2$, $\lambda = 0.5$, $f = 0.05$, $\phi = 0.5$, $\beta = 0.5$, $\alpha_0 = 0$ and $\alpha_1 = 0.2$.

(a) Optimal Policy θ^*



(b) Net Deposit Flows

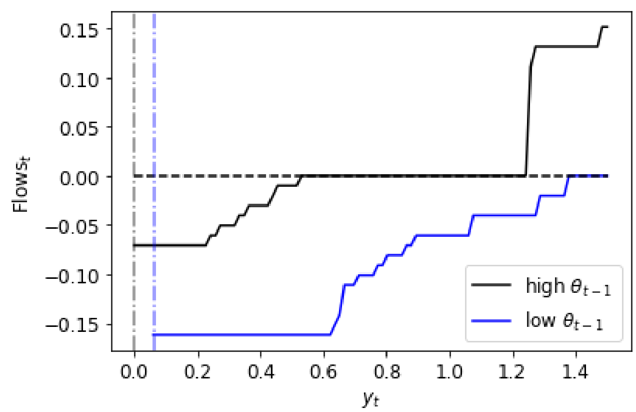
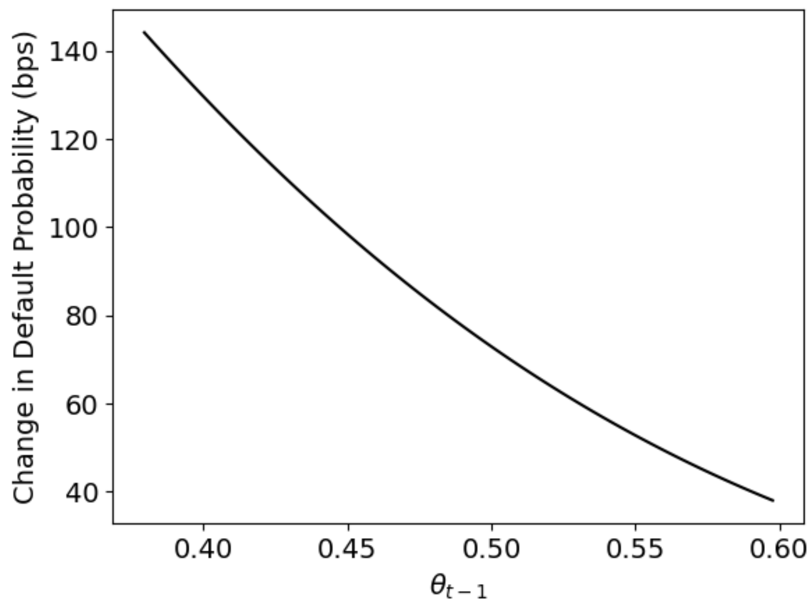


Figure 10: Effect of Rate Hikes on Bank Default Probability

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 let the rate hike be persistent with an auto-regressive coefficient of 0.67. We use calibrated parameter values in Table 5b. 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 when the 2% increase happens in one period ("Drastic") with the effect when the Fed Fund rate first increases unexpectedly by 1% in the first period, and then by another 1% in the second period ("Gradual").

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



(b) Change in Default Probability from Drastic versus Gradual Rate Hikes by Marginal Investor Type

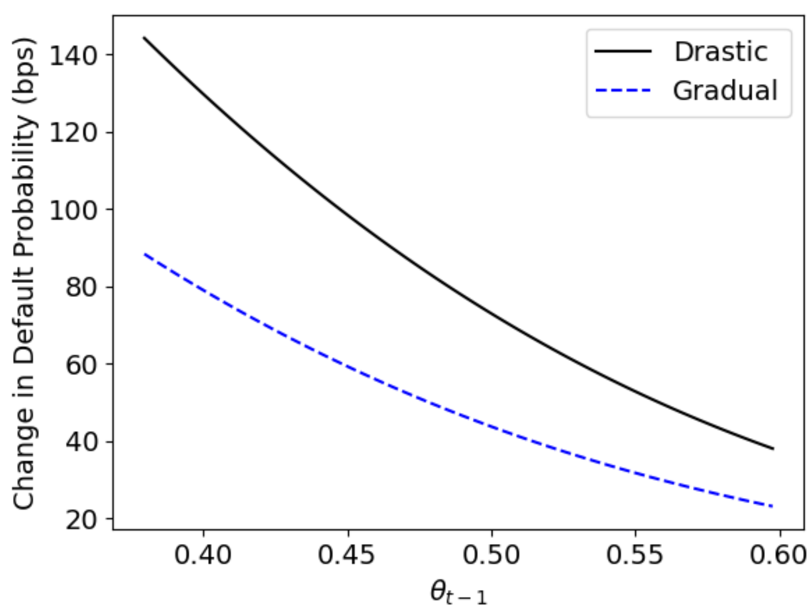


Figure 11: Effect of Rate Hikes on Bank Default Probability under different Scenarios

This figure compares the change in bank default probability with respect to a 2% rate hike under different scenarios. The starting point fundamental value y is set to match the asset return in 2022Q1. In the no "QE" case, the starting point of the marginal depositor is equal to the median marginal depositor in the simulation. In the "QE" case, we adjust the starting point of the marginal depositor such that the depositor base is 18.5% larger than the baseline. In the "Gradual w/ QE" case, we start with the same marginal depositor as in the "QE" case, and the Fed Fund rate first increases unexpectedly by 1% in the first period and then by another 1% in the second period.

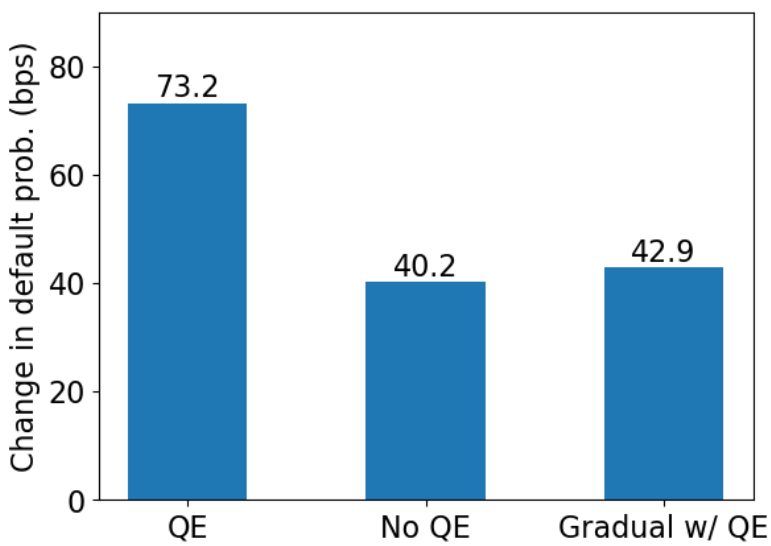


Table 1: Total Deposit Flow Sensitivity

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. The upper and lower panels show statistics for household and corporate depositors, respectively. In each panel, 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 average number of times per month in which a depositor had flows between banks and between banks and outside investment options, and the standard deviation in flows between banks and between banks and outside investment options scaled by total payment flows.

	Mean	SD	Median	25^{th} Pct	75^{th} Pct
Household Depositors					
Proportion of Months with Investment Flows (%)	4.44	8.71	1.06	0.00	4.30
Proportion of Months with Interbank Flows (%)	13.32	23.37	2.13	0.00	14.89
Number of Investment Flows per Month	2.31	2.67	1.40	1.00	2.29
Number of Interbank Flows per Month	0.37	0.99	0.01	0.00	0.30
SD (Proportion of Investment Flows)	0.49	0.76	0.14	0.03	0.59
SD (Proportion of Interbank Flows)	1.12	2.42	0.17	0.04	0.77
Corporate Depositors					
Proportion of Months with Investment Flows (%)	22.40	27.22	10.64	1.09	35.11
Proportion of Months with Interbank Flows (%)	33.32	24.24	28.72	13.19	49.45
Number of Investment Flows per Month	2.83	4.06	1.75	1.15	2.85
Number of Interbank Flows per Month	0.84	1.57	0.47	0.18	1.03
SD (Proportion of Investment Flows)	2.52	4.64	0.33	0.04	2.48
SD (Proportion of Interbank Flows)	1.13	1.81	0.25	0.05	1.36

Table 5: Calibration Moments and Estimates

Panel (a) summarizes the empirical moments we target. The moments are size-weighted averages of banks in the U.S. Our sample period is from 2000Q1 to 2023Q2. Panel (b) shows the calibrated parameter values.

(a) Empirical Moments

Parameter	Empirical target	Empirical moments
ρ	Persistence of asset returns	0.82
μ	Average asset return	5.43%
λ	Average loan maturity	1.64
α	Average asset discount	21.69%
ϕ	Ample reserve proportion	9.83%
R	Average Fed Fund Rate	1.86%
β	Discount rate	0.98
f	Median deposit rate	0.80%
σ	Median default prob.	0.75%
θ^{max}	Deposit flow sensitivity	0.39

(b) Parameter Estimates

Parameter	Description	Value
ρ	Persistence of y_t	0.82
μ	Mean of y_t	1.089
λ	Maturity rate	0.61
α	Liquidity discount	0.78
ϕ	Ample reserve proportion	0.098
R	Value of outside option	0.93
β	Discount rate	0.98
f	Switching cost	0.06
σ	Sd of shock in asset return	0.45
θ^{max}	Upper limit of deposit convenience	1.13

A Deposit Rates and Betas

Figure 12 shows how the Fed-funds-deposit spreads relate to deposit flow sensitivities over time. Another seminal concept that is often linked to depositors' rate sensitivity is the deposit beta. Introduced by Drechsler et al. (2017) and Drechsler et al. (2021), deposit betas measure the passthrough of monetary policy rates to deposit rates. The original deposit beta in Drechsler et al. (2017) and Drechsler et al. (2021) is calculated at the bank-level and associated with deposit market power in the cross-section of banks. To shed light on the variation of deposit betas over time, we follow Kang-Landsberg et al. (2024) to calculate cumulative deposit betas q quarters into each rate hike cycle as

$$\beta_q = \frac{DepositRate_q - DepositRate_0}{FFR_q - FFR_0}, \tag{A.1}$$

where $DepositRate_q$ is the average deposit rate q quarters into the rate hike, $DepositRate_0$ is the average deposit rate in the quarter before the rate hike, FFR_q is the Fed Funds rate q quarters into the rate hike, and FFR_0 is the Fed Funds rate in the quarter before the rate hike.

In Figures 13a and 13b, we plot the cumulative deposit betas for total deposits and savings deposits, respectively. For a given number of quarters since the rate hike, we find that the deposit betas for the current rate hike cycle that started in 2022 are higher than those in the previous rate hike cycle that started in 2015. This observation is consistent with the large influx of depositors from additional rounds of QE following the Covid-19 crisis that started in March 2020. As our paper shows, this influx of investors increased the flightiness of the depositor base in the banking system and raised deposit flow sensitivities to historical highs before the start of the 2022 rate hike cycle. Thus, the presence of highly rate-sensitive investors may have contributed to banks passing through rate hikes by more than before.

Figures 13a and 13b also show that deposit betas were higher in the rate hike cycles before the 2008 financial crisis, even though deposit flow sensitivities were lower during those rate hikes. One likely explanation comes from the asset side of bank balance sheets. Figures 14a and 14b show the cumulative betas for banks' asset returns. The pattern of asset betas across rate hike cycles resembles the pattern of deposit betas, which reflects that bank asset and liability side exposure to interest rates are well aligned (Drechsler et al., 2021). In other words, the relative deposit betas are also influenced by changes in the asset side of banks and the passthrough of policy rates to asset returns.

Although our model does not focus on the passthrough of monetary policy to deposit rates and asset returns, it does predict that the interest rate set by banks is affected by their asset-side returns in addition to depositors' rate sensitivity. In particular, banks set lower deposit rates when their return on assets declines, all else equal (we discuss the model's prediction on deposit rates in Appendix D.6). Empirically, the gross return on banks' assets has indeed been structurally declining both in absolute terms and relative to the Fed Funds rate (Figure 15).[16] For the same depositor base, these lower asset returns reduce the deposit rates that banks are willing to pay.

Taken together, deposit rates and betas are closely related to the rate-sensitivity of deposit flows. However, deposit rates and betas are also influenced by banks' asset returns so that deposit rates and deposit betas may not fully predict deposit flightiness. Rather, the sensitivity of deposit flows to deposit rates is a direct measure of how flighty the depositor base is at any given point in time and provides complementary information to the deposit beta.

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.

[16]The increase in reserves from QE Diamond et al. (2023) and the increased holding of liquid assets on bank balance sheets may have contributed to the decline in banks' gross asset returns.

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 17a 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 17b 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

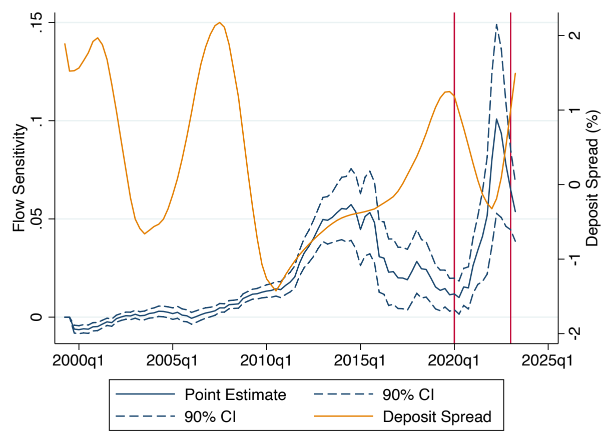
While we can link accounts belonging to the same depositor, the specific banks where these accounts are held remain unknown because bank identifiers for each account and bank names in transfer descriptions are redacted. To identify deposit flows between accounts of the same depositor at different banks, 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 12: Flow Sensitivity and Deposit Spreads

Panel (a) shows deposit flow sensitivities and the average deposit spreads 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. To obtain average deposit spreads, we first take the difference between the Fed Funds rate and the bank-level deposit rates, average across banks, and then calculate the 8-quarter cumulative average. Panel (a) shows deposit flow sensitivities and the average deposit spreads over time for savings deposits. The vertical red line corresponds to 2020Q1. Standard errors are clustered at the bank level.

(a) All Deposits



(b) Savings Deposits

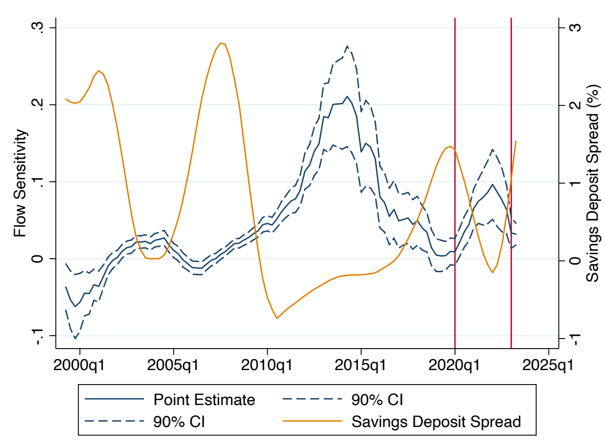
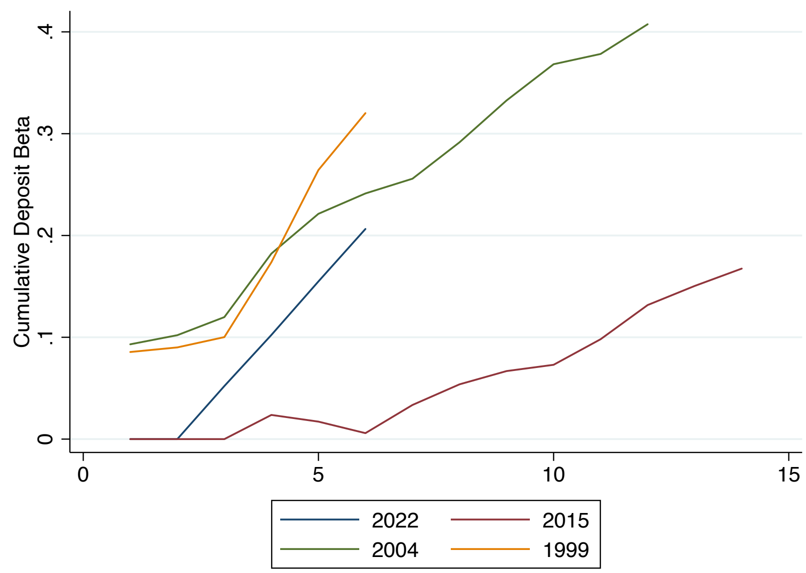


Figure 13: Cumulative Deposit Betas

Panel (a) shows the cumulative deposit beta over different rate hike cycles. Following Kang-Landsberg et al. (2024), we calculate cumulative deposit betas as the change in the average deposit rate from before the start of the rate hike divided by the change in the Fed funds rate from before the start of the rate hike. Panel (b) shows the cumulative deposit beta over different rate hike cycles for savings deposits.

(a) All Deposits



(b) Savings Deposits

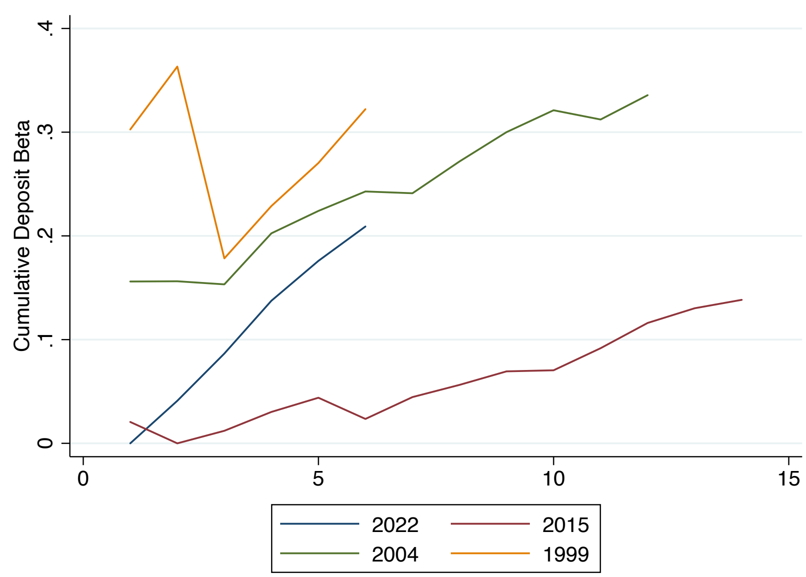
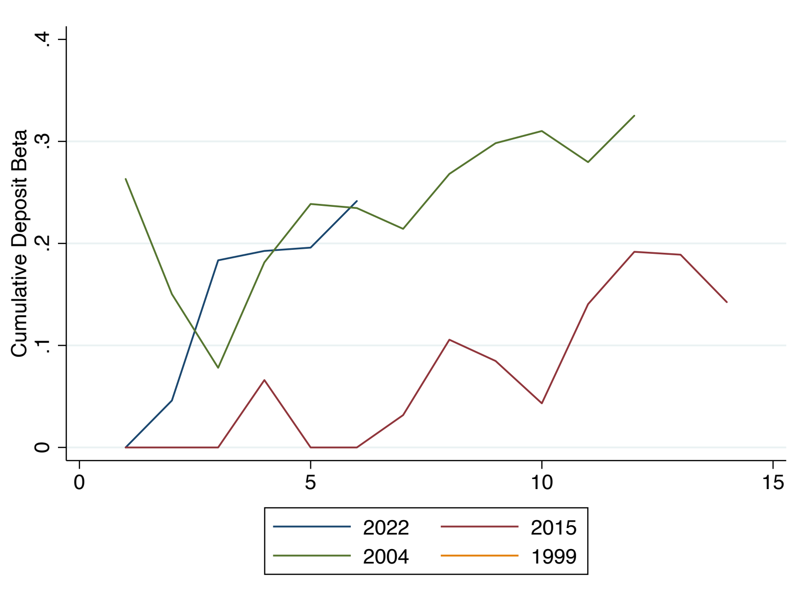


Figure 14: Cumulative Income Betas

Panel (a) shows the cumulative income beta over different rate hike cycles. We calculate cumulative income betas as the change in the average gross return on assets from before the start of the rate hike divided by the change in the Fed funds rate from before the start of the rate hike. The gross return on assets includes all income. Panel (b) shows the cumulative income beta over different rate hike cycles for interest income.

(a) All Income



(b) Interest Income

Figure 15: Gross Income on Assets

This figure shows the gross return on assets and the spread between the gross return on assets and the Fed Funds rate over time. The gross return on assets is calculated as the interest income on assets divided by total assets and then averaged across banks. The vertical red line corresponds to 2020Q1.

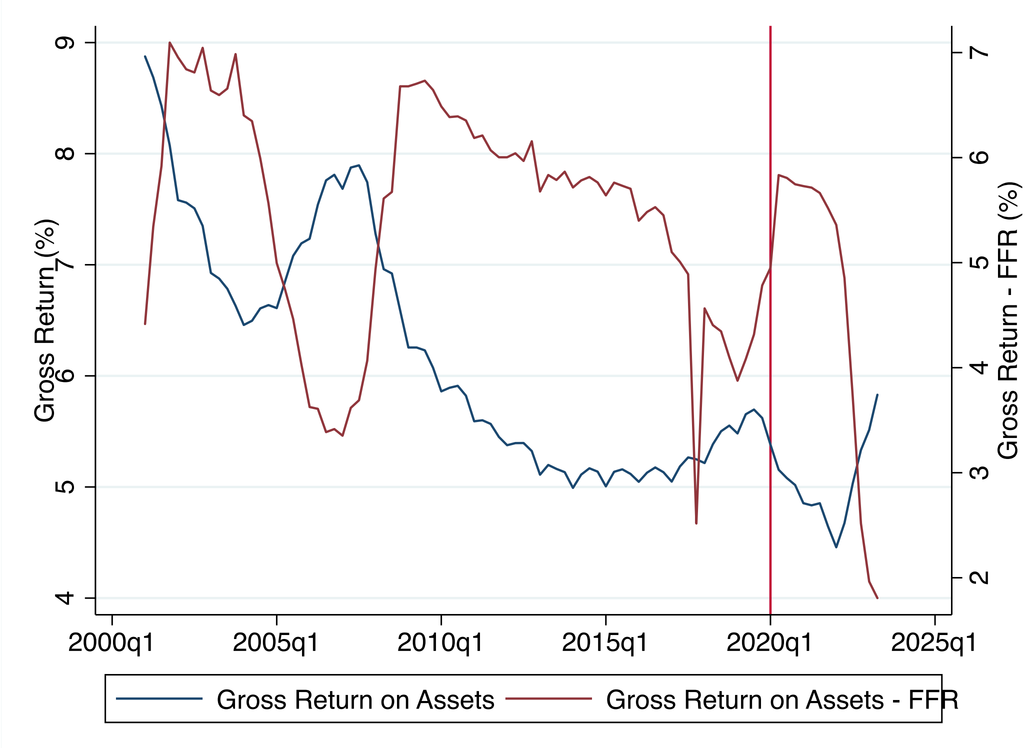
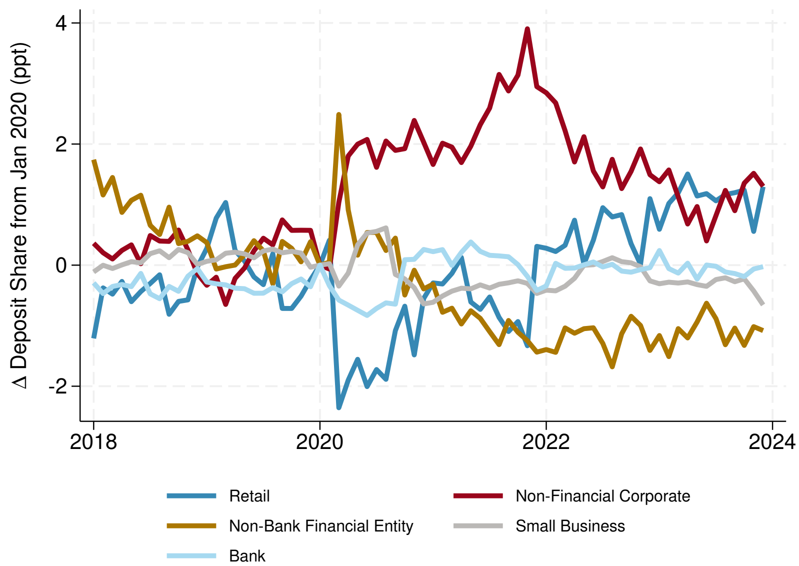


Figure 16: Deposit Composition by Counterparty and Account Type

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

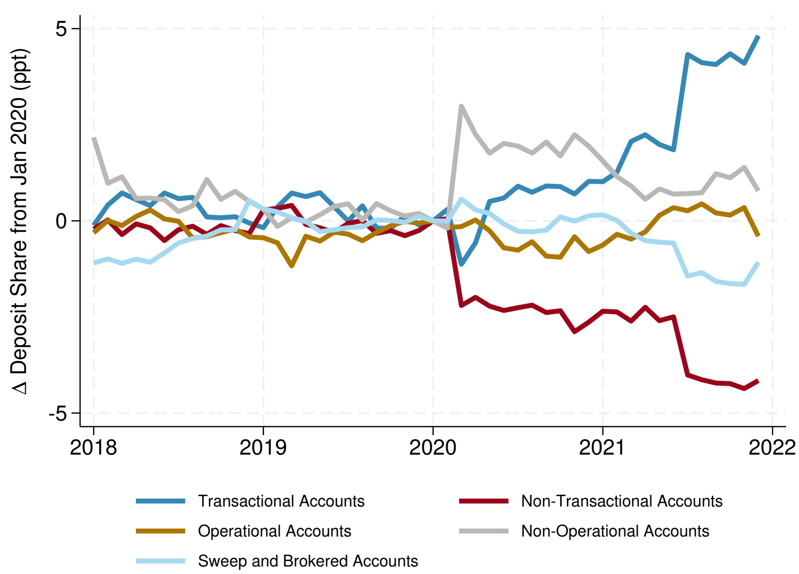
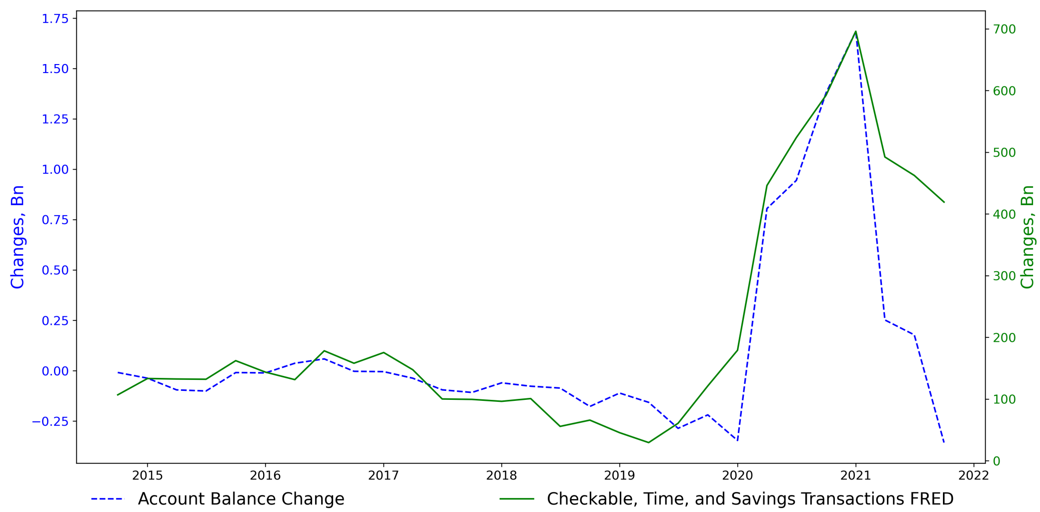


Figure 17: Account-level Data versus Aggregate Data

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

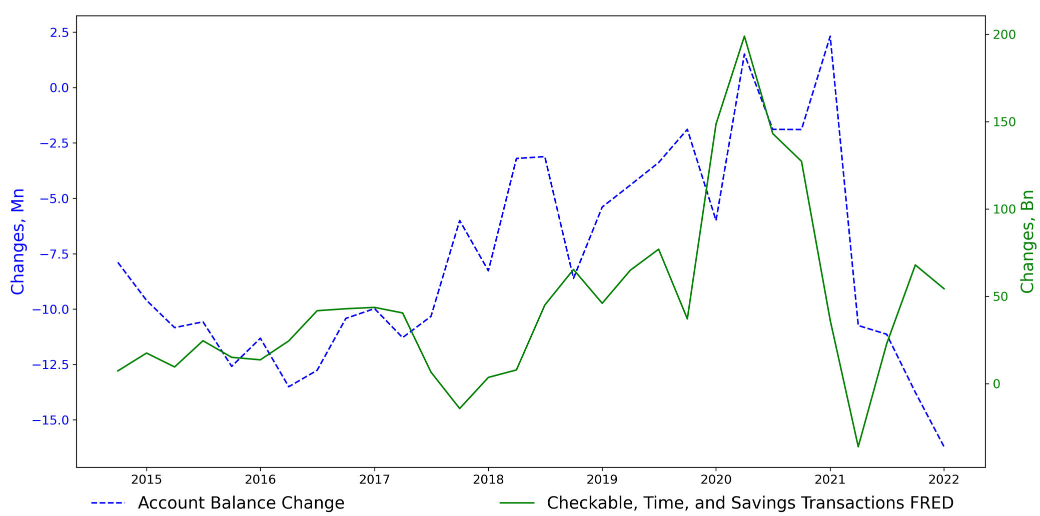


Table 6: First Stage: Effect of Fixed Cost and Salary Expense on Deposit Rates

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 2

To investigate the run condition, we look at the deposit value when the bank promises the highest interest rate possible to its depositors. We denote this value by $\tilde{D}(y_t, \theta_i, \theta_t)$, where

$$\tilde{D}(y_t, \theta_i, \theta_t) = \lambda y_t a_t + \theta_i + (1-\lambda)\mathbb{E}[\mathbf{1}_{y_{t+1} \geq y^*(\theta_t, a_t)} \max\{\tilde{D}_{in}(F_{y,t+1}, \theta_i, \theta_{t+1}), R - f\} + \mathbf{1}_{y_{t+1} < y^*(\theta_t, a_t)} L(y_{t+1})] \tag{D.1}$$

$$a_t = \frac{G(\theta_{t-1})(1-\phi) - \frac{G(\theta_{t-1}) - G(\theta_t) - \phi G(\theta_{t-1})}{L(y_t)}}{G(\theta_t)} = \frac{1}{L(y_t)} + \frac{(1-\phi)G(\theta_{t-1})}{G(\theta_t)}\left(1 - \frac{1}{L(y_t)}\right) \tag{D.2}$$

a_t is the number of assets that is backing per unit of debt claim.

Notice that when $L(y_t) = 1$, i.e., no liquidity discount, $a_t = 1$, and we do not need to track the number of assets backing each unit of debt claim. The expression of $\tilde{D}(y_t, \theta_i, \theta_t)$ simplifies to $D(y_t, \theta_i, \theta_t)$.

Given the marginal depositor is θ_t, the investor with the smallest θ_i who is willing to stay in the bank is given by

$$\tilde{D}(y_t, \theta_i, \theta_t) = R - f \tag{D.3}$$

To find an equilibrium, we need to solve a fixed point problem where $\theta_i(\theta_t; y_t) = \theta_t$. Furthermore, for the equilibrium to be stable, the function $\theta_i(\theta_t)$ defined by Equation D.3 implicitly crosses the 45 degree line from above.

When $\theta_t \leq \bar{\theta}_t$, $a_t = 1$. As we will see later, in this case, y^* is decreasing in θ_t. Hence, in this region, $\theta_i'(\theta_t) \leq 0$. This implies that as long as $\theta_i(\bar{\theta}_t) \leq \bar{\theta}_t$, there exists $\theta < \bar{\theta}_t$, such that $D(y_t, \theta, \theta) = R - f$. In other words, under the maximum interest rate, the bank retains enough depositors such that it sells less than ϕ fraction of its assets. Furthermore, $\theta_i(\bar{\theta}_t) \leq \bar{\theta}_t$ is equivalent to $D(y_t, \bar{\theta}_t, \bar{\theta}_t) \geq R - f$.

When $\theta_t > \bar{\theta}_t$, $a_t < 1$. In this case,

$$\theta_i'(\theta_t) = -\frac{\partial \tilde{D}/\partial \theta_t}{\partial \tilde{D}/\partial \theta_i} \tag{D.4}$$

$$= -\lambda y_t \frac{(1-\phi)G(\theta_{t-1})G'(\theta_t)}{G(\theta_t)^2}\left(\frac{1}{L(y_t)} - 1\right) \tag{D.5}$$

$$+ (1-\lambda)\frac{\partial \mathbb{E}[\mathbf{1}_{y_{t+1} \geq y^*(\theta_t, a_t)} \max\{\tilde{D}_{in}(F_{y,t+1}, \theta_i, \theta_{t+1}), R - f\} + \mathbf{1}_{y_{t+1} < y^*(\theta_t, a_t)} L(y_{t+1})]}{\partial \theta_t} \tag{D.6}$$

If $\theta_i'(\theta_t) > 1$ for all $\theta_t > \bar{\theta}_t$, then the only stable equilibrium that exists in this region is all depositors leaving the bank. Notice that when $\alpha_0 \to 0$ and $\alpha_1 \to 0$, we have $\frac{1}{L(y_t)} \to \infty$. This means that when α_0 and α_1 are small, $\theta_i'(\theta_t)$ is dominated by the term in Equation D.5, which is positive and decreasing in $L(y_t)$. When $L(y_t)$ is small enough, we have $\theta_i'(\theta_t) > 1$, implying that a stable equilibrium with a positive amount of deposits does not exist when $\theta_t > \bar{\theta}_t$.

As a result, a stable equilibrium with a positive amount of deposits only exists in the region below $\bar{\theta}_t$. For an equilibrium to exist in this region, we need $D(y_t, \bar{\theta}_t, \bar{\theta}_t) \geq R - f$. Hence, the run threshold is determined by Equation 4.12.

D.2 Proof of Proposition 1

Given that the definition of critical investor in Equation 4.11,

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

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

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.3 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 4.14, 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 (4.13), $\frac{\partial \bar{\theta}}{\partial \theta_{t-1}} > 0$. 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 (4.13).

D.4 Proof of Proposition 2

From Equation 4.10, we derive a relationship between deposit rate r_t and marginal depositor type θ_t, given the previous period depositor base θ_{t-1}. First, define

$$\begin{aligned}\Delta(\theta_t) = R - \theta_t - (1-\lambda)\mathbb{E}[\mathbf{1}_{y_{t+1} \geq y^*(\theta_t)} \max\{D(r^*(y_{t+1}, \theta_t), \theta_t, \theta^*_{t+1}(y_{t+1}, \theta_t)), R - f\} \\ + (1 - \mathbf{1}_{y_{t+1} < y^*(\theta_t)})L(y_{t+1})]\end{aligned} \tag{D.15}$$

The deposit rate that is consistent with the marginal depositor type θ_t can be expressed as

$$r(\theta_t, \theta_{t-1}) = \begin{cases} \frac{\Delta(\theta_t) - f}{\lambda} & \text{if} \quad \theta_t \geq \theta_{t-1} \\ \frac{\Delta(\theta_t) + f}{\lambda} & \text{if} \quad \theta_t < \theta_{t-1} \end{cases} \tag{D.16}$$

We can rewrite the bank's problem as choosing the depositor base θ_t to maximize equity value subject to the constraint that the deposit rate has to be consistent with the marginal depositor type it attracts.

$$V^*(y_t, \theta_{t-1}) = \max_{\theta_t} \quad V(y_t, r(\theta_t, \theta_{t-1}), \theta_t) \tag{D.17}$$

$$s.t. \quad \theta_t \leq \bar{\theta}_t. \tag{D.18}$$

$$V(y_t, r(\theta_t, \theta_{t-1}), \theta_t) = \begin{cases} \tilde{V}(y_t, \theta_t) - fG(\theta_t) & \text{if} \quad \theta_t < \theta_{t-1} \\ \tilde{V}(y_t, \theta_t) + fG(\theta_t) & \text{if} \quad \theta_t \geq \theta_{t-1} \end{cases} \tag{D.19}$$

$$\tilde{V}(y_t, \theta_t) \equiv \lambda y_t G(\theta_t) - \Delta(\theta_t) G(\theta_t) + (1-\lambda)\beta \mathbb{E}[\mathbf{1}_{y_{t+1} \geq y^*(\theta_t)} V^*(y_{t+1}, \theta_t)] \tag{D.20}$$

where $\tilde{V}$ is the value function ignoring the current period switching cost.

Because of the switching cost f, the bank's value function is discontinuous in θ_t. If the bank wants to attract inflows relative to the previous period, then the bank needs to pay higher deposit rate to compensate outsiders for their switching cost. Hence, compared to the no-switching cost value function $\tilde{V}$, the actual value function is shifted downward by $fG(\theta_t)$ if $\theta_t < \theta_{t-1}$. If the bank does not want to attract inflows, then the deposit rate just needs to convince existing depositors to stay. This rate is lower than otherwise due to the switching cost. As a result, the bank's value function is shifted upward by $fG(\theta_t)$ if $\theta_t \geq \theta_{t-1}$.

The switching cost affects the first order condition in different directions depending on whether there is inflow or outflow

$$\frac{\partial V(y_t, \theta_t; \theta_{t-1})}{\partial \theta_t} = \begin{cases} \frac{\partial \tilde{V}}{\partial \theta_t} + fG'(\theta_t) & \text{if} \quad \theta_t \geq \theta_{t-1} \\ \frac{\partial \tilde{V}}{\partial \theta_t} - fG'(\theta_t) & \text{if} \quad \theta_t < \theta_{t-1} \end{cases} \tag{D.21}$$

Hence, the condition pinning down the optimal policy θ_t^* depends on which side of θ_{t-1} it falls on. To help characterize the optimal solution, we first define $\theta_1(y)$ and $\theta_2(y)$ as the implicit solution to the following conditions,

$$\left(\frac{\partial \tilde{V}(y, \theta)}{\partial \theta} + fG'(\theta) \right) \Big|_{\theta = \theta_1} = 0 \tag{D.22}$$

$$\left(\frac{\partial \tilde{V}(y,\theta)}{\partial \theta} - fG'(\theta)\right)\Big|_{\theta=\theta_2} = 0 \tag{D.23}$$

where $\theta_1(y)$ is the bank's best response function if depositor's outside option is $R - f$, and $\theta_2(y)$ is the bank's best response function if depositor's outside option is $R + f$.

Because of the second order conditions, Equation D.22 and Equation D.23 are decreasing in θ around the optimal points. Furthermore, $\frac{\partial \tilde{V}}{\partial \theta}$ is decreasing in y. Hence, by implicit function theorem, θ_1 and θ_2 are both decreasing in y. Finally, because $G'(\theta) < 0$,

$$\begin{aligned} &\frac{\partial \tilde{V}(y,\theta)}{\partial \theta} - fG'(\theta) > \frac{\partial \tilde{V}(y,\theta)}{\partial \theta} + fG'(\theta) \\ &\Rightarrow \theta_2(y) > \theta_1(y) \end{aligned}$$

We definite the $y_{out}(\theta)$ as the inverse of $\theta_1(y)$ in Equation D.22,

$$y_{out}(\theta) = \theta_1^{-1}(\theta). \tag{D.24}$$

when $y < y_{out}(\theta)$, we have $\theta_1(y) > \theta$.

Given θ_2, we can define y_{in} in the following equation,

$$\tilde{V}(y_{in}, \theta_2(y_{in})) - fG(\theta_2(y_{in})) = \tilde{V}(y_{in}, \theta_{t-1}) + fG(\theta_{t-1}). \tag{D.25}$$

Furthemore,

$$\frac{\partial(\tilde{V}(y,\theta_2(y)) - \tilde{V}(y,\theta_{t-1}))}{\partial y} = \lambda(G(\theta_2) - G(\theta_{t-1})) \tag{D.26}$$

When $\theta_2 < \theta_{t-1}$, $\frac{\partial(\tilde{V}(y,\theta_2(y)) - \tilde{V}(y,\theta_{t-1}))}{\partial y} > 0$. Hence, when $y > y_{in}$,

$$\tilde{V}(y,\theta_2(y)) - fG(\theta_2(y)) > \tilde{V}(y,\theta_{t-1}) + fG(\theta_{t-1}) \tag{D.27}$$

We are now ready to prove the main proposition. The first order conditions in Equation D.22 and Equation D.23 do not fully determine the solution because the switching cost causes differential level shifts on the two sides of θ_{t-1}.

Case 1: When $y \in [y^*, y_{out})$, because θ_1 is decreasing in y, we have $\theta_1(y) > \theta_{t-1}$. For any $\theta < \theta_{t-1}$

$$V(y, \theta) = \tilde{V}(y, \theta) - fG(\theta) < \tilde{V}(y, \theta) + fG(\theta) \leq \tilde{V}(y, \theta_1) + fG(\theta_1) \tag{D.28}$$

For any $\theta \geq \theta_{t-1}$, $V(y, \theta) < V(y, \theta_1)$ given the definition of θ_1. So the optimal $\theta^* = \theta_1(y)$ as long as $\theta_1(y) \leq \bar{\theta}_t$. When $\theta_1(y) > \bar{\theta}_t$, the constraint D.18 starts to bind. Hence, $\theta^* = \min(\theta_1(y), \bar{\theta}_t)$. Because $\theta^* > \theta_{t-1}$, there is positive deposit outflow in this case.

Case 2: When $y \in [y_{in}, y_{out}]$, for any $\theta > \theta_{t-1}$,

$$V(y, \theta_{t-1}) = \tilde{V}(y, \theta_{t-1}) + fG(\theta_{t-1}) > \tilde{V}(y, \theta) + fG(\theta) = V(y, \theta) \tag{D.29}$$

For any $\theta < \theta_{t-1}$,

$$V(y, \theta_{t-1}) = \tilde{V}(y, \theta_{t-1}) + fG(\theta_{t-1}) > \tilde{V}(y, \theta) - fG(\theta) = V(y, \theta) \tag{D.30}$$

Hence, the optimal solution is $\theta^* = \theta_{t-1}$, i.e., there is no deposit flow.

Case 3: When $y > y_{out}$, for any $\theta > \theta_{t-1}$,

$$V(y, \theta_{t-1}) = \tilde{V}(y, \theta_{t-1}) + fG(\theta_{t-1}) > \tilde{V}(y, \theta) + fG(\theta) = V(y, \theta) \tag{D.31}$$

For any $\theta < \theta_{t-1}$,

$$V(y, \theta_{t-1}) = \tilde{V}(y, \theta_{t-1}) + fG(\theta_{t-1}) < \tilde{V}(y, \theta_2) - fG(\theta_2) = V(y, \theta_2) \tag{D.32}$$

Hence, the optimal solution is $\theta^* = \theta_2(y)$. Given that $\theta_2 < \theta_{t-1}$, there is deposit inflow in this case.

D.5 Proof of Corollary 2

The optimal 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 incresing 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

$$y^*(\theta_{t-1,1}) > y^*(\theta_{t-1,2}) \tag{D.33}$$

$$y_{out}(\theta_{t-1,1}) > y_{out}(\theta_{t-1,2}) \tag{D.34}$$

$$y_{in}(\theta_{t-1,1}) > y_{in}(\theta_{t-1,2}) \tag{D.35}$$

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,

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

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

$$G(\theta^*(y, \theta_{t-1,1})) - G(\theta_{t-1,1}) = 0 \tag{D.37}$$

$$G(\theta^*(y, \theta_{t-1,2})) - G(\theta_{t-1,2}) < 0 \tag{D.38}$$

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

$$G(\theta^*(y, \theta_{t-1,1})) - G(\theta_{t-1,1}) > 0 \tag{D.39}$$

$$G(\theta^*(y, \theta_{t-1,2})) - G(\theta_{t-1,2}) = 0 \tag{D.40}$$

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.36 holds.

D.6 Deposit Rates and y_t

Given the marginal depositor type θ_t, the equilibrium deposit rate is given by Equation D.16. Moreover, $\Delta(\theta_t)$ is decreasing in θ_t, which implies the deposit rate is also decreasing in θ_t. Intuitively, if the bank is attracting flightier investors, i.e. smaller θ_t, it must be paying higher deposit rate.

Corollary 2 shows that θ_t is decreasing in y_t. This implies that the deposit rate is increasing in y_t, everything else equal. If the bank has stronger fundamentals, the marginal value of deposits is higher. As a result, the bank pays higher deposit rate in equilibrium in order to attract more investors.