VALUING STICKY DEPOSITS

Abstract. We develop a formal fixed-income framework to value sticky deposits. This framework provides closed-form expressions for deposit values and allows us to study the impact of stickiness on deposit interest-rate and runoff risks. The duration of a bank deposit can be either positive or negative, which has important implications for hedging the interest-rate risk of bank balance sheets. Banks that maximize deposit value by following optimal deposit beta strategies may significantly increase their interest-rate and deposit runoff risks. We test the empirical implications of the valuation model using market deposit premia observed in bank merger and acquisition transactions. The results provide strong empirical support for the model's predictions.

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1. INTRODUCTION

Bank deposits represent one of the most important asset classes available to consumers in the fixed-income markets. The size of this market has grown rapidly in recent years and is now on an order of magnitude comparable to the Treasury market. As of June 30, 2025, total deposits in the banking system were $18.21 trillion. In addition, deposits account for nearly 70 percent of total bank liabilities, making them a core element of the banking system.

Despite their importance, deposits are often modeled as short-term liabilities that support long-term lending (Diamond and Dybvig (1983), Diamond (1984), Gorton and Pennacchi (1990), Calomiris and Kahn (1991), Diamond and Rajan (2001), Kashyap, Rajan, and Stein (2002)). In reality, sticky behavior by depositors can have profound effects on the valuation, interest-rate risk, and expected life of deposit accounts. These effects are directly analogous to how interest-rate-sensitive household prepayment behavior impacts the pricing and risk of mortgage-backed securities. The potential consequences of not taking stickiness into account are significant. Banks may hedge incorrectly through flawed duration matching, regulators may fail to capture embedded vulnerabilities, and the financial system may remain exposed to sudden destabilizing waves of deposit flight during tightening cycles.

Our research addresses this critical gap by introducing a rigorous fixed-income valuation model for sticky bank deposits. In the absence of deposit stickiness, this exercise would be trivial since the value of a deposit account would simply be its book value. If depositors are slow to withdraw their funds to reinvest in higher yielding alternatives, however, the value of a deposit account to a bank may be substantially higher than its book value, and its risk could depend in complex ways on depositor behavior. The central research question driving our work is: what is the true economic value of sticky deposits, and how does depositor behavior shape their risk and optimal management?

In this valuation framework, we use the novel approach of modeling deposit accounts as if they were perpetual floating-rate notes that can be put back to the bank at par value at any time. To model the stickiness of these deposits, we assume that depositors are inattentive ("sleepy") until the realization of a Poisson event ("wake-up call"), at which time they evaluate whether it is optimal to exercise their put option. The intensity of the Poisson event depends on both the frequency of liquidity shocks and the response of sticky depositors to rate-related withdrawal incentives. This feature has the important advantage of allowing the model to endogenize the relation between bank deposit pricing and deposit runoff. Furthermore, this framework provides a robust theoretical foundation that links micro-depositor behavior to macro-bank risk management. Using a simple model for the dynamics of the riskless rate, we obtain a closed-form expression in which the value of a sticky deposit account is an explicit function of the level and volatility of interest rates, the deposit beta of the bank, the frequency of liquidity shocks, and the stickiness of depositors.

The valuation framework provides us with a number of important new insights about the nature of sticky deposits, and raises challenges to some of the fundamental assumptions in the banking literature. First, the results indicate that the value of a bank deposit account can be substantially higher than its book value. One implication of this is that the stickiness of bank deposits may play a major role in determining the valuation premium paid in bank mergers and acquisitions that involve the assumption of bank liabilities.[1] The results also indicate, however, that the simplistic linear models of stickiness often used in the literature may lead to unreliable estimates of the value of the deposit franchise, particularly in low-rate/high-rate environments.

Second, the valuation framework also reveals that stickiness fundamentally changes the nature of the interest-rate risk of deposit accounts. Unlike conventional fixed-income securities, we show that the value of a deposit account can be an increasing function of the riskless rate for some values, but a decreasing function for other values. An important implication of this is that the standard banking practice of attempting to match the duration of assets and liabilities is flawed since deposits have nonmonotonic interest-rate sensitivity that can actually amplify bank risk rather than hedge it. Consequently, deposit values should exhibit time-series variation driven by both interest rate levels and interest rate volatility.

Third, the valuation model allows us to assess directly how changes in interest rates and deposit stickiness impact the deposit runoff risk of banks. In particular, the valuation framework can also be used to calculate the expected maturity of a deposit account. In turn, this allows us to evaluate how the funding stability of a bank and its deposit runoff speed change as interest rates, deposit betas, and stickiness parameters vary.

We validate the valuation model by testing its empirical implications. In doing this, we use two different sources of deposit pricing data. The first consists of the values of acquired deposit accounts recorded on the balance sheets of acquiring banks in conventional bank merger and acquisition transactions. These values are known as core deposit intangibles and represent the premium above par that acquiring banks pay for the deposits of another institution as part of actual market transactions. The second consists of the market premia paid by banks to acquire the deposit accounts of failing financial institutions in FDIC auctions. Both data sources represent revealed preferences in which bidders put real money behind their assessment of deposit franchise value.

The results provide strong support for the empirical implications of the valuation model. Using two decades of core deposit intangible and FDIC auction data, we doc-

[1]Deposit valuation issues played a key role in recent FDIC auctions of failed institutions. Examples of major recent bank failures and FDIC auctions include Silicon Valley Bank, Signature Bank, and First Republic Bank.

ument that market deposit values are very similar in both their levels and nonlinear interest-rate characteristics to those implied by a simple calibrated form of the model. For example, the average premium for the deposits in the core deposit intangible sample is 1.95 percent, which closely matches the corresponding average model-implied value of 1.76 percent. Similar results hold for the FDIC sample. Furthermore, we find that there is a strong positive correlation between market deposit premia and model-implied values over time. We also document that historical deposit premia increase with interest rates when rates are low, but then decrease once rates exceed a critical tipping point. This pattern provides direct validation of one of the key empirical implications of the valuation model. Again, this nonmonotonic pattern has profound implications for the interest-rate risk of bank deposits.

Finally, having a valuation framework for sticky deposits also allows us to identify the optimal deposit beta strategy a bank should follow to maximize the value of its deposit accounts. In particular, we solve for the optimal deposit beta as a function of the riskless interest rate and illustrate how following the optimal strategy impacts the value and risk of bank deposit accounts. A surprising but important consequence of the optimizing behavior of banks, however, is that it can increase their risk profile, creating higher interest-rate risk and deposit runoff precisely when banks think they are maximizing value.

These theoretical insights, validated by our market-based empirical evidence, help explain why monetary tightening can suddenly trigger widespread bank fragility and why deposit franchise values can evaporate overnight during crises as witnessed in 2023. Bank sales create unique moments of price discovery where bidders reveal exactly how much they believe deposits are worth given current interest rate conditions, turning auctions and acquisitions into natural laboratory stress tests that confirm our model's predictions about nonlinear depositor behavior.

Empirical evidence indicates that deposits function not merely as short-term funding sources, but as complex derivative-like instruments necessitating advanced risk management. This complexity is demonstrated by real market transactions, where money changes hands based on participants' assessments of deposit stability and value.

2. RELATED LITERATURE

A growing literature examines the economics of bank deposits, highlighting their central role in financial stability and monetary policy transmission. Our paper connects most directly to two strands of this work—deposit franchise valuation and deposit pricing pass-through.

Our work builds on early frameworks for valuing deposits using equilibrium and no-arbitrage approaches to estimate deposit duration and interest-rate risk (Hutchison and Pennacchi (1996), Jarrow and van Deventer (1998)), though these studies do not directly address deposit stickiness. Subsequent work, including Sheehan (2013), uses econometric approaches to estimate deposit retention rates and infer franchise values.

Several recent papers develop frameworks for valuing deposit franchises. Drechsler, Savov, and Schnabl (2021) argue that a deposit franchise behaves like a long-duration bond, providing a natural hedge for a bank's asset portfolio. Their framework suggests that sticky deposits create negative duration that offsets interest-rate risk from long-term securities. In contrast, DeMarzo, Krishnamurthy, and Nagel (2024) argue that deposits have positive duration, such that rising rates erode franchise values and amplify banks' exposure to interest-rate shocks. Our structural model reconciles these competing views by demonstrating that deposit duration can be positive, negative, or zero depending on interest-rate levels and depositor stickiness parameters. We provide a rigorous closed-form framework that endogenizes the link between depositor behavior and franchise valuation.

Understanding this valuation has important implications for financial fragility. Haddad, Hartman-Glaser, and Muir (2023) and Drechsler, Savov, Schnabl, and Wang (2023) highlight how rising interest rates can trigger funding instability even when banks' assets remain liquid. These papers show that losses in deposit franchise value can drive systemic banking stress, establishing franchise value as central to both bank risk and monetary policy transmission. Our model complements this work by offering a structural mechanism that generates the nonlinear and state-dependent valuation dynamics documented in these studies.[2]

While the pricing literature establishes that deposit betas vary across banks and time, it largely treats rate-setting and withdrawal behavior as separate phenomena. Recent work on financial fragility connects these elements by showing how pricing dynamics affect stability. For example Drechsler, Savov, and Schnabl (2017) show that variation in deposit betas across banks shapes monetary policy transmission, with limited pass-through reflecting banks' market power. Subsequent work examines the mechanisms underlying this stickiness. Wang, Whited, Wu, and Xiao (2022) develop a dynamic model linking bank capital, deposit rates, and franchise values, while Begenau and Stafford (2023) show how deposit market power affects banks' interest-rate risk management.

Other research explores regulatory and behavioral factors driving rate-setting. Bolton, Li, Wang, and Yang (2023) examine deposit pricing under capital constraints, Corbae and Levine (2023) study how competition shapes financial stability, and Hanson, Ivashina, Nicolae, Stein, Sunderam, and Tarullo (2024) emphasize the role of "sleepy"

[2]Other important papers on deposit franchise value and risk include Flannery (1981, 1983), Diebold and Sharpe (1990), Hannan and Berger (1991), Neumark and Sharpe (1992), Driscoll and Judson (2013), English, Van den Heuvel, and Zakrajšek (2018), Drechsler, Savov, and Schnabl (2017, 2021), Whited, Wu, and Xiao (2021), Begenau and Stafford (2022, 2023), Wang, Whited, Wu, and Xiao (2022), Choi and Rocheteau (2023), Yankov (2023), Erel, Liebersohn, Yannelis, and Earnest (2023), and Jiang, Matvos, Piskorski, and Seru (2024).

depositors who adjust slowly to rate changes—a behavioral mechanism directly related to our Poisson "wake-up" modeling approach. While this literature advances our understanding of deposit pricing, it largely treats rate-setting behavior and depositor withdrawal as separate processes. Our paper brings these elements together by showing how deposit rates and depositor stickiness jointly determine the economic value and run risk of deposits. This connects deposit pricing to franchise valuation and provides a structural framework for understanding when stable funding can suddenly unravel during periods of rising rates.

In summary, our paper contributes to the literature in three ways. First, we provide a rigorous closed-form framework that endogenizes the relationship between deposit pricing and withdrawal behavior, whereas prior work typically treats these as separate processes. Second, we reconcile competing theoretical predictions about deposit duration by showing that sign and magnitude depend on rate levels and depositor stickiness. Third, we validate the framework using actual market prices from two decades of transactions, providing direct evidence that market participants' valuations align with the model's predictions about nonlinear rate sensitivity.

3. MODELING STICKINESS

In this section, we describe the approach used to model the sticky behavior of bank deposits. In doing this, our focus is on non-maturing deposits such as conventional checking accounts, savings accounts, and money market accounts. For expositional convenience, we refer to these types of accounts simply as deposits. As discussed, deposits represent an important asset class available to households. The total notional amount of non-maturing deposits was roughly \$14.5 trillion as of the end of 2024. At this stage, we focus specifically on insured deposits. The framework, however, can easily be extended to uninsured deposits—we discuss potential extensions in a later section of the paper.

A key insight guides our modeling approach. While deposits are legally withdrawable at any moment, their economic characteristics differ fundamentally from overnight funding. The appropriate valuation framework must capture both the floating-rate nature of deposit pricing and the embedded withdrawal option. Non-maturing deposits are typically viewed as short-term fixed-income instruments in the literature since the deposits can be withdrawn at any time.

In this paper, we take a very different approach in modeling these types of deposits. In particular, the cash flows actually received by a depositor are identical to the cash flows that would be paid by a hypothetical perpetual floating-rate note which the depositor could put back to the bank at par at any time. We model the deposit as if it were a floating-rate note because the interest rate paid to the depositor can vary over time. Since this rate is typically less than the market rate, the present value of the cash flows received by the depositor (or paid by the bank) will generally be less than par. We model the floating-rate note as a perpetual instrument to make clear that the effective tenor of the underlying deposit account can be much longer than the timeframe over which the put option operates. This approach is also more consistent with standard fixed-income frameworks which differentiate between the actual maturity of a bond and the horizon of any embedded optionality. For example, the maturity of a callable bond is typically not the same as the time until the earliest call date of the bond.[3]

To model the floating rate paid by banks to depositors, we draw on an extensive literature documenting that banks tend to pay below-market rates on deposits and are slow to adjust their rates when interest rates increase. This behavior is often described in terms of the concept of the deposit beta. Important recent papers in this area include Drechsler, Savov, and Schnabl (2017, 2021), Wang, Whited, Wu, and Xiao (2022), Begenau and Stafford (2023), and Kundu, Muir, and Zhang (2024). Motivated by this literature, we use the following approach to model the deposit pricing behavior of a bank. Let r_t denote the short-term riskless interest rate in money markets such as the Treasury bill rate or the federal funds rate (for brevity, we will typically leave off time subscripts unless necessary). We assume that the bank pays the rate $\beta\, r$ on its deposits, where $0 \leq \beta \leq 1$. In this context, β has a simple interpretation as the deposit beta for the bank. In particular, when β is less than one and market interest rates increase by 100 basis points, the bank only increases its deposit rate by $100 \times \beta$ basis points. Furthermore, when β is less than one, bank deposit rates will be less than market interest rates. Thus, this assumption allows the modeling framework to capture the key stylized facts about bank deposit pricing.

To model the stickiness of deposits, we assume that depositors are completely inattentive to their withdrawal option (sleepy) until the realization of a Poisson event (a wake-up call). In particular, the model allows for two types of Poisson events. The first occurs when a random liquidity shock makes it necessary for the depositor to withdraw the funds from the deposit account. We denote the intensity of this Poisson liquidity shock by the parameter λ and assume that it is constant over time. Note that deposits become more sticky as the value of λ decreases since it then becomes less likely that a depositor will withdraw funds for liquidity-related reasons.

The second Poisson event occurs with an intensity that is directly related to the size of the deposit spread, which is defined as the difference between the market interest rate and the rate paid by the bank to depositors. Since the rate paid by the bank is $\beta\, r$, the deposit spread is simply $(1-\beta)\, r$. Specifically, we assume that the intensity of this Poisson event is proportional to the squared deposit spread, $\alpha\, (1-\beta)^2\, r^2$, where α is a parameter reflecting how sensitive depositors are to the spread between market rates

[3]Our approach is also consistent with DeMarzo, Krishnamurthy, and Nagel (2024), who model bank deposits as sticky liabilities that generate franchise value and whose economic maturity differs from their contractual withdrawal terms. Their framework distinguishes between the legal right to withdraw and the behavioral persistence of deposit funding. Our closed-form framework extends these insights by allowing for both positive and negative duration regimes under varying levels of depositor stickiness and interest-rate volatility.

and the rate paid by the bank. Note that if α is zero, then depositors never respond to the deposit spread and only withdraw funds when a liquidity shock occurs. In this situation, deposits can display extreme stickiness, particularly if λ is close to zero. If α is greater than zero, however, then the intensity of the Poisson process increases rapidly with the deposit spread. In turn, this makes it much more likely that the depositor receives a wake-up call, and then exercises the withdrawal-related put option optimally. It is easily shown that it is always optimal for an attentive depositor to exercise the put option whenever $\beta < 1$. Thus, lower values of α translate into higher levels of deposit stickiness.

In summary, the probability of a withdrawal over the next instant is the sum of the intensities of the two Poisson processes, $(\lambda \; + \; \alpha \; (1-\beta)^2 \; r^2) \; dt$. This expression illustrates that deposit stickiness is characterized by two key parameters in this model. The first is λ which reflects the intensity of liquidity-related deposit runoff. The second is α which determines the intensity of deposit-spread-related deposit runoff in the model. These two parameters allow the model to capture a rich set of potential deposit stickiness patterns. In particular, the parameters can be calibrated to match the specific characteristics of depositors across different banks, geographic, economic, and demographic characteristics, deposit balances, types of deposit accounts, etc.

Finally, we note that these two parameters induce deposit runoff behavior that parallels the nature of prepayment behavior in recent models of the pricing of mortgage-backed securities. For example, Chernov, Dunn, and Longstaff (2018) present a model in which prepayments occur for exogenous non-rate-related reasons as well as in response to refinancing incentives. The former is closely related to the notion of liquidity-related withdrawals, while the latter is analogous to the deposit-spread-related withdrawals that occur in this model of deposit stickiness.

4. THE VALUATION MODEL

In this section, we present a closed-form valuation model for sticky bank deposits. In doing this, we value deposits from the bank's perspective. When the deposit beta is less than one, the present value of the cash flows paid by the bank to the depositor (or, equivalently, the value of the hypothetical perpetual floating-rate note representing the cash flows received by the depositor) is less than the par or notional amount of the deposit. Thus, the difference between the cash (notional amount) received from a depositor and the present value of the cash flows the bank will pay is the value of the deposit account to the bank. We denote this value as $V(r)$. Alternatively, $V(r)$ can also be viewed as the premium above book value a bank would be willing to pay for a deposit account.

4.1 The Valuation Framework

Standard results imply that the value of a floating-rate note that always pays the market interest rate r is par (for any stopping time). Thus, $V(r)$ can also be viewed as the difference in the values of two floating-rate notes, the first paying the market rate and the second paying only $\beta\ r$. In other words, $V(r)$ can be viewed as the value of a long/short portfolio consisting of a floating-rate note paying r, and a floating-rate note paying $\beta\ r$. The difference in the values of these notes is clearly just the present value of the difference in the coupon rates $(1-\beta)\ r$ (the deposit spread) over the period between time zero and the stopping time at which the floating-rate note (deposit) is put back to the bank at par.

The valuation formula captures three economic forces. The bank receives the spread $(1-\beta)\ r$ at each instant, generating value. However, two factors work against the bank—discounting at the riskless rate reduces the present value of future spreads, and the risk of Poisson-triggered withdrawal terminates the spread stream. The optimal deposit value balances these forces. This implies that the value of the deposit account can be expressed formally as

$$V(r) = E\left[\int_0^\infty (1-\beta)\ r_t\ \exp(-\int_0^t r_s\ ds)\exp(-\int_0^t \lambda + (1-\beta)^2\ r_s^2\ ds)\ dt\right], \qquad (1)$$

where the expectation is taken with respect to the risk-neutral pricing measure. The first exponential term in this expression is the discounting factor applied to the cash flow received at time t. The second exponential term is the probability that no Poisson event has occurred prior to time t.

Differentiating this expression shows that $V(r)$ is a decreasing function of both the liquidity intensity parameter λ as well as the stickiness parameter α. The intuition for this is simply that an increase in the intensity of the Poisson process has the effect of reducing the expected time until the deposit is put back to the bank. This follows since the expected time to the first arrival of a Poisson event is inversely related to the intensity. In turn, this means that the bank has less time to benefit from paying a below-market rate on the deposit account, reducing the net present value of the account to the bank.

4.2 The Closed-Form Valuation Model

In this continuous-time framework, we model the dynamics of the short-term riskless rate under the risk-neutral pricing measure as

$$dr\ =\ \theta\ r\ dt\ +\ \sigma\ r\ dZ, \qquad (2)$$

where θ and σ are constants and Z is a standard Brownian motion. This model implies that the riskless rate is conditionally lognormally distributed.

Under the risk-neutral pricing measure, the expected return to the bank from investing in a deposit account is simply the riskless rate. Applying Itô's Lemma to $V(r)$ and taking expectations provides another expression for the expected return from investing in the deposit account,

$$\frac{\frac{1}{2}\,\sigma^2\,r^2\,V_{rr} + \theta\,rV_r - (\lambda + \alpha(1-\beta)^2 r^2)\,V + (1-\beta)r}{V}. \tag{3}$$

This expression indicates that there are three components contributing to the expected return. The first is the expected return resulting from changes in the riskless rate. From Itô's Lemma, this component includes the first and second derivatives of $V(r)$ with respect to r. This component is given by the sum of the first two terms in the numerator in Equation (3). There is no derivative with respect to time because of the perpetual nature of the deposit account. The second component is the return resulting from the realization of a Poisson event in which the depositor puts back the floating-rate note at par. In this situation, the bank is then no longer able to receive the spread $(1-\beta)\,r$ going forward, and the value of the deposit account to the bank therefore jumps to zero. The probability or intensity of a Poisson event occurring over the next instant is given by $(\lambda\,+\,\alpha\,(1-\beta)^2\,r^2)\,dt$. Thus, the probability of a Poisson event is a function of the riskless rate in this framework.[4] This component consists of the third term in the numerator of Equation (3) involving $V(r)$. The third component of the expected return is the net coupon spread received by the bank $(1-\beta)\,r$ prior to the realization of a Poisson event given by the last term in the numerator in Equation (3).[5]

Setting the expression for the expected return given in Equation (3) equal to the riskless rate and rearranging terms results in the following nonhomogeneous differential equation for $V(r)$

$$\tfrac{1}{2}\,\sigma^2\,r^2\,V_{rr} + \theta\,r\,V_r - (\lambda\,+\,r\,+\,\alpha\,(1-\beta)^2\,r^2)\,V = -(1-\beta)\,r. \tag{4}$$

The two boundary conditions for this differential equation are given by $\lim_{r\to 0} V(r) = 0$, and $\lim_{r\to\infty} V(r) = 0$. The economic intuition behind the first boundary condition is that as the riskless rate approaches zero, the deposit rate paid by the bank converges to the market rate. Thus, there is no difference between the value of a floating-rate note paying r and one paying $\beta\,r$ when the riskless rate is zero. The intuition behind the second boundary condition is similar. As the riskless rate increases, the intensity of the Poisson event also increases unboundedly. In turn, this means that the deposit is put back to the bank at par immediately by a depositor, and the bank is no longer able to receive the spread $(1-\beta)\,r$ going forward.

[4]Following the standard Merton (1976) assumption, we assume that jump risk is unpriced in the market. This assumption is common in credit risk and deposit pricing models. Alternatively, λ and α could be interpreted as risk-neutral parameters.

[5]Consistent with market practice, we assume the coupon is paid continuously by the bank.

This nonhomogeneous differential equation for $V(r)$ can be solved directly using standard techniques. The resulting closed-form solution for the value of a deposit account to the bank is given by

$$V(r) = \kappa \; (1 - \beta) \; (\phi r)^{-\theta/\sigma^2} \; N^{\nu}_{\kappa,\mu}(\phi r), \tag{5}$$

where $N^{\nu}_{\kappa,\mu}(z)$ denotes the nonhomogeneous Whittaker function given in Babister (1967) Section 5.4. This function is a generalized form of the Whittaker function described in Chapter 13 of Abramowitz and Stegun (1964) and is widely used in a variety of disciplines such as quantum field theory. The constants ν, κ, μ, and ϕ are given by

$$\nu = \theta/\sigma^2 - 1/2, \tag{6}$$

$$\kappa = 1/\big(\sqrt{2\alpha}\sigma(\beta - 1)\big), \tag{7}$$

$$\mu = \sqrt{\nu^2 + 2\lambda/\sigma^2}, \tag{8}$$

$$\phi = \sqrt{8\alpha}(1 - \beta)/\sigma. \tag{9}$$

Babister (1967) shows that $N^{\nu}_{\kappa,\mu}(z)$ can be expressed in the form of a power series

$$N^{\nu}_{\kappa,\mu} = z^{\nu+3/2} \sum_{n=0}^{\infty} a_n z^n. \tag{10}$$

The first two coefficients of the series are given by the following expressions:

$$a_0 = \big[(\nu + 1)^2 - \mu^2\big]^{-1}, \tag{11}$$

$$a_1 = -\kappa a_0 \big[(\nu + 2)^2 - \mu^2\big]^{-1}. \tag{12}$$

For $n \geq 2$, the coefficients satisfy the recurrence relation

$$\big[(\nu + n + 1)^2 - \mu^2\big] a_n = -\kappa a_{n-1} + \tfrac{1}{4} \; a_{n-2}, \tag{13}$$

Finally, we note that while this closed-form solution is expressed in terms of higher transcendental functions readily available in mathematical software libraries, it may be easier to implement the valuation model using standard techniques to solve the nonhomogeneous differential equation in Equation (4) numerically.

5. ANALYSIS

In this section, we analyze the model's implications for deposit valuation, interest-rate sensitivity, and funding stability. In doing this, we focus on the value of a deposit account from the perspective of the bank as given by $V(r)$.

5.1 Sticky Deposit Values

To introduce the valuation model, we begin by providing graphs of the value of a deposit account implied by the model. Figure 1 plots the value of a deposit as a function of the riskless rate for various parameter values. In doing this, we use a baseline set of parameters, but then vary one parameter at a time in the individual graphs in Figure 1 to show the specific effects of the individual parameters on the valuation function.[6]

The graphs in Figure 1 illustrate several key features of the valuation model. First, the graphs show that the value of a deposit account can be very significant from an economic perspective. In particular, the graphs indicate that the value of a deposit account can be as much as five percent of its notional amount for some values of the riskless rate. As we discuss later, the range of values shown in these graphs are consistent with industry estimates.

Second, the graphs show that the value of a deposit account is not a monotonic function of the riskless interest rate. When the riskless rate is zero, the value of the deposit is zero. For small values of the riskless rate, the value of the deposit increases rapidly with the riskless rate. At some intermediate riskless rate, however, the value of a deposit attains a maximum and then becomes a decreasing function of the riskless rate for larger values. As the riskless rate increases to infinity, the value of the deposit converges to zero. The shape of the valuation expression is typically right-skewed, but the exact pattern can vary based on the specific parameter values. The nonmonotonicity of deposit values with respect to the riskless interest rate has many important implications for the risk of a deposit account, which we explore next.

5.2 Interest-Rate Risk

Understanding deposit interest-rate risk is perhaps the most critical application of the valuation framework. Banks hold trillions of dollars in long-term securities funded by deposits, making duration matching a cornerstone of asset-liability management. If the conventional wisdom that deposits have fixed positive duration is flawed, banks following traditional hedging strategies may be creating risk rather than reducing it. This section demonstrates that deposits indeed have fundamentally different risk characteristics than typically assumed.

Non-maturing deposit accounts are typically categorized as short-term fixed-income investments since they can be put back to the bank at par at any time. Market par-

[6] The baseline set of parameters consists of $\lambda = 0.30$, $\alpha = 500$, $\theta = 0.10$, $\sigma = 0.30$, and $\beta = 0.50$.

ticipants recognize, however, that since households are slow to withdraw funds when interest rates increase, these types of deposit accounts can have a more-stable longer-term nature. Accordingly, an extensive literature focuses on estimating the expected life or duration of deposit accounts. Important examples include Hutchison and Pennacchi (1996), who develop an equilibrium framework for estimating deposit duration, Jarrow and van Deventer (1998), who use arbitrage-free methods to value and hedge deposits, and O'Brien (2000), who estimates deposit duration using historical runoff rates.

Several recent papers implicitly assume that the expected life or duration of a deposit account constitutes the relevant measure of its interest-rate risk. For example, these papers essentially take the view that if a deposit account has an expected life of, say, five years, then its interest-rate risk is the same as that of a five-year fixed-rate bond. In particular, Drechsler, Savov, and Schnabl (2021) argue that deposits with multi-year duration provide natural hedges for long-term assets on bank balance sheets. Similarly, Egan, Hortaçsu, and Matvos (2017) and Egan, Lewellen, and Sunderam (2022) model deposit franchise values under the assumption that duration captures interest-rate sensitivity. These arguments frequently appear in discussions about whether the multi-year duration of deposit accounts allows them to serve as hedges for the interest-rate risk of longer-term assets held on bank balance sheets.[7]

The graphs in Figure 1 illustrate, however, that the interest-rate risk of a deposit account is very different from that of a fixed-rate bond with the same expected life. Recall that the value of a fixed-rate bond is always a decreasing function of r. In contrast, the value of a deposit account $V(r)$ is an increasing function of the riskless rate for small r, but becomes a decreasing function for larger values of r. Thus, the interest-rate risk of a deposit is fundamentally different in nature from that of a matched-maturity fixed-rate bond.

To provide some perspective on why the interest-rate risk of a deposit is not connected to its expected life or duration, consider a ten-year floating-rate note that pays the riskless rate as its coupon. The expected life or duration of this instrument is ten years. Because of the floating-rate coupon, however, this instrument is always worth par. Thus, the interest-rate risk of the floating-rate note is zero since its price does not change as the interest rate increases. Another way of describing this is by using the notion of a DV01, which is defined as the change in the value of an investment in response to a one-basis-point change in the riskless rate. The DV01 of the floating-rate note is zero. This means that there is no relation between the interest-rate risk of a floating-rate note and its duration. In contrast, the DV01 of a fixed-rate bond is directly proportional to its duration. Bottom line, the financial economics of floating-rate and fixed-rate instruments are fundamentally different from each other.

[7]For example, see Flannery and James (1984), who examine how deposit duration affects banks' stock return sensitivity to interest rates, and English, Van den Heuvel, and Zakrajšek (2018), who analyze how deposit characteristics influence bank equity valuations.

The distinction between duration and DV01 is important but often overlooked. Duration measures the weighted-average time to receive cash flows, while DV01 measures the actual sensitivity of value to interest rate changes. For fixed-rate bonds, these concepts are tightly linked—longer duration implies higher DV01. However, for instruments with embedded options or floating rates, duration and DV01 can diverge dramatically. A floating-rate note has positive duration (since it pays cash flows over time) but zero DV01 (since its value stays at par). Deposits share this characteristic—they have positive expected life but variable, and sometimes negative, interest-rate sensitivity.

An important implication of these results is that the interest-rate risk of a bank will typically not be fully hedged by its deposit franchise. This is because the DV01 of the deposit account will not match that of the bank's assets even if they both have a similar expected life or duration. Furthermore, the fact that the DV01 of the deposit account can change signs implies that for some ranges of the riskless rate, the deposit account actually increases the overall risk of the bank, rather than serving as a hedge. As we discuss later, this problem can become even more severe when banks manage deposit betas in order to maximize the value of their deposit accounts.

5.3 The Greeks

This section examines how deposit values respond to changes in the model's key parameters. Following option-pricing convention, we call these partial derivatives "Greeks." We analyze five effects: liquidity shocks (λ), depositor stickiness (α), expected rate changes (θ), interest-rate volatility (σ), and deposit betas (β). Understanding these sensitivities is essential for both deposit pricing and risk management.

5.3.1 Liquidity Effects

To examine the effects of the liquidity parameter λ on the value of a deposit account, the first graph in Figure 1 displays the value of a deposit for different values of λ. As discussed earlier, the value of a deposit account is always a decreasing function of the liquidity parameter λ. This is confirmed in Figure 1 which shows that $V(r)$ decreases with λ for all values of the riskless rate. Thus, V_λ (the derivative of $V(r)$ with respect to λ) is uniformly negative in sign (as can be seen from the slope of the function). Again, the reason for this is that an increase in λ has the effect of reducing the expected horizon over which the bank benefits by paying below-market interest rates to its depositors.

While V_λ is always negative in sign, Figure 1 also indicates that the sensitivity to the liquidity parameter varies dramatically in magnitude as the riskless interest rate changes. In particular, the effect of an increase in λ is much larger in absolute value for small to intermediate values of r. The intuition is that when interest rates are low, liquidity-driven withdrawals dominate depositor behavior since the spread-related withdrawal intensity $\alpha\ (1-\beta)^2\ r^2$ remains small. An increase in λ therefore has a first-order effect on the total withdrawal probability. Conversely, when rates are high, spread-related withdrawals already generate substantial outflows, so marginal changes in λ have less relative impact. This suggests that deposit franchise values may be particularly vulnerable to liquidity shocks during low-rate environments—a finding with important implications for understanding the 2023 banking crisis, which occurred after a prolonged period of near-zero rates.

5.3.2 Stickiness Effects

Unlike liquidity shocks which affect all rate environments similarly, the stickiness parameter α exhibits rate-dependent effects that intensify as rates rise. To examine these effects, the second graph in Figure 1 shows $V(r)$ for different values of α. Similar to the effects of λ discussed above, $V_\alpha \leq 0$, implying that the value of a deposit account is always a decreasing function of the stickiness parameter α. The intuition is also similar since an increase in α implies that the expected time until the depositor puts the deposit back to the bank declines. Where the liquidity and stickiness effects differ, however, is that the impact of α on the expected life of a deposit grows quadratically with the riskless rate. This suggests that the stickiness of a bank's customer base may play a much larger role in deposit pricing when interest rates are relatively high than when they are lower.

5.3.3 Term Structure Effects

A positive drift parameter θ implies that rates are expected to rise over time, while a negative θ implies that rates are expected to fall. To explore the effects of expected rate changes on the value of a deposit account, the third graph in Figure 1 shows $V(r)$ for different values of θ.

The results reveal that expected rate changes have asymmetric effects depending on the current rate level, indicating that V_θ can be either positive or negative. When θ is positive (rates expected to rise), deposit values decline most sharply in the intermediate rate range. This occurs because higher future rates increase the likelihood of spread-driven withdrawals, reducing the expected horizon over which banks earn below-market rates. The effect is strongest when current rates are already moderate, since the proportional increase in withdrawal intensity is largest there. Conversely, when θ is negative (rates expected to fall), deposit values increase modestly, particularly at higher current rate levels. Falling future rates reduce withdrawal incentives, extending the expected life of the deposit account. However, this positive effect is smaller in magnitude than the negative effect of rising rates because withdrawal intensities are bounded below by the liquidity parameter λ but unbounded above as rates rise. This asymmetry implies that deposit franchise values face greater downside risk from adverse rate movements than upside potential from favorable movements.

5.3.4 Volatility Effects

Interest-rate volatility can have important effects on the value of a deposit account. The intuition behind this is that the value of a deposit account depends on the path of interest rates over time. When rates increase, it is much more likely that the deposit will be put back to the bank. This implies that the value of a deposit account will not be the same when interest rates increase and then decrease by 100 basis points as it would be if interest rates had remained unchanged. This aspect parallels the familiar pattern of the effects of path-dependent household prepayment behavior on the pricing of mortgage-backed securities. As interest rates become more volatile, interest rates are able to follow a much broader set of possible paths over time.

The fourth graph in Figure 1 shows $V(r)$ for different values of σ. As shown, the volatility of interest rates can have a significant effect on the value of a deposit account. The actual effect, however, can be complex and the sign of V_σ can be either positive or negative. In particular, V_σ tends to be negative for smaller values of r, but positive for larger values of r. The sign of the volatility effect depends on whether the deposit value function $V(r)$ is convex or concave in r. When rates are low and $V(r)$ is increasing and concave in r, higher volatility reduces expected deposit values through a negative convexity effect. Conversely, when rates are higher and $V(r)$ becomes convex, volatility increases expected values through a positive convexity effect. This pattern has important implications. Banks benefit from rate volatility in high-rate environments because the optionality embedded in deposit stickiness gains value. However, in low-to-moderate rate environments, volatility works against banks by increasing the likelihood of withdrawal-triggering rate spikes. This suggests that banks with sticky deposits may prefer stable rate environments when rates are low but become less averse to volatility as rates rise—a preference pattern opposite to that of holders of traditional fixed-income securities.

Figure 1 also shows that the magnitude of the effect of interest rate volatility is larger for some ranges of r than others. In particular, the effect of an increase in σ for values of r in the intermediate range can be much larger than the effect for rates near zero or for higher rates.

5.3.5 Deposit Beta Effects

Having examined exogenous parameters, we turn now to the deposit beta β which represents a strategic choice variable for banks. The fifth graph in Figure 1 shows $V(r)$ for different values of β. As shown, the effect of the deposit beta β on the value of a deposit account can be quite complex. Intuitively, this is because there are multiple channels by which β impacts the potential cash flows associated with a deposit account. For example, an increase in β has the effect of narrowing the deposit spread for a bank. In particular, as β increases, the bank earns a smaller spread from its sticky depositors, which results in a less-profitable deposit franchise. Because of deposit stickiness, however, there is also an offsetting effect as β increases. Specifically, as β increases, the deposit is less likely to be put back to the bank. Thus, an increase in the deposit beta results in a tradeoff between the deposit spread the bank can earn, and the expected horizon over which the bank can earn that spread. Figure 1 illustrates that V_β is negative for lower values of r, but becomes positive for higher values of r.

5.4 Implications for Deposit Runoff

The valuation framework also allows us to analyze deposit runoff risk, an important cornerstone for bank funding stability. While the Greeks examined above capture how deposit values change, banks also care about how the expected life of deposits varies with interest rates and stickiness parameters. Shorter expected lives correspond to faster runoff, creating funding pressures. We now examine these dynamics.

As discussed above, stickiness has major effects on the interest-rate risk of bank deposits. It is important to recognize, however, that stickiness also has important implications for the funding risk that a bank may face. In particular, a bank that experiences high levels of deposit runoff has to deal with the challenge of either finding alternative sources of financing or scaling back its operations.

In this section, we explore the effects of changes in interest rates and deposit stickiness on bank funding risk. We examine this issue through the lens of the impact on the expected life or duration of deposit accounts. Changes that result in a shorter expected life create additional funding risk for a bank since it will need to raise new funds sooner and more frequently. We note, of course, that the expected life of a deposit is just another way of expressing the speed of deposit runoff. For example, if the expected life of a deposit decreases from four to two years, we can interpret the change simply as a doubling of the average speed of deposit runoff over the life of the deposit. Intuitively, we can think of the rate of deposit runoff as being proportional to one over the expected life of a deposit.

As described in the Internet Appendix, we can solve directly for the expected life of a deposit account using the valuation framework. Figure 2 plots the expected life as a function of the riskless rate for various parameter values. Using the same format as in Figure 1, we again use a baseline set of parameters, and then vary one parameter at a time to show the specific effects of the individual parameters on the expected life.

Figure 2 shows that the expected life of a deposit is a uniformly decreasing function of the riskless interest rate. The intuition for this result follows directly from Equation (2) which shows that the instantaneous probability of a Poisson-triggered withdrawal increases with the riskless rate. In turn, an increase in the instantaneous probability maps into a cumulative long-term effect that reduces the expected life of the deposit.

Figure 2 also shows that changes in interest rates can have major effects on the expected life of a deposit. For example, Figure 2 illustrates that the expected life can vary from more than three years when the riskless rate is close to zero, to less than one year when the riskless rate is close to ten percent. Changes in the expected life as large as these clearly have serious implications for deposit runoff speeds and bank funding risk.

The plots in Figure 2 also indicate that the impact of an increase in interest rates on the expected life of a deposit is much larger when interest rates are relatively low than otherwise. This is particularly evident in the first graph that shows that the expected life for one calibration decreases from ten to five years as the riskless rate increases from zero to two percent. This suggests that bank funding risk may be particularly susceptible to spikes during periods when interest rates are relatively low.

Finally, Figure 2 shows that changes in the stickiness parameters can also have large effects on the expected life of a deposit account. The first graph demonstrates that an increase in the liquidity parameter λ can result in large declines in the expected life. Furthermore, this decline is particularly acute when interest rates are low. In contrast, the second graph shows that the effects of an increase in the stickiness parameter α are larger when interest rates are at higher levels.

In summary, our results indicate that deposit runoff speeds and bank funding risk can vary significantly as interest rates and/or deposit stickiness behavior changes. The results also highlight the role that the interest-rate environment may play in creating additional bank funding vulnerabilities to shocks.

6. EMPIRICAL ANALYSIS

In this section, we test the empirical implications of the valuation framework. In doing this, we make use of two different sources of deposit pricing data. The first consists of the value of acquired deposit accounts recorded on the balance sheet of an acquiring bank in conventional bank merger and acquisition transactions. These values are known as core deposit intangibles (CDI) and represent the premium the acquiring bank pays above book value to acquire the deposits of another institution as part of an actual market transaction. The second data source consists of the observed market premia banks pay to acquire the deposit accounts of failing financial institutions in FDIC auctions. Unlike CDI values, which are determined through bilateral negotiations, FDIC auction premia emerge from competitive bidding processes, providing an alternative market-based measure of deposit franchise value.

6.1 Calibrating the Valuation Model

Our primary empirical approach compares the market pricing of deposits from the two data sources with the values implied by a calibrated version of the model. In this section, we summarize the key steps of this calibration.[8] The model requires six inputs—the five parameters α, β, λ, θ, and σ, as well as the riskless interest rate.

In the model, the value of a deposit is a function of the riskless rate. Following standard practice in the banking literature, we use the effective federal funds rate as the riskless rate. We take the deposit beta β_i for each bank as the relevant measure of how that bank's deposit rates respond to changes in market interest rates. Deposit betas for most banks are obtained from Drechsler, Savov, and Schnabl (2021). For banks not covered in their sample, we supplement these values by estimating deposit betas following the same methodology using quarterly Call Reports data.

The parameters α and λ, which govern the intensity of Poisson arrivals in the model, are estimated using a Poisson regression framework. Specifically, we collect quarterly deposit growth data for all commercial banks from the Call Reports, producing

[8]The Internet Appendix provides full details about the calibration algorithm.

a panel of 161,461 bank-quarter observations across 5,921 unique institutions from 2017 to 2025. We focus on this recent period because it includes two complete monetary policy cycles with substantial rate variation from near-zero levels to rates exceeding five percent, avoiding the zero lower bound period that dominated 2009–2015 and providing the necessary variation to identify both liquidity-driven and spread-driven withdrawal parameters. We define a wake-up event as a decline in deposits of three percent or more during the previous four quarters. Accordingly, we construct an indicator variable $I_{i,t}$ that equals one if bank i's deposits fall by at least three percent over the prior year, and zero otherwise. We then estimate the following Poisson specification:

$$I_{i,t} = \lambda \ + \ \alpha \ (1 - \beta_i)^2 \ r_t^2 \ + \ \epsilon_{i,t}, \tag{14}$$

where $\epsilon_{i,t}$ is the regression residual. The point estimates of α and λ from this regression are used as inputs in the calibrated valuation model. Table 1 reports the results from this estimation.

Finally, we calibrate the parameters of the interest rate process, θ and σ. We use data on one-year into one-year at-the-money swaption volatilities from Bloomberg (2000–2025) to estimate σ. These implied volatilities, computed using the lognormal Black model, can be used directly as model inputs. The value of θ for each date t is then calibrated using the slope of the federal funds futures curve over a one-year horizon.

6.2 Results Based on Core Deposit Intangibles

When a bank acquires another bank in a merger/acquisition transaction, current generally accepted accounting principles (GAAP) in the U.S. require the acquiring bank to use the fair value method in recording the business combination in its financial statements. The specific requirements are detailed in two pronouncements by the Financial Accounting Standards Board (FASB) designated as FAS ASC 805 *Business Combinations* and FAS ASC 820 *Fair Value Measurements and Disclosures*.[9]

As part of this process, the bank records the fair value of the intangibles acquired in the transaction, the most common of which is designated as the core deposit intangible. As discussed above, the core deposit intangible represents the difference between the acquiring bank's estimate of the value of the acquired deposits and the book value of those deposits. Since a core deposit intangible is recorded only when an actual merger/acquisition transaction occurs, the core deposit intangible can be interpreted as the deposit premium paid in a successful merger/acquisition transaction to acquire the target bank's deposits. In this sense, the core deposit intangible can be viewed as the market-clearing price for the target bank's deposits.

We collect data on the core deposit intangibles reported in 2,134 merger/acquisition transactions that occurred from 1988 to 2025 from the S&P Capital IQ Pro data set. Using the calibrated valuation model, we then solve for the model-implied value for the

[9] For example, see Wilary Winn (2018).

deposit premium as of the announcement date for each of the merger/acquisition transactions. Finally, we compare these model-implied values to the observed core deposit intangibles recorded by the acquiring banks.

Table 2 provides summary statistics for the market and model-implied values of the deposit premia as well as for the differences between the two. As shown, the market values closely match the model predictions. In particular, the average market deposit premium is 1.95 percent compared to the average model-implied premium of 1.76 percent. We note that while the 0.19 percent difference between the two averages is statistically significant, this difference is less than ten percent of the average market premium and is unlikely to be material in economic terms.

To provide a broader historical perspective, the upper panel in Figure 3 graphs the time series of the market deposit premia along with the corresponding model-implied values. As shown, the two time series tend to track each other closely over time. Although the market deposit premia are noisy, it is clear that there is meaningful variation in their values over time which is closely paralleled by the model-implied values. In particular, the market premia are elevated during the early part of the sample period, peak around the 2008 financial crisis, and then decline substantially during the low-interest-rate environment of the post-crisis period These time series patterns are consistent with the empirical implications of the valuation model.

The valuation framework implies that the value of a deposit account should be a nonlinear function of the riskless interest rate similar to those shown in Figure 1. To examine this implication, the lower panel in Figure 3 graphs the market and model-implied deposit premia as functions of the federal funds rate. As shown, the functional form of the relation between market premia and the federal funds rate clearly approximates that implied by the model. In particular, the market deposit premia are initially increasing in the riskless rate when rates are low, but then reach a maximum value for intermediate values, and then begin to decrease as the riskless rate increases further. The correlation between the market premia and the model-implied premia is 42 percent and is highly significant. Again, this pattern is consistent with the valuation model. We acknowledge that the relation between the market deposit premia and the riskless rate is noisy. Even with this caveat, however, these results provide strong validation for the empirical implications of the valuation model.

6.3 Results Based on FDIC Auction Deposit Premia

Having validated the model using CDI data from merger transactions, we now examine a complementary data source—deposit premia paid in FDIC auctions of failed institutions. These auctions provide several advantages for testing the valuation framework. First, bidding occurs under standardized procedures with compressed timeframes, reducing the influence of bilateral negotiation dynamics that may affect M&A transactions. Second, the FDIC reports winning bids and often multiple competing bids, allowing us to observe the distribution of market valuations rather than a single negotiated price. Third, failed banks typically have weaker deposit franchises than merger targets, providing variation in franchise quality that tests whether the model captures differences in deposit stickiness across institutions. Finally, FDIC resolutions occur throughout the business cycle, including crisis periods, generating observations across a wider range of stressed conditions than typical mergers.

The FDIC has the regulatory responsibility to take action when an insured banking institution fails in order to protect depositors. Typically, this process involves an FDIC-organized auction in which qualified potential participants sign a confidentiality agreement. They are then granted access to the failing bank's detailed financial records and given a short time to submit a sealed bid to acquire the bank's assets and assume its liabilities. Potential bidders in FDIC auctions include other insured banks and financial institutions as well as private investors.

Typically, the FDIC auction process results in the winning bidder entering into a purchase and assumption agreement to acquire the assets of the failing bank and assume its deposit liabilities. In these agreements, the acquirer generally purchases the assets at a discount or enters into some type of loss-sharing agreement with the FDIC. As part of the auction process, bidders also specify the premium over book value they are willing to pay to acquire the deposit accounts of the failing bank. This premium can represent an important component of the overall price that the winning bidder pays. The FDIC typically awards the auction to the bidder whose bid results in the least cost to the FDIC in the resolution of the failing bank. Note that the winning bidder is not necessarily the one that offers the highest premium for the bank deposits since the winning bid nets multiple components. Fortunately, however, the FDIC reports the deposit premia offered by bidders separately from their overall bids. Thus, we can directly observe the actual prices paid for deposit accounts in these market transactions.[10]

The FDIC reports summary information for the 572 banks that failed during the 2000 to 2025 period. We hand collect data from the bid summaries provided by the FDIC on the premia offered by auction participants when the resolution of the failing bank was accomplished via a purchase and assumption agreement. Specifically, we collect data on the deposit premium offered by the winning bidder. We note that the FDIC does not always provide a bid summary for auctions of failing banks during the earlier part of the sample period. In these cases, we examine the press release provided by the FDIC which often provides information about the deposit premium paid by the winning bidder. This process results in a subsample of 503 banks for which we have market pricing data for deposit accounts.

Using the calibrated valuation model, we again solve for the model-implied value for the deposit premium and compare it to the observed deposit premium for each of the 503 FDIC auctions in the sample.[11]

[10]See Giliberto and Varaiya (1989), Granja, Matvos, and Seru (2017), Allen, Clark, Hickman, and Richert (2023), and Johnston-Ross, Ma, and Puri (2025) for discussions of the FDIC auction process.

[11]In implementing the valuation model, we value the deposit premium using the federal funds rate as of the announcement date of the purchase and assumption agreement.

Table 3 compares the observed deposit premia in FDIC auctions with the model-implied premia. The model closely matches the observed deposit premia. The average model-implied premium is 0.78 percent compared to the average winning bid premium of 0.62 percent. While the 0.17 percent difference between these two averages is statistically significant, it is again unlikely to be economically material.

The upper panel in Figure 4 graphs the time series of the market deposit premia and the corresponding model-implied values. The two time series tend to track each other over time. While the market deposit premia in FDIC auctions are noisy and likely influenced by other factors besides those incorporated into the valuation model, it is easily seen that the model-implied values tend to increase when market premia increase, and vice versa. The correlation between the market and model-implied deposit premia is 33 percent and is highly significant.

To explore the relation between deposit premia and the riskless rate in more depth, the lower panel in Figure 4 graphs the market and model-implied deposit premia as functions of the federal funds rate. Despite the noisiness of the data, it is clear that the market deposit premia approximate the model-implied value both in their levels and in their functional form. The deposit premia in FDIC auctions tend to have small values when rates are low, increase as rates become larger, but then flatten out and decline as rates increase further. This nonlinear functional relation with the riskless rate is consistent with the implications of the valuation framework.

7. OPTIMAL BANK DEPOSIT PRICING

The preceding analysis treated deposit betas as fixed parameters. We now relax this assumption. An important advantage of the valuation framework is that it allows us to endogenize the deposit pricing strategies of banks. In this section, we consider the valuation and risk management implications of banks following deposit pricing strategies designed to maximize the value of their deposit accounts. In particular, we solve for the optimal deposit beta strategy, study how it impacts the valuation of deposit accounts, and examine how following it affects the interest-rate and deposit runoff risks of the bank.

To convey the intuition as simply as possible, it is useful to focus primarily on the special case in which the interest rate is constant (given by the parameter restrictions $\theta = \sigma = 0$). With these restrictions, the Internet Appendix shows that the nonhomogeneous differential equation in Equation (4) can be reduced to a simple algebraic expression that can be solved explicitly for $V(r)$. The resulting closed-form expression is

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This date is likely to be very close to the actual date of the deposit premium offer made by a bidder given the compressed timeframe over which FDIC auctions are conducted.

$$V(r) = \frac{(1-\beta)r}{\lambda + r + \alpha(1-\beta)^2\ r^2}. \tag{15}$$

Now suppose that instead of holding the deposit beta fixed, a bank chooses to actively manage its deposit beta in order to maximize the value of the deposit premium. It is readily shown that the optimal deposit beta takes one of two distinct functional forms, depending on which region of the state space includes the value of the riskless rate.

The first region consists of the range $0 \leq r \leq \bar{r}$, where

$$\bar{r} = \frac{1 + \sqrt{1 + 4\alpha\lambda}}{2\alpha}. \tag{16}$$

In this region, the optimal deposit beta β^* is simply zero since we assume that deposit betas must be nonnegative. Substituting $\beta = 0$ into the expression in Equation (15) implies that the value of the deposit premium in this region is

$$V(r) = \frac{r}{\lambda + r + \alpha r^2}. \tag{17}$$

The second region consists of the range $\bar{r} \leq r$. In this region, the optimal deposit beta is given by

$$\beta^* = 1 - \sqrt{\frac{\lambda + r}{\alpha r^2}}. \tag{18}$$

Substituting this expression for the optimal deposit beta into Equation (15) implies that the value of the deposit premium in this region is

$$V(r) = \frac{1}{2\sqrt{\alpha(\lambda + r)}}, \tag{19}$$

To provide some visual perspective, the top panel in Figure 5 shows the optimal deposit beta as a function of the riskless rate using the calibrated parameters from the previous section (for comparison, we also graph the deposit beta held fixed at 0.500.) As shown, the optimal strategy exhibits two distinct regimes reflecting a fundamental shift in depositor behavior. Below the threshold rate $\bar{r}$ (roughly 2.55 percent), liquidity shocks dominate withdrawal decisions. Depositors withdraw primarily for exogenous reasons unrelated to rate spreads. In this environment, banks maximize value by minimizing deposit rates ($\beta = 0$) since doing so increases the spread without materially accelerating withdrawals. Above the threshold, spread-related withdrawals dominate. Depositors become increasingly rate-sensitive, making it optimal for banks to raise deposit betas to retain funds. In this regime, the optimal deposit beta becomes highly sensitive to the riskless rate, particularly when the riskless rate is just slightly higher than the threshold. The optimal β^* increases monotonically with rates, eventually approaching one as the withdrawal sensitivity becomes extreme. This regime shift creates the kink visible in Figure 5's top panel.

The efforts of banks to manage their deposit betas to maximize the value of the deposit premium has important implications for the interest-rate and runoff risks of the bank. To illustrate this, it is useful to compare results under a baseline scenario in which the deposit beta is held fixed to the case where a bank optimally manages its deposit beta.

The middle panel in Figure 5 shows the deposit premium as a function of the riskless interest rate for the scenario in which the deposit beta is held fixed at 0.50 and for the scenario in which the bank follows the optimal deposit beta strategy. Since the optimal deposit strategy is chosen to maximize the value of the deposit premium, it is not surprising that the deposit premium is higher when the optimal strategy is followed. Figure 5 shows that the deposit premium can be substantially higher when the bank follows the optimal strategy rather than a fixed deposit beta strategy, in some cases more than doubling its value.

This graph also provides insights about the impact of following the optimal deposit beta strategy on bank risk. As shown, the risk consequences of optimization are substantial. The graph illustrates that the interest-rate risk of a deposit account can be significantly higher when the bank follows the optimal strategy than when it holds the deposit beta fixed, particularly when the riskless rate is low. In particular, optimized deposits can have two to three times the DV01 of fixed-beta deposits in the intermediate range. More dramatically, the sign of interest-rate sensitivity can reverse, creating scenarios where rate increases reduce deposit value for optimizing banks while increasing it for banks with fixed betas. A bank following the optimal strategy near the threshold rate faces "wrong-way" risk—rising rates that should benefit deposit franchises instead trigger value destruction through accelerated withdrawals.

These findings have important implications for banks, regulators, and market participants. Efforts by banks to maximize deposit value through optimal beta adjustments can unintentionally increase their exposure to interest-rate risk, leading to scenarios where deposit accounts become substantially more sensitive to rate movements than under fixed-beta policies. This dynamic is particularly relevant during monetary policy tightening cycles—when rates start from low levels, banks initially keep betas low to maximize spreads, but as rates reach a threshold $\bar{r}$, the optimal beta rises sharply, necessitating rapid deposit rate adjustments to prevent outflows. Institutions that delay such adjustments risk accelerated deposit runoff precisely when their franchise values are highest—a pattern observed during the 2022–2023 tightening cycle.

Finally, the lower panel in Figure 5 shows the expected life of a deposit for the two scenarios. As shown, following the optimal deposit beta strategy can result in a significantly higher level of deposit runoff when interest rates are at lower to intermediate levels. In some cases, the rate of deposit runoff resulting from following the optimal strategy can be twice that from using a constant beta. The plot also shows, however, that the situation can be reversed for higher levels of interest rates. In particular, following the optimal strategy results in a much lower rate of deposit runoff when interest rates are higher than five percent. Interestingly, the rate of deposit runoff tends to be much more stable when a bank follows the optimal strategy. Thus, there may be a deposit runoff predictability argument to make in favor of following an optimal deposit beta strategy.

These findings have important regulatory implications. Supervisory stress tests typically assume banks maintain stable deposit betas when projecting interest-rate risk. However, if banks optimize betas in response to rate changes, as our framework predicts they should, conventional stress tests may systematically underestimate risk. Regulators might consider incorporating state-dependent deposit pricing into stress scenarios and requiring banks to demonstrate robust funding plans that account for potential regime shifts in depositor behavior.

8. EXTENSION TO UNINSURED DEPOSITS

As a final analysis, we consider how the basic valuation framework could be extended to incorporate uninsured deposits in a setting with bank failure risk. Intuitively, two effects could emerge. First, a sudden increase in failure risk could trigger a bank run as depositors attempt to withdraw their funds before default occurs. Second, higher failure risk would reduce deposit value since the likelihood of suffering a principal loss increases.

To illustrate how these two effects could be incorporated within our valuation framework, we follow Duffie and Singleton (1999) and assume that bank failure is triggered by the realization of an independent Poisson event. Let X_t denote the intensity of this Poisson process where X_t follows a stochastic process. We allow for complete generality by leaving the dynamics of X_t unspecified, but note that the process could have both continuous and jump components. To capture the effect of an increase in X_t on the rate of deposit runoff, we extend the model to allow the intensity of a withdrawal wake-up call to be

$$\lambda + \alpha\ (1-\beta)^2\ r^2 + \eta\ X^2, \tag{20}$$

where η is a constant reflecting how responsive depositors are to credit concerns. Thus, an increase in the risk of failure can result in a large nonlinear increase on the speed of deposit runoff. To keep things simple, we also assume that if the bank fails, uninsured depositors do not recover any of their principal (although this assumption is easily relaxed).

Given these modeling assumptions, the value of an uninsured deposit can be expressed formally as

$$V(r) = E\Bigg[\int_0^\infty (1-\beta)\ r_t\ \exp(-\int_0^t r_s\ ds)$$

$$\exp(-\int_0^t \lambda + \alpha\ (1-\beta)^2\ r_s^2\ + \eta\ \ X_s^2\ ds)\ \exp(-\int_0^t X_s\ ds)\ dt\Bigg], \qquad (21)$$

where the last exponential term in the integral is the probability that no default has occurred prior to time t.

Although we leave a complete analysis of the implications of this valuation model for uninsured deposits to future research, we observe that the uninsured deposits would have similar patterns of interest-rate risk to those described earlier. In particular, the interest-rate risk of an uninsured deposit can be either positive or negative in sign. Furthermore, the speed of deposit runoff could accelerate dramatically with a sudden jump in X_t.

9. CONCLUSION

We present a formal fixed-income framework for valuing sticky bank deposits and analyzing their risk properties. This framework provides a closed-form model in which the value of a sticky deposit account is an explicit function of the level and volatility of interest rates, the deposit beta of the bank, the frequency of liquidity shocks, and the stickiness of depositors. The model allows us to study the impact of stickiness on deposit values, the interest-rate risk of bank deposits, and the runoff risk faced by banks as interest rate shocks occur. The valuation framework also allows us to endogenize banks' deposit pricing decisions and study how value-maximizing strategies affect their interest-rate and deposit runoff risks.

We examine the empirical implications of the valuation model using the market premia for deposit accounts observed in bank merger and acquisition transactions. The model-implied values closely approximate the corresponding market premia in terms of their levels and their nonlinear convex/concave relation to the riskless rate. These results provide strong validation for the key empirical implications of the valuation model.

Finally, while the theoretical framework employs representative depositors for tractability, the empirical validation exploits heterogeneity through actual cross-sectional variation in merger activity, both in terms of acquisition pricing and FDIC auction outcomes. The structural model identifies key determinants analogous to asset pricing factors—interest rate levels, deposit betas, stickiness parameters, and liquidity shock frequencies. The results suggest that this framework could be used to predict which banks should command higher deposit premia based on observable characteristics like market concentration, customer demographics, branch network density, or digital versus traditional banking models. Thus, the model could provide both theoretical grounding and practical tools for understanding cross-sectional deposit franchise heterogeneity across the banking system.

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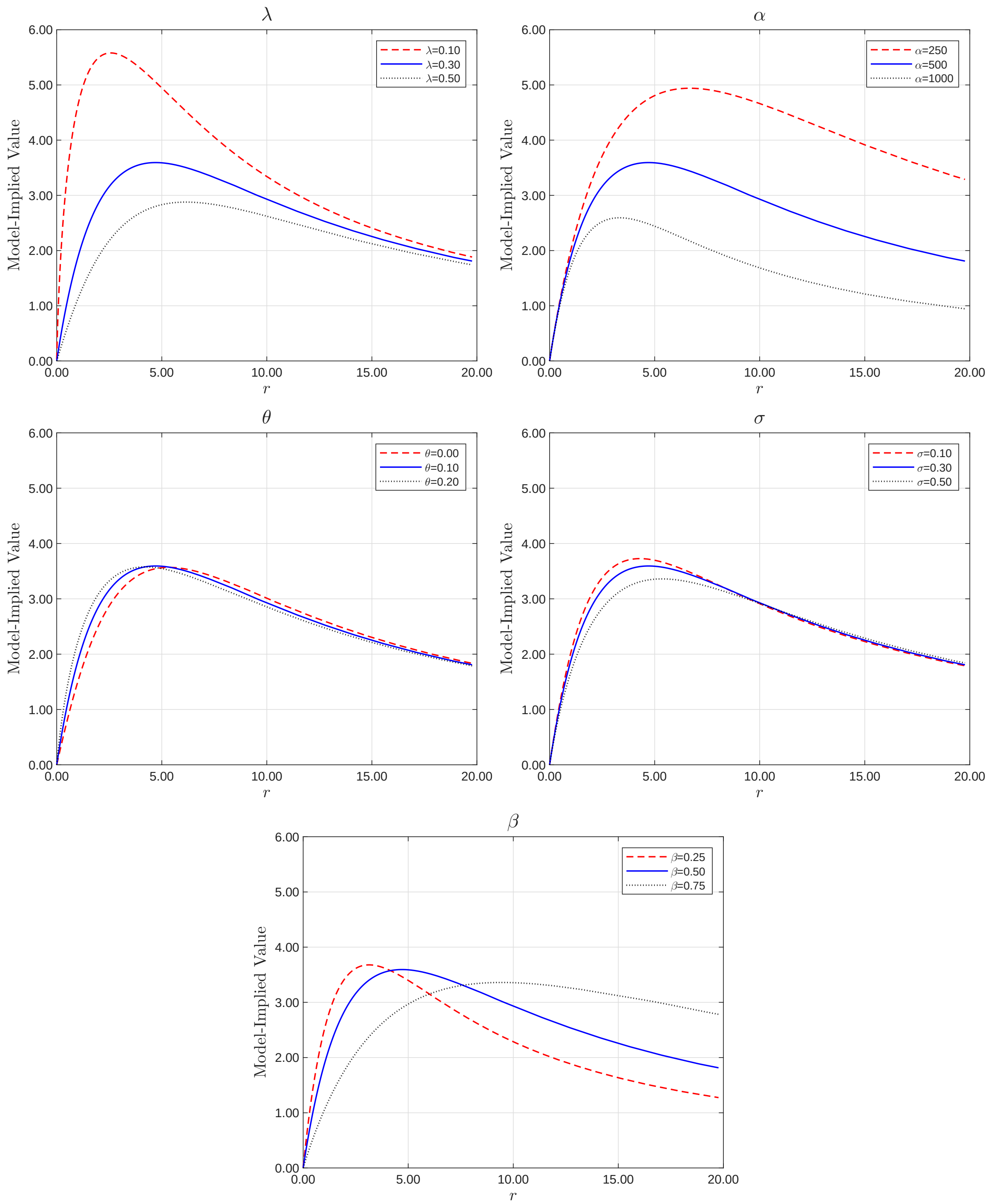

Figure 1. This figure presents graphs of the value of a deposit account as a function of the riskless interest rate and for the indicated parameter values. The value is expressed as a percentage of the book value of the deposit account.

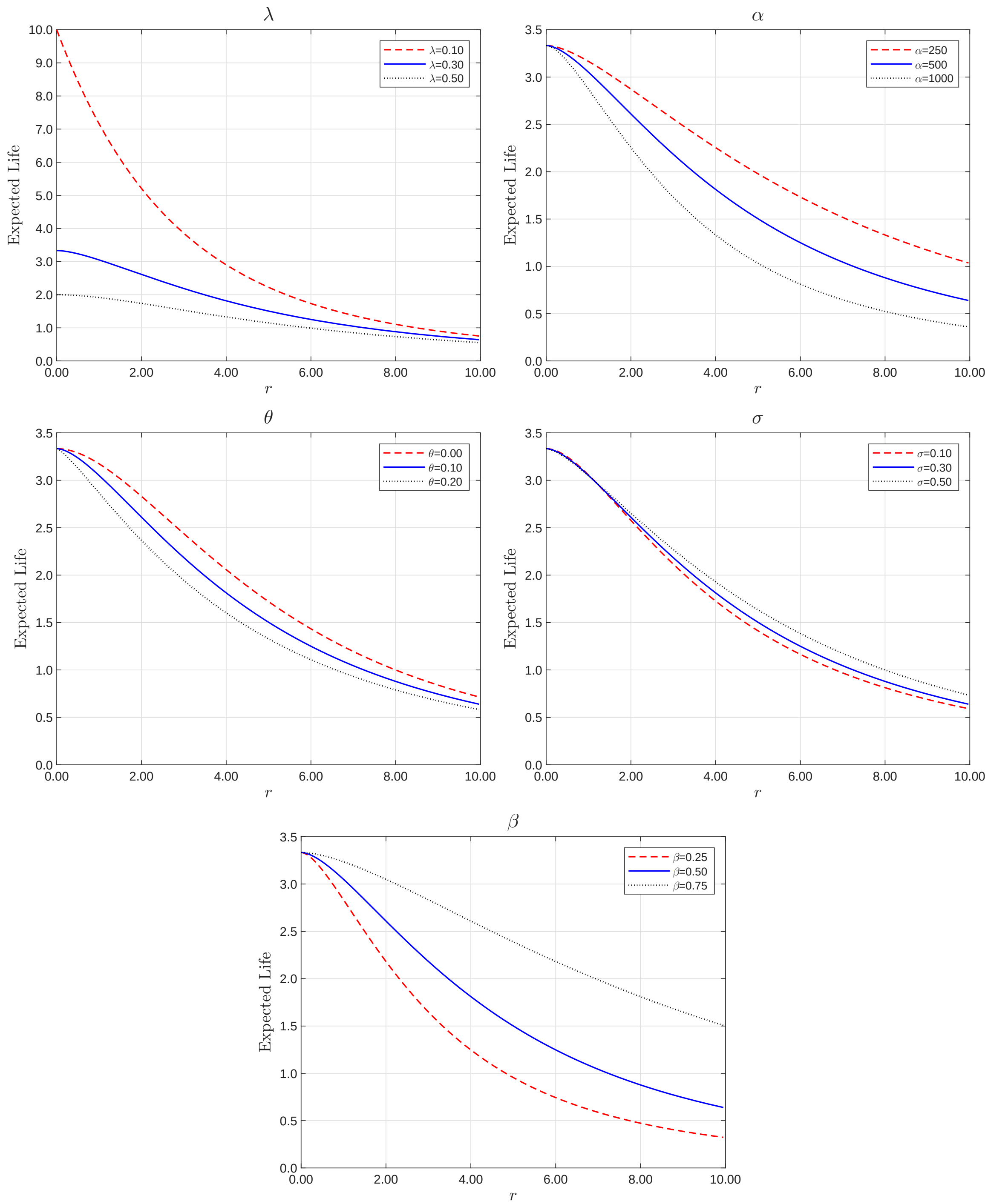

Figure 2. This figure presents graphs of the expected life expressed in years of a deposit account as a function of the riskless interest rate and for the indicated parameter values.

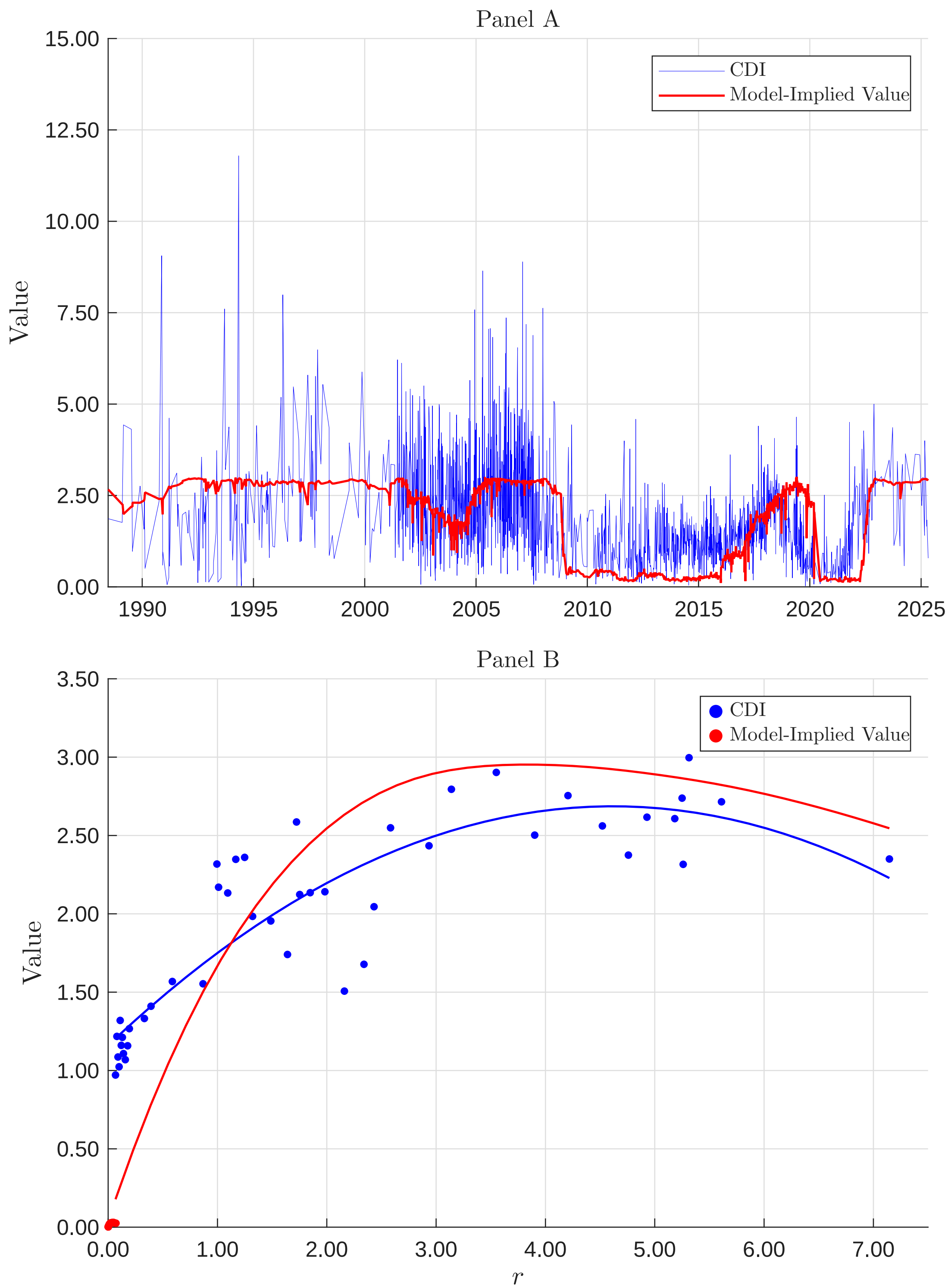

Figure 3. The upper panel graphs the time series of the core deposit intangibles (CDI) and the corresponding model-implied deposit values. The lower panel presents bin-scatter graphs of the core deposit intangibles and the corresponding model-implied deposit values as a function of the overnight federal funds rate. Core deposit intangibles and the model-implied values are expressed as percentages of the book value of the deposit accounts.

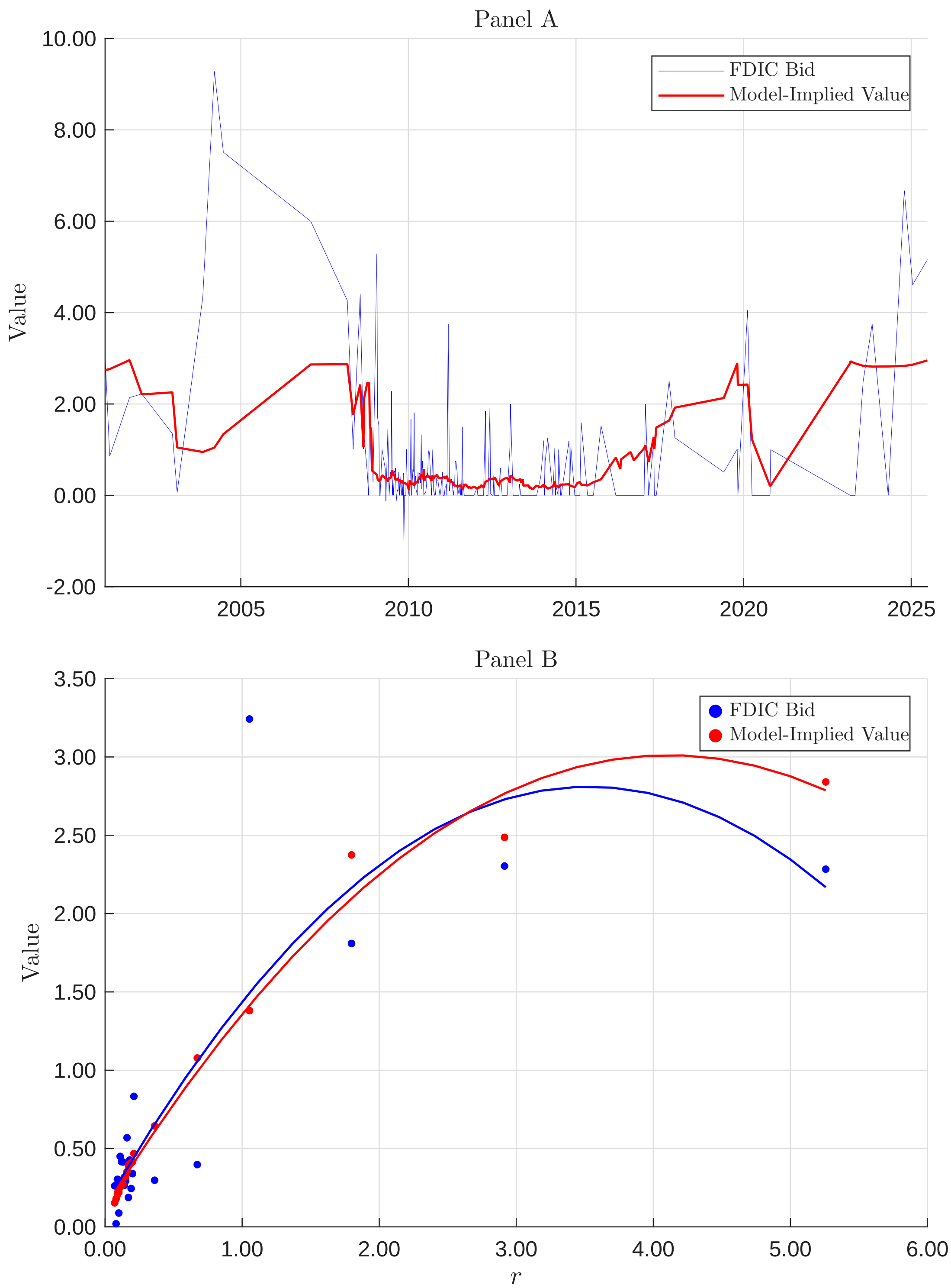

Figure 4. The upper panel graphs the time series of the deposit premium paid by the winning bidder in FDIC auctions of failed banks and the corresponding model-implied deposit values. The lower panel presents bin-scatter graphs of the deposit premium and the corresponding model-implied deposit values as a function of the overnight federal funds rate. The deposit premia and the model-implied values are expressed as percentages of the book value of the deposit accounts.

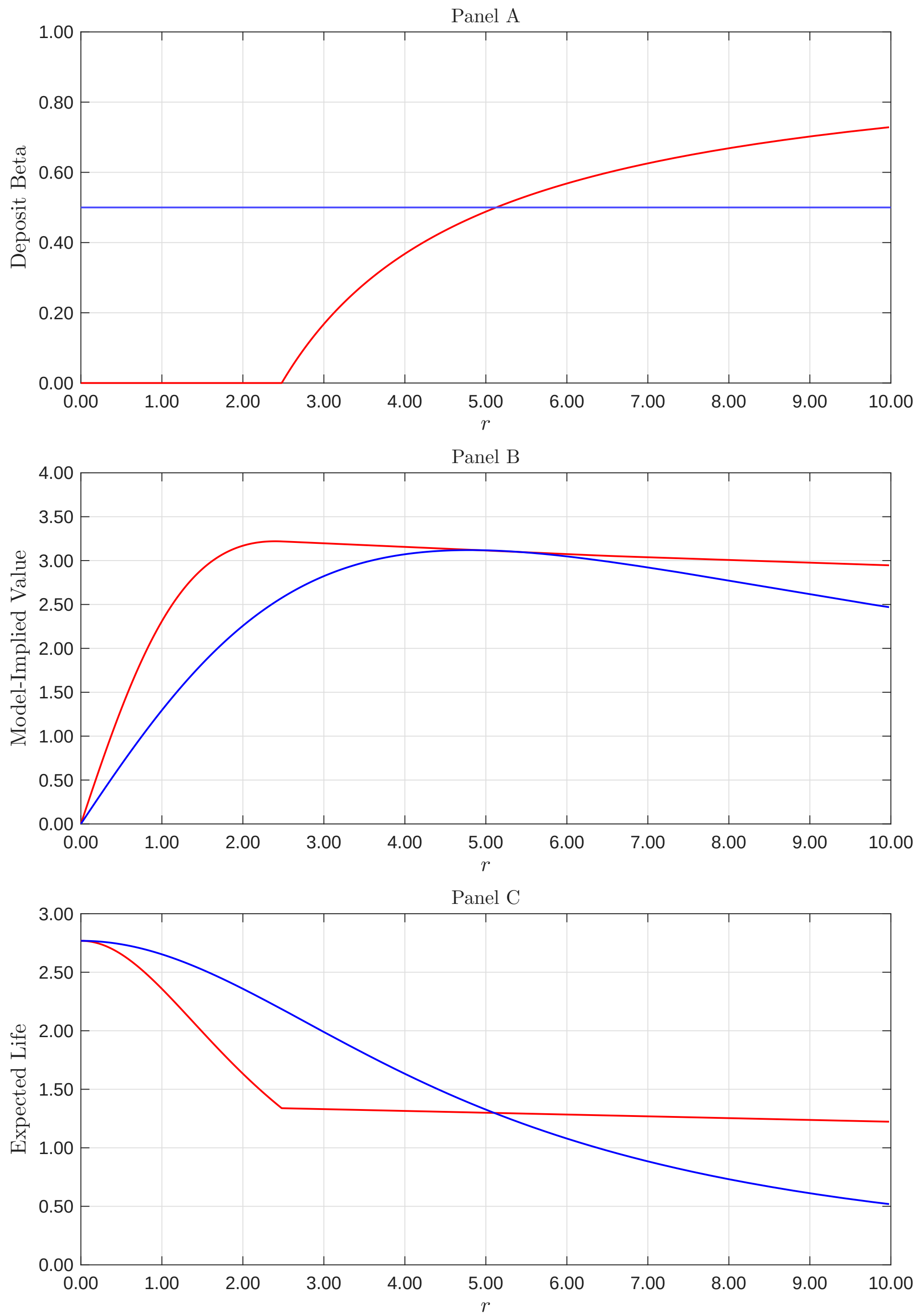

Figure 5. The upper panel graphs the optimal deposit beta as a function of the riskless rate as well as a static deposit beta of 0.500. The middle panel graphs the value of a deposit account as a percentage of book value as a function of the riskless rate based on the optimal deposit beta as well as a static deposit beta of 0.500. The lower panel graphs the expected life expressed in years of a deposit account as a function of the riskless rate based on the optimal deposit beta as well as a static deposit beta of 0.500.

Table 1

Valuation Model Parameters. This table reports empirical estimates for the parameters of the valuation model that are constant throughout the empirical analyses. The parameters α and λ are estimated using the Poisson regression methodology described in Section X of the paper. The parameter μ is the median rate implied by daily prices of 6-month Fed funds futures over the period from December 6, 1988 to June 30, 2025. The parameter σ is the median of daily implied volatilities on one-year into one-year at-the-money swaptions over the period from from January 24, 1997 to June 30, 2025.

Parameter	Value
α	625.2078
λ	0.3612
μ	0.1014
σ	0.3736

Table 2

Summary Statistics for CDI and Model-Implied Premia. This table reports summary statistics for core deposit intangibles (CDI) reported in 2,134 merger/acquisition transactions that occurred between June 1988 and April 2025 and the associated premia implied by the valuation model. CDI values are computed as the ratio of the reported CDI and total core deposits subject to the transaction. Mean, SDev, Min, Med, and Max present the mean, standard deviation, minimum, and maximum, respectively. p–Val reports the p-values from two-sided t-tests of the null hypothesis of zero mean. N denotes the number of observations. Data on CDI are from S&P Capital IQ Pro.

	CDI	Model	Difference
Mean	0.0195	0.0176	0.0018
p–Val	0.0000	0.0000	0.0000
SDev	0.0136	0.0109	0.0134
Min	0.0000	0.0006	-0.0291
Med	0.0165	0.0207	0.0023
Max	0.1179	0.0301	0.0884
N	2,134	2,134	2,134

Table 3

Summary Statistics for FDIC and Model-Implied Premia. This table reports summary statistics for premia paid by banks to acquire the deposit accounts of failing financial institutions in FDIC auctions that occurred between December 2000 and June 2025 and the associated premia implied by the valuation model. Mean, SDev, Min, Med, and Max present the mean, standard deviation, minimum, and maximum, respectively. p–Val reports the p-values from two-sided t-tests of the null hypothesis of zero mean. N denotes the number of observations. Data on failed bank auctions are collected from the Failed Bank List database furnished by the FDIC.

	FDIC	Model	Difference
Mean	0.0053	0.0049	0.0004
p–Val	0.0000	0.0000	0.4123
SDev	0.0121	0.0057	0.0111
Min	−0.0150	0.0011	−0.0294
Med	0.0000	0.0035	−0.0023
Max	0.0928	0.0296	0.0824
N	503	503	503

INTERNET APPENDIX

VALUING STICKY DEPOSITS

IA.1. THE DATA

This section provides details about the datasets used in the analyses. Table IA.1 provides a description of all the data and variables used in the study along with their definitions and corresponding sources.

IA.1.1. Federal Funds Futures and Interest Rate Swaption Data

We collect daily prices of federal funds futures with six months to expiration for the period from December 6, 1988, to June 30, 2025, from the Bloomberg system. Federal funds futures are quoted as 100 minus the average daily effective federal funds rate over the delivery month. For instance, on January 3, 2000, the market price of the federal funds futures contract expiring in June 2000 was 93.82. This means that the market is pricing in an average daily federal funds rate of $100 - 93.82 = 6.18\%$ over the month of June 2000.[1]

We also collect daily data on one-year into one-year at-the-money swaption volatilities for the period from January 24, 1997 to June 30, 2025 from the Bloomberg system.[2] Prior to June 30, 2023, swaptions reference interest rate swaps where the cash flows on the floating leg are based on the 3-month LIBOR rate. Following LIBOR's official discontinuation in the U.S. on June 30, 2023, we use swaptions where the floating rate of the underlying swap is the Secured Overnight Financing Rate (SOFR) for the period from July 1, 2023 onward.

IA.1.2. Call Reports and Federal Funds Rate

We use quarterly bank-level data from the Consolidated Reports of Condition and Income (Call Reports) provided by the Federal Financial Institutions Examination Council (FFIEC). From the Call Reports, we construct key variables including total domestic deposits and interest expense on domestic deposits. We supplement this with data on the federal funds rate from the Federal Reserve Bank of St. Louis FRED database (FRED).

IA.1.3. Core Deposit Intangibles

The primary measure of deposit value is derived from the core deposit intangibles recorded in typical bank merger and acquisition transactions. These values represent

[1] For detailed specifications of federal funds futures contracts, see www.cmegroup.com/markets/interest-rates/stirs/30-day-federal-fund.contractSpecs.html.

[2] Swaptions data first become available in the Bloomberg system on January 24, 1997.

the premium that an acquiring bank pays for the deposits of a target institution as part of an actual market transaction.

When a bank acquires another bank in a merger or acquisition transaction, current generally accepted accounting principles (GAAP) in the U.S. require the acquiring bank to use the fair value method in recording the business combination in its financial statements. The specific requirements are detailed in two pronouncements by the Financial Accounting Standards Board (FASB) designated as ASC 805 *Business Combinations* and ASC 820 *Fair Value Measurements and Disclosures*.

As part of this process, the acquiring bank records the fair value of the intangibles acquired in the transaction, the most common of which is designated as the core deposit intangible (CDI). The CDI represents the difference between the acquiring bank's estimate of the economic value of the acquired deposits and the book value of those deposits. Since a core deposit intangible is recorded only when an actual merger/acquisition transaction occurs, the core deposit intangible can be interpreted as the deposit premium paid in a successful merger/acquisition transaction to acquire the target bank's deposits. In this sense, the core deposit intangible can be viewed as the market-clearing price for the target bank's deposits.

Formally, under ASC 805, goodwill and identified intangibles are created on the buyer's consolidated financial statements as a result of the transaction. For bank and thrift deals, the CDI is separated from goodwill and other identified intangibles, and represents specifically the premium paid to acquire the deposit base. This premium is amortized over the expected life of the acquired deposits, typically 5 to 10 years.

We collect data on CDI from 2,134 merger and acquisition transactions that occurred from 1988 to 2025 from S&P Capital IQ Pro.[3] This database aggregates information from multiple sources including regulatory filings (Call Reports, FR Y-9C reports), company press releases and deal documents, advisor websites, and stock exchanges. We calculate the CDI premium as follows:[4]

$$\text{CDI Premium }\% = \frac{\text{Core Deposit Intangible}}{\text{Total Core Deposits Excl. Gov. Assisted Deals}} \times 100. \quad (1)$$

CDI premia in our sample range from 0.13% to 11.80%, with a mean of 1.95% and standard deviation of 1.36%. Figures IA.1 and IA.2 present the frequency distribution and time series of CDI premia.

[3]We exclude one observation for which the reported CDI is more than 13 standard deviations above the sample average.

[4]When the denominator in Equation (1) is not available, we use total core deposits.

IA.1.4. FDIC Failed Bank Auction Data

IA.1.4.1 FDIC Bidding Process

The FDIC's resolution process follows a structured timeline mandated by the Federal Deposit Insurance Corporation Improvement Act of 1991 (FDICIA). When a bank becomes critically undercapitalized, the Prompt Corrective Action provision generally requires closure within 90 days. During this period, the FDIC prepares to resolve the bank by marketing it to potential acquirers through a competitive auction process.

The FDIC solicits bids for failing institutions from qualified, financially sound FDIC-insured banks that meet established regulatory requirements. Potential bidders access confidential information about the failing institution through secure virtual data rooms (VDRs), which contain financial data, loan files, and details about the resolution transaction structure. The compressed timeframe, often just a few weeks between when detailed information becomes available and when bids are due, can create an environment of significant information asymmetry and time pressure for potential acquirers.

Bidders submit sealed bids specifying which assets they will purchase, which liabilities (particularly deposits) they will assume, and what cash payment they require from (or will pay to) the FDIC. Each bidder essentially states the amount of additional cash needed to cover any shortfall between the value of assumed liabilities and purchased assets. If liabilities exceed assets, the acquirer typically requests cash from the FDIC. Conversely, if assets exceed liabilities, the acquirer pays the FDIC. The FDIC is required by statute to select the bid that imposes the least cost on the Deposit Insurance Fund. This involves comparing each bid to the estimated cost of a "payout" scenario, where the FDIC would pay insured depositors directly and liquidate all assets through the receivership. The winning bid is the one that minimizes expected losses to the Deposit Insurance Fund while meeting regulatory requirements.

IA.1.4.2 Data Collection Process

We obtain deposit premium data from failed bank auctions conducted by the Federal Deposit Insurance Corporation (FDIC) during the 2000–2025 period. The FDIC provides summary information for banks resolved through purchase and assumption agreements on its failed bank list website.[5] We hand-collect data by downloading and examining the purchase and assumption agreements and bid summaries for each failed bank auction.

[5] See https://www.fdic.gov/bank-failures/failed-bank-list.

For each failed bank in our sample, we extract information directly from the FDIC's bid summaries and publicly available purchase and assumption agreements. These legal documents contain detailed terms of the transactions, including the deposit premiums offered by winning bidders. When bid summaries are not available (primarily in the earlier part of the sample period), we examine the FDIC press releases, which often contain information about the deposit premium paid by the winning bidder. This process yields a sample of 503 failed banks for which we have observable market pricing data for deposit accounts.[6] Figure IA.3 presents the incidence of bank failures by year.

IA.1.4.3 Deposit Premium

The deposit premium—the primary variable of interest in our analysis—emerges directly from this bidding structure. When an acquirer assumes deposits (liabilities) and purchases assets worth less than those deposits, the difference represents the capital shortfall. The deposit premium is the amount the acquirer is willing to pay (or requests in subsidy) per dollar of deposits assumed, reflecting the acquirer's valuation of those deposit balances. The deposit premium is given by

$$\text{Deposit Premium \%} = \frac{(\text{Assets Purchased - Deposits Assumed})}{\text{Deposits Assumed}} \times 100\,. \quad (2)$$

A positive premium indicates that the acquirer values the target's deposits above their book value, while a negative premium (or required payment from the FDIC) indicates that the target's deposits are worth less than their book value when considering the associated assets and franchise value.

These FDIC auction premia are particularly well-suited for testing our model for several reasons. First, they represent actual market-clearing prices determined through competitive bidding among qualified financial institutions. Second, the auctions provide a relatively clean setting where banks evaluate deposits in isolation from other strategic considerations that might complicate merger and acquisition transactions. Third, the compressed timeframe of acquisitions (auctions typically conducted over a few days) ensures that deposit premia reflect contemporaneous market conditions and interest rate environments, allowing us to examine how deposit values vary with the riskless rate as predicted by our model.

Typical deposit premia range from -1.50% to 9.28%. The average bid is 0.53%

[6] There are 504 failed bank transactions with associated premia. We exclude one transaction since its press release is ambiguous about whether the reported premium refers to assumed assets and/or deposits.

with a standard deviation of 1.21%. Overall, the distribution is more skewed than that of the CDI premia, reflecting the fact that these transactions often involve distressed institutions, unlike voluntary bank merger and acquisition transactions, which typically include healthier banks. Figure IA.4 presents a scatterplot of the deposit premia by year.

Additional variables extracted from the purchase and assumption agreements and bid summaries include bank name, geographic location of the failed bank's headquarters, FDIC certificate ID, approximate total assets and deposits of the failed bank, name of the institution acquiring the failed bank, date the bank is closed by regulators, classification of bid (winning, cover, or other), premium or discount on assets acquired, nature of transaction (e.g., whole-bank purchase and assumption, insured deposit transfer), whether all deposits or only insured deposits are assumed, whether the transaction involves whole bank or partial bank assets, and whether the transaction includes a loss-sharing agreement with the FDIC.

We match each failed bank auction to the average federal funds rate for the month prior to the date of the purchase and assumption agreement announcement. This captures the prevailing interest rate environment immediately surrounding the bid submission and bank closure dates, given the compressed timeline of FDIC auctions.

IA.2. THE VALUATION MODEL

In this section, we derive a closed-form expression for the value of a bank deposit account, denoted by $V(r)$, as viewed from the bank's perspective. As shown in Equation (4) in the paper, the valuation model leads to a nonhomogeneous ordinary differential equation (ODE) for $V(r)$ given by

$$\frac{\sigma^2}{2}\, r^2\, V_{rr} + \theta\, r\, V_r - \Big(r + \lambda + \alpha\,(1-\beta)^2\, r^2\Big)\ V = -(1-\beta)\, r, \tag{3}$$

where $V_{rr} = \frac{d^2V}{dr^2}$ and $V_r = \frac{dV}{dr}$. The deposit beta satisfies $0 \leq \beta < 1$, and $\sigma, \theta, \lambda, \alpha$ are constants. The function to be solved for is $V(r)$.

The solution is required to satisfy the boundary conditions

$$\lim_{r\to\infty} V(r) = 0\,, \tag{4}$$

$$\lim_{r\to 0} V(r) = 0\,. \tag{5}$$

We will first transform this equation into the nonhomogeneous Whittaker equation (Babister (1967), Equation (5.26)) given by

$$y_{zz} + \left(-\frac{1}{4} + \frac{\kappa}{z} + \frac{\frac{1}{4} - \mu^2}{z^2}\right) y = z^{\nu - 1/2}\,, \tag{6}$$

where y_{zz} denotes the derivative $\frac{d^2y}{dz^2}$. As the first step, we express the ODE in its normal form, which lacks a first-derivative term. To do this, we normalize the leading coefficient and transform the dependent variable. We begin by dividing Equation (3) by the coefficient of the second-derivative term, $\frac{\sigma^2}{2}r^2$, resulting in

$$V_{rr} + \frac{2\theta}{\sigma^2 r} V_r - \left(\frac{2(r+\lambda)}{\sigma^2 r^2} + \frac{2\alpha(1-\beta)^2}{\sigma^2}\right) V = -\frac{2(1-\beta)}{\sigma^2 r}\,. \tag{7}$$

This equation is of the form $V_{rr} + P(r)V_r + Q(r)V = F(r)$, with

$$P(r) = \frac{2\theta}{\sigma^2 r}\,, \tag{8}$$

$$Q(r) = -\frac{2}{\sigma^2 r} - \frac{2\lambda}{\sigma^2 r^2} - \frac{2\alpha(1-\beta)^2}{\sigma^2}\,, \tag{9}$$

$$F(r) = -\frac{2(1-\beta)}{\sigma^2 r}\,. \tag{10}$$

Next, we introduce a transformation of the dependent variable of the form $V(r) = r^p\, y(r)$, where p is a constant to be determined. The derivatives of $V(r)$ are

$$V_r = p\, r^{p-1}\, y + r^p\, y_r\,, \tag{11}$$

$$V_{rr} = p\,(p-1)\, r^{p-2}\, y + 2\,p\, r^{p-1}\, y_r + r^p\, y_{rr}\,. \tag{12}$$

Substituting these into the normalized ODE in Equation (7) and dividing the entire equation by the common factor r^p yields

$$\begin{aligned} y_{rr} &+ \left(\frac{2p}{r} + \frac{2\theta}{\sigma^2 r}\right) y_r \\ &+ \left(\frac{p(p-1)}{r^2} + \frac{2\theta p}{\sigma^2 r^2} - \frac{2}{\sigma^2 r} - \frac{2\lambda}{\sigma^2 r^2} - \frac{2\alpha(1-\beta)^2}{\sigma^2}\right) y = -\frac{2(1-\beta)}{\sigma^2 r^{p+1}}\,. \end{aligned} \tag{13}$$

To eliminate the first-derivative term y_r in Equation (13), we set its coefficient to zero, resulting in $p = -\frac{\theta}{\sigma^2}$. With this value for p, Equation (13) simplifies to the normal form

$$y_{rr} + I(r)\, y = G(r)\,, \tag{14}$$

where the coefficient $I(r)$ is given by

$$I(r) = \frac{p(p-1)}{r^2} + \frac{2\theta p}{\sigma^2 r^2} - \frac{2}{\sigma^2 r} - \frac{2\lambda}{\sigma^2 r^2} - \frac{2\alpha(1-\beta)^2}{\sigma^2}. \tag{15}$$

Using $p = -\frac{\theta}{\sigma^2}$ and after some rearranging and canceling terms, this expression simplifies to

$$I(r) = \left(\frac{\theta}{\sigma^2} - \frac{\theta^2}{\sigma^4} - \frac{2\lambda}{\sigma^2}\right)\frac{1}{r^2} - \frac{2}{\sigma^2 r} - \frac{2\alpha(1-\beta)^2}{\sigma^2}\,. \tag{16}$$

The nonhomogeneous term in Equation (14) is

$$G(r) = -\tfrac{2(1-\beta)}{\sigma^2 r^{p+1}}. \tag{17}$$

Lastly, the transformed equation for $y(r)$ is given by

$$y_{rr} + \left[-\frac{2\alpha(1-\beta)^2}{\sigma^2} - \frac{2}{\sigma^2 r} + \left(\frac{\theta}{\sigma^2} - \frac{\theta^2}{\sigma^4} - \frac{2\lambda}{\sigma^2}\right)\frac{1}{r^2}\right] y = -\frac{2(1-\beta)}{\sigma^2} r^{-p-1}. \tag{18}$$

The next step is to perform a linear transformation of the independent variable, $z = c\,r$, where c is a constant to be determined. This scaling is chosen to match the coefficients of the normal-form equation (Equation (18)) with those of the Whittaker equation (Equation (6)). Using the chain rule, we transform the derivatives with respect to r into derivatives with respect to z. First, note that the chain rule implies $y_r = c\, y_z$ and $y_{rr} = c^2\, y_{zz}$. Next, we substitute these expressions into Equation (18) and replace r with z/c. After dividing by c^2, we obtain the transformed equation for y given by

$$y_{zz} + \left[-\frac{2\alpha(1-\beta)^2}{c^2\sigma^2} - \frac{2}{c\sigma^2 z} + \left(\frac{\theta}{\sigma^2} - \frac{\theta^2}{\sigma^4} - \frac{2\lambda}{\sigma^2}\right)\frac{1}{z^2}\right] y = -\frac{2(1-\beta)}{c^2\sigma^2}\left(\frac{c}{z}\right)^{p+1}. \tag{19}$$

We now compare Equation (19) term-by-term with the nonhomogeneous Whittaker equation in Equation (6). Note that the target form has a coefficient of unity on the right-hand side. The transformation will yield a constant pre-factor, k, which carries through the derivation. We begin by matching the constant term

$$-\frac{2\alpha(1-\beta)^2}{c^2\sigma^2} = -\frac{1}{4}\,. \tag{20}$$

Solving for the constant c yields

$$c = \frac{2\sqrt{2\alpha}(1-\beta)}{\sigma}\,. \tag{21}$$

Next, matching the $1/z$ term gives us

$$\kappa = -\frac{2}{c\sigma^2} = -\frac{2}{\sigma^2}\left(\frac{\sigma}{2\sqrt{2\alpha}(1-\beta)}\right) = \frac{1}{\sigma\sqrt{2\alpha}(\beta-1)}\,, \tag{22}$$

where we have substituted Equation (21) for c.

Turning next to the $1/z^2$ term, results in

$$\frac{\frac{1}{4}-\mu^2}{z^2} = \left(\frac{\theta}{\sigma^2} - \frac{\theta^2}{\sigma^4} - \frac{2\lambda}{\sigma^2}\right)\frac{1}{z^2}\,. \tag{23}$$

After rearranging, we obtain

$$\mu^2 = \frac{1}{4} - \left(\frac{\theta}{\sigma^2} - \frac{\theta^2}{\sigma^4} - \frac{2\lambda}{\sigma^2}\right) = \frac{1}{4} - \frac{\theta}{\sigma^2} + \frac{\theta^2}{\sigma^4} + \frac{2\lambda}{\sigma^2}\,. \tag{24}$$

This can be rewritten by completing the square as

$$\mu^2 = \left(\frac{1}{2} - \frac{\theta}{\sigma^2}\right)^2 + \frac{2\lambda}{\sigma^2}\,. \tag{25}$$

Since λ and σ are strictly positive, the term under the square root is strictly positive. We define μ as the positive root without loss of generality, as only μ^2 appears in the differential equation, which results in

$$\mu = \sqrt{\left(\frac{1}{2} - \frac{\theta}{\sigma^2}\right)^2 + \frac{2\lambda}{\sigma^2}}\,. \tag{26}$$

Finally, we match the nonhomogeneous term. The right-hand side of the transformed equation is $-\frac{2\,(1-\beta)}{c^2\,\sigma^2}\,c^{p+1}\,z^{-p-1}$. Comparing exponents with the target form $z^{\nu-1/2}$ implies

$$\nu - \frac{1}{2} = -p - 1\,, \tag{27}$$

which can be solved for ν after substituting in $p = -\frac{\theta}{\sigma^2}$, resulting in

$$\nu = -p - \frac{1}{2} = \frac{\theta}{\sigma^2} - \frac{1}{2}\,. \tag{28}$$

The constant k is thus given by

$$k = -\frac{2(1-\beta)}{c^2\sigma^2}c^{p+1}\,, \tag{29}$$

which, using $c^2\sigma^2 = 8\alpha(1-\beta)^2$ and substituting in the expressions for c and p, simplifies to

$$k = -\frac{1}{4\alpha(1-\beta)}\left(\frac{2\sqrt{2\alpha}(1-\beta)}{\sigma}\right)^{1-\theta/\sigma^2}\,. \tag{30}$$

Thus, the transformed equation is given by

$$y_{zz} + \left(-\frac{1}{4} + \frac{\kappa}{z} + \frac{\frac{1}{4}-\mu^2}{z^2}\right)y = k\,z^{\nu-1/2}. \tag{31}$$

Lastly, to match Equation (6), we define a rescaled function $w(z) = y(z)/k$. The equation for $w(z)$ is then given by

$$w_{zz} + \left(-\frac{1}{4} + \frac{\kappa}{z} + \frac{\frac{1}{4}-\mu^2}{z^2}\right)w = z^{\nu-1/2}\,, \tag{32}$$

and the full transformation for $V(r)$ is

$$V(r) = k\,r^p\,w(c\,r)\,. \tag{33}$$

Homogeneous Solution. Next, we analyze the solution to the homogeneous Whittaker equation, which is given by Equation (6) with the right-hand side set to zero,

$$w^h_{zz} + \left(-\frac{1}{4} + \frac{\kappa}{z} + \frac{\frac{1}{4} - \mu^2}{z^2}\right) w^h = 0\,. \tag{34}$$

Equation (34) is a second-order linear ODE, and its solution is a linear combination of two linearly independent solutions. These are given by the Whittaker functions $M_{\kappa,\mu}(z)$ and $W_{\kappa,\mu}(z)$ (see Abramowitz and Stegun (1965)). These functions are themselves defined in terms of the confluent hypergeometric (Kummer) functions of the first and second kind, $M(a, b, z)$ and $U(a, b, z)$, respectively, and are given by

$$M_{\kappa,\mu}(z) = e^{-z/2}\, z^{\mu+1/2}\, M\left(\mu - \kappa + \tfrac{1}{2}, 2\mu + 1, z\right)\,, \tag{35}$$

$$W_{\kappa,\mu}(z) = e^{-z/2}\, z^{\mu+1/2}\, U\left(\mu - \kappa + \tfrac{1}{2}, 2\mu + 1, z\right)\,. \tag{36}$$

The solution to Equation (34) is therefore

$$w^h(z) = m\, M_{\kappa,\mu}(z) + w\, W_{\kappa,\mu}(z), \tag{37}$$

where m and w are arbitrary constants. The corresponding homogeneous solution for the original variable $V(r)$, denoted $V^h(r)$, is

$$V^h(r) = k\, r^p\, w^h(c\, r) = k\, m\, r^p\, M_{\kappa,\mu}(c\, r) + k\, w\, r^p\, W_{\kappa,\mu}(c\, r)\,. \tag{38}$$

Next, we consider the boundary conditions given in Equations (4) and (5). To do this, we examine the asymptotic behavior of the homogeneous solutions as $r \to \infty$ and as $r \to 0$. First, recall from Equation (21) that $c = \frac{2\sqrt{2\alpha}(1-\beta)}{\sigma} > 0$. The asymptotic expansions for the Whittaker functions for large $c\, r$ are

$$\begin{aligned} M_{\kappa,\mu}(c\, r) \sim\ & \frac{\Gamma(2\mu+1)}{\Gamma(\mu-\kappa+1/2)} e^{\pi i(\mu-\kappa+1/2)} e^{-c\, r/2} (c\, r)^{-\kappa} \\ & + \frac{\Gamma(2\mu+1)}{\Gamma(\mu+\kappa+1/2)} e^{c\, r/2} (c\, r)^{\kappa}\,, \end{aligned} \tag{39}$$

$$W_{\kappa,\mu}(c\, r) \sim e^{-c\, r/2} (c\, r)^{\kappa}\,. \tag{40}$$

The solution based on $M_{\kappa,\mu}(c\, r)$ contains a term that grows exponentially as $r \to \infty$. The polynomial factor r^p cannot suppress this exponential growth. Consequently, for the solution to vanish at infinity, the coefficient of the $M_{\kappa,\mu}(c\,r)$ term in Equation (38) must be zero, resulting in

$$m = 0\,. \tag{41}$$

In contrast, the solution based on $W_{\kappa,\mu}(c\,r)$ decays exponentially as $e^{-c\,r/2}$. This term satisfies the boundary condition at infinity. Therefore, any valid homogeneous component of the solution satisfying the boundary condition in Equation (4) must be of the form

$$V^h(r) = w\,k\,r^p\,W_{\kappa,\mu}(z(r)) = w\,k\,r^p\,W_{\kappa,\mu}(c\,r)\,. \tag{42}$$

Next, we examine the behavior of the remaining homogeneous solution near the origin. As $r \to 0$, the behavior of $W_{\kappa,\mu}(c\,r)$ for small $c\,r$ is generally a linear combination of a regular and an irregular solution, unless 2μ is an integer, which would introduce logarithmic terms. Assuming 2μ is not a nonnegative integer, the behavior is given by

$$W_{\kappa,\mu}(c\,r) = \frac{\Gamma(-2\mu)}{\Gamma(1/2-\mu-\kappa)}M_{\kappa,\mu}(c\,r) + \frac{\Gamma(2\mu)}{\Gamma(1/2+\mu-\kappa)}M_{\kappa,-\mu}(c\,r)\,. \tag{43}$$

For small $c\,r$, $M_{\kappa,\pm\mu}(c\,r) \sim (c\,r)^{\pm\mu+1/2}$. Since we have defined μ to be positive, the dominant ("most singular") term for small $c\,r$ comes from $M_{\kappa,-\mu}(c\,r)$ which behaves as $(c\,r)^{-\mu+1/2}$. Thus, the leading-order behavior of $V^h(r)$ as $r \to 0$ is

$$V^h(r) \sim k\,w\,r^p(c\,r)^{-\mu+1/2} \sim k\,w\,r^p(c\,r)^{-\mu+1/2} \propto r^{p-\mu+1/2}\,. \tag{44}$$

The exponent of r in Equation (44) is

$$p - \mu + \frac{1}{2} = -\frac{\theta}{\sigma^2} - \sqrt{\left(\tfrac{1}{2} - \tfrac{\theta}{\sigma^2}\right)^2 + \tfrac{2\lambda}{\sigma^2}} + \frac{1}{2}\,. \tag{45}$$

It is straightforward to show that the exponent of r in Equation (45) is strictly negative. This means that $V^h(r)$ diverges as $r \to 0$, implying that $V^h(0) = 0$ requires

$$w\ = 0, \tag{46}$$

leading to the trivial solution $V^h(r) = 0$. This may seem puzzling at first. However, consider the case $\beta = 1$. The right-hand side in Equation (3) is identically zero. In this case, the deposit earns the prevailing market rate, and therefore confers no economic benefit to the bank. Accordingly, the underlying economics require that the value of $V(r)$ is zero for all values of r. This situation corresponds precisely to the case in which the homogeneous ordinary differential equation determines $V(r)$, and it is thus consistent with the solution to the homogeneous equation being identically zero.

Particular Solution. We next derive a particular solution to the ODE for the deposit account in Equation (3) using the results from Section 5.4 in Babister (1967). First, a particular solution $w^p(z)$ for the normalized ODE in Equation (32) is given by

$$w^p(z) = N^{\nu}_{\kappa,\mu}(z)\,. \tag{47}$$

This function, referred to as the nonhomogeneous Whittaker function, has the series representation

$$N^{\nu}_{\kappa,\mu}(z) = z^{\nu+3/2} \sum_{n=0}^{\infty} a_n z^n\,. \tag{48}$$

The first two coefficients of the series are

$$a_0 = \left[(\nu+1)^2 - \mu^2\right]^{-1}, \tag{49}$$

$$\begin{aligned} a_1 &= -\kappa \left[\left((\nu+1)^2 - \mu^2\right)\left((\nu+2)^2 - \mu^2\right)\right]^{-1} \\ &= -\kappa\, a_0 \left[(\nu+2)^2 - \mu^2\right]^{-1}, \end{aligned} \tag{50}$$

and for $n \geq 2$, the coefficients satisfy the recurrence relation

$$\left[(\nu+n+1)^2 - \mu^2\right] a_n \;=\; -\kappa\, a_{n-1} + \tfrac{1}{4}\, a_{n-2}\,. \tag{51}$$

This series solution is valid provided that $\nu \pm \mu$ is not a negative integer, which would result in one of the denominators in the recurrence relation to become zero, leading to infinite coefficients. However, since λ and σ are positive constants, it is straightforward to show that this condition is satisfied for typical parameter values in the empirical settings we consider in the analyses.

Lastly, a particular solution to the ODE for the deposit account in Equation (3) is given by

$$V^p(r) = k\, r^p\, N^{\nu}_{\kappa,\mu}(c\, r)\,. \tag{52}$$

Next, we consider the boundary conditions given in Equations (4) and (5) by examining the asymptotic behavior of $V^p(r)$ as $r \to 0$ and $r \to \infty$. First recall from Equation (21) that $c = \frac{2\sqrt{2\alpha}(1-\beta)}{\sigma} > 0$. Next, for small r, the series for $N^{\nu}_{\kappa,\mu}(c\,r)$ is dominated by its first term

$$N^{\nu}_{\kappa,\mu}(c\,r) \sim a_0 (c\,r)^{\nu+3/2}\,. \tag{53}$$

Therefore, the behavior of $V^p(r)$ near the origin is given by

$$V^p(r) \sim k\, r^p\, a_0 (c\,r)^{\nu+3/2} = (k\, a_0\, c^{\nu+3/2})\, r^{p+\nu+3/2}\,. \tag{54}$$

The exponent of r is

$$p + \nu + \frac{3}{2} = \left(-\frac{\theta}{\sigma^2}\right) + \left(\frac{\theta}{\sigma^2} - \frac{1}{2}\right) + \frac{3}{2} = 1\,. \tag{55}$$

Thus, $V^p(r) \propto r^1$ as $r \to 0$. This implies that the particular solution satisfies the boundary condition at the origin, $\lim_{r\to 0} V^p(r) = 0$.

Turning next to the asymptotics for $r \to \infty$, we first note that the function $N^{\nu}_{\kappa,\mu}(c\,r)$ is defined by a power series in $c\,r$. Moreover, as $r \to \infty$, it decays exponentially (see Equations (5.30)–(5.33) in Babister (1967)). Since $c > 0$,

$$\lim_{r\to\infty} V^p(r) = \lim_{r\to\infty} \left(k\, r^p\, N^{\nu}_{\kappa,\mu}(c\,r)\right) = \lim_{r\to\infty} \left(k\, r^{-\frac{\theta}{\sigma^2}}\, N^{\nu}_{\kappa,\mu}(c\,r)\right) = 0\,. \tag{56}$$

General Solution. The general solution $V(r)$ to the nonhomogeneous ODE in Equation (3) is the sum of the homogeneous solution $V^h(r)$ and the particular solution $V^p(r)$. Recall that $V^h(r)$ is the solution to the associated homogeneous equation. To satisfy specific boundary conditions, it is possible for $V^h(r)$ to be identically zero. We have shown that the boundary conditions $\lim_{r\to\infty} V(r) = 0$ and $\lim_{r\to 0} V(r) = 0$, require the constants w and m to be zero, leading to $V^h(r)$ being identically zero. Thus, the general solution is identical to the particular solution

$$V(r) = V^p(r) = k\, r^p\, N^{\nu}_{\kappa,\mu}(c\, r)\,. \tag{57}$$

After substituting the parameters into Equation (57), this expression becomes

$$V(r) = \frac{1}{4\alpha(\beta-1)} \left(\frac{2\sqrt{2\alpha}(1-\beta)}{\sigma} \right)^{1-\theta/\sigma^2} r^{-\theta/\sigma^2} N^{\nu}_{\kappa,\mu} \left(\frac{2\sqrt{2\alpha}(1-\beta)}{\sigma} r \right)\,. \tag{58}$$

Lastly, we rewrite Equation (58) more compactly. To do this, first recall the parameters

$$\nu = \theta/\sigma^2 \,-\, 1/2\,, \tag{59}$$

$$\kappa = 1/\left(\sqrt{2\alpha}\,\sigma\,(\beta-1)\right)\,, \tag{60}$$

$$\mu = \sqrt{\nu^2 + 2\lambda/\sigma^2}\,. \tag{61}$$

Letting

$$\phi = \sqrt{8\alpha}\,(1-\beta)/\sigma\,, \tag{62}$$

the closed-form solution for the value of a deposit account to the bank is

$$V(r) \;=\; \kappa\;(1-\beta)\,(\phi\, r)^{-\theta/\sigma^2}\; N^{\nu}_{\kappa,\mu}\,(\phi\, r)\;, \tag{63}$$

which matches Equation (5) in the paper.

IA.2.1. Expected Maturity

In this section, we derive the expected life of a deposit account. To begin, recall that the dynamics of the short-term riskless rate under the risk-neutral pricing measure are

$$dr = \theta\, r\, dt + \sigma\, r\, dZ, \tag{64}$$

where θ and σ are constants and Z is a standard Brownian motion. The instantaneous cash flow on the deposit account is $\beta\, r\, dt$ and the depositor withdraws with intensity $\lambda + \alpha\,(1-\beta)^2\, r^2$ over the next instant. For notational convenience, we set

$$\Lambda(r) = \lambda + \alpha\,(1-\beta)^2\, r^2\,. \tag{65}$$

Let τ denote the random withdrawal time. The expected life is the expected time to withdrawal under the risk-neutral pricing measure, conditional on the current short-term riskless rate r,

$$L(r) = E\left[\tau \,|\, r\right]. \tag{66}$$

We will provide an intuitive derivation of the ODE for $L(r)$.[7] Consider the expected life $L(r)$ at time t. Over the next instant, the probability of withdrawal is $\Lambda(r)dt$ and the probability of survival is $1 - \Lambda(r)dt$. This implies that

$$L(r) = (\Lambda(r)dt)\,dt + (1 - \Lambda(r)\,dt)\,(dt + E[L(r + dr)]). \tag{67}$$

Next, we apply Itô's Lemma to $L(r)$, giving

$$dL(r) = L_r(r)\,dr + \tfrac{1}{2}L_{rr}(r)\,(dr)^2. \tag{68}$$

Substituting the dynamics of r and taking expectations under the risk-neutral measure gives

$$E\left[dL(r)\right] = \Big(\theta\, r\, L_r(r) + \tfrac{1}{2}\,\sigma^2\, r^2\, L_{rr}(r)\Big)\,dt. \tag{69}$$

Substituting the expectation back into Equation (67) gives us

$$L(r) = (\Lambda(r)\,dt)\,dt + (1 - \Lambda(r)\,dt)\,\Big(dt + L(r) + \Big(\theta\, r\, L_r(r) + \tfrac{1}{2}\,\sigma^2\, r^2\, L_{rr}(r)\Big)dt\Big). \tag{70}$$

Expanding the terms and ignoring terms of order $(dt)^2$ results in

$$\Big(\theta\, r\, L_r(r) + \tfrac{1}{2}\,\sigma^2\, r^2\, L_{rr}(r)\Big) - \Lambda(r)L(r) + 1 = 0. \tag{71}$$

Lastly, using (65) and re-arranging, gives us the resulting ODE for the expected life of the deposit account $L(r)$,

$$\tfrac{1}{2}\,\sigma^2\, r^2\, L_{rr}(r) + \theta\, r\, L_r(r) - \Big(\lambda + \alpha\,(1 - \beta)^2\, r^2\Big)\,L(r) = -1\,. \tag{72}$$

We next consider the boundary conditions for this ODE. First, as $r \to \infty$, the

[7] A more formal treatment of stopping times can be found in Karatzas and Shreve (1998).

rate-driven component of the withdrawal intensity, $\alpha\,(1-\beta)^2\,r^2$, grows without bound and dominates the constant term λ. The instantaneous probability of withdrawal becomes infinitely high. In such a high-rate environment, any rational depositor would immediately withdraw their funds to reinvest at the much higher market rate. Therefore, the expected time until withdrawal should approach zero, resulting in the first boundary condition,

$$\lim_{r\to\infty} L(r) = 0\,. \tag{73}$$

Second, as $r \to 0$, the rate-driven incentive to withdraw vanishes. The term $\alpha\,(1-\beta)^2\,r^2$ approaches zero and thus the total withdrawal intensity approaches the constant baseline intensity λ. In this limiting case, the withdrawal process simplifies to a standard Poisson process with a constant rate λ. The waiting time for the first event in such a process is known to be exponentially distributed with a mean of $1/\lambda$. Thus, the average life of the deposit must converge to this value as rates approach zero, giving us the second boundary condition,

$$\lim_{r\to 0} L(r) = \tfrac{1}{\lambda}\,. \tag{74}$$

The ODE in Equation (72) can be solved using the same techniques as those used to derive the closed-form solution for $V(r)$ in Section IA.2. Instead of presenting the full solution here, we solve Equation (72) directly using standard numerical techniques.

IA.2.2. Special Case of Constant Interest Rates

In the case of constant interest rates, Equation (3) simplifies significantly, since V_r and V_{rr} are zero. Specifically, we obtain

$$-\left(r+\lambda+\alpha(1-\beta)^2 r^2\right)V = -(1-\beta)r, \tag{75}$$

which can be solved directly for $V(r)$, giving

$$V(r) = \frac{(1-\beta)\,r}{r+\lambda+\alpha(1-\beta)^2 r^2}. \tag{76}$$

An important advantage of this special case is that it allows us to endogenize the deposit pricing strategies of banks. Specifically, we can solve for the optimal deposit beta that maximizes the value of the deposit premium to a bank.

To derive the optimal deposit beta, we first take the derivative of Equation (76) with respect to β. Using the quotient rule results in

$$V_\beta = \frac{-r(\lambda + r) + \alpha(1-\beta)^2 r^3}{\left[\lambda + r + \alpha(1-\beta)^2 r^2\right]^2}. \tag{77}$$

Next, we set the derivative to zero and solve for the optimal deposit beta, denoted by $\beta^\star$. Using $\alpha > 0$ and $r \geq 0$, we get

$$\beta^\star = 1 - \sqrt{\frac{\lambda + r}{\alpha r^2}}. \tag{78}$$

We assume that the deposit betas must be nonnegative, which implies

$$\sqrt{\frac{\lambda + r}{\alpha r^2}} \leq 1 \iff \alpha r^2 - r - \lambda \geq 0. \tag{79}$$

Let $\bar{r}$ denote the positive root of the equation $\alpha r^2 - r - \lambda = 0$. Standard results imply

$$\bar{r} \;=\; \frac{1 + \sqrt{1 + 4\alpha\lambda}}{2\alpha}\,. \tag{80}$$

We thus have two cases.

Case 1: $0 < r < \bar{r}$**.** In this case, the optimal deposit beta is zero:

$$\beta^\star \;=\; 0\,. \tag{81}$$

The corresponding value for the deposit premium is

$$V(r) = \frac{r}{\lambda + r + \alpha r^2}\,. \tag{82}$$

Case 2: $r \geq \bar{r}$**.** In this case, the optimal deposit beta is given by

$$\beta^\star \;=\; 1 - \sqrt{\frac{\lambda + r}{\alpha r^2}}\,. \tag{83}$$

The corresponding value for the deposit premium is

$$V(r) = \frac{(1-\beta^\star)r}{\lambda + r + \alpha(1-\beta^\star)^2 r^2} = \frac{1}{2\sqrt{\alpha(\lambda + r)}}\,. \tag{84}$$

IA.3. CALIBRATION

In this section, we describe how we estimate the model parameters. Our empirical work combines three main datasets: quarterly bank-level financial data from Call Reports, market-based deposit premia from FDIC failed bank auctions and merger and acquisition transactions, and macroeconomic indicators from FRED. The construction of bank-specific parameters, including deposit betas and Poisson intensity estimates, relies on these foundational data sources along with our theoretical framework described in Section 4.

IA.3.1. Estimating the Parameters of the Interest Rate Process

We estimate the drift and volatility parameters of the interest rate process using federal funds futures and interest rate swaptions data, respectively.[8] To begin, recall that the interest rate follows the lognormal process given by

$$dr = \theta\, r\, dt + \sigma\, r\, dZ, \tag{85}$$

where θ and σ are the constant parameters to be estimated, and Z is a standard Brownian motion. Note that this model implies that the riskless rate is conditionally lognormally distributed. This also implies that the expected level of the riskless rate at time T conditional on the current short-rate r is given by

$$E\left[r_T\right] = r\, e^{\theta T}\,. \tag{86}$$

We use the following simple approach to estimate θ. On each date t, we first set r equal to the current level of the federal funds rate and $E\left[r_T\right]$ equal to the federal funds futures rate for the futures expiring in six months ($T = 0.5$), denoted by F. We then solve Equation (86) for θ on each day during the December 6, 1988–June 30, 2025 period:

$$\theta = \tfrac{1}{0.5}\Big(\log(F) - \log(r)\Big)\,. \tag{87}$$

[8] See Section IA.1.1 for a description of this data.

As the point estimate for θ we use the median value of the daily estimates, giving us a value of $\theta = 0.1041$.

Next, we turn to estimating σ. Recall that swaption volatilities are quoted relative to the Black (1976) model. Thus, the swaption volatility observed in the market at date t can be used directly in the model as the estimate of σ for that date. As the point estimate for σ we again use the median value of the daily estimates over the January 24, 1997 to June 30, 2025 period, giving us a value of $\sigma = 0.3736$.

IA.3.2. Estimating the Parameters of the Intensity Process

To estimate the parameters of the intensity process (λ and α), we use each bank's deposit beta (β) following a tiered approach. First, we use deposit betas from Drechsler, Savov, and Schnabl (2021) where available. Second, for banks not in their sample, we estimate deposit betas following their methodology using either quarterly Call Reports data from 1984 through 2024 or by matching to bank holding company data from the CDI dataset. Third, for banks where estimation is not feasible, we assign the sample average deposit beta. Next, we define "wake-up" or "run" events and use them to estimate the Poisson parameters λ and α.

Event definition. We define a wake-up (or run) event as a cumulative decline in a bank's total deposits of at least 3% over the preceding four quarters. More specifically, we define an indicator variable $I_{i,t}$ that equals one if bank i's deposits fall by at least 3% over the prior year, and zero otherwise. This cutoff corresponds roughly to the 95th percentile of the distribution of annual deposit changes across our sample, capturing economically significant outflows rather than normal seasonal fluctuations. Alternative thresholds yield similar parameter estimates and model-implied valuations, and results remain stable when allowing bank-specific or quarter-specific cutoffs that adjust for heterogeneity in deposit growth volatility.

Modified Poisson specification. In a standard Poisson model, the dependent variable represents a count variable—in our context, the expected number of depositor wake-ups for a given bank i in quarter t. Empirically, we do not observe multiple wake-ups per bank–quarter. Instead, we observe whether any wake-up occurred, i.e., whether deposit growth falls below a threshold. Accordingly, we estimate the conditional expectation of a binary indicator rather than a count outcome.

We use a modified Poisson regression with an identity link to estimate the mean function. This approach follows Gouriéroux et al. (1984) and Cameron and Trivedi (2013), who show that Poisson quasi-maximum likelihood consistently estimates parameters of the conditional mean as long as the conditional expectation is correctly specified, even when the dependent variable is binary. This approach is also widely used for binary and fractional outcomes (see Santos Silva and Tenreyro (2006) and Papke and Wooldridge (1996)).

Intuitively, the Poisson specification remains appropriate because the model's structure is continuous-time—it governs the intensity of rare depositor wake-up events, not the realized number of counts. When events are infrequent, as in our data, the Poisson and Bernoulli likelihoods coincide to a first-order approximation, so the modified Poisson regression estimates recover the parameters of the intensity process directly. In contrast, using a logit or linear probability model would consistently estimate the probability of a wake-up but would not preserve the structural mapping between the regression coefficients and the Poisson hazard parameters λ and α implied by the model.

We estimate the following specification from 2017 through 2025.[9]

$$I_{i,t} = \lambda + \alpha(1 - \beta_i)^2 r_t^2 + \varepsilon_{i,t}, \tag{88}$$

where r_t denotes the federal funds rate and β_i denotes bank i's deposit beta.

IA.3.3. Mapping of the Valuation Framework

Both the CDI (Section IA.1.3) recorded in bank merger and acquisition transactions and the deposit premia observed in FDIC auctions (Section IA.1.4) provide direct empirical counterparts to the theoretical deposit value $V(r)$ in our model. In the valuation framework presented in Section 4 of the paper, we define $V(r)$ as the value of a deposit account to the bank—specifically, the difference between the par value of the deposit and the present value of cash flows paid to depositors. The deposit premia paid by acquiring institutions represent their willingness to pay above book value for the right to assume deposit liabilities, reflecting their assessment of the economic value of these sticky deposits.

The two measures complement each other in important ways. FDIC auction premia reflect valuations under distressed conditions with compressed due diligence periods, potentially leading to higher information asymmetry and risk premias (Granja (2013) and Granja, Matvos, and Seru (2017)). In contrast, bank merger and acquisition transactions involve voluntary deals between typically healthy institutions with more extensive due diligence periods. FDIC premia may thus

[9] Restricting the estimation to this window ensures comparability with the environment of positive nominal rates and meaningful variation in the federal funds rate. Earlier periods with near-zero short-term rates are excluded, as deposit rate adjustments were largely constrained by the effective lower bound, leading to biased or truncated beta estimates.

represent lower bounds on deposit values, while CDI premia from bank merger and acquisition transactions may better reflect equilibrium valuations in normal market conditions.

Our empirical strategy compares the observed deposit premiums from FDIC auctions to the model-implied values $V(r)$ calculated using the calibrated valuation framework. This comparison allows us to test the key predictions of our model, particularly the nonlinear relationship between deposit values and interest rates, and to validate whether the economic forces captured in our theoretical framework, i.e., deposit beta, stickiness parameters, and interest rate dynamics, can explain real-world deposit pricing.

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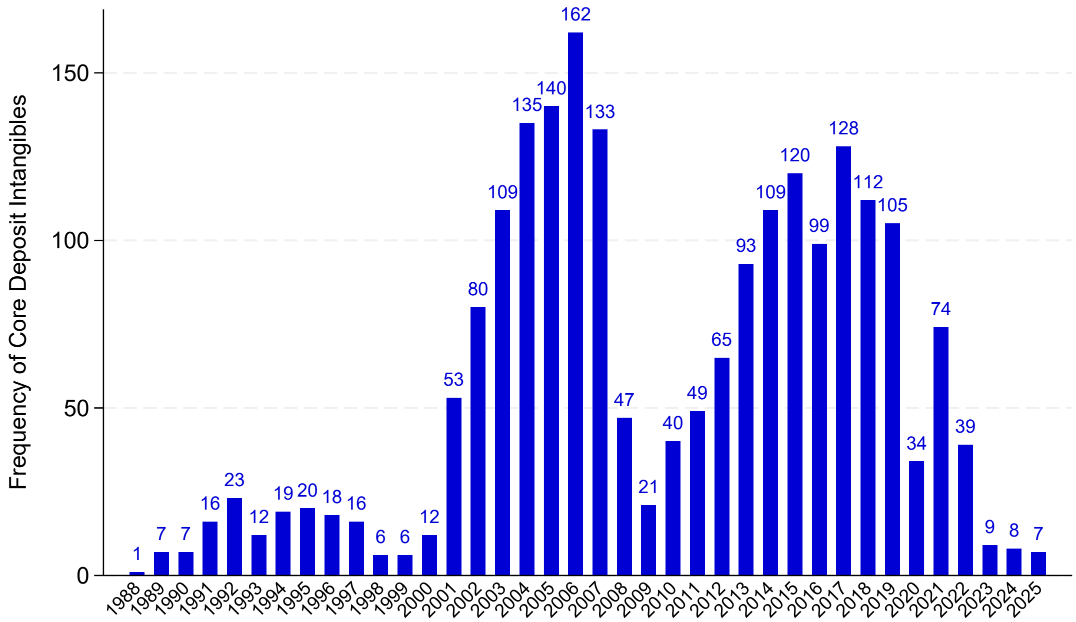

Figure IA.1. Distribution of CDI Premia

This figure shows the frequency distribution of core deposit intangibles (CDI) premia by year from 1988 to 2025. CDI premia are recorded in merger and acquisition transactions and represent the premium paid by acquiring banks for the target institution's deposit base. The sample includes 2,134 bank merger and acquisition transactions from S&P Capital IQ Pro.

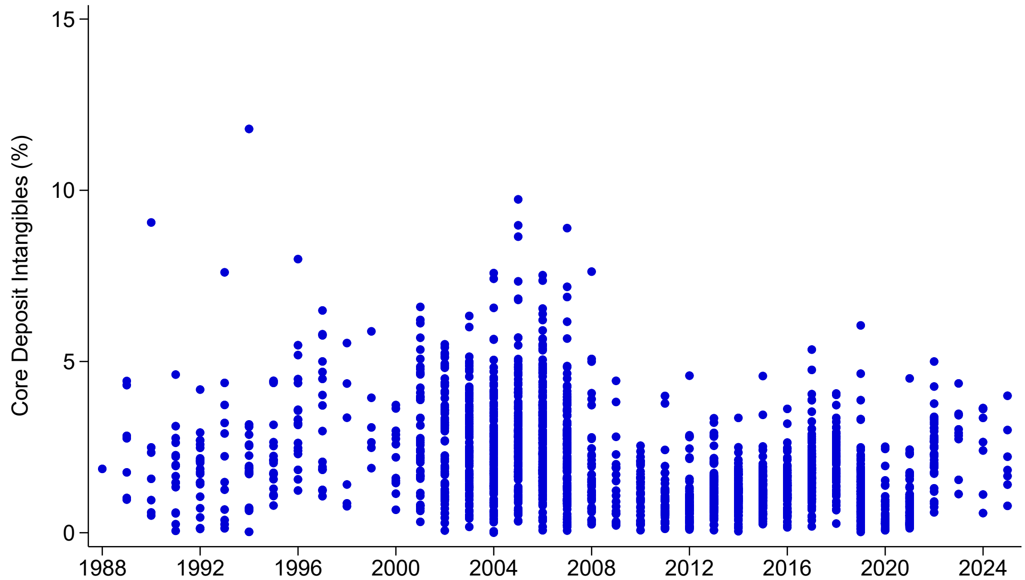

Figure IA.2. CDI Premia

This figure presents a scatterplot of core deposit intangibles (CDI) premia over time from 1988 to 2025. Each point represents the CDI premium (as a percentage) recorded in a bank merger or acquisition transaction. CDI premia range between 0% and 11.80%, with a mean of 1.95% and standard deviation of 1.36%.

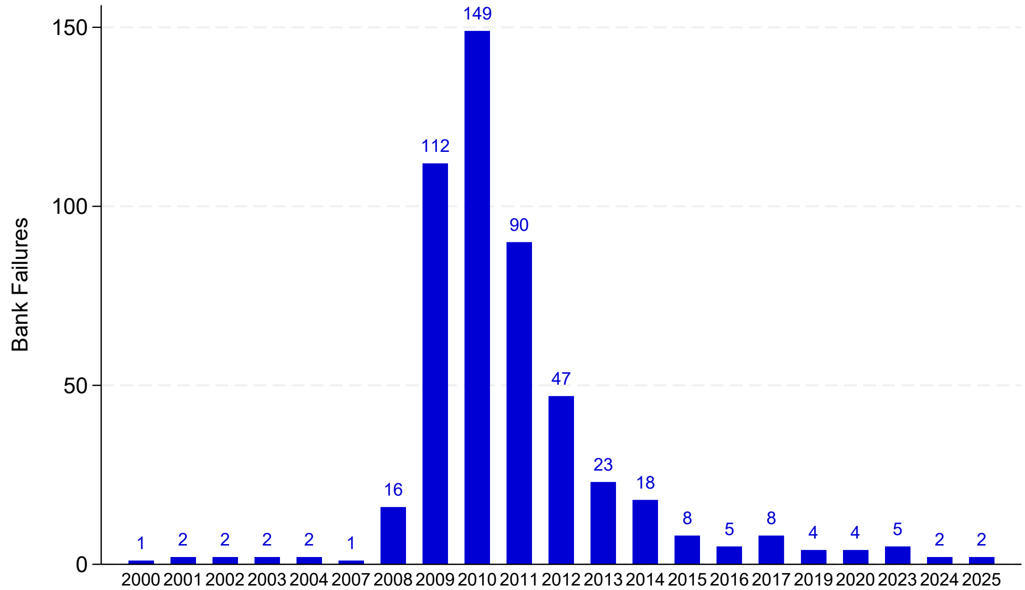

Figure IA.3. Bank Failures

This figure shows the frequency of bank failures by year from 2000 to 2025. The sample includes 503 failed banks resolved through FDIC purchase and assumption agreements with observable deposit premium data. Bank failures peaked during the 2008–2012 financial crisis period.

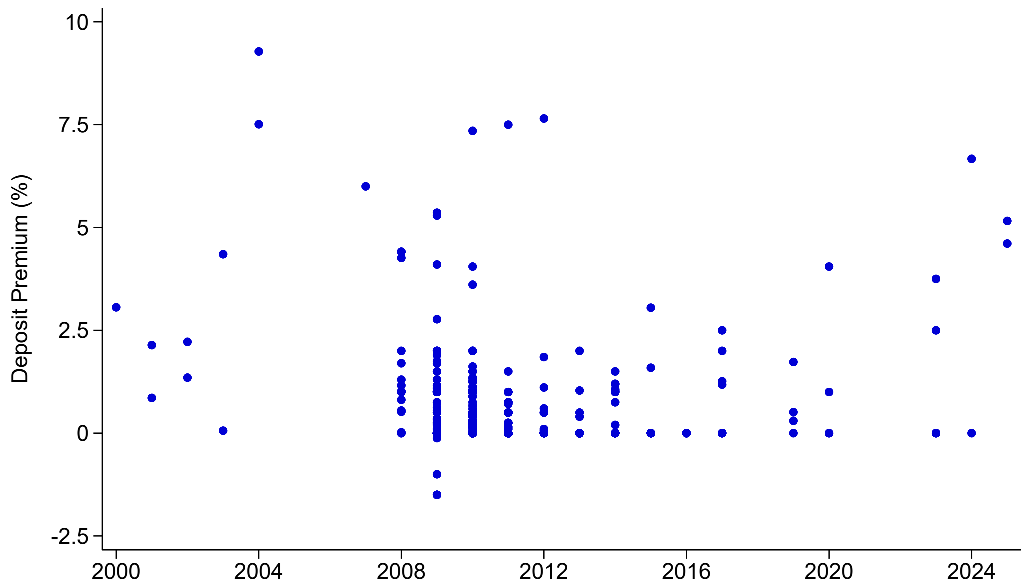

Figure IA.4. FDIC Deposit Premia

This figure presents a scatterplot of deposit premia from FDIC failed bank auctions over time from 2000 to 2025. Each point represents the deposit premium (as a percentage) paid by the winning bidder in a purchase and assumption agreement. Deposit premia range from -1.50% to 9.28%, with a mean of 0.53% and standard deviation of 1.21%.

Table IA.1. Variables and Estimated Parameters

This table summarizes the variables and estimated parameters used in the structural model. Panel A describes the parameters for the interest rate process. Panel B describes bank-level variables constructed from FFIEC Call Reports, for the period from 1984Q1 through 2024Q4. Panel C lists the parameters associated with the withdrawal intensity process. Panel D describes market-based measures of deposit premia from bank merger and acquisition transactions and FDIC failed bank auctions.

Variable	Description	Frequency	Source
Panel A: Interest Rate Process			
Riskless rate (r_t)	Short-term riskless rate (see Equation (85)).	Daily	Effective federal funds rate for the period from from December 6, 1988, to June 30, 2025. Data obtained from the Federal Reserve Economic Data (FRED), St. Louis Fed.
Drift (θ)	Drift parameter of the interest rate process (see Equation (85)).	Daily	Federal funds futures contracts with six months to expiration for the period from December 6, 1988, to June 30, 2025. Data obtained from the Bloomberg Terminal.
Volatility (σ)	Volatility parameter of the interest rate process (see Equation (85)).	Daily	Implied volatilities of one-year into one-year interest rate swaptions for the period from January 24, 1997 to June 30, 2025. Data obtained from the Bloomberg Terminal.
Panel B: Bank-Level Variables			
Total Domestic Deposits	Total deposits held in domestic offices (Schedule RC-E).	Quarterly	FFIEC Call Reports (RCON2200) for the period from 1984Q1 through 2024Q4.
Interest Expense on Deposits	Total interest expense paid on domestic deposits during the quarter.	Quarterly	FFIEC Call Reports (RIAD4170) for the period from 1984Q1 through 2024Q4.
Deposit Rate	Interest expense on deposits divided by average total deposits, annualized by multiplying by 4.	Quarterly	Constructed from FFIEC Call Reports for the period from 1984Q1 through 2024Q4.
Deposit Growth	Percentage change in total domestic deposits over four quarters: $(\text{Deposits}_t - \text{Deposits}_{t-4})/\text{Deposits}_{t-4} \times 100$.	Quarterly	Constructed from FFIEC Call Reports for the period from 1984Q1 through 2024Q4.
Wake-Up Event Indicator ($I_{i,t}$)	Binary indicator that equals 1 if bank i experienced deposit decline $\geq 3\%$ over the preceding four quarters, and equals 0 otherwise.	Quarterly	Constructed from FFIEC Call Reports.
Panel C: Withdrawal Intensity Process			
Deposit Beta (β_i)	Sensitivity of bank deposit rates to federal funds rate changes, estimated over the 1984–2024 period.	Bank-level	Estimated following Drechsler, Savov, and Schnabl (2021) using FFIEC Call Reports and St. Louis FRED
Baseline Intensity (λ)	Baseline Poisson wake-up intensity parameter.	Constant	Estimated via modified Poisson regression on Call Reports data.
Rate-Sensitivity (α)	Sensitivity of wake-up intensity to interest rate spreads.	Constant	Estimated via modified Poisson regression on Call Reports data.
Panel D: Market-Based Deposit Premia			
Core Deposit Intangible (CDI) Premia	Core deposit intangible asset as percentage of acquired core deposits in voluntary bank merger and acquisition transactions.	Transaction-level	Data are from S&P Capital IQ Pro for the period from January 1988 to June 2025.
FDIC Deposit Premia	Premium paid per dollar of acquired deposits in FDIC-assisted Purchase and Assumption (P&A) agreements for failed bank resolutions.	Transaction-level	Data are hand-collected from FDIC P&A agreements for the period from January 2000 to June 2025.