Dynamic Banking with Non-Maturing Deposits*

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Abstract

The majority of bank liabilities are deposits typically not withdrawn for extended periods. We propose a dynamic model of banks in which depositors forecast banks' leverage and default decisions, and withdraw optimally by trading off current against future liquidity needs. Endogenous deposit maturity creates a time-varying dilution problem that has major effects on bank dynamics. Interest rate cuts produce delayed increases in bank risk which are stronger in low rate regimes. Deposit insurance can exacerbate the deposit dilution and amplify the increase in bank risk.

Keywords: Deposits, debt maturity, dilution, time inconsistency, monetary policy.

JEL codes: G21, G28, E44.

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1 Introduction

According to the FDIC, deposits account for 83% of U.S. banks' balance sheets at the end of 2021. Time deposits with limited maturities account for only 6% of all deposits. The remaining deposits are non-maturing: they have no explicit maturity date and are typically not withdrawn for extended periods. Because these deposits can be withdrawn at any time, their maturity varies with bank risk and market conditions.

In this paper, we bring to center stage this feature of bank liabilities and develop a dynamic model of banks with endogenous deposit maturity. Banks create liquidity through issuing deposits and are exposed to the risk of default. Depositors withdraw from their accounts optimally by trading off between current and future risk-adjusted liquidity benefits. We highlight the first-order effects the endogenous deposit maturity has on bank dynamics.

In typical macro-finance banking models, deposits are modelled as one-period debt. As such, when banks issue new deposits, there is no outstanding deposits that can be diluted. With long-term debt, when new debt is issued, borrowers do not internalize the reduction in value of the outstanding debt. This gives rise to debt dilution. Recent studies have shown that dilution affects debt dynamics in major ways (Gomes, Jermann and Schmid, 2016; Admati, DeMarzo, Hellwig and Pfleiderer, 2018).

In our model, there are frictional costs that prevent deposits from being withdrawn and repriced every period. Depositors face liquidity shocks and they withdraw only if the liquidity value net of withdrawal costs exceeds the expected future liquidity benefit of the deposit. This converts redeemable deposits into long-term debt with endogenous maturity, and thus exposes deposits to time-varying dilution. Banks cannot credibly commit to not dilute depositors in the future. We show that bank dynamics are affected by time-varying dilution in significant ways through the lens of banks' responses to interest rate shocks. Overall, our analysis suggests that accounting for endogenous deposit withdrawals is important for modeling banks and studying monetary policy transmission.

First, we find that an interest rate cut generates an initial reduction in bank default risk but is followed by an extended period of significantly higher default risk and higher leverage. Endogenous maturity is key for such boom-bust dynamics. Following a rate reduction, future liquidity benefits of deposits become more valuable. Deposit withdrawals decline and lengthen the maturity, which gives rise to stronger debt dilution incentives. Banks issue new deposits and drive up the subsequent default risk.

A second finding is that such a delayed bust is more pronounced in a low interest environment than in a high interest environment. In a low interest environment, future liquidity benefits of deposits are large and deposit withdrawals are less sensitive to marginal variations in banks' default risk. As a result, when absorbing new deposits and driving up the default risk, banks are less worried about existing depositors pulling out their money. This means deposit dilution is less disciplined in a low interest environment. Banks in this case would like to dilute more aggressively the additional unwithdrawn deposits created by an interest rate cut, relative to banks in a high interest environment.

It is important to notice that the key mechanism in the model—deposit dilution—does not vanish with the presence of deposit insurance. The FDIC estimates 53.3% of US bank deposits to be insured at the end of 2021. We extend our model to include both uninsured and insured deposits. Issuing insured deposits does not dilute the value of legacy insured depositors who are protected by the deposit insurance against default. However, issuing insured deposits can dilute the value of uninsured depositors because banks' default decisions are also affected by the amount of insured deposits. We show that giving banks the choice to substitute into insured deposits can exacerbate the dilution of uninsured deposits and in turn amplify the increase in bank risk following an interest rate cut.

Literature—Our paper contributes to the literature on dynamically modeling banks. In particular, we study bank deposits with endogenous maturity and when dilution is possible. Our work is related to several research areas.

Since the pioneering work by Farmer (1984), Williamson (1987), and Bernanke and Gertler (1989), a large literature has emerged to study the macroeconomic implications of financial markets and institutions, i.e. banks.[1] While many papers in

[1]Recent work using macro-banking models for policy analyses includes e.g., Gertler and Karadi (2011), Angeloni and Faia (2013), Gertler and Kiyotaki (2015), Davydiuk (2017), Brunnermeier

the literature follow a tradition of modeling lending-side frictions, our focus is on the liability side. Van den Heuvel (2008) and Begenau (2020) model the liquidity value of bank liabilities for households through a deposit-in-utility setup. In more micro-founded environments, Williamson (2012) highlights how bank liabilities facilitate transactions, and Quadrini (2017) highlights how they provide insurance. Begenau and Landvoigt (2020) propose a model where bank and shadow-bank liabilities provide different liquidity values. Egan, Hortaçsu and Matvos (2017) estimate a model where banks compete for insured and uninsured deposits. Different from these papers, we model explicitly deposit withdrawals and our analysis highlights long-term debt subject to dilution.

There are several studies that have emphasized the rich dynamics of long-term corporate debt with dilution, for instance, Gomes, Jermann and Schmid (2016), Crouzet (2017), Admati, DeMarzo, Hellwig and Pfleider (2018), Demarzo and He (2021), Malenko and Tsoy (2021), and Jungherr and Schott (2022). Different from these, our model features endogenous maturity. Xiang (2023) shows how covenant violations and subsequent debt restructuring generate endogenous debt maturity. In our paper, maturity is driven by deposit withdrawals, and how depositors respond to interest rate shocks is key to our results.

Dilution has been studied in the sovereign debt literature, for example Hatchondo and Martinez (2009), Arellano and Ramanarayanan (2012), Chatterjee and Eyigungor (2012), Aguiar, Amador, Hopenhayn and Werning (2019), Bocola and Dovis (2019). The problem of a sovereign differs in a number of ways from the problem of a bank. One key difference is that a bank in our model can issue equity, but a sovereign does not have this option. Another difference is that bank debt in our model generates direct service flows, for sovereigns debt serves only as an instrument for intertemporal substitution.

The liability-side theory where banks engage in maturity transformation by offering the option to withdraw deposits early is central to a large finance literature building on Diamond and Dybvig (1983). In this approach, a sequential service con-

and Koby (2018), Mendicino, Nikolov, Suarez, and Supera (2018), Corbae and D'Erasmo (2019), Malherbe (2020), Porcellacchia (2020), Elenev, Landvoigt and Van Nieuwerburgh (2021), Bianchi and Bigio (2022), and Xiang (2022). In a companion paper, we apply the framework developed in this paper to study bank capital requirements (Jermann and Xiang, 2023).

straint can lead to bank runs. Instead, our model features debt dilution. Models have mostly abstracted from time-varying maturity. Exceptions are several papers interested in the valuation of non-maturing deposits from a bank's perspective where maturity is exogenously specified, including Hutchison and Pennacchi (1996), Jarrow and van Deventer (1998), Nyström (2008) and Wolff (2000). Some recent macro-finance studies also emphasize the long-term nature of bank deposits. For instance, Bolton, Li, Wang and Yang (2020) present a model where banks have limited control over deposit inflows, and Drechsler, Savov and Schnabl (2021) present empirical evidence suggesting that bank franchise value confers long duration to bank deposits. Different from these, we model the dilution problem associated with long-term debt.

The paper proceeds as follows. Section 2 presents our model for non-maturing deposits and studies banks' responses to interest rate shocks. Section 3 considers extensions with insured deposits and when bank asset profitability comoves with interest rates. Section 4 discusses our model ingredients and empirical implications. Section 5 concludes.

2 Non-maturing deposits and interest rate shocks

In this section, we present our model for non-maturing deposits and study the impact of interest rate shocks on bank dynamics. The model is presented in Section 2.1, followed by an illustration of the time-varying dilution mechanism in Section 2.2. Results about interest rate shocks are in Section 2.3.

2.1 Setup

We start with presenting our model of deposit withdrawals, followed by bank leverage choice and the pricing of deposits.

2.1.1 Deposit withdrawals

Time is discrete and all agents are risk neutral. The economy is populated with a continuum of banks, each of whom creates value by providing liquidity services to a continuum of depositors. Consider an individual bank. The liquidity value derived by depositor i with deposits b_i has two components. The first is the benefit of *holding* deposits, captured by μ. In particular, a depositor can use the bank account for transactions within the period, such as receiving wage bills, paying for online shopping, meeting margin requirements, etc (Gorton and Pennacchi, 1990). Moreover, the depositors may have the option to pursue illiquid investments with high risk-adjusted returns.

The second is the benefit of *withdrawing*. The depositor can withdraw from the account to meet a need for cash at the period end (Diamond and Dybvig, 1982). Specifically, depositor i encounters a liquidity shock at the end of each period. In addition to the principal redemption, there is an extra marginal benefit ν when withdrawing an additional dollar with c.d.f. (p.d.f.) $F(\nu)$ ($f(\nu)$) over support $[\underline{\nu}, \infty)$. We assume that $f(\nu)$ is decreasing, capturing the reality that encountering a large liquidity need is rare. Withdrawal incurs a marginal cost of κ.[2] As a result, depositor i withdraws the entire deposit b_i if the shock is large enough such that

$$(1 + \nu - \kappa)b_i \geq qb_i, \tag{1}$$

where q is the price of the deposit. The endogenously determined price equals the present value of future liquidity benefits adjusted for the default risk of the bank. The depositor keeps b_i in the bank if the above condition is not satisfied. Condition (1) implies that when interest rates increase or the bank becomes riskier, both leading to a lower q, the mass of withdrawing depositors, $\lambda(q) = 1 - F(q + \kappa - 1)$, becomes larger and deposit maturity shortens. The time-varying deposit maturity is the key distinction of our model relative to typical macro-banking models which usually fix $\lambda = 1$ and thus force depositors to withdraw and re-deposit every period.

Because the withdrawal decision of depositor i does not depend on b_i, the bank's problem only depends on the total amount of deposits on the balance sheet, $b = \int_i b_i di$, rather than the whole distribution of b_i's. Summing up the two components of liquidity benefits and integrating over the optimal withdrawal set, the liquidity value

[2]It would be equivalent to model a net withdrawal benefit, but we find it more natural to have a withdrawal cost and a withdrawal benefit that are both positive. This assumption does not introduce a redundant parameter because the distribution of the withdrawal benefit has only one parameter.

per unit of deposit, from the bank's perspective, can be written as

$$l\,(q) = \mu + \int_{q+\kappa-1}^{\infty} (\nu - \kappa) dF(\nu).$$

2.1.2 Bank problem

A bank makes its leverage decision each period conditional on the total outstanding deposits b and the withdrawal rule of depositors. The assets of the bank generate a per-period profit of $R + z$, where R is constant for simplicity and z is a zero-mean bank-specific i.i.d. profit shock with c.d.f. (p.d.f.) $\Phi(z)$ ($\phi(z)$) over support $[-\bar{z}, \bar{z}]$. Government interest rate policy determines the discount rate for banks and depositors since treasury bills serve as the outside option for both groups. That is, the discount rate in this economy is given by $1/r$ where interest rate r follows an exogenous process $\Gamma(r'|r)$.

Bank equity value and deposit policy are given by:

$$\begin{aligned} z + v^e(r, b) = z + \max_{b'} \Bigg\{ & R - \lambda(q(r, b'))b + q(r, b')\{b' - [1 - \lambda(q(r, b'))]b\} \\ & + \frac{1}{r} \mathbf{E}_{r'|r} \left[\int_{-v^e(r', b')}^{\bar{z}} [v^e(r', b') + z'] d\Phi(z') \right] \Bigg\}, \end{aligned} \quad (2)$$

where deposit pricing schedule $q(r, b')$ and depositors' withdrawal rule $\lambda(q)$ are taken as given.

As shown in (2), bank equity value consists of two parts. First is the current period net cash flow, which includes profits $R+z$, repayment to withdrawing depositors λb, and proceeds from new deposits $q[b'-(1-\lambda)b]$. Second is the continuation value, which incorporates the bank's default option tomorrow. After the realization of two shocks r' and z', the bank defaults if its equity value goes below zero, i.e. $z' + v^e(r', b') < 0$.

When typical models assume $\lambda = 1$, a bank reissues all deposits every period and thus fully internalizes the price impact of its choice for b'. In contrast, with the presence of future liquidity benefits and the withdrawal cost, our model features deposits that can be potentially long-term. A dilution problem arises when the bank does not need to compensate non-withdrawing depositors $(1 - \lambda)b$ for how its choice for b' changes the risk of default.

2.1.3 Deposit pricing

The deposit price $q(r, b')$ is pinned down by the zero profit condition of depositors. For a non-defaulting bank, the payoff to depositors in the current period consists of the liquidity value lb, principal repayment to withdrawing depositors λb, and the value of unwithdrawn deposits $q(1-\lambda)b$. That is, depositors' value is given by:

$$v^b(b, q) = \left\{ l(q) + \lambda(q) + q[1 - \lambda(q)] \right\} b,$$

which does not depend on z because its realization does not affect the equilibrium choice for b', as suggested by (2).

Our formulation of default follows Gomes, Jermann, and Schmid (2016). Upon default, depositors take over the bank and initiate a restructuring. They first collect current profits $R+z$ and then sell off the equity portion to new owners while continuing to hold their deposits. After going through the restructuring, individual depositors again decide on whether to withdraw their money or not. This means that depositors have a claim over the total bank franchise value $z + v^e(r, b) + v^b(b, q)$ in default states. However, restructuring incurs a dead-weight loss for depositors that is increasing in the amount of deposits, ξb, reflecting a larger difficulty to restructure a more levered bank. Under this formulation, we do not need to keep track of the distribution of b's when considering the aggregate economy.

To sum up, the deposit price is given by

$$\begin{aligned} q(r, b')b' = \frac{1}{r}\mathbf{E}_{r'|r}\Bigg[& \int_{-v^e(r',b')}^{\bar{z}} v^b(b', q(r', h_b(r', b'))) d\Phi(z') \\ & + \int_{-\bar{z}}^{-v^e(r',b')} [z' + v^e(r', b') + v^b(b', q(r', h_b(r', b'))) - \xi b'] d\Phi(z') \Bigg], \end{aligned} \tag{3}$$

which is affected by bank's future choice for $b'' = h_b(r', b')$ because deposits have effectively a maturity that is longer than one period. This implies that future deposit dilution is priced in at the issuance stage.

2.1.4 Equilibrium

At each point in time, interest rate r, depositors' idiosyncratic withdrawal benefits $\{\nu\}$, and banks' idiosyncratic profits $\{z\}$ realize. Given existing deposits $\{b\}$, realizations of current shocks, and rational expectation of law of motions, depositors choose how much to withdraw and the amount to put into new deposits; banks choose to default or not and a pricing schedule at which they are willing to absorb new deposits. All actions happen at the same time.

We consider a Markov-perfect equilibrium with a set of time-invariant rules and functions:

- Bank's deposit policy $b'(r, b)$ with associated equity value $v^e(r, b)$ given by (2);
- A deposit pricing schedule $q(r, b')$ given by (3);
- Banks' optimal default set $\{z|z + v^e(r, b) < 0\}$ and depositors' optimal withdrawal set $\{\nu|1 + \nu - \kappa \geq q(r, b')\}$.

2.2 Model mechanisms

We now illustrate the key mechanisms of our model. We first show the dilution incentive of banks when deposits are long-term. We then illustrate how deposit dilution varies over time under endogenous withdrawals.

2.2.1 Dilution

The key feature of our model, relative to previous work on macro-banking, is that non-maturing deposits are plausibly long-term because depositors do not withdraw and reprice deposits period by period due to future liquidity services and withdrawal cost. As a result, banks make leverage decisions with the presence of unwithdrawn deposits $(1 - \lambda)b$. In this section, we illustrate how this leads to a dilution problem—that is, banks have a tendency to over-borrow and incur an excessive default risk.

First, for simplicity, we shut down the withdrawal feature and consider a fixed-maturity defaultable debt model—that is, only a fixed fraction of depositors withdraw each period, i.e. $\lambda(.) \equiv \hat{\lambda} \in [0, 1]$, and they get a net benefit of $\nu - \kappa \equiv 0$. In this setting, $l(.) \equiv \mu > 0$. To further simplify notations, we assume default recovery is zero, and then some straightforward algebra gives the following first-order condition for b':[3]

$$\frac{1}{r}\mu \mathbf{E}_{r'|r}[1-\Phi(-v^e(r',b'))] = -[b'-(1-\hat{\lambda})b]\frac{\partial q(r,b')}{\partial b'}, \tag{4}$$

where the price impact on the right hand side (RHS) is given by:

$$\begin{aligned}\frac{\partial q(r,b')}{\partial b'} = \frac{1}{r}\mathbf{E}_{r'|r}\Bigg[&[\mu+\hat{\lambda}+(1-\hat{\lambda})q(r',h_b(r',b'))]\phi(-v^e(r',b'))\frac{\partial v^e(r',b')}{\partial b'} \\ &+[1-\Phi(-v^e(r',b'))](1-\hat{\lambda})\frac{\partial q(r',h)}{\partial h}|_{h=h_b(r',b')}\frac{\partial h_b(r',b')}{\partial b'}\Bigg].\end{aligned} \tag{5}$$

Equation (4) describes the trade-off behind absorbing an additional unit of deposit. On the left hand side (LHS) is the marginal benefit—additional liquidity value μ in non-default states. On the RHS is the marginal cost. As can be verified numerically, pushing up b' reduces the debt price $q(r,b')$. This is not surprising as it reduces equity value $v^e(r',b')$ and therefore leads to a higher default probability tomorrow, captured by the first term in (5).

Deposit dilution arises because banks only internalize the negative price impact on new deposits. Unwithdrawn deposits, $(1-\hat{\lambda})b$, also have to bear a larger default risk associated with a higher b' but are not repriced to current market conditions. As a result, banks would like to keep absorbing new deposits even when default risk has become excessively large. By doing so, they keep capturing the additional liquidity value but do not have to pay fully for the incremental default risk. As $(1-\hat{\lambda})b$ increases, banks would choose a larger b' and dilution becomes severer.

At the time of issuance, depositors will price in the banks' future incentive to over-

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[3]The bank problem in this simplified setup evolves into: $\max_{b'} R + z - \hat{\lambda}b + q(r,b')[b'-(1-\hat{\lambda})b] + \frac{1}{r}\mathbf{E}_{r'|r}[\int_{-v^e(r',b')}^{\bar{z}}[v^e(r',b')+z']d\Phi(z')]$. The deposit pricing equation evolves into: $q(r,b') = \frac{1}{r}\mathbf{E}_{r'|r}[\mu+\hat{\lambda}+q(r',h_b(r',b'))(1-\hat{\lambda})][1-\Phi(-v^e(r',b'))]$. First-order condition for b' is given by:

$$[b'-(1-\hat{\lambda})b]\frac{\partial q(r,b')}{\partial b'} + q(r,b') + \frac{1}{r}\mathbf{E}_{r'|r}\left\{[1-\Phi(-v^e(r',b'))]\frac{\partial v^e(r',b')}{\partial b'}\right\} = 0.$$

Utilizing the envelope theorem, i.e., $\frac{\partial v^e(r,b)}{\partial b} = -\hat{\lambda} - q(r,b')(1-\hat{\lambda})$, and the pricing function to simplify, and we get equation (4).

borrow. Depositing an additional dollar into the bank today amplifies the conflict of interest tomorrow. This is recognized by $\frac{\partial h_b(r',b')}{\partial b'}$ in the second term in (5). That first-order condition contains the derivative of the policy function reflecting the fact that dilution is a time inconsistency problem in nature—banks would be better off if they could commit to not over-borrow in the future.

When deposits are short-term, i.e. $\hat{\lambda} = 1$, the debt dilution problem disappears. Banks have no incentive to over-borrow unless some other exogenous frictions are built in. Analyses of dilution in fixed-maturity long-term corporate debt models can be found also in e.g., Gomes, Jermann and Schmid (2016) and Admati, DeMarzo, Hellwig and Pfleiderer (2018).

2.2.2 Endogenous withdrawals and time-varying dilution

Deposit maturity in our model is not fixed because of the withdrawal options of the depositors, which contrasts against a typical long-term debt model that we have analyzed in the previous section. The left panel of Figure 1 presents the mass of withdrawing depositors $\lambda(q(r,b'))$. There are two key patterns.

First, $\lambda(q(r,b'))$ is upward sloping with respect to b'. This is because, starting with a nontrivial leverage choice b', a marginal increase implies a larger default risk and thus a lower discounted future liquidity benefit. This means, endogenous deposit withdrawals create a disciplining effect on dilution, even though limited by frictions.

Second, $\lambda(q(r,b'))$ depends on interest rate r. As r increases, λ increases because of a heavier discount over future liquidity benefits. Moreover, λ also becomes more sensitive to b' when r increases. The key driver is a decreasing p.d.f. $f(.)$. When r becomes large, q becomes small and thus $f(q+1-\kappa)$ becomes large, which means that $\lambda = 1 - F(q+1-\kappa)$ becomes more sensitive to changes in q caused by changes in b'. In other words, when future liquidity benefits are high, only a few depositors would encounter a big enough liquidity shock today so that withdrawing or not becomes a relevant decision. In that case, a marginal variation in future default risk will not change withdrawals much. As future liquidity value becomes small, a large mass of depositors are on the margin of withdrawing, and therefore a variation in future default risk will have a big impact. Broadly, this feature is consistent with the well recognized reality that banks with poorer financial health are more unstable.[4]

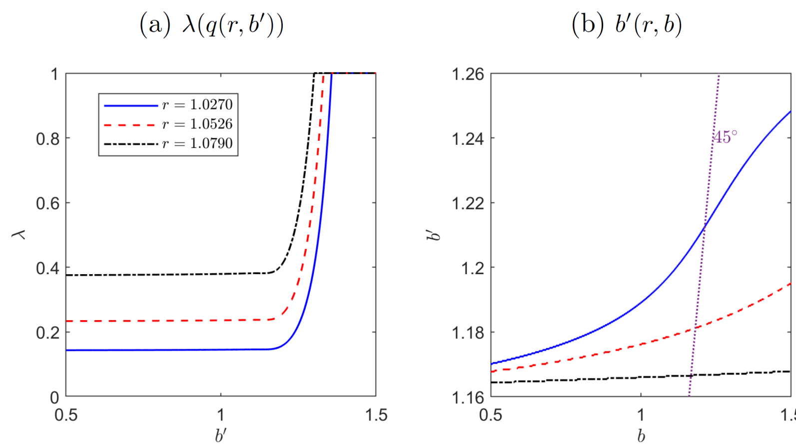

Figure 1: Policy functions. *Notes*: We set $\kappa = 0.1, \xi = 0.2, \mu = 0.04$, $R = 0.02$, $\bar{z} = 0.22$. r takes value $\{1.0270, 1.0526, 1.0790\}$ with probability $\{1/6, 2/3, 1/6\}$. We set $f(\nu) = a \exp(-a\nu)$ where $a = 20$.

The right panel presents banks' deposit policy function $b'(r, b)$ in our baseline model. It is upward sloping, which clearly contrasts the flat policy function that $\hat{\lambda} = 1$ would imply and reveals the impact of dilution. Importantly, $b'(r, b)$ also depends on r, and their relationship is governed by how $\lambda(q(r, b'))$ depends on r as we have pointed out previously.

First, an interest rate cut leads to a higher b'. This directly follows the fact that $\lambda(q(r, b'))$ increases with r. In particular, for a given b, a decrease in r creates a larger amount of unwithdrawn deposits $(1 - \lambda)b$ that banks can dilute, which in turn changes the marginal calculation in equation (4) and amplifies banks' incentive to issue new deposits. This mechanism is key to our results in Section 2.3. Second, the effect of an interest rate cut on b' decreases with r, for a high enough b. This is because $\lambda(q(r, b'))$ becomes less sensitive to b' for a low r. When r is low, banks are much less worried about additional withdrawals if they dilute and are thus able to choose a much higher b'. A smaller disciplining effect of endogenous withdrawals in this case implies that the additional unwithdrawn deposits created by an interest

[4] In Diamond and Dybvig (1983) and numerous follow-up papers, fragility caused by strategic complementarity in early withdrawals becomes relevant only when bank fundamental becomes weak enough. Gorton and Ordoñez (2014) argue that a deterioration in collateral quality can trigger a regime shift and make bank debt sensitive to information.

rate cut will have a bigger effect on banks' over-borrowing. This mechanism is key to our state dependence results in Section 2.4.

2.3 Interest rate shocks and boom-bust dynamics

In this section, we show how banks respond to interest rate shocks. We assume that the interest rate r follows an AR(1) process and set $\Gamma(r'|r)$ accordingly—that is, $r = r^* + \exp(x) - 1$ where r^* is the long-run interest rate level and $x' = \rho_x x + \sigma_x \tilde{\epsilon}, \tilde{\epsilon} \sim \mathcal{N}(0, 1)$. We simulate 200,000 firms with 20 periods as burn-ins to compute moments and impulse responses.

2.3.1 I.i.d. shocks

We first consider i.i.d. interest rate shocks to cleanly show the workings of endogenous deposit maturity. The parameterization is a proof of concept and, even though we approximately match empirical counterparts, it cannot be interpreted as a full-blown calibration. The presented impulse responses are not very sensitive to varying parameter values within reasonable ranges. A period is a year. For the interest rate process, we set $r^* = 1/0.95, \rho_x = 0$ and $\sigma_x = 0.015$. We set $R = 0.02$, which delivers an average profitability of bank assets of about $R/(v^e + v^b) = 1.22\%$. According to the FDIC, the average profitability of bank assets before subtracting interest expenses is slightly below 2% between 2010 and 2021. The default loss is $\xi = 0.2$, close to what has been documented by Granja, Matvos, and Seru (2017). For the zero-mean i.i.d. shocks to profitability, we follow Gomes, Jermann and Schmid (2016) and set $\phi(z) = \iota_0 - \iota_1 z^2$. By imposing $\phi(\bar{z}) = 0$ and $\Phi(\bar{z}) = 1$, we can use $\bar{z}$ to pin down ι_0 and ι_1. We set $\bar{z} = 0.22$, which leads to an average bank default probability of 82 basis points. We are not aware of an obvious empirical counterpart for the withdrawal frequency. Wolff (2000) argues that as a rule-of-thumb 20% of deposits are highly volatile. We set withdrawal cost to $\kappa = 0.1$, which implies an average withdrawal mass of $\lambda = 0.2574$. Regarding liquidity parameters, we set $\mu = 0.04$ and assume ν to follow an exponential distribution, i.e., $f(\nu) = a\exp(-a\nu)$, with $a = 20$. Under these two parameters, average bank equity ratio $1 - b/(v^e + v^b) = 0.162$. If we consider maturity to be about $1/\lambda \approx 4$ years, the deposit rate is about $(1/q - 1)/4 \approx 77$ bps.

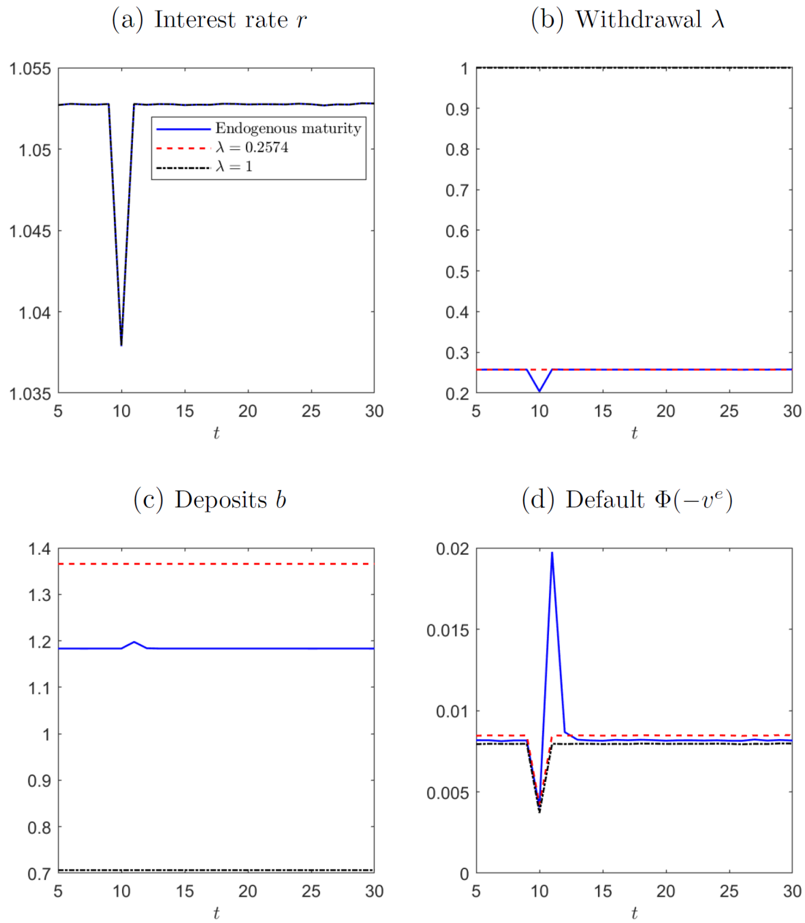

Figure 2: Banks' responses to i.i.d. interest rate shocks. *Notes*: $r^* = 1/0.95, a = 20, \kappa = 0.1, \xi = 0.2, \mu = 0.04$, $R = 0.02$, $\bar{z} = 0.22$, $\rho_x = 0, \sigma_x = 0.015$. For fixed-maturity models, we adjust $\mu = 0.045, \bar{z} = 0.21$ for the $\hat{\lambda} = 0.2574$ case and $\mu = 0.051, \bar{z} = 0.4$ for the $\hat{\lambda} = 1$ case for comparability.

The blue solid lines in Figure 2 describe how banks respond to a one-time interest rate cut.[5] At $t = 10$, the interest rate is reduced and thus the discount rate becomes high, the present value of future liquidity services becomes larger. Fewer depositors choose to withdraw. With the presence of more unwithdrawn deposits to dilute at $t = 10$, banks increase their deposit taking b_{11}. A higher b_{11} in turn leads to a b_{12} that is still noticeably higher than the long-run deposit level.

[5]With the chosen parameters, for banks at the steady state, the asymmetry between their responses to one-standard-deviation positive and negative interest rate shocks is small.

The default probability exhibits a boom-bust feature. At $t = 10$, bank default probability shrinks in response to the contemporaneous rate cut. Similar to the reason behind depositors' increasing willingness to stay, the equity value of banks becomes larger due to a higher discount rate. However, going forward, as the interest rate returns to normal but b_{11} and b_{12} remain high, the default probability becomes higher than its long-run level. In other words, an interest rate cut makes banks safer in the short run but leads to a subsequent increase in risk.

Crucial for our results is the endogenous withdrawal feature. Figure 2 compares our results against those coming out of fixed-maturity models, as characterized before by equations (4) and (5). The red dashed lines show banks' responses to an identical rate cut in a fixed-maturity long-term deposit model. We fix the withdrawal mass $\hat{\lambda} = 0.2574$, which is equal to the average withdrawal rate in our baseline model. We re-set $\mu = 0.045$ and $\bar{z} = 0.21$ so that the average default rate is roughly the same as that in the baseline. The black dotted lines show the responses under short-term deposits, i.e. $\hat{\lambda} = 1$, where we re-set $\mu = 0.051$ and $\bar{z} = 0.4$. In both cases with fixed maturity, i.i.d. interest rate shocks produce no impact on leverage dynamics. This is because shocks to r do not change the marginal trade-off for b' in these cases. In contrast, unwithdrawn deposits $[1 - \lambda(q(r, b'))]b$ and thus bank's dilution incentive change with r when maturity is endogenous.

Formally, we can show that in a model with a fixed deposit maturity, i.e., $l(.) \equiv \mu$ and $\lambda(.) \equiv \hat{\lambda}$, the amount of deposits stays constant upon i.i.d. interest rate shocks.[6]

2.3.2 Persistent shocks

Now we consider persistent shocks to interest rates by setting $\rho_x = 0.8$ and $\sigma_x = 0.005$. We adjust $\mu = 0.0415$ while keeping all the other parameter values to be same as those in the i.i.d.-shock case, and unconditional simulated moments are comparable to the i.i.d.-shock ones. The blue solid lines in Figure 3 describe how banks respond to persistently low interest rates. Again, we compare our benchmark model to two alternatives with fixed maturities: long-term deposits where $\hat{\lambda} = 0.2357, \mu = 0.045, \bar{z} = 0.24$ and short-term deposits where $\hat{\lambda} = 1, \mu = 0.0529, \bar{z} = 0.42$.

[6] Substituting equation (5) into (4), the first-order condition for b' under a fixed maturity does not depend on r.

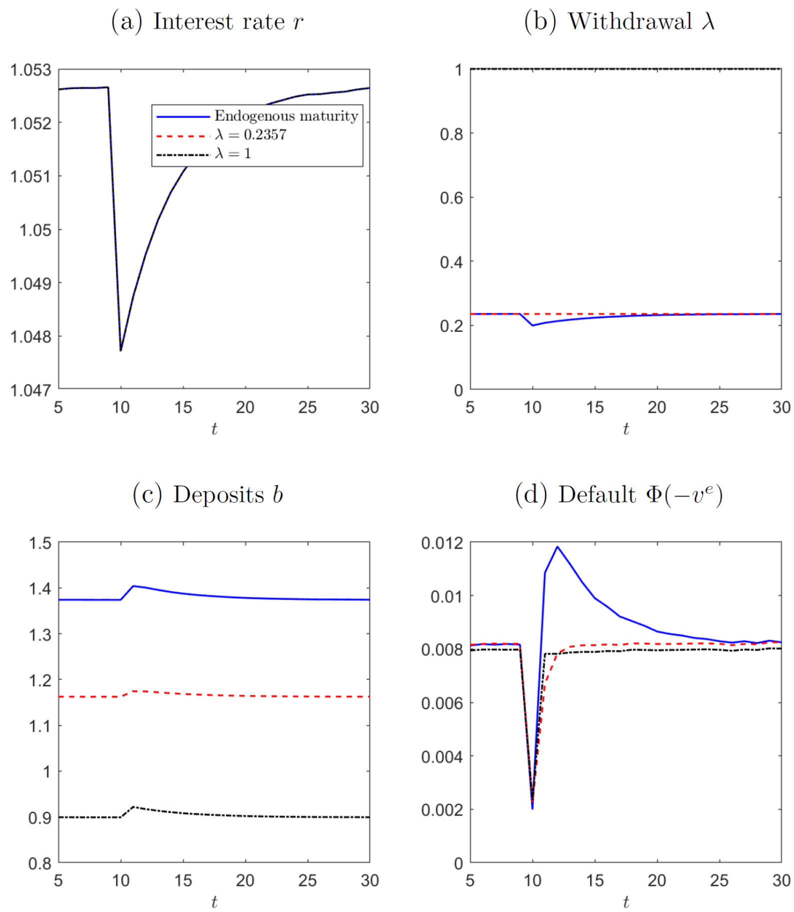

Figure 3: Banks' responses to persistent interest rate shocks. *Notes*: $r^* = 1/0.95, a = 20, \kappa = 0.1, \xi = 0.2, \mu = 0.0415$, $R = 0.02$, $\bar{z} = 0.22$, $\rho_x = 0.8, \sigma_x = 0.005$. For fixed-maturity models, we adjust $\mu = 0.045, \bar{z} = 0.24$ for the $\lambda = 0.2357$ case and $\mu = 0.0529, \bar{z} = 0.42$ for the $\lambda = 1$ case for comparability.

When the interest rate cut becomes persistent, banks' deposit choice starts to respond to the rate cut even if deposit maturity is fixed. Again, by inspecting (4) and (5), one can see that $1/r$ cancels out but the conditional expectation $E_{r'|r}[.]$ does not. When expecting rates to be low in the future, banks start to absorb more deposits.

Under short-term deposits, the default probability does not exhibit boom-bust dynamics even though debt remains persistently high after $t = 10$. Banks do not have a dilution incentive. They increase deposits simply because of a smaller marginal cost—that is, with an increase in discount rates, default risk becomes less sensitive to deposit absorption. As the interest rate returns to normal, banks adjust leverage downward rather quickly, and the equilibrium default risk remains moderate.

Under fixed-maturity long-term deposits, debt dilution kicks in. However, even though banks are reluctant to delever quickly as the rate cut leads to a larger amount of deposits at $t = 11$, such an effect turns out to be dominated quantitatively in this case by the persistently low interest rate for $t \geq 11$. Overall, the bank default rate remains low after the shock. By comparing the blue solid and red dashed lines, one can clearly see the important role played by the endogenous maturity. The additional unwithdrawn deposits caused by the rate cut greatly exacerbate the dilution problem and are key for the delayed increase in default rates.

2.4 State-dependency in responses

In this section, we show that the impact of an interest rate cut is different if rates have been low for a while. Specifically, the subsequent surge in default risk following a rate cut is much stronger in a low-rate environment.

Formally, we consider a regime-switching model of interest rates. In either the high- or low-rate regime, i.e. $s \in \{H, L\}$, x follows an AR(1) process:

$$x' = (1 - \rho_x)\bar{x}(s) + \rho_x x + \sigma_x \tilde{\epsilon}$$

where $\bar{x}(H) > \bar{x}(L)$. State s shifts with probability p. In the period where the shift takes place, x is drawn from the stationary distribution of the new regime.

2.4.1 I.i.d. shocks

We first consider a case where shocks to interest rates are i.i.d. in any given regime. More specifically, we set $\rho_x = 0, \sigma_x = 0.007, \bar{x}(H) = -\bar{x}(L) = 0.015, p = 0.4$. All bank- and depositor-related parameters are set to be same as those in the i.i.d.-shock case of Section 2.3.1 without regime switches. Figure 4 compares how banks' responses to an identical interest rate cut differ across regimes. Specifically, we compute impulse responses by taking the difference between the following two paths. The first averages banks who have been in one regime for quite a long time and then start to transit (shown as $t = 10$ in the figures) to the ergodic distribution. The second averages banks facing an identical situation except that they receive an interest rate shock right when the transition starts.

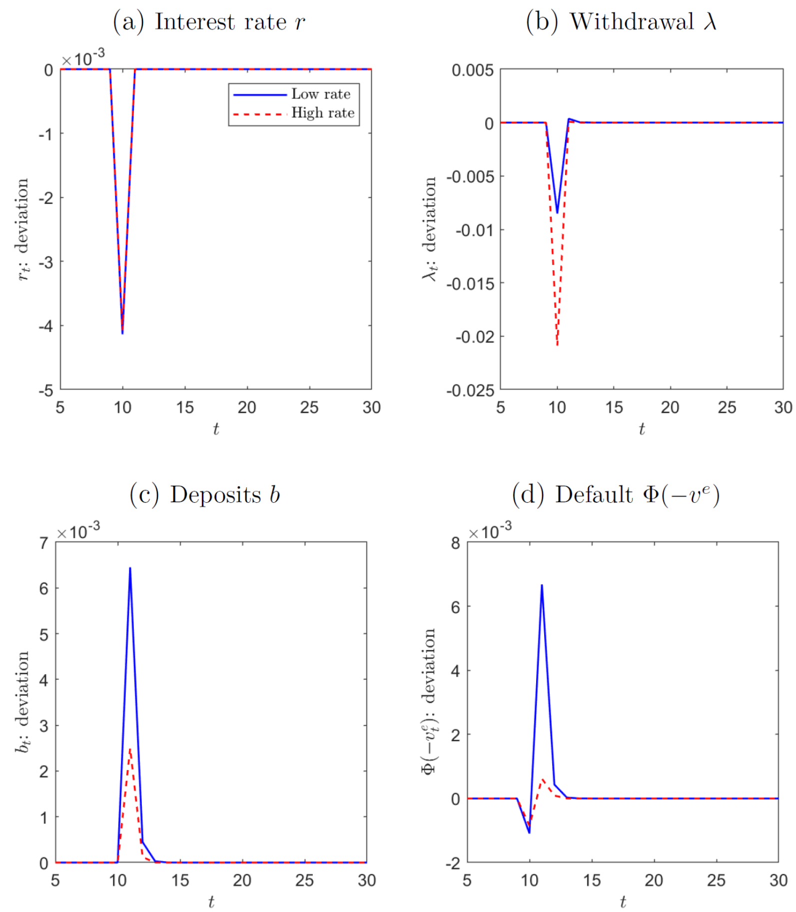

Figure 4: State dependency of banks' responses to i.i.d. interest rate shocks. *Notes*: $r^* = 1/0.95, a = 20, \kappa = 0.1, \xi = 0.2, \mu = 0.04,\ R = 0.02,\ \bar{z} = 0.22,\ \rho_x = 0, \sigma_x = 0.007, \bar{x}(H) = 0.015, \bar{x}(L) = -0.015, p = 0.4$.

In the low-rate regime, bank leverage is higher (b=1.097 as opposed to 1.060 for the high-rate regime) and fewer depositors withdraw their money each period ($\lambda = 0.1951$ as opposed to 0.3355). Even though a high discount rate can be helpful for the bank, a larger amount of unwithdrawn deposits can also worsen banks' dilution problem.

Combining these two offsetting effects, the average default probability turns out to be higher ($\Phi(-v^e) = 0.0097$ as opposed to 0.0032), which is largely consistent with our previous finding that the default probability increases following interest rate cuts when deposits are endogenously long-term.

Responding to the rate cut, in the low-rate regime, banks increase leverage more aggressively and the subsequent surge in default risk is also stronger. As we have highlighted the unappealing consequence of interest rate cuts in the previous section, this result calls for central banks' exercising additional caution when the economy has been in a low-rate environment for a while. To understand this result, recall our policy function for $b'(r, b)$ in Figure 1. When interest rates are low, deposit withdrawals respond less aggressively to deposit issuances, resulting in dilution being less disciplined. The additional unwithdrawn deposits caused by the interest cuts encourage banks to dilute in a much more significant way. Consistently, we observe a weaker reduction in the withdrawal amounts in the low rate regime despite larger increases in deposit issuance and default risk.

2.4.2 Persistent shocks

Considering persistent shocks, we set $\rho_x = 0.8, \sigma_x = 0.005$ and adjust $\mu = 0.0415$ while keeping all the other parameter values to be same as those in the i.i.d.-shock case with regime switches. Figure 5 shows that the results we find in the i.i.d.-shock case are largely preserved. Again, an interest rate cut creates a stronger surge in bank leverage and default risk in the low-rate environment.

In the last two panels of Figure 5, we show the state dependency for a short-term deposit model, $\lambda = 1$, with persistent shocks. We adjust $\mu = 0.0529$ and $\bar{z} = 0.42$ for comparability. We consider the same shock as in our baseline model. According to Section 2.3.1, bank leverage does not move upon i.i.d. interest rate shocks with short-term deposits, and thus there is naturally no state dependency in responses of aggregate quantities in that case. Figure 5 shows that even with persistent shocks, state dependency in b is trivial. Different from our baseline model, the average default probability of banks is lower in the low-rate regime (0.0014 as opposed to 0.0109 for the high-rate regime). Also, because default probabilities are bounded by 0 from below, they respond by less in the low-rate regime.

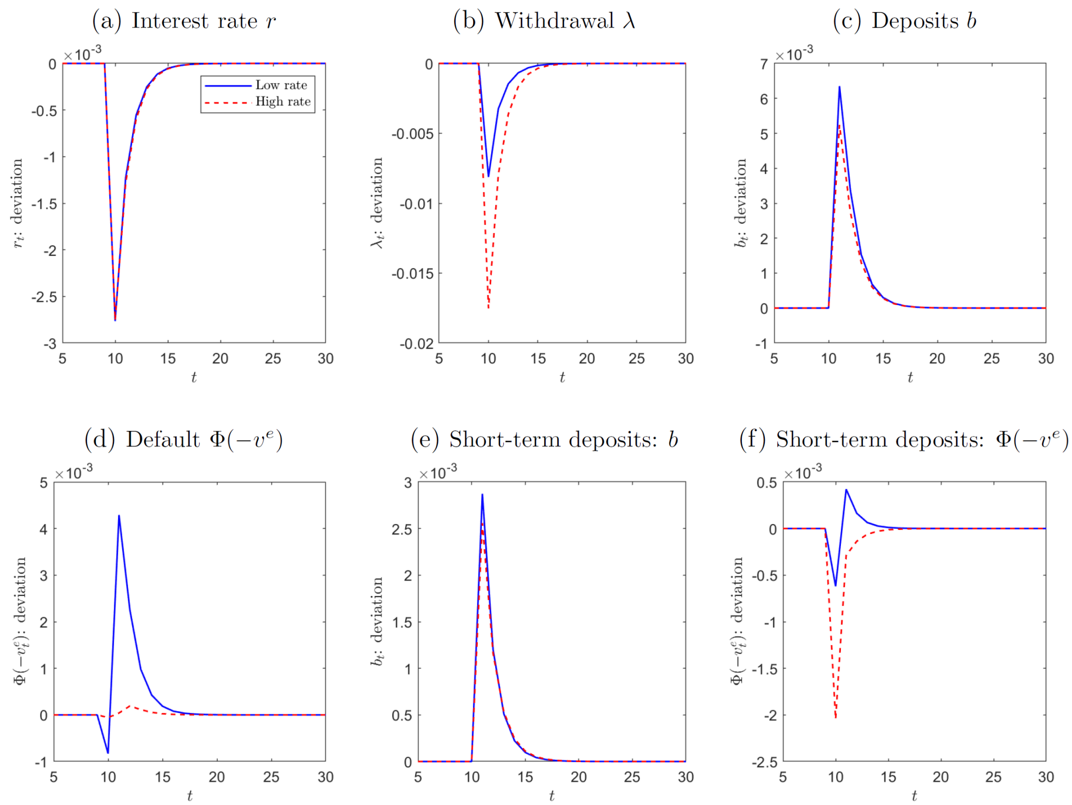

Figure 5: State dependency of banks' responses to persistent interest rate shocks. *Notes*: $r^* = 1/0.95, a = 20, \kappa = 0.1, \xi = 0.2, \mu = 0.0415$, $R = 0.02$, $\bar{z} = 0.22$, $\rho_x = 0.8, \sigma_x = 0.005, \bar{x}(H) = 0.015, \bar{x}(L) = -0.015, p = 0.4$. For the fixed-maturity model with $\hat{\lambda} = 1$, we adjust $\mu = 0.0529$ and $\bar{z} = 0.42$ for comparability.

3 Extensions

This section considers two extensions of our baseline model. Section 3.1 analyzes a model with insured and uninsured deposits. We highlight that issuing insured deposits can be an effective way to dilute uninsured deposits. Section 3.2 considers banks' responses to an interest rate cut when bank asset profitability worsens at the same time.

3.1 Insured deposits

At the heart of debt dilution lies the conflict between bank shareholders and depositors with the presence of default risks. As around 50% of US bank deposits are insured by the FDIC, one might wonder if debt dilution and thus our results will vanish with the presence of risk insensitive deposit insurance assessments. In this section, we show this is not the case.

To do so, we revisit our problem in Section 2, but this time allow banks to issue both uninsured b' and insured deposits b'_i. Similarly to uninsured depositors, insured depositors enjoy liquidity benefits and withdraw at period ends upon a large liquidity shock. We carry previous notations while using subscript i to denote variables and functions associated with insured deposits when needed.

Bank equity now depends on both deposits and is given by:

$$\begin{aligned} v^e(r,b,b_i) = \max_{b',b'_i} \Bigg\{ & R - \lambda_i(q_i(r))b_i - \lambda(q(r,b',b'_i))b + q_i(r)\{b'_i - [1-\lambda_i(q_i(r))]b_i\} \\ & - \frac{\gamma}{2}(b'_i - \bar{b}_i)^2 + q(r,b',b'_i)\{b' - [1-\lambda(q(r,b',b'_i))]b\} \\ & + \frac{1}{r}\mathbf{E}_{r'|r}\left[\int_{-v^e(r',b',b'_i)}^{\bar{z}} [z' + v^e(r',b',b'_i)]d\Phi(z')\right] \Bigg\} \end{aligned}$$

where $\frac{\gamma}{2}(b'_i - \bar{b}_i)^2$ represents the cost associated with issuing insured deposits, such as that for building ATMs to attract retail depositors. The price of insured deposits is given by

$$q_i(r)b'_i = \frac{1}{r}\mathbf{E}_{r'|r}v_i^b(b'_i, q_i(r')),$$

and the price of uninsured deposits is:

$$\begin{aligned} q(r,b',b'_i)b' = \frac{1}{r}\mathbf{E}_{r'|r}\Bigg[& \int_{-v^e(r',b',b'_i)}^{\bar{z}} v^b(b', q(r', h_b(r',b',b'_i), h_{b_i}(r',b',b'_i)))d\Phi(z') \\ & + \int_{\underline{z}}^{-v^e(r',b',b'_i)} \frac{b'}{b'_i + b'}\Big[v^e(r',b',b'_i) + z' + v_i^b(b'_i, q_i(r')) \\ & + v^b(b', q(r', h_b(r',b',b'_i), h_{b_i}(r',b',b'_i))) - \xi(b'_i + b'_u)\Big]d\Phi(z')\Bigg], \end{aligned}$$

where $v^b(b,q) = \{\lambda(q) + l(q) + [1-\lambda(q)]q\}b$ and $v_i^b(b_i,q_i) = \{\lambda_i(q_i) + l_i(q_i) + [1 - \lambda_i(q_i)]q_i\}b_i$. $h_{b_i}(.)$ and $h_b(.)$ denote equilibrium policies for insured and uninsured deposits, respectively. We assume that depositors of different types have the same seniority and split the recovered value according to how much they are owed. For insured depositors, the FDIC covers the remaining gap.

A key observation here is that the equity value and the price of uninsured deposits depends on insured deposits. This is because when a bank issues more insured deposits, a default becomes more likely. Therefore, with the presence of uninsured deposits, issuing insured deposits can also be an effective way to dilute. For a simple illustration, consider the first-order condition for insured deposits b_i' under fixed maturity and a constant interest rate, i.e. $\lambda(.) \equiv \lambda_i(.) \equiv \hat{\lambda}$, $l(.) \equiv l_i(.) \equiv \mu \equiv \mu_i$ and $r \equiv r^*$:

$$q_i - \frac{1}{r^*}\left\{[1-\Phi(-v^e(b',b_i'))][\hat{\lambda}+(1-\hat{\lambda})q_i]\right\} + \frac{\partial q(b',b_i')}{\partial b_i'}[b'-(1-\hat{\lambda})b] - \gamma(b_i'-\bar{b}_i). \quad (6)$$

The term $\frac{\partial q(b',b_i')}{\partial b_i'}$ reflects the marginal impact of issuing insured deposits on the price of uninsured deposits. The dilution is thus reflected by $-\frac{\partial q(b',b_i')}{\partial b_i'}(1-\hat{\lambda})b$, which disappears when uninsured deposits are short-term.

We solve our extended model with insured deposits under the following parameters: $R = 0.03, 1/r^* = 0.95, a = a_i = 30, \kappa = \kappa_i = 0.1, \xi = 0.4, \mu = 0.01, \mu_i = 0.05, \bar{z} = 0.5, \rho_x = 0, \sigma_x = 0.015$.[7] Figure 6 compares the impulse responses to a one-time interest rate cut with $\gamma = 0.2$ and $\bar{b}_i = 0.75$ (blue solid lines) against those with $\gamma = 20$ and $\bar{b}_i = 0.855$ (red dashed lines). What is different between these two cases is that banks have different abilities to adjust insured deposits over time.

The key takeaway from Figure 6 is that the presence of insured deposits does not necessarily weaken debt dilution. In fact, one can notice that when banks are able to dilute more easily through issuing more insured deposits, the boom-bust dynamics in default probability can actually become more pronounced. On the margin, dilution through issuing insured deposits can actually be more aggressive because the risk insensitive deposit insurance has eliminated most of the price impact banks have to bear. In contrast, when banks dilute through issuing more uninsured deposits, they still have to bear a nontrivial proportion of the price impact, even though not fully because of non-withdrawing uninsured depositors.

[7]Results for persistent shocks are similar and ommitted to save space.

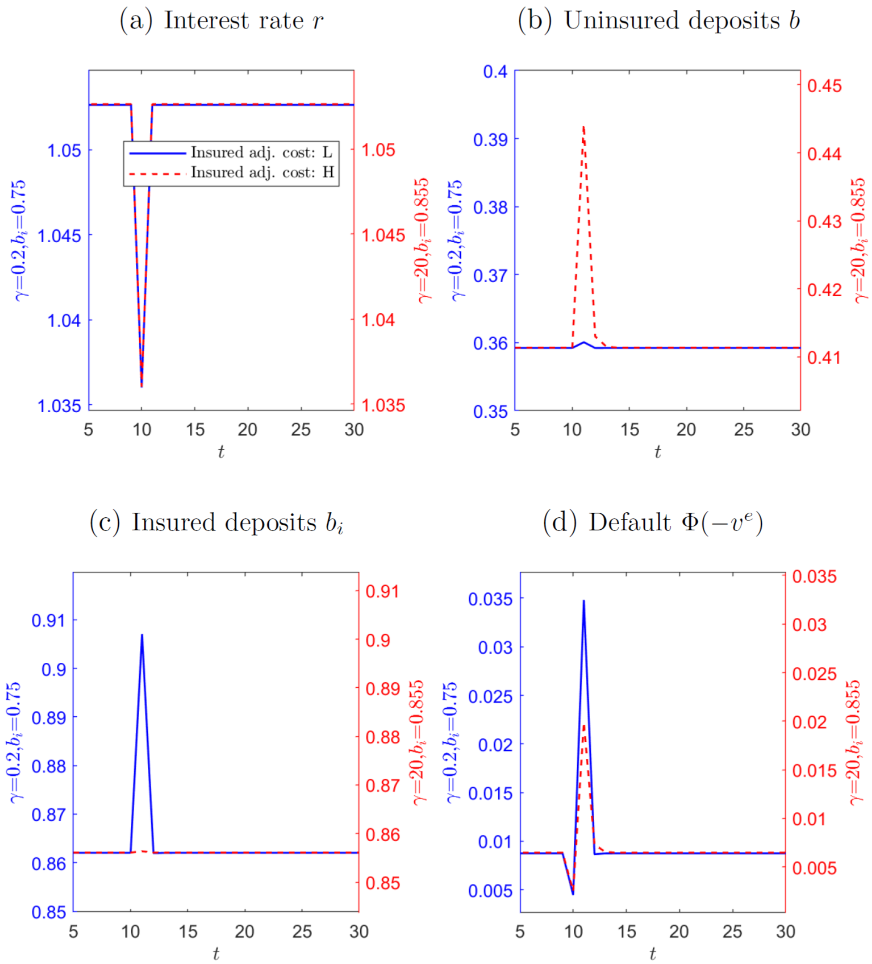

Figure 6: Banks' responses to i.i.d. interest rate shocks with insured and uninsured deposits. *Notes*: $R = 0.03, 1/r^* = 0.95, a = a_i = 30, \kappa = \kappa_i = 0.1, \xi = 0.4, \mu = 0.01, \mu_i = 0.05, \bar{z} = 0.5, \rho_x = 0, \sigma_x = 0.015$. The left axis considers $\gamma = 0.2, \bar{b}_i = 0.75$ and the right axis considers $\gamma = 20, \bar{b}_i = 0.855$.

3.2 Time-varying asset profitability

We have fixed the average bank asset profitability R in our previous analyses for transparency. In reality, interest rates typically serve as the benchmark for loan pricing—this means, as the central bank cuts interest rates, loan rates decline. Banks' monopoly power in the lending market implies a weaker decline in loan rates relative to that in interest rates. For instance, Wang (2020) shows that a 100-bps increase in interest rates increases bank lending rates by about 50 bps, using data on ARM (adjustable-rate mortgages) and auto loans. Therefore, we connect the average bank asset profitability R and interest rates r by parameterizing

$$R = R^* + 0.5 \times (r - r^*),$$

where r^* and R^* are respective long-run means, and we resolve our model.

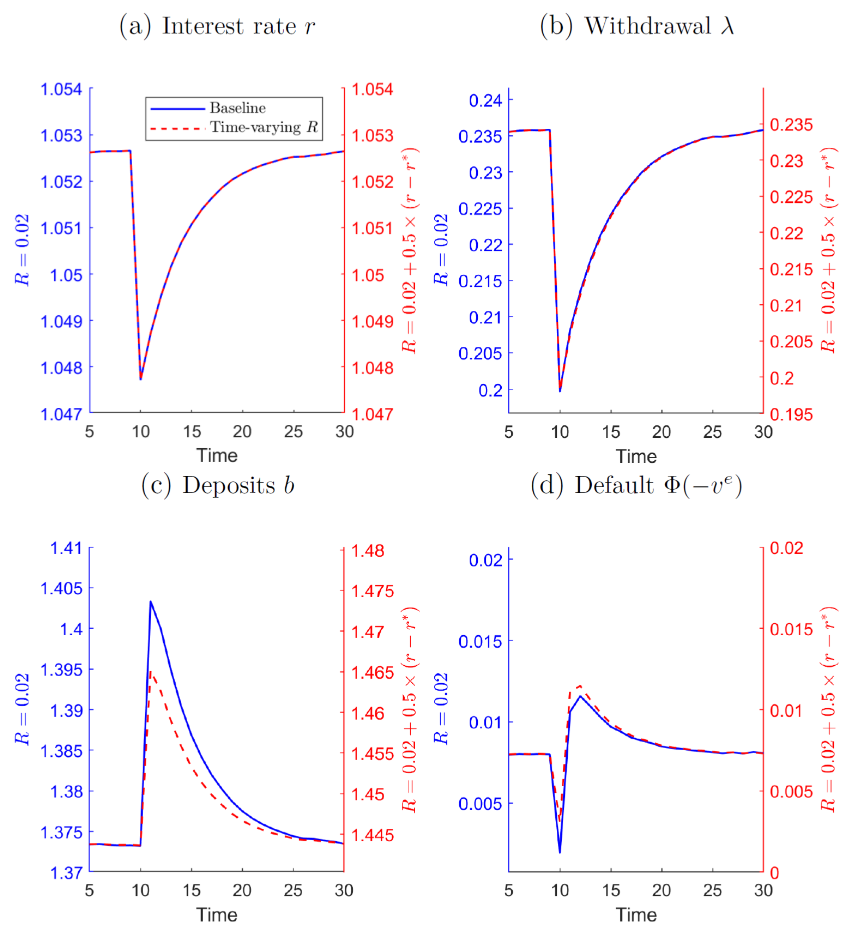

Figure 7: Time-varying bank asset profitability. *Notes*: The average bank asset profitability is specified as: $R = R^* + 0.5 \times (r - r^*)$. Parameters are: $r^* = 1/0.95, a = 20, \kappa = 0.1, \xi = 0.2, \mu = 0.0415$, $R^* = 0.02$, $\bar{z} = 0.22$, $\rho_x = 0.8, \sigma_x = 0.005$.

Under i.i.d. interest rate shocks, connecting R with r has minimal impacts on bank dynamics. This is because a one-time shock to R has no long-term impact—deposit issuance b', deposit price q and withdrawals λ do not change. In the end, the additional effect of a decrease in R is mostly reflected in a smaller drop in default rates on impact.[8]

When r shocks are persistent, which means that R stays low for some time after an interest cut, our main result in fact becomes stronger—that is, bank risk increases more drastically following the interest cut. Figure 7 compares banks' responses in our baseline in Section 2.3.2 (blue solid lines) and those in the extended setup (red dashed lines). The drop in default rates on impact weakens when R declines together with r. In contrast, the delayed increase in bank risk becomes more pronounced, even though banks scale back their deposit issuance on impact to some extent for precautionary purposes. The impact of the decline in R on withdrawals is fairly small.

4 Discussions

Before closing the paper, we provide further discussions about our model ingredients and results. In particular, Section 4.1 discusses the implications of our model and points out questions for future empirical work to investigate. Section 4.2 elaborates about non-maturing deposits.

4.1 Empirical implications

In reality, US commercial banks and supervisors from the FDIC employ various econometric models to predict the inflows and outflows of deposits as they are considered important for bank stability. However, these account-level data are largely proprietary, and the bank-level data that are easily accessible provide aggregated positions that only allow the computation of *net* deposit flows. The lack of data on *gross* flows creates a challenge for empirical research—for instance, it is impossible to identify how much of an increase in deposits is driven by fewer withdrawals and how much is driven by new deposits. One promising direction is to use the data from failed banks in the US—for instance, Martin, Puri and Ufier (2022) utilize such data to study how uninsured depositors withdraw from one distressed bank. Interestingly, they show

[8] Such a connection introduces a source of randomness and under a global solution will affect expected values in the future. However, we find this impact to be tiny.

that banks issue a lot of new insured deposits close in time to failure, which is consistent with our theory that banks dilute by issuing insured deposits when distress risk is high.[9] Going forward, being able to collect time series of *gross* deposit flows will be key for empirical work.[10] We provide two potential directions to bring our theory to the data.

First, one can test directly how outflows and inflows of deposits interact with each other dynamically. Banks compete for uninsured depositors shopping around and compensate the risk they bear by offering higher rates, giving coupons, etc. For instance, it is interesting to test if an outflow of uninsured deposits that is orthogonal to a bank's risk profile, due to say a headquarter move of a corporate client, implies that new uninsured deposits are absorbed at a lower rate. Moreover, do bank leverage and other risk-taking activities get constrained in a persistent manner after the outflow? Alternatively, one can use public asset market data to test if the outflow predicts a decrease in bank risk.

Second, one can combine monetary policy surprises to test if interest rate shocks affect bank leverage and default risk as our model suggests. For instance, is it the case that an interest rate cut predicts a future increase in bank risk and does such an increase become more pronounced in a low interest environment? One can utilize heterogeneity in bank characteristics to test the role of endogenous maturity. For instance, some banks build more ATMs, which corresponds to a lower κ in our model. Some banks devote a lot of resources to Fintech, which facilitates online transactions and corresponds to a higher μ. It can be interesting to first establish if deposit flows within these banks behave differently. Furthermore, it would be promising to see if these cross-sectional differences in the characteristics of deposit flows affect banks' responses to interest rate shocks. For instance, our model suggests that banks with stickier deposits would see a smaller increase in risk following an interest rate cut.

[9] In a different modeling environment, Egan, Hortaçsu and Matvos (2017) argue that distressed banks have a comparative advantage in competing for insured deposits.

[10] See e.g. Iyer and Puri (2012) for a study of deposit withdrawals triggered by a fraud, based on proprietary data from a cooperative bank in India.

4.2 Non-maturing deposits

Our model builds on the prevalence of uninsured demand deposits that are subject to default risk but are not continuously repriced. First, it is worth noting that even though large depositors, such as big corporations, can split their deposits across multiple banks and get a better deposit insurance coverage, such behavior is quite limited in reality. For instance, it is hard for large companies that frequently pay employees and suppliers to manage large numbers of bank accounts. According to the FDIC, about half of deposits in the US end up uninsured, to which hair-cuts might apply when banks fail.[11]

Second, depositors do not reprice their claims as frequently. Using a sample of insured depositors, Drechsler, Savov and Schnabl (2021) show that deposit rates are insensitive to interest rate changes. Martin, Puri and Ufier (2022) show that for a bank at the edge of failing, uninsured depositors actively pull their money out. Nonetheless, a large amount of uninsured transactional deposits remain on the bank's balance sheet, and those who have a longer relationship with the bank appear to be more reluctant to withdraw.

At last, we offer alternative ways to connect our theory with reality. For instance, while certificates of deposits (CD) have fixed maturity, in many cases they are automatically renewed without lenders taking any actions. As frictions prevent lenders from constantly shopping around for the best CD rate, our modeling of non-maturing deposits also captures to some extent the feature of CDs on the balance sheets of financial institutions. More broadly, the essence of our theory is that some creditors are willing to extend funding to financial institutions without perfectly pricing default risks, and such willingness varies with market conditions including e.g. the level of interest rates. In this sense, our mechanism is also relevant for the rollover of other types of risky debt issued by banks and shadow banks in a complex financial market with physical and informational frictions.

[11]Between 2008 and 2014, there were 30 US bank failures in which uninsured depositors suffer a nominal loss (https://www.cato.org/commentary/fdic-invents-costly-solution-imaginary-problem). In other cases, the FDIC did manage to sell the bank and ultimately bailed out uninsured deposits. However, the resolution process usually takes time and uninsured depositors effectively suffer a real loss, which corresponds to our restructuring cost $\xi b'$ in (3).

5 Conclusions

The macro-finance literature has found it convenient to model bank liabilities as short-term debt. However, bank deposits are mostly non-maturing, and this effectively converts deposits into debt with endogenous maturity that are subject to time-varying dilution. In this paper, we have demonstrated that explicitly modeling the non-maturing nature of deposits is first-order for studying the leverage dynamics of banks and the impact of monetary policy shocks on the banking sector.

In a companion paper, we apply this framework to policy analyses and show that the non-maturing nature of deposits has first-order effects on bank capital requirements (Jermann and Xiang, 2023). For future research, our model can be incorporated into a full-blown general equilibrium model for quantitative analyses. One interesting direction to extend the model would be to formulate the competition among banks, on both the loan and deposit sides. Another interesting extension would be to incorporate and quantify the factors that shape the behavior of depositors, such as limited attention or bounded rationality.

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