

Will Central Bank Digital Currency Disintermediate Banks?

Toni M. Whited, Yufeng Wu, and Kairong Xiao*

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Abstract

This paper studies how introducing a central bank digital currency (CBDC) can affect the banking system. We show that a CBDC need not reduce bank lending unless frictions and synergies bind deposits and lending. We estimate a dynamic banking model to quantify the role of these frictions in shaping the impact of a CBDC on the banking system. Our counterfactual analysis shows that a CBDC can replace a significant fraction of bank deposits, especially when it pays interest. However, a CBDC has a much smaller impact on bank lending because banks can replace a large fraction of lost deposits with wholesale funding. Substitution with wholesale funding makes banks' funding costs more sensitive to changes in short-term rates, increasing their exposure to interest rate risk. We also show that a CBDC amplifies the impact of monetary policy shocks on bank lending.

JEL Codes: E51, E52, G21, G28

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*Whited is from the University of Michigan and the NBER; twhited@umich.edu. Wu is from the University of Illinois; yufengwu@illinois.edu. Xiao is from Columbia University; kairong.xiao@gsb.columbia.edu. None of the authors have any relevant or material financial interests related to the research described in this paper. We thank Jonathan Berk, Juliane Begenau, Greg Buchak, Sylvain Catherine, Darrell Duffie, Arvind Krishnamurthy, Jiaqi Li, Christine Parlour, Monika Piazzesi, Claudia Robles-Garcia, Antoinette Schoar, David Sraer, Harald Uhlig, and Andrew Usher for their helpful comments and discussions. We also thank participants at Stanford GSB, LSE, University of Rochester, European Central Bank, Federal Reserve Bank of Dallas, Macro Finance Workshop, the JHU Carey Finance Conference, the Brazilian Society of Econometrics Annual Meeting, the Canadian Economic Association Special Session on Digital Currency, the Desmarais Global Finance Lecture at McGill University, the Intermediation and Bank Liquidity Conference at Richmond Fed, and the UBC summer conference for their helpful comments.

1. Introduction

A central bank digital currency (CBDC) is a country's official currency in digital form. CBDC differs from existing digital money such as bank deposits because a CBDC is a direct liability of the central bank rather than of a commercial bank. While a CBDC potentially offers safer, faster, and cheaper payments for the general public, it also raises complex policy issues and risks. A prominent concern is that a CBDC might disintermediate the existing banking system and reduce the availability of credit. For instance, a report from the Federal Reserve notes that "a widely available CBDC . . . could reduce the aggregate amount of deposits in the banking system, which could in turn increase bank funding expenses, and reduce credit availability or raise credit costs for households and businesses."¹

An implicit assumption underlying many existing discussions of CBDC is that shocks to bank deposits are necessarily transmitted to bank lending. Greg Baer, the president and CEO of the Bank Policy Institute, writes that "given that the average loan-to-deposit ratio for banks is generally around 1:1, every dollar that migrates from commercial bank deposits to CBDC is one less dollar of lending."² This assumption is also present in academic research on CBDC. For example, [Keister and Sanches \(2021\)](#), [Andolfatto \(2021\)](#), and [Chiu, Davoodalhosseini, Jiang, and Zhu \(2019\)](#) study CBDC with models in which bank lending is entirely funded by deposits. While banks are still largely funded by deposits, in a counterfactual world with CBDC, deposits need not be the only source of funding. Even in our current banking system, many banks, especially large ones, can fund deposit shortfalls using wholesale funding. More fundamentally, the assumption that bank lending has to be funded by deposits rests upon the fundamental question of whether loan origination is bound to deposit creation.

¹See "Money and Payments: The U.S. Dollar in the Age of Digital Transformation," January 2022.

²See "Confronting the hard truths and easy fictions of a CBDC," *Business Reporter*, September 23, 2021.

To address the question of the effect of CBDC on bank lending, we start with a baseline result that in a frictionless world, deposit creation and loan origination can be entirely separable because banks can replace deposits with wholesale funding. Shocks to bank deposits, including those from the introduction of a CBDC, should have no impact on bank lending. Intuitively, loans are priced at the market interest rate rather than the deposit rate. Therefore, loans would remain profitable even if banks lose cheap deposits.³ While banks do not operate in a frictionless world, this baseline allows us to isolate the various frictions that do allow a CBDC to affect the banking system.

To this end, we construct an infinite-horizon, quantitative banking model to evaluate the frictions and synergies that connect loans to deposits. We start by modeling the deposit and lending markets with a characteristic-based demand approach from the industrial organization literature (Berry, Levinsohn, and Pakes 1995; Nevo 2001). While our baseline model does not contain a CBDC, the system allows us to introduce CBDC counterfactually as a new bundle of existing characteristics and examine the introduction of this new product on optimal bank behavior. This demand system is also conducive to policy analysis because we can flexibly vary the attributes of CBDC under different policy proposals concerning CBDC implementation.

In the model, banks optimally choose deposit and lending rates to maximize profits, facing several realistic frictions. First, banks face external financing frictions when accessing wholesale funding (Kashyap and Stein 1995). As a result, shocks to bank deposits from the introduction of a CBDC have the potential to affect bank lending. Second, banks are imperfectly competitive. Third, banks face regulatory constraints such as capital requirements. These second two frictions imply that an increase in deposit competition induced by a CBDC can reduce bank capital and, consequently, the capacity to lend. Fourth,

³A similar argument was made by Darrel Duffie in his testimony before the U.S. Senate Committee on Banking, Housing, and Urban Affairs in June 2021, when he said, “Banks do not currently offer unprofitable loans using the irrational justification that they can recoup the associated losses by exploiting their below-market deposit rates.” See U.S. Senate Subcommittee Hearing, “Building A Stronger Financial System: Opportunities of a Central Bank Digital Currency.”

as in [Drechsler, Savov, and Schnabl \(2021\)](#), deposits provide a natural hedge against the interest rate risk that stems from maturity transformation because deposit rates are sticky and behave as if they have long duration. This synergy between deposits and loans makes it more costly to substitute deposits for alternative funding sources.

We discipline the model using U.S. bank data following [Wang, Whited, Wu, and Xiao \(2022\)](#). We first use demand estimation techniques to obtain the elasticities of loan and deposit demand to interest rates. We then plug these estimates into our model and use simulated minimum distance to obtain estimates of parameters that quantify financial frictions and operating costs.

In the estimated model, a CBDC is introduced to the deposit market as a direct central bank liability that households can hold. The central bank does not participate in the loan market. It invests the raised funds in government securities. Facing deposit competition from the CBDC, banks can increase deposit rates, replace deposits with wholesale funding, or cut lending. The exact margins that banks use to accommodate the introduction of CBDC depend on the frictions and synergies that link deposit-taking and loan origination.

To understand the effects of a CBDC on the banking system, we conduct a variety of counterfactual experiments. First, we consider a CBDC that pays no interest and provides the same transaction services as bank checking accounts. We find that CBDC can significantly affect banks' deposit-taking business: a one dollar increase in CBDC reduces bank deposits by around 70 cents. Contrary to the assumption underlying many existing discussions on CBDC that shocks to bank deposits are necessarily transmitted to bank lending, only a third of the impact on deposits is passed through to lending: a one dollar increase in CBDC reduces bank lending by around 20 cents. The attenuated impact on bank lending happens because banks can replace deposits with wholesale funding.

However, the substitution is not perfect because of external financing frictions and the synergy between deposits and loans. Banks cannot replace all of the lost deposits

with wholesale funding and instead have to cut lending partially. Introducing CBDC also lowers banks' profits from the deposit market. Lower profits, in turn, reduce bank capital and lending capacity. Finally, as banks replace interest-insensitive deposits with wholesale funding, banks' exposure to interest rate risk also rises.

The impact of CBDC is heterogeneous across banks of different sizes. Big banks rely less on deposits and have better access to non-deposit financing. As a result, they are better equipped to adapt to a financial system with CBDC than small banks. Indeed, we find the impact of CBDC on bank lending is three times greater for small banks than for big banks even though CBDC has comparable effects on deposits across the two groups. The impact of CBDC also depends on local deposit market concentration. In a highly concentrated market, the impact of CBDC on the quantities of deposits and loans is less pronounced because high markups cushion the extra competition CBDC poses for deposits. In comparison, in a less concentrated market, the impact of CBDC is more pronounced on both deposits and loans. The results have important redistributive implications across banks of different sizes and regions with different bank competition.

We also consider an alternative policy proposal that allows CBDC to pay interest. On the one hand, this proposal forces banks to pay higher deposit rates, which benefit depositors. On the other hand, interest-bearing CBDC might be too disruptive because it would divert a significant amount of deposits from the banking sector. Indeed, we find that banks would lose around 30% of their deposits if a CBDC paid the federal funds rate, despite the competitive response from banks to raise deposit rates. An interest-bearing CBDC also generates substitution patterns that differ from those introduced by a non-interest bearing CBDC. Banks would lose more savings deposits because an interest-bearing CBDC represents a closer substitute for savings deposits.

We consider possible policy responses to alleviate the adverse impacts of CBDC on the banking system. Because CBDC increases the effective maturity mismatch of private banks, central banks could undo this effect by using any raised funds from CBDC to

make term loans to banks. This policy would allow banks to access more long-duration liabilities, thus reducing their interest rate risk. The downside of this policy would be the transfer of interest rate risk to the central bank, as the central bank could incur losses when the interest rate changes. Another issue is that CBDC could adversely affect bank profitability. One policy to alleviate this concern would be to use an “intermediated account-based” CBDC in which private banks are allowed to earn a fee by offering accounts or digital wallets to facilitate the management of CBDC holdings.

This paper contributes to a fast-growing body of research on CBDC.⁴ We add to this literature in several ways. First, we clarify an important conceptual issue underlying the existing discussion of CBDC by emphasizing an irrelevance result, that is, deposit-taking and loan origination are entirely separable in a frictionless world. Therefore, to understand the impact of CBDC, one has to gauge the frictions and synergies that connect deposits and loans and examine how these mechanisms are amplified or disrupted by the introduction of CBDC.

Furthermore, because CBDCs have not been widely implemented and discussion about them has been mostly at the policy deliberation stage, the literature has largely been theoretical. While the existing studies are helpful for illustrating particular mechanisms, the predictions are often quantitatively ambiguous. For instance, the prior literature disagrees on whether CBDC can crowd out or crowd in deposits (Keister and Sanches 2021; Fernández-Villaverde, Sanches, Schilling, and Uhlig 2021; Kumhof and Noone 2018; Chiu et al. 2019). Our paper adds to this literature by providing quantitative estimates disciplined by the data. We show that in an estimated differentiated products demand system, introducing CBDC would crowd out deposits despite the competitive response from banks to raise deposit rates.

⁴See Piazzesi and Schneider (2020), Schilling, Fernández-Villaverde, and Uhlig (2020), Niepelt (2022), Williamson (2019), Cong and Mayer (2021), and Burlon, Montes-Galdon, Muñoz, and Smets (2022). Recent surveys of the literature can be found in Carapella and Flemming (2020), Ahnert, Assenmacher, Hoffmann, Leonello, Monet, and Porcellacchia (2022), and Duffie, Foucault, Veldkamp, and Vives (2022).

Finally, this paper contributes to the broader banking literature. A long-lasting issue in the banking literature is the merit of narrow banking, which is the idea that deposit-taking and loan origination can be done separately by different financial intermediaries (Pennacchi 2012). The policy debate about CBDC is reminiscent of this question, as CBDC replaces private banks' deposit-taking but not loan origination. We provide a quantitative model to evaluate how the private banking system would realign itself following such a structural change and how such a realignment is constrained by the frictions and synergies that bind deposits and loans. This paper also adds to a fast-growing literature that studies the competition between traditional banks and various forms of shadow banks and fintech (Buchak, Matvos, Piskorski, and Seru 2018; Xiao 2020; Begenau and Landvoigt 2022). Although this study focuses on CBDC, this analysis has broader implications for the rise of vertically disintegrated shadow banks and decentralized finance.

2. Simple Model

This section provides a simple static model to clarify a key conceptual issue in the current discussion on CBDC.

2.1. Frictionless benchmark

We start with a frictionless benchmark. Banks take deposits, D , and make loans, L . If banks do not have enough deposits to fund loans, they can borrow via wholesale funding, $N = L - D$. We assume that banks face no external financing frictions so that they can borrow any amount of wholesale funding at the current federal funds rate, f . Conversely, when there are excess deposits, banks can invest this surplus, $D - L$, in government securities and earn the federal funds rate, f . We also assume that both deposits and loans have a maturity of one year, thus precluding any maturity mismatch on the balance sheets.

Banks choose deposit rates and lending rates, r^d and r^l , to maximize profits, following:

$$\Pi = \max_{\{r^l, r^d\}} r^l L(r^l) - r^d D(r^d) - fN, \quad \text{s.t. } L(r^l) = D(r^d) + N. \quad (1)$$

The dependence of L and D on their respective rates reflects possible market power in the loan and deposit markets.

The optimal lending and deposit rates in this frictionless benchmark are given by

$$r^l = f + \left(-\frac{L'}{L} \right)^{-1}, \quad (2)$$

$$r^d = f - \left(\frac{D'}{D} \right)^{-1}, \quad (3)$$

where $L' \equiv \frac{\partial L}{\partial r^l}$ and $D' \equiv \frac{\partial D}{\partial r^d}$.

The optimal lending rate and the equilibrium quantity of lending do not depend on the deposit market in this frictionless benchmark. In fact, the deposit and the lending decisions are completely separable. Any shock to deposits, D , including those from the introduction of a CBDC, would have no impact on lending, L . This result also does not depend on the nature of the competition. The demand curves for loans and deposits can be perfectly elastic or perfectly inelastic.

The intuition behind this irrelevance result rests on the notion that if banks can substitute wholesale funding for deposits at the same rate, then a loan is priced at the market interest rate, f , rather than at the deposit rate, r^d . Therefore, a profitable loan would remain so even if banks have fewer deposits or must pay higher rates on deposits, r^d .

In this frictionless benchmark, introducing CBDC would still negatively affect bank profits as banks lose a cheap source of financing. However, bank lending remains unaffected because deposits are not the marginal source of financing. This point is often missed in many discussions of CBDC, as exemplified by the argument that “given that the average loan-to-deposit ratio for banks is generally around 1:1, every dollar that migrates

from commercial bank deposits to CBDC is one less dollar of lending.”⁵ This quotation illustrates a fallacy that confuses the *average* source of financing with the *marginal* source of financing.

2.2. External financing frictions

Next, we model the effects of external financing frictions, which can connect the two sides of banks’ balance sheets. We assume that the cost of wholesale borrowing is $f + \Phi(N)$, in which $\Phi(N)$ is convex. We motivate this cost by the fact that wholesale funding is not insured, so banks need to pay a credit spread to compensate funding suppliers for default risk. In addition, accessing the wholesale funding market involves building and maintaining relationships with counterparties, which could also be costly. In this case, the banks’ optimization problem is:

$$\Pi = \max_{\{r^l, r^d\}} r^l L(r^l) - r^d D(r^d) - fN - \Phi(N), \quad \text{s.t. } L(r^l) = D(r^d) + N. \quad (4)$$

The optimal lending and deposit rates in this frictionless benchmark are given by

$$r^l = f + \left(-\frac{L'}{L}\right)^{-1} + \Phi'(L - D), \quad (5)$$

$$r^d = f - \left(\frac{D'}{D}\right)^{-1} - \Phi'(L - D). \quad (6)$$

Note that banks’ optimal lending rate and the equilibrium lending quantity are now a function of the marginal external financing cost, $\Phi'(L - D)$, which itself depends on the quantity of deposits, D . In this world, if a CBDC reduces bank deposits, it would force banks to raise more wholesale funding, $L - D$, which drives up the marginal external financing cost. As a result, some loans that were profitable before CBDC become unprofitable afterward. As a result, banks cut lending.

⁵See “Confronting the hard truths and easy fictions of a CBDC,” *Business Reporter*, September 23, 2021.

2.3. Maturity mismatch

Another way to connect the two sides of banks' balance sheets is to introduce a maturity mismatch. We assume that loans mature in η periods. In each period, $\frac{1}{\eta}$ fraction of the loans are repriced. The federal funds rate, f , is uncertain. Banks' profit conditional on a realization of the federal funds rate is given by

$$\Pi(f) = \bar{r}^l L - r^d D - fN, \quad \text{s.t. } L(r^l) = D(r^d) + N, \quad (7)$$

where r_{-1}^l is the rate on the old loans, which was set in the past and cannot be changed in this period. Thus, $\bar{r}^l = (1 - 1/\eta)r_{-1}^l + r^l/\eta$ is the average interest rate on the loan portfolio. Banks can only reprice a fraction, $1/\eta$, of the loans on the asset side, but the entire liability side is repriced at the realized federal funds rate. With a maturity mismatch, an unexpected increase in the federal funds rate would drive up funding costs, but a large fraction of the assets would be locked in at a low rate, r_{-1}^l . Banks' profits would fall, thus reducing bank capital. If banks behave as though they are risk averse,⁶ they would try to match the interest sensitivity of their assets with that of their liabilities:

$$\text{Asset interest sensitivity} = \underbrace{\frac{1}{\eta} \frac{\partial r^l}{\partial f}}_{<1}, \quad (8)$$

$$\text{Liability interest sensitivity} = \frac{D}{D+N} \underbrace{\frac{\partial r^d}{\partial f}}_{<1} + \frac{N}{D+N} \underbrace{\frac{\partial f}{\partial f}}_{=1}. \quad (9)$$

If banks are funded by wholesale funding, it is difficult to match the interest sensitivities of assets and liabilities. In this simple setting, the interest rate sensitivity of wholesale funding, N , is one. However, deposit market power implies that deposit rates are sticky (Drechsler, Savov, and Schnabl 2017), so the interest sensitivity of deposits is less than one. Thus, deposits are a natural hedge for the interest rate risk stemming from maturity transformation (Drechsler et al. 2021).

⁶Financial frictions can induce this behavior.

If CBDC crowds out bank deposits and forces banks to rely more on wholesale funding, banks become more exposed to interest rate risk, which in turn endogenously raises the credit spreads that banks face in the wholesale funding market. As a result, it becomes more costly for banks to raise funding on the margin, which reduces bank lending.

2.4. Capital requirements

Finally, banks face capital regulation, which connects banks' assets to liabilities and creates another channel through which CBDC can influence bank lending. Suppose banks face capital regulation that requires bank capital to exceed a certain fraction of bank assets. Banks' optimization problem becomes

$$\Pi = \max_{\{r^l, r^d\}} r^l L(r^l) - r^d D(r^d) - fN, \quad (10)$$

$$\text{s.t. } L(r^l) = D(r^d) + N \quad (11)$$

$$E + \Pi \geq \kappa L, \quad (12)$$

where E is a bank's initial capital, Π is the bank's profit, and κ is the minimum capital requirement. Because we assume no dividends in our static model, the bank's end-of-period capital is given by $E + \Pi$.

Equation (12) shows that in the presence of capital regulation, CBDC can affect banks' lending capacity through bank capital. When CBDC forces banks to raise deposit rates, banks' profit margins are squeezed, resulting in a lower $E + \Pi$. Hence, the introduction of CBDC can reduce banks' lending capacity.

3. Model

After clarifying the conceptual issues underlying the debate about CBDC, we present the full model. We consider an infinite-horizon bank industry equilibrium model with four sectors: households, firms, banks, and a central bank. Figure 1 illustrates the flow of funds in the model. In the model, households and firms solve static discrete-choice

problems in which they choose from several saving and financing vehicles. Banks act as intermediaries by taking short-term deposits from households and providing long-term loans to firms. Banks can also finance loans with wholesale funding or equity if deposits are insufficient. The central bank offers CBDC to households and invests the funds in Treasuries. The central bank, however, cannot lend to firms directly, which we motivate by a lack of local information and expertise.

3.1. Households

At each time t , the economy contains a mass W_t of households, each of which is endowed with one dollar. Because the households' problem is static, we drop the t subscript hereafter for convenience. There are \hat{J} banks in the economy, each of which offers two types of deposits: transaction and savings deposits. Modeling transaction and savings deposits separately allows us to study the different substitution patterns generated when introduce CBDC. In addition, households can also hold cash and Treasury bills. In our counterfactual analysis below, we extend this set of assets to include CBDC. We further assume that each depositor can choose only one option. This one dollar, one option assumption is without loss of generality. For example, we can interpret this setting as if households make multiple discrete choices for each dollar they have. The probability of choosing each option can be interpreted as a portfolio weight.

Each option is characterized by a yield, r_j^d , and a vector of product characteristics, x_j^d , which capture the convenience of each option. For example, a household might value branches and staffing when choosing a bank. The yield on cash is 0, and the yield on Treasuries is the federal funds rate, f , where we abstract from differences between short-term Treasury yields and the federal funds rate.⁷ All interest rates are quoted in real terms, as we assume inflation expectations are anchored at zero.

⁷The results are robust if we include a premium for Treasury securities. See Internet Appendix Section IA.1 for details.

The household chooses the best option to maximize its utility:

$$\max_{j \in \mathcal{A}^d} u_{i,j} = \alpha_i^d r_j^d + \beta_i^d x_j^d + \zeta_j^d + \epsilon_{i,j}^d, \quad (13)$$

where $i \in 1, 2, \dots, I$ indicates the type of depositor and \mathcal{A}^d is the households' choice set, described above. The utility for household i from choosing option j is $u_{i,j}$. The sensitivity to the yield, r_j^d , is α_i^d , and β_i^d is a vector of sensitivities to the non-rate product characteristics, x_j^d . In our estimation below, x_j^d includes a dummy variable that indicates whether the product allows households to make transactions, the number of branches, the number of employees per branch, and time and product fixed effects. We allow the sensitivities to the rate and the transaction dummy to differ across households. We refer to $q_j^d \equiv \beta_i^d x_j^d$ as the perceived quality of the product j , where β^d is the vector of average sensitivities to the non-rate characteristics. Finally, ζ_j is the unobservable product-level demand shock, and $\epsilon_{i,j}^d$ is a relationship-specific shock to the choice of option j by household i . $\epsilon_{i,j}^d$ captures horizontal differentiation across banks and induces imperfect substitution between products.

The optimal choice for household i is given by an indicator function:

$$\mathbb{I}_{i,j}^d = \begin{cases} 1, & \text{if } u_{i,j} \geq u_{i,k}, \text{ for } k \in \mathcal{A}^d \\ 0, & \text{otherwise.} \end{cases} \quad (14)$$

We aggregate the optimal choices across all households to compute the deposit market share of each bank j . Adopting the standard assumption that $\epsilon_{i,j}^d$ follows a generalized extreme value distribution with a cumulative distribution function given by $F(\epsilon) = \exp(-\exp(-\epsilon))$, we can derive the standard logit market share, s_j^d , as follows:

$$s_j^d(r_j^d | f) \equiv \int \mathbb{I}_{i,j}^d dF(\epsilon) = \sum_{i=1}^I \mu_i^d \frac{\exp(\alpha_i^d r_j^d + \beta_i^d x_j^d + \zeta_j^d)}{\sum_{m \in \mathcal{A}^d} \exp(\alpha_i^d r_m^d + \beta_i^d x_m^d + \zeta_m^d)}, \quad (15)$$

where μ_i^d is the fraction of total wealth, W , held by households of type i . The numerator represents the utility from option j . The demand function for option j is then given by the

market share multiplied by total wealth,

$$D_j \left(r_j^d \right) = s_j^d \left(r_j^d \right) W. \quad (16)$$

3.2. Firms

There is a mass, K , of firms, each of which wants to borrow one dollar, so aggregate borrowing demand is K . Firms can borrow by issuing long-term bonds or taking out long-term bank loans. We assume each bank is a differentiated lender because of the different geographic locations, industry expertise, and prior lending relationships with firms. Letting each option be indexed by j , the firms' choice set is given by \mathcal{A}^l , which in addition to bonds and loans, includes the option not to borrow at all.

For tractability, we assume that both bonds and bank loans have the following repayment schedule. The firm has to pay back a fraction, η , of its outstanding principal plus interest in each period. Thus, if the firm borrows one dollar at a fixed interest rate r , the repayment stream, starting in the next period, is $(1 - \eta) \times (\eta + r)^t$, $t = 0, \dots, \infty$. Accordingly, all firm debt has an average maturity of $1/\eta$ periods.

Each of the firm's financing options is characterized by a rate, r_j^l , and a vector of product characteristics, x_j^l , which capture the convenience of using each of the financing options. If a firm chooses not to borrow, the interest rate is zero. If a firm chooses to issue bonds, the interest rate is given by the long-term bond interest rate, which equals the expected default cost, $\bar{\delta}$, plus the expected weighted average of future federal funds rates, \bar{f}_t :

$$\bar{f}_t = \eta f_t + \mathbb{E}_t \left[\sum_{n=1}^{\infty} \eta (1 - \eta)^n f_{t+n} \right]. \quad (17)$$

The firm then chooses the best option to maximize its profits:

$$\max_{j \in \mathcal{A}^l} \pi_{i,j} = \alpha_i^l r_j^l + \beta^l x_j^l + \bar{\zeta}_j^l + \epsilon_{i,j}^l, \quad (18)$$

where $\pi_{i,j}$ is the profits of firm i from choosing option j , and α_i^l is the sensitivity to the interest rate r_j^l . This sensitivity is distributed uniformly with mean, α^l , and standard deviation, σ_α^l . The sensitivities to non-rate characteristics, x_j^l , are given by β^l ; ζ_j^l is the unobservable product-level demand shock; and $\epsilon_{i,j}^l$ is an idiosyncratic shock when firm i borrows from bank j .

The optimal choice of firm i is given by an indicator function:

$$\mathbb{I}_{i,j}^l = \begin{cases} 1, & \text{if } \pi_{i,j} \geq \pi_{i,k}, \text{ for } k \in \mathcal{A}^l \\ 0, & \text{otherwise.} \end{cases} \quad (19)$$

We aggregate the optimal choices across all the firms to compute the loan market share of each bank j . Assuming that $\epsilon_{i,j}^l$ follows a generalized extreme value distribution with a cumulative distribution function given by $F(\epsilon) = \exp(-\exp(-\epsilon))$, we can derive the standard logit market share:

$$s_j^l(r_j^l|f) \equiv \int \mathbb{I}_{i,j}^l dF(\epsilon) = \sum_{i=1}^I \mu_i^l \frac{\exp(\alpha_i^l r_j^l + \beta^l x_j^l + \zeta_j^l)}{\sum_{m \in \mathcal{A}^l} \exp(\alpha_i^l r_m^l + \beta^l x_m^l + \zeta_m^l)}, \quad (20)$$

where μ_i^l is the fraction of type i firms. The numerator represents the utility from borrowing from bank j . The demand function for loans is then given by the market share multiplied by the total loan market size:

$$B_j(r_j^l|f) = s_j^l(r_j^l|f) K. \quad (21)$$

3.3. Banks

To simplify notation, we suppress the subscript j and use the superscripts S and T to denote savings and transaction deposits. Each bank simultaneously sets its deposit rates for savings and transaction deposits, $\{r_t^{d,S}, r_t^{d,T}\}$, and its loan rate, r_t^l , given the federal funds rate, f_t , which we assume is an exogenous state variable. These rate-setting decisions implicitly determine the quantities of deposits to take from households and credit to extend to firms. For example, given banks' choice of deposit rates, households solve

the utility maximization problem in equation (13). The solution yields the quantity of deposits supplied to each bank, given by equation (16). Banks face a zero lower bound for deposit rates:

$$r_t^{d,T} \geq 0, r_t^{d,S} \geq 0. \quad (22)$$

The zero lower bound can be motivated by the availability of zero-return storage technologies available to households, such as holding cash or buying durable goods. Similarly, given banks' choice of lending rates, firms solve their profit-maximization problem, which yields the quantity of loans borrowed from each bank given by equation (21).

Lending involves a maturity transformation between assets and liabilities. On the asset side, let L_t denote the amount of loans the bank holds. As in the case of bonds, in each period, a fraction, η , of a bank's outstanding loans matures. This assumption about long-term loans captures a traditional maturity transformation role for banks, in which they convert one-period deposits into long-term bank loans with a maturity of $1/\eta$. As noted above, banks can also issue new loans at an annualized interest rate of r_t^l . The new loans, once issued, have the same maturity structure as the existing ones, and the interest rate is fixed over the life of the new loans. From the bank's perspective, the present value of interest income is:

$$I_t = \sum_{n=0}^{\infty} \frac{(1-\eta)^n B_n r_n^l}{\prod_{s=1}^n (1+\gamma_s)}, \quad (23)$$

where γ_s is the bank's discount rate in period s , and a bank's outstanding loans evolve according to:

$$L_{t+1} = (1-\eta)(L_t + B_t). \quad (24)$$

We assume that in each period a random fraction of loans, $\delta_t \in [0, \eta]$, becomes delinquent. The bank takes δ as an exogenous state variable in its decision-making problem. Although we assume that the bank writes off delinquent payments, with charge-offs equal to $L_t \times \delta_t$, defaulting on payment in one period does not exonerate the borrower

from future payments. Therefore, delinquency does not affect the evolution of loans in equation (24).

In each period, the bank can obtain outside financing via deposits or wholesale funding, N_t . Bank deposits are insured, and depositors receive a rate $\{r_t^{d,S}, r_t^{d,T}\}$ on their transactions and savings deposits from banks. Wholesale funding is uninsured, and the suppliers of these funds (e.g., money market mutual funds and corporations) are competitive. The interest rate that they charge, r_t^N , is such that it allows them to break even. We discuss the determination of r_t^N in Section 3.5. Banks incur additional costs beyond the interest payment to use wholesale funding, such as the costs to build and maintain relationships with counterparties. We model these costs as a quadratic function of the borrowing amount. Thus, the total cost from wholesale borrowing can be expressed as:

$$\Phi^N(N_t) = \left[r_t^N + \frac{\phi^N}{2} \cdot \left(\frac{N_t}{D_t^S + D_t^N} \right)^2 \right] N_t. \quad (25)$$

Banks incur costs for serving depositors, such as hiring employees. We assume that costs are linear in the dollar amount of deposits:

$$\Phi^d(D_t^S, D_t^T) = \phi^d (D_t^S + D_t^T). \quad (26)$$

Similarly, we assume that lending incurs costs, such as paying loan officers to screen loans or maintain client relationships. Again, we assume a linear functional form:

$$\Phi^l(B_t) = \phi^l B_t. \quad (27)$$

We model fixed operating costs and non-interest income, which we assume to be independent of the deposit and lending rate decisions. Specifically, we let χ represent the difference between fixed operating expenses and non-interest income per unit of steady-state equity capital, denoted by \bar{E} . Therefore, the net fixed operating cost is $\chi \bar{E}$.

The rest of the asset side of each bank's balance sheet consists of reserves, R_t , and holdings of government securities, G_t , which the bank can accumulate if the supply of

funds exceeds demand from the lending market. These assets earn the federal funds rate, f_t . The bank's holdings of loans, government securities, deposits, reserves, and wholesale borrowing must satisfy the standard condition that assets equal liabilities plus equity:

$$L_t + B_t + R_t + G_t = D_t^S + D_t^T + N_t + E_t, \quad (28)$$

where E_t is the bank's beginning-of-period book equity. E_t itself evolves according to:

$$E_{t+1} = E_t + \Pi_t(1 - \tau) - C_{t+1}, \quad (29)$$

where Π_t represents the bank's total operating profits from its deposit-taking, security investments, and lending decisions:

$$\Pi_t = I_t - (L_t + B_t)\delta_t + G_t f_t - r_t^{d,S} D_t^S - r_t^{d,T} D_t^T - \Phi^d - \Phi^l - \Phi^N - \chi \bar{E}. \quad (30)$$

In equation (29) τ denotes the linear tax rate on banks' profits, and C_{t+1} is the cash dividends distributed to the shareholders, s.t.

$$C_{t+1} \geq 0. \quad (31)$$

This constraint implies that a bank can increase its inside equity only via retained earnings but cannot raise equity capital to replace deposits or wholesale borrowing.⁸

3.4. Federal funds rate

We model the federal funds rate as an AR(1) process, with its law of motion governed by:

$$\ln f_{t+1} - \mathbb{E}(\ln f) = \rho_f [\ln f_t - \mathbb{E}(\ln f)] + \sigma_f \varepsilon_{t+1}^f. \quad (32)$$

⁸In the Internet Appendix, we replace this assumption with costly equity issuance, finding only a limited impact on our results, as banks' equity issuances are both tiny and rare, both in the extended model and the data.

We model the bank-level idiosyncratic loan charge-off as the sum of a component that is correlated with the current federal funds rate and an *i.i.d.* shock component:

$$\ln \delta_{t+1} - \mathbb{E}(\ln \delta) = \rho_{\delta f} [\ln f_t - \mathbb{E}(\ln f)] + \sigma_{\delta} \varepsilon_{t+1}^{\delta}. \quad (33)$$

3.5. Bank default and the wholesale funding cost

Let Γ_t denote the cross-sectional distribution of bank states, and P^{Γ} denote the probability law governing the evolution of Γ_t . We can express the evolution of Γ_t as:

$$\Gamma_{t+1} = P^{\Gamma}(\Gamma_t). \quad (34)$$

In every period, after observing the federal funds rate, f_t , and the random fraction of defaulted loans, δ_t , an incumbent bank first chooses whether to default. We define a variable $\omega = 1$ if the bank chooses to default and $\omega = 0$ otherwise:

$$V(f_t, \delta_t, L_t, E_t | \Gamma_t) = \max_{\omega \in \{0,1\}} (1 - \omega) \times V^c(f_t, \delta_t, L_t, E_t | \Gamma_t), \quad (35)$$

where $V^c(\cdot)$ denotes the value if a bank continues its business without default. If an incumbent bank chooses to continue, it then decides the optimal balance sheet variables to maximize the expected discounted cash dividends to shareholders:

$$V^c(f_t, \delta_t, L_t, E_t | \Gamma_t) = \max_{\{r_t^l, r_t^{d,S}, r_t^{d,T}, R_t, E_{t+1}\}} \frac{1}{1 + \gamma_t} \{C_{t+1} + \mathbb{E}V(f_{t+1}, \delta_{t+1}, L_{t+1}, E_{t+1} | \Gamma_{t+1})\}, \quad (36)$$

$$\text{s.t. } r_t^d \geq 0, \quad (37)$$

$$E_{t+1} \geq \kappa \times (L_t + B_t), \quad (38)$$

$$R_t \geq \theta \times D_t, \quad (39)$$

where $\gamma_t = f_t + \gamma$ captures the bank's discount rate in period t . Banks' equity holders discount their cash flows using the current federal funds rate plus a wedge, γ , which captures their impatience. Equation (37) is a zero lower bound for deposit rates, which

we motivate households' option to hold cash, which has a zero nominal return. Equations (38) and (39) are the capital and reserve regulations.

A bank chooses to default when its continuation value, $V^c(\cdot)$, falls below zero. In that case, a fraction ζ of the bank's assets are lost. We assume a government insurer auctions off the failed bank and uses the proceeds to pay the insured depositors first. If any cash flow remains, it goes to the wholesale lenders. If the auction proceeds fall short of the bank's liabilities, then the insurer uses its own resources to repay the insured depositors fully but does not cover the wholesale lenders.

To characterize the risky interest rate on wholesale function, we let Ω_t denote the probability of a bank default conditional on the current state, which can be expressed as:

$$\Omega(f_t, \delta_t, L_t, E_t | \Gamma_t) = \mathbb{E} \{ V^c(f_{t+1}, \delta_{t+1}, L_{t+1}, E_{t+1} | \Gamma_{t+1}) \leq 0 \}. \quad (40)$$

Given banks' default decisions, the break-even interest rate charged by wholesale lenders, r_t^N , should satisfy the following zero-profit condition:

$$N_t \times f_t = N_t r_t^N \times \Omega_t + (1 - \Omega_t) \times \left\{ [\eta(1 - \delta_t) + (1 - \eta)(1 - \zeta)] (L_t + B_t) + G_t + R_t - D_t^S - D_t^T \right\}^+, \quad (41)$$

where the last term in equation (41) captures the wholesale lenders' expected recovery in the event of a bank default.

The insurer auctions the failed bank to a pool of H potential investors via a second-price auction. Investors are indexed by their private costs to participate in the auction, that is, $\varsigma_{1,t} < \varsigma_{2,t} < \varsigma_{3,t} < \dots < \varsigma_{H,t}$. The winner of the auction recapitalizes the banks at a required level of equity capital, \underline{E} . The recapitalized banks have the same expected default rate conditional on the current interest rate environment, $\tilde{\delta}_t = \mathbb{E}(\delta_t | f_t)$. Thus, the price submitted by the second highest bidder is equal to:

$$V^c(f_t, \tilde{\delta}_t, 0, E | \Gamma_t) - \varsigma_{2,t}. \quad (42)$$

The investor with the lowest cost, $\zeta_{1,t}$, pays this price and takes over the failed bank.

This characterization of bank failure captures the auction process used by the Federal Deposit Insurance Corporation. This modeling also allows us to have a constant number of representative banks in the model. Finally, it allows the parameters, H and ζ , to be irrelevant for banks' actions once they are active. These parameters only determine the split of rent.

3.6. Equilibrium

We define equilibrium in this economy as follows.

Definition 1 *A recursive competitive equilibrium occurs when:*

1. All banks solve the problem given by equation (36), taking as given the other banks' choices of loan and deposit rates.
2. When a bank fails, the government insurer auctions the failed bank following equation (42), taking as given other solvent banks' choices of loan and deposit rates.
3. Suppliers of wholesale funding price their loans according to equation (41).
4. Households and firms maximize their utilities in equations (13) and (18), given the list of rates put forth by banks.
5. In each period, the deposit and loan markets clear.
6. The probability law governing the evolution of the industry, P^Γ , is consistent with the market participants' optimal choices.

One of the state variables for the banks' problem (Γ_t) is an object whose dimension depends on the number of banks in the economy. We use a low-dimensional approximation of Γ_t , as in [Wang et al. \(2022\)](#).

4. Estimation

This section describes our estimation methods, presents results, and conducts counterfactuals to assess the effect of a newly introduced CBDC on the banking system.

We estimate the model in two stages. First, we estimate the loan and deposit demand functions. Second, we plug these estimates into the model and use simulated minimum distance (SMD) to estimate the remaining parameters that describe banks' balance sheet frictions. While the technical details regarding the estimation procedure can be found in Wang et al. (2022), a few points specific to our model deserve discussion. First, we allow each bank to offer transaction and savings deposits separately in our setting. Therefore, we use bank-level data on both the rate and quantity of these two types of deposits for the estimation. Second, depositors in our setting have heterogeneous sensitivities not only to yields but also to the transactions dummy.

We briefly discuss the identification of the SMD parameter vector, $(\gamma, W_0, q_n^l, \phi^d, \phi^l, \phi^N, \chi)$. We use two moments to identify the net fixed operating cost, χ . The first is average net non-interest expenses, scaled by assets. This moment measures banks' costs outside their routine deposit and loan-servicing business. The second moment is the banks' average leverage ratio, which indirectly reflects fixed operating costs, as higher fixed costs induce banks to operate with lower leverage. We use banks' average dividend yield to identify the discount rate, γ . Intuitively, a high discount rate makes banks impatient, so they pay out more of their profits to shareholders instead of retaining the funds to finance future business.

To identify the relative size of the deposit market, W/K , as well as the value of firms' outside option of not borrowing, q_n^l , we include banks' average deposits-to-assets ratio and the sensitivity of total borrowing to the federal funds rate, which we estimate using a vector autoregression (VAR). These two moments suit this purpose because holding banks' market shares constant, when W/K increases, the deposits-to-assets ratio rises, as the volume of deposits rises relative to the value of loans. Next, when the outside option becomes less valuable, its market share remains low, regardless of the federal funds rate. Thus, the sensitivity of aggregate corporate borrowing to the federal funds rate falls as q_n^l falls. In addition, the high loan-to-deposits ratio is inversely related to q_n^l because loan

demand is weaker when firms value the option not to borrow. Finally, we include banks' average market-to-book ratio to ensure that our model predicts the right valuation for banks. We set the fire sale discount, ζ , to 30%, which implies that banks in our model pay, on average, a risk premium of 21 basis points. With a recovery rate of 70%, banks' default probability is around 64 basis points. The magnitude is closely aligned with the evidence from bank credit default swaps documented in [Berndt, Duffie, and Zhu \(2019\)](#). Table 2 presents parameter estimates.

5. Counterfactuals

5.1. The impact of CBDC on deposits and lending

This section examines how introducing a non-interest-bearing CBDC would influence banks' competitiveness in the deposit market, their cost of funding, and their capacity to extend loans.

We conceptualize CBDC as a new product provided by the central bank that competes with bank deposits. Like other products in the deposit market, CBDC is characterized by a vector of characteristics: the interest rate on CBDC, the transactions dummy, and the perceived quality. This characteristics-based demand approach allows us to consider different policy proposals for CBDC, such as whether CBDC bears interest.

We construct the vector of characteristics of CBDC as follows. First, and in contrast to the profit-maximizing decisions made by banks, we assume the interest rate on CBDC is determined by an exogenous policy decision. Second, we set the transactions dummy to one because CBDC will likely allow payment processing. Third, we use the quality estimate of cash as an intuitive starting point for the perceived quality of CBDC because both instruments are issued by the government. We then capture the digital nature of a CBDC by adjusting the quality of cash upwards by 20%. Because there exist no direct estimates of the quality of CBDC, this figure is from the evidence in [Koont \(2022\)](#), which

collects the release dates of mobile banking apps by U.S. commercial banks and finds that deposit demand increases by around 20% after the digital app release.

Admittedly, there is great uncertainty regarding the quality parameter of the CBDC because it depends on how CBDC is implemented and how the general public perceives this new product, which are difficult to predict *ex ante*. Li (2021) attempts to predict the market share of CBDC and infers its quality using survey data from Canada. However, such surveys are not available in the United States. Therefore, instead of taking a strong stance on the “correct” value of this parameter, we vary the quality of CBDC to estimate the elasticities of bank outcomes to a marginal dollar increase in CBDC holdings induced by changes in quality.

Finally, we assume the central bank does not make loans directly to firms because it requires local information and expertise unavailable to the central bank. Instead, the central bank invests the funds raised by CBDC in government securities. This assumption is consistent with the existing policy proposals on CBDC.

Next, we perform a sequence of counterfactuals, with the results in Table 4. Column (1) of Table 4 corresponds to the case in which CBDC is absent from the deposit market; column (5) shows the results for a case in which CBDC is fully adopted. In columns (2)–(4), we examine cases in which we let the quality of CBDC vary from zero to the full value. This experiment can be interpreted as a phase-in period for a new CBDC, in which households have not fully accepted it. In those cases, the CBDC suffers a “quality discount.”

Table 4 shows that introducing CBDC results in lower market shares for cash, transaction deposits, and savings deposits. Banks partially replace their lost deposits with more expensive wholesale funding. Banks also endogenously raise deposit rates to reduce deposit outflows, resulting in low deposit spreads. The combined effects from both the extensive margin (replacing deposits with wholesale funding) and the intensive margin (paying higher rates on deposits) lead to higher funding costs for banks. As a result,

banks cut dividends, and their value falls. The fall in bank profits and value also makes default more likely, so banks face a higher credit spread on their wholesale funding. This higher cost of financing also generates a feedback effect that amplifies the fall in bank profits and value.

In the last column of Table 4, we report the sensitivities of bank characteristics to changes in the market share of CBDC. A one-dollar increase in CBDC crowds out transaction deposits by 64 cents and savings deposits by 10 cents. However, a one-dollar increase in CBDC only decreases bank lending by 19 cents.⁹ In other words, only a quarter of the impact on deposits is passed through to bank lending. This result suggests that the claim that “every dollar that migrates from commercial bank deposits to CBDC is one less dollar of lending” is not well founded because banks can substitute deposits with wholesale funding.

Finally, a one-dollar increase in CBDC crowds out cash by 11 cents. The crowding-out effect on cash is smaller than those on bank deposits because cash has a small market share to start with. If we normalize the sensitivity by the initial market share, the normalized crowding-out effect on cash is greater than the effect on bank deposits.

5.2. Decomposition of channels

The next step of our analysis is to decompose the channels through which CBDC affects bank lending. We consider the three channels discussed in Section 2. First, introducing CBDC can reduce bank lending by reducing the quantity of deposits available for banks and forcing them to use costly wholesale funding. Second, introducing CBDC can increase banks’ interest rate risk exposure and force banks to scale back lending. Third, introducing CBDC can reduce bank profits and make capital constraint bind.

⁹The pass-through from deposit shocks to bank lending is broadly in line with the prior reduced-form evidence in [Khwaja and Mian \(2008\)](#) and [Gilje, Loutskina, and Strahan \(2016\)](#). See Internet Appendix Section IA.2 for details.

Table 5 shows the results. We start with the baseline case in which one dollar of CBDC reduces bank lending by 19 cents in row (1). Row (2) examines the first channel in which a drop in lending stems from falling deposits that force banks to turn to costly wholesale funding. To isolate this channel, we set banks' interest rate risk exposure and profits to the same levels as the baseline case when CBDC is absent, so the documented effect on lending only operates through the deposit-quantity channel. We find that a one-dollar increase in CBDC holdings reduces bank lending by 15.8 cents through this channel. Row (3) examines the second channel: CBDC introduction influences banks' interest rate risk exposure. As banks are increasingly financed with rate-sensitive wholesale funding, banks become more exposed to interest rate risk and hence face a higher marginal cost from financing their loans with uninsured funding. Our results show that a one-dollar increase in CBDC holdings reduces bank lending by 8.4 cents through this channel.¹⁰ Finally, row (4) examines the third channel: CBDC reduces banks' competitiveness in the deposit market and squeezes their profit margin. This effect impedes banks' accumulation of a capital buffer and makes the capital regulation more likely to bind, thus lowering banks' capacity to lend. We find that a one-dollar increase in CBDC holdings reduces bank lending by 11.4 cents through this profit channel. Comparing the three channels, the most important channel is the first that operates through lower deposits. Note that the sum of the effects of the individual channels does not necessarily equal the combined effect of all three channels because the banks' optimization problem is highly non-linear.

5.3. Consumer and producer surplus

So far, we show that CBDC can benefit depositors by providing an alternative in the deposit markets and forcing banks to pay higher deposit rates. At the same time, CBDC can hurt borrowers by reducing bank credit supply. A natural question is whether the benefits outweigh the costs. To this end, we calculate the consumer surplus for depos-

¹⁰If banks can costlessly use interest rate swaps to hedge interest rate risks or access long-term funding markets to match duration, then the interest rate channel will be muted.

itors and borrowers before and after the introduction of a non-interest-bearing CBDC, using the estimated depositor and borrower preference parameters, as in [Nevo \(2001\)](#). We use the deposit market to illustrate the estimation of depositor surplus, but borrower surplus can be calculated analogously. We first compute the expected utility for each type of depositor i from its optimal choice. We then divide the expected utility by the yield sensitivity to calculate the equivalent utility in units of deposit rates. Finally, we aggregate across depositor types and multiply by the deposit market size W to calculate the aggregate surplus in the deposit market,

$$\text{Depositor Surplus}_t = W \sum_i \mu_i \frac{1}{\alpha_i} E \left[\max_{j \in \{0,1,\dots,J\}} u_{i,j} \right]. \quad (43)$$

We find that one dollar of CBDC increases depositor surplus by 16.5 basis points but only decreases borrower surplus by -1.9 basis points. Therefore, the net effect on consumer surplus is positive.

While CBDC increases total consumer surplus, banks possibly stand to lose from the stiffer competition. We calculate the banking sector surplus, which equals the return on capital, multiplied by steady-state bank capital. We find that one dollar of CBDC lowers the banking sector surplus by 9.5 basis points. Overall, the reduction in producer surplus does not completely offset the gain in consumer surplus. Each dollar of CBDC generates $16.5 - 1.9 - 9.5 = 5.1$ basis points of surplus gain in the deposit and lending markets.

Note that the above exercise is not a comprehensive welfare analysis of CBDC because it does not include many other potential impacts, such as helping the U.S. dollar maintain the reserve currency status in the world. Nevertheless, the analysis provides a starting point for us to understand the extent to which the impact of CBDC might vary across different groups of key stakeholders in the economy.

5.4. The impact of an interest-bearing CBDC

The impact of CBDC can be further amplified if the Fed pays interest on its digital currency. To examine the impact of an interest-bearing CBDC, we perform a sequence of counterfactuals in Table 6 with respect to the interest rate on CBDC. The first column of Table 6 corresponds to the case in which CBDC pays no interest; column (5) shows the results for a case in which CBDC pays the federal funds rate. In columns (2)–(4), we examine cases in which CBDC pays a fraction of the federal funds rate. The quality parameter is set at the same baseline value as in column (5) of Table 4.

As shown in the top row of Table 6, a non-interest-bearing CBDC captures 7.6% of the deposit market. In contrast, if the Fed pays an interest rate that equals the federal funds rate, CBDC captures 31.3% of the deposit market. Consequently, the impact on bank lending also moves from -1.4% in the non-interest-bearing case to -7.9% in the interest-bearing case, relative to the economy without CBDC.

An interest-bearing CBDC also generates substitution patterns across different types of deposits that differ from those stemming from a non-interest-bearing CBDC. As shown by column (5) of Table 6, the crowding-out effect of CBDC on savings deposits increases from 10.3 cents to 27.8 cents because an interest-bearing CBDC is a closer substitute for savings deposits. The marginal impact on deposit spreads is also greater because an interest-bearing CBDC forces banks to pay higher deposit rates. The sharper increase in the deposit spread contributes to a greater sensitivity of bank lending to CBDC holdings. In addition, when CBDC pays interest, each additional percentage increase in CBDC's market share also leads to larger declines in bank value.

The results suggest a trade-off between different policy objectives. On the one hand, policymakers are wary of possible disruptions of CBDC on the existing banking system. Paying interest on CBDC will likely increase its impact on private banks significantly. On the other hand, one motivation for introducing CBDC is improving financial inclusion.

Not paying interest on CBDC appears to be at odds with this goal because CBDC will not be an effective savings vehicle for people with limited access to the private banking system.

Our counterfactual exercise shows that an increase in the CBDC interest rate crowds out bank deposits and lending. In comparison, in the model in [Chiu et al. \(2019\)](#), an increase in the CBDC interest rate could “crowd in” deposits and lending. Our result differs from theirs because of different assumptions regarding the degree of product differentiation between CBDC and retail deposits. [Chiu et al. \(2019\)](#) implicitly assumes that CBDC and retail deposits are perfect substitutes so that the interest rate on CBDC sets a floor for bank deposit rates. As a result, an increase in the CBDC rate can significantly drive up deposit rates and crowd in savings. In comparison, in our model, the substitutability between CBDC and retail deposits is determined by an empirically estimated demand system in which depositors not only care about the interest rate, r_j^d , but also the non-rate characteristics x_j^d . Furthermore, the estimated retail depositors’ preferences have a large idiosyncratic component $\epsilon_{i,j}^d$, so that a product with a lower rate and poorer services will still get some market share in equilibrium. As a result, in our model, banks can pay a rate lower than the CBDC rate without losing all of their deposits. Although bank deposit rates would increase in response to the introduction of CBDC, the rates would not rise to the level that could lead to a crowding-in effect.

Although the CBDC rate does not naturally emerge as a deposit rate floor in the estimated deposit demand system, in certain scenarios, it might make sense to impose it as an exogenous constraint in the model. One possibility is that the CBDC rate becomes a psychological reference point for depositors, and banks are reluctant to pay deposit rates below it.¹¹ Nevertheless, it is important to note that even if such an exogenous deposit rate floor is imposed, the crowd-in effect on deposits may not necessarily lead to

¹¹Another possibility is that bank regulators could impose a deposit rate floor that equals the CBDC rate. Note, however, that the Federal Reserve has neither imposed any deposit rate floor before nor indicated any plan to do so in the future.

more lending because CBDC can still depress bank profits and capital, thus constraining banks' capacity to lend.

5.5. The heterogeneous impact of CBDC

In the previous sections, we show that CBDC affects bank lending mainly by reducing deposits and increasing banks' reliance on costly wholesale funding. Although the aggregate effect on bank lending is only moderate, the degree of disintermediation could be quite different in the cross-section of banks because of substantial heterogeneity in banks' costs of accessing the wholesale funding market.

To explore this mechanism, in Figure 2, we calculate how many dollars of deposits and loans would be crowded out by a one-dollar increase in CBDC (the deposits-CBDC and loan-CBDC sensitivities) for different levels of the wholesale funding cost, $r^N - f$. We find that when banks face a small wholesale funding cost, the introduction of CBDC reduces bank loan provision only slightly. CBDC competes away deposits, but the effect on lending is largely neutralized, as banks replace the deposits with wholesale funding. However, when banks' external financing costs rise, banks find it increasingly difficult to replace lost deposits. As a result, the decline in deposits leads banks to cut their lending.

Interestingly, the impact on deposits follows the opposite pattern. The reduction in deposits is smaller when the wholesale funding cost is higher because banks are more reluctant to tap into wholesale funding. Instead, they raise deposit rates to keep depositors from moving toward the CBDC. This result is another piece of evidence that deposits and lending do not necessarily move in tandem, in contrast to the common assumptions in the prior literature on CBDC.

The results above are particularly relevant when considering the heterogeneous impact of introducing CBDC across the bank size distribution. As shown by [Kashyap and Stein \(1995\)](#), small banks face particularly high frictions in accessing the wholesale funding market, so their supply of loans could be affected more severely when their retail

deposits are competed away by CBDC. To test this hypothesis, we perform a subsample estimation by splitting banks based on their size. We refer to banks in the top one percentile of the asset size distribution as big banks and the rest as small banks. As of 2019, there were around 50 big banks, and their total market share of assets was around 80%, and the cutoff was around 40 billion.

We re-estimate five key parameters related to bank operations that are likely to vary across banks of different sizes: the cost of accessing wholesale funding, the size of the depositor base, the costs of taking deposits and servicing loans, and the fixed cost of operation. We hold constant households' and firms' preferences because they are not bank-specific. We also fix banks' discount rates because most small banks are private banks with insufficient data to construct the corresponding identifying moment. We target eight moments in our subsample estimation: all of those reported in Table 3, except the dividend yield and market-to-book ratio, as we cannot calculate these statistics for the small private banks.

The estimation results reported in Table 7 show that big and small banks differ significantly regarding their external financing costs and fixed operating costs. These parameters imply that for a bank with a deposits-to-assets ratio of 0.8, the cost of accessing wholesale funding is 52 basis points for the small banks, which is significantly higher than the figure for big banks, which is 33 basis points. Next, we introduce CBDC into the model and examine how it affects banks' loan provision. We find that the introduction of CBDC leads to similar deposit outflows: a one-dollar increase in CBDC lowers deposits by 60.2 cents and 67.5 cents for small and big banks, respectively. However, the impact on lending is stronger for small banks. A one-dollar increase in CBDC lowers big banks' lending by only 14.6 cents but lowers small banks' lending by 40.7 cents. This result stems from wholesale funding costs that we find to be smaller for large banks than for small banks.

Next, we examine the possibility that CBDC might have heterogeneous effects across deposit markets with different degrees of competitiveness. Figure 3 examines how the impact of CBDC varies with market concentration, as measured by the number of competing banks in the deposit market. In this experiment, we hold the loan market concentration fixed and only vary banks' deposit market power, so the results only reflect the impact of deposit market concentration. We calculate how many dollars of deposits and loans would be crowded out by a one-dollar increase in CBDC (the deposits-CBDC and loan-CBDC sensitivities) under different numbers of competing banks, \hat{J} , which is six in our baseline estimation. We find that a one-dollar increase in CBDC crowds out bank lending by 5 cents when the number of competing banks is four (corresponding to the 50th percentile of the county-level market concentration in 2019) and 42 cents when the number of competing banks is eight (corresponding to the 10th percentile of the county-level market concentration in 2019). We conclude that the impact of CBDC on bank lending is more muted when the market is more concentrated because banks have a greater buffer to absorb the impact of the CBDC.

The heterogeneity of the effects of CBDC across banks and regions has important policy implications. Because small firms disproportionately rely on small banks for credit, the introduction of CBDC could affect credit access for small firms more than for big firms. Furthermore, in regions with more competitive deposit markets, depositors benefit less from the additional competition from CBDC, while borrowers lose more from reduced bank lending. Therefore, the introduction of CBDC could have redistributive implications across regions with different degrees of bank competition.

5.6. CBDC, bank capital cushions, and resilience

A concern among policymakers about the implications of CBDC is financial stability. The existing literature primarily focuses on the issue of whether CBDC would increase run incentives relative to an economy in which cash holdings are the only alternative to

bank deposits (Williamson 2021; Skeie 2020; Ahnert, Hoffmann, Leonello, and Porcellacchia 2020). We instead focus on the issue of whether CBDC can reduce bank resilience by compressing banks' profit margins and slow bank recapitalization.

To study this question, we consider a situation in which banks experience large, unexpected loan default shocks. To make our exercise empirically relevant, we calibrate the severity and length of the default shock to match the 2007–2009 Global Financial Crisis (GFC). Using our estimated model, we examine the degree to which default shocks affect bank lending and the speed at which banks recover from these shocks. We compare our model predictions when CBDC is introduced into the deposit market with zero interest rates and when it is absent, with the results reported in Figure 5.

Panel B of Figure 5 shows that a GFC-equivalent loan default shock leads to a 21% reduction in bank capital. The magnitude increases by 6% when CBDC is introduced. Banks become less profitable when facing the competition from CBDC, so they have a thinner capital cushion. Therefore, the same shock to bank capital induces them to deleverage even more by reducing their loans. Panel C shows that the ensuing lower bank capital also gives rise to higher credit spreads for wholesale funding. The average spread rises by over fourfold during the crisis without CBDC and sixfold when CBDC is present. Moreover, the higher credit spread induces banks to refrain from wholesale borrowing, leading to additional declines in lending.

As shown in Panel D, the introduction of CBDC leads to a 4% further decline in bank lending and slower recovery from default shocks. Banks have a more sluggish recovery because they accumulate retained earnings and replenish their capital more slowly with fewer profits from the deposit market.

5.7. Policy implications

Our counterfactual exercises show that CBDC can greatly affect bank deposits, especially when it is interest-bearing. Although banks can substitute a large fraction of the

lost deposits with wholesale funding, the impact of CBDC on the lending of small banks could be disproportionately larger because of the external financing frictions that these institutions face. Moreover, because small firms usually borrow from small banks, they could suffer more when a CBDC is introduced. To address this concern, the central bank could possibly lend the funds raised by CBDC back to banks, as suggested by [Brunnermeier and Niepelt \(2019\)](#). Nevertheless, passing the funds back to banks is subject to the same frictions that limit the central bank's involvement in the private lending market because the central bank may not have enough information to evaluate the creditworthiness of each bank.

The second policy issue is bank stability. Even if banks can replace a large fraction of lost deposits with wholesale funding, these alternative funds come with different terms. Deposits offer a natural hedge against interest rate risk, but wholesale funding does not. In a financial system with CBDC, banks may become more exposed to interest rate risk because they have a greater maturity mismatch on their balance sheets. One possible way to address this issue is a modification of the [Brunnermeier and Niepelt \(2019\)](#) proposal, in which the central bank term funding to banks. Note that this policy effectively transfers interest rate risk to the central bank.

The final issue is bank profitability. Although the competition from CBDC can raise depositor surplus, bank profitability can fall and banks can become less resilient. One potential way to alleviate the impact of CBDC on bank profitability is to use an "intermediated account-based" CBDC. Under this approach, private banks would offer accounts or digital wallets to facilitate the management of CBDC holdings, and they would earn a fee. This approach also has the advantage of addressing money laundering concerns for an anonymous "token-based" CBDC because banks have the infrastructure to verify the account holders' identities. Banks would earn a fee from providing these valuable services, thus reducing the impact of CBDC on bank profitability.

6. Conclusion

This paper studies the implications of CBDC on the banking system. We first clarify an important conceptual issue underlying many existing debates about CBDC, that is, CBDC need not reduce bank lending unless frictions and synergies bind deposits and lending. Therefore, evaluating the potential impact of CBDC on bank lending is effectively an evaluation of these frictions and synergies. To this end, we then estimate a dynamic banking model to quantify how important these frictions and synergies are in the U.S. banking system. Our counterfactual analysis shows that a CBDC replaces a significant fraction of bank deposits, especially when it pays interest. However, CBDC has a much smaller impact on bank lending because banks replace a large fraction of the lost deposits with wholesale funding. Substitution to wholesale funding makes banks' funding costs more sensitive to changes in short-term rates, increasing their exposure to interest rate risk. We discuss the policy implications of these results for the implementation of CBDC.

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Table 1: Summary Statistics

In this table, we report summary statistics for our sample. The sample period is 1994–2019. Deposits, wholesale borrowing, loans, and expenses related to fixed assets and salaries are scaled by the total assets. Deposit and loan rates are calculated using interest expense and income. Deposit and loan rates are reported in percentages. Asset maturity is reported in years. The data sources are the Call Reports and the FDIC Summary of Deposits.

	mean	sd	p10	p25	p50	p75	p90
Transaction deposits	0.112	0.087	0.023	0.053	0.091	0.142	0.236
Savings deposits	0.678	0.185	0.494	0.586	0.668	0.746	0.932
Wholesale borrowing	0.126	0.103	0.001	0.039	0.104	0.202	0.289
Loans	0.565	0.172	0.330	0.461	0.591	0.683	0.761
Transaction deposit rates	0.299	0.432	0.018	0.051	0.128	0.353	0.820
Savings deposit rates	1.435	1.304	0.087	0.227	1.026	2.475	3.249
Loan rates	6.439	2.146	3.732	4.534	6.208	7.835	9.176
Charge-off rate	0.783	1.077	0.008	0.154	0.393	0.985	2.079
Non-interest income	0.019	0.017	0.006	0.010	0.017	0.023	0.031
Non-interest expenses	0.031	0.015	0.020	0.024	0.028	0.035	0.043
No. of branches	1.387	2.005	0.003	0.016	0.313	1.847	5.413
No. of employees per branch	66.385	80.890	12.600	18.000	29.663	54.019	246.500
Expenses of fixed assets	0.032	0.011	0.010	0.037	0.037	0.037	0.037
Salaries	0.125	0.040	0.044	0.141	0.141	0.141	0.141
Loan-to-deposit ratio	0.735	0.264	0.404	0.518	0.740	0.909	1.066
Borrowing-to-deposit ratio	0.190	0.186	0.001	0.045	0.130	0.285	0.467
Book leverage	11.395	3.154	7.564	9.239	11.238	13.446	15.543
Asset maturity	4.745	2.434	1.884	3.034	4.330	6.338	8.077

Table 2: Parameter Values

In this table, we report the model parameter estimates. Panel A presents calibrated parameters. Panel B presents values for parameters that can be calculated as simple averages or by simple regression methods. Panel C presents results for parameters estimated via [Berry, Levinsohn, and Pakes \(1995\)](#) (BLP). Panel D presents results for parameters estimated via Simulated Minimum Distance (SMD). Standard errors for the estimated parameters are clustered at the bank level and reported in brackets.

Panel A. Statutory Parameters		
τ_c	Corporate tax rate	0.35
θ	The reserve ratio	0.02
κ	The capital ratio	0.06
Panel B. Parameters Estimated Separately		
μ	Average loan maturity	3.425
ξ	Firesale discount	0.3
\hat{J}	Number of representative banks	6
$\beta_{digital}^d$	Digital premium	0.2
\bar{f}	Log federal funds rate mean	-4.342
σ_f	std of innovation to Log federal funds rate	0.761
ρ_f	Log federal funds rate persistence	0.901
$\bar{\delta}$	Log loan charge-offs mean	-5.678
σ_δ	Log loan charge-offs std	1.434
$\rho_{\delta f}$	Correlation between federal funds rate and charge-offs	-0.102
Panel C. Parameters Estimated via BLP		
α^d	Depositor sensitivity to deposit rates	1.469
σ_{α^d}	Dispersion of sensitivity to deposit rates	0.842
σ_{β^d}	Dispersion of sensitivity to transaction dummy	0.214
α^l	Borrower sensitivity to loan rates	-1.847
$q^{d,T}$	Convenience of transaction deposits	5.389
$q^{d,S}$	Convenience of non-transaction deposits	4.556
q_c^d	Convenience of holding cash	3.706
q_l^l	Convenience of borrowing through loans	1.784
Panel D. Parameters Estimated via SMD		
γ	Banks' discount rate	0.009
W_0	Relative size of the deposit market	0.325
q_n^l	Value of firms' outside option	-11.63
ϕ^d	Bank's cost of taking deposits	0.003
ϕ^l	Bank's cost of servicing loans	0.011
ϕ^N	External financing cost	0.010
χ	Net operating cost	0.007

Table 3: Moment Conditions

This table presents the empirical and simulated moments that we target in our SMD estimation, along with the standard errors for testing the pair-wise difference between the empirical and simulated moments.

	Actual Moment	Simulated Moment	Standard Error
Dividend yield	0.034	0.026	0.006
Borrowing-to-deposits ratio	0.190	0.197	0.022
Borrowing-to-deposits ratio dispersion	0.096	0.094	0.027
Deposit spreads	0.013	0.012	0.001
Loan spreads	0.020	0.022	0.002
Deposits-to-assets ratio	0.771	0.761	0.037
Net non-interest expenses	0.012	0.008	0.001
Leverage	11.395	10.901	0.504
Market-to-book ratio	2.059	1.909	0.253
Total credit-FFR sensitivity	-1.062	-0.926	0.299

Table 4: Counterfactual: Varying CBDC Quality

In this table, we examine how banks' deposits, cost of funding, and other balance sheet variables respond to the introduction of CBDC. Column (1) corresponds to our baseline model in which CBDC is absent from the deposit market; column (5) shows the results when CBDC is fully incorporated following our conceptualization in Section 5.1. In columns (2)–(4), we examine cases in which CBDC is introduced but suffers a “quality discount”—we set the quality of CBDC ($q_{j=CBDC}^d$) to 25%, 50%, and 75% of the value we use in column (5), respectively. In column (6), we calculate the sensitivity of each variable of interest to changes in the market share of CBDC. Transaction deposits, savings deposits, and loans are all normalized by the size of the deposit market.

	(1) No CBDC	$\times q_{CBDC}$				(6) Sensitivity
		(2) 25%	(3) 50%	(4) 75%	(5) 100%	
CBDC Share	0.000	0.005	0.012	0.030	0.076	1.000
Transaction deposits	0.589	0.585	0.581	0.566	0.541	-0.634
Savings deposits	0.287	0.287	0.287	0.285	0.272	-0.197
Loan	1.021	1.016	1.015	1.016	1.007	-0.189
Cash	0.070	0.069	0.068	0.066	0.062	-0.107
Deposit spread (%)	1.125	1.117	1.117	1.113	1.092	-0.432
Loan spread (%)	2.177	2.182	2.183	2.182	2.189	0.147
Bank CDS spread (%)	0.100	0.112	0.112	0.112	0.132	0.414
Funding cost (%)	1.291	1.305	1.321	1.335	1.357	0.874
M/B	1.846	1.843	1.835	1.833	1.821	-0.338

Table 5: Decomposing the Impact of CBDC

This table presents the results of a series of counterfactual experiments in which we explore the channels through which the introduction of CBDC affects bank lending. We consider a CBDC that pays zero interest. Row (1) presents the total effect on bank lending; row (2) examines the channel through which CBDC introduction only influences the quantity of deposits; row (3) explores the channel through which CBDC only changes banks' interest rate risk exposure and widens the credit spreads on wholesale funding; row (4) corresponds to the channel through which CBDC only influences bank profit by making them less competitive on the deposit market.

		Loan-CBDC sensitivity
(1)	With CBDC	-0.189
(2)	Influencing deposit quantity	-0.158
(3)	Influencing interest rate exposure	-0.084
(4)	Influencing profit	-0.114

Table 6: Counterfactual: Varying the CBDC Rate

In this table, we examine how banks' deposits, cost of funding, and other balance sheet variables respond to the introduction of CBDC. Column (1) corresponds to our baseline model in which CBDC is absent from the deposit market; column (5) shows the results when CBDC pays the federal funds rate. In columns (2)–(4), we examine cases in which the rate on CBDC ($r_{j=CBDC}^d$) is set to 25%, 50%, and 75% of the federal funds rate. In column (6), we calculate the sensitivity of each variable of interest to changes in the market share of CBDC. Transaction deposits, savings deposits, and loans are all normalized by the size of the deposit market.

	(1) Zero rate	×FFR				(6) Sensitivity
		(2) 25%	(3) 50%	(4) 75%	(5) Pays FFR	
CBDC Share	0.076	0.099	0.139	0.209	0.313	1.000
Transaction deposits	0.513	0.498	0.474	0.433	0.374	-0.585
Savings deposits	0.255	0.250	0.239	0.216	0.189	-0.278
Loan	1.007	1.003	1.001	0.975	0.942	-0.271
Cash	0.062	0.060	0.057	0.053	0.047	-0.063
Deposit spread (%)	1.092	1.078	1.060	1.014	0.965	-0.536
Loan spread (%)	2.189	2.185	2.186	2.202	2.203	0.061
Bank CDS spread (%)	0.132	0.143	0.147	0.374	0.625	2.054
Funding cost (%)	1.357	1.396	1.470	1.635	2.104	3.147
M/B	1.821	1.795	1.724	1.511	1.184	-2.682

Table 7: The Heterogeneous Impact of CBDC

In Panel A, we present subsample estimation results by splitting banks based on their size. “Big” consists of banks whose sizes are in the top one percentile, and “Small” consists of all the other banks. In Panel B, we examine how banks’ deposits, cost of funding, and lending decisions respond to the introduction of CBDC. Deposit-CBDC sensitivity measures the responsiveness in banks’ deposit base to each dollar increase in households’ CBDC holdings; Loan-CBDC sensitivity and funding cost-CBDC sensitivity are defined analogously. CBDC has quality of q^{CBDC} as described in Section 5.1 and it bears a zero interest rate.

		Small Banks	Big Banks
Panel A: Subsample Parameter Estimates			
ϕ^N	External financing cost	0.040	0.011
W_0	Relative size of the deposit base	0.390	0.328
ϕ^d	Bank’s cost of taking deposits	0.012	0.011
ϕ^l	Bank’s cost of servicing loans	0.006	0.006
χ	Net operating cost	0.196	0.108
Panel B: Impact of Introducing CBDC			
	Deposit-CBDC sensitivity	-0.602	-0.675
	Loan-CBDC sensitivity	-0.407	-0.146
	Funding cost-CBDC sensitivity	1.533	0.852

Figure 1: Flows of Funds in the Banking System

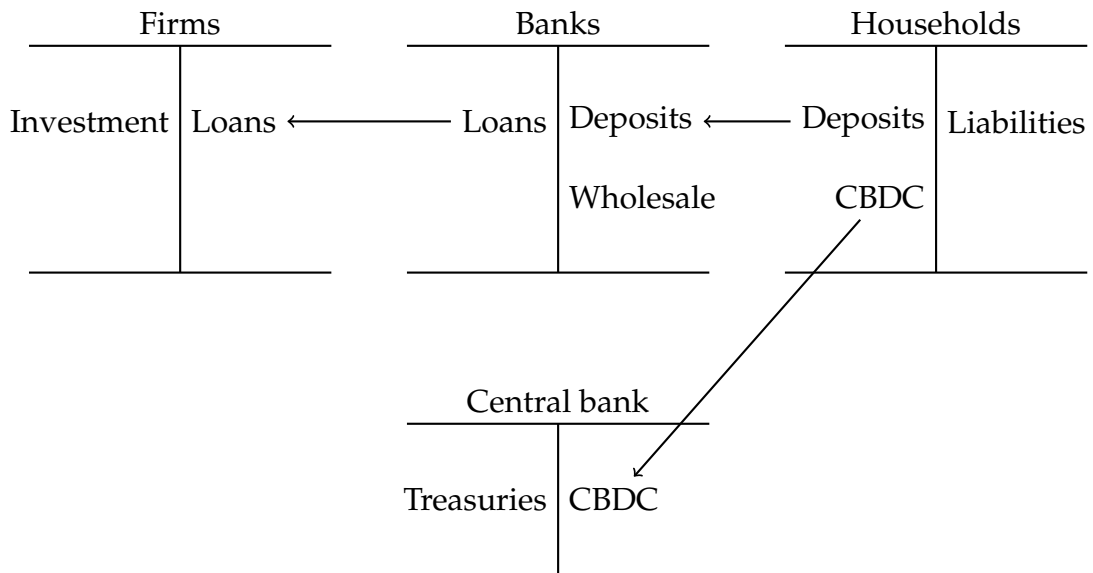
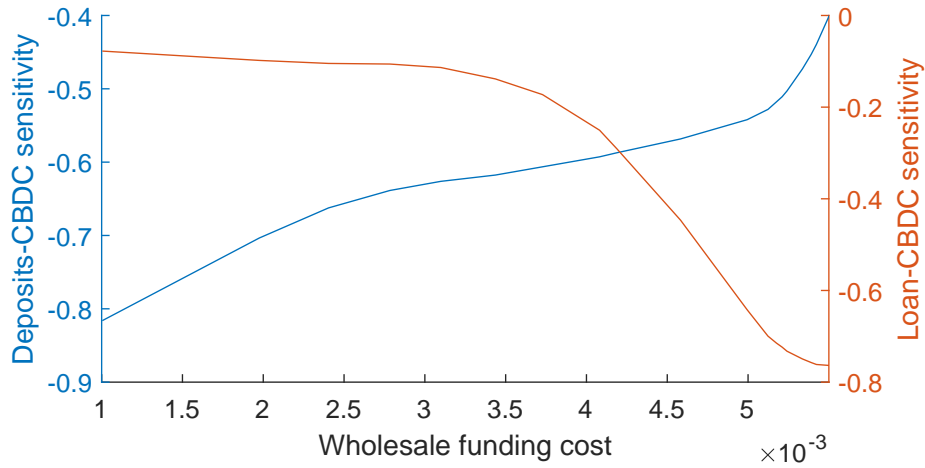
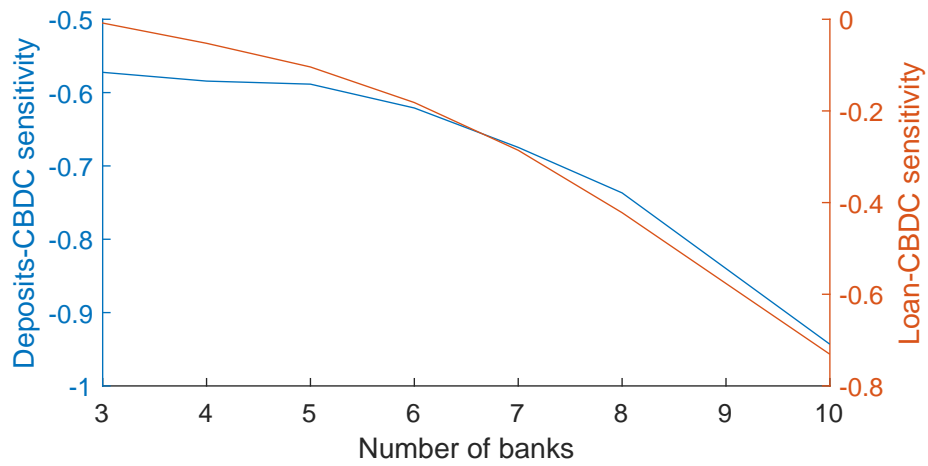


Figure 2: The Role of Wholesale Funding Costs



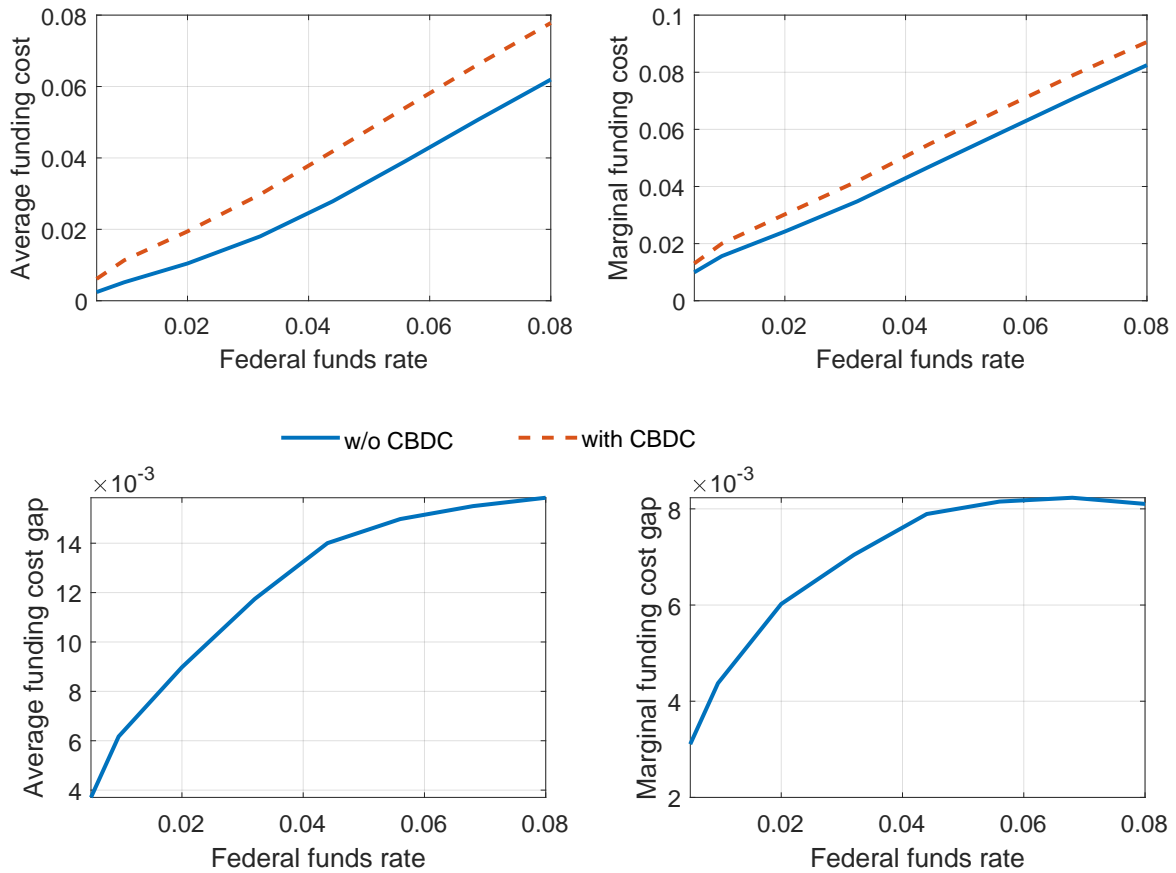
This figure shows the sensitivities of bank deposit intake and loan provision when the CBDC is introduced with quality equals q^{CBDC} and a zero interest rate. The sensitivities are calculated under varying levels of wholesale funding cost, which is defined as $r^N - f$, with r^N being the wholesale funding lenders' break even rate defined in equation (41)

Figure 3: The Role of Deposit Concentration



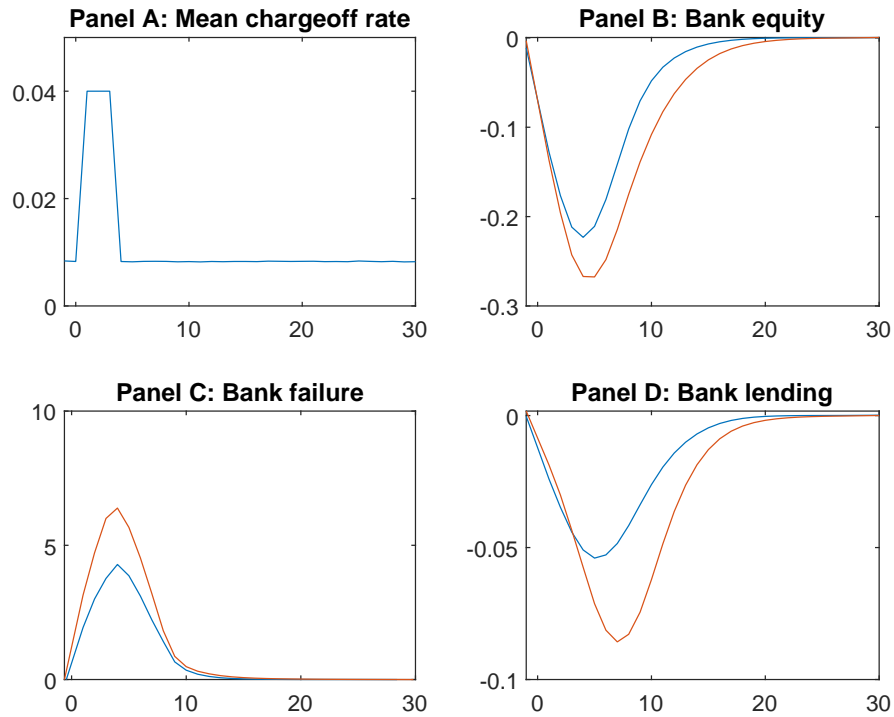
This figure shows the sensitivities of bank deposit intake and loan provision when the CBDC is introduced with quality equals q^{CBDC} and a zero interest rate. The sensitivities are calculated under varying concentration levels, which is measured by the number of competing banks, J , on the deposit market. High J corresponds to less-concentrated markets.

Figure 4: CBDC, Bank Funding Costs, and Interest Rate Levels



These figures show how banks' average and marginal funding costs change with the level of the interest rate, with and without the introduction of CBDC. The average/marginal funding cost difference measures the gap in funding costs in a scenario in which CBDC is introduced and when it is absent.

Figure 5: CBDC and Bank Recovery Following a Negative Shock



These figures simulate how banks recover from large unexpected shocks to equity capital in the baseline model without CBDC and in a counterfactual case in which CBDC is introduced. Panel A presents the charge-off shock process, which is calibrated to match the severity and duration of the 2007–09 Global Financial Crisis; Panel B reports the change in bank equity, scaled by the respective pre-crisis levels in the two simulations; Panel C corresponds to changes in the probability of bank failure, scaled by the mean probability in the baseline model without CBDC and the counterfactual model in which CBDC is introduced; Panel D reports the change in outstanding bank loans, scaled by the respective pre-crisis levels in the two simulations. The fed funds rate is fixed at 2% in all years.

Will Central Bank Digital Currency Disintermediate Banks?

Internet Appendix

IA.1. Robustness: with Treasury premium

In the baseline model, we assume that the Treasury market clears at the prevailing Federal Funds rate. However, in practice, Treasuries can have a liquidity premium. Furthermore, the Treasury premium potentially increases if the central bank invests funds raised from CBDC into Treasuries. In this section, we introduce the Treasury premium as a function of the central bank demand for Treasuries. Specifically, we consider a simple constant semi-elasticity demand function for Treasuries:

$$p = a - b \ln(Q - C), \quad (44)$$

where p is the Treasury premium, $\ln(Q - C)$ is the log Treasury net supply, Q is the total quantity issued by the Treasury Department, C is the quantity held by the central bank, and b is the demand elasticity of the Treasuries. Intuitively, if the total quantity issued Q is lower, or the central bank buys more Treasuries from the market C , Treasuries become more scarce and the premium would increase. Note that we normalize the quantity of Treasuries using the total deposits so Q and C are expressed as a ratio relative to the size of the deposit market. In our sample period, the Treasury net supply over the total deposit is around 1. The value of the semi-elasticity of demand, b , is $1/58$ based on the estimates by (Jiang, Richmond, and Zhang 2022, page 24). To calibrate the intercept of the demand function a , we note that Nagel (2016) estimates the average Treasury premium is around 24 basis points. We plug in the average Treasury premium into equation (44) and solve a .

We first confirm the intuition that introducing CBDC can indeed drive up the Treasury premium as central bank invests the funds raised by CBDC to Treasuries. the average Treasury premium increases from 24 basis points in the baseline economy without CBDC to 38 basis points with a non-interest-bearing CBDC, and to 84 basis points with an interest-bearing CBDC that pays the Federal Funds rate. However, introducing an endogenous Treasury premium does not significantly change our baseline results. Ta-

ble IA.1 shows that a one dollar increase in a non-interest-bearing CBDC crowds out 89 cents of deposits and 14 cents of loans. These numbers are similar to the baseline results in Table 4. Furthermore, Table IA.1 shows that one dollar increase in an interest-bearing CBDC crowds out 77 cents of deposits and 28 cents of loans, which are also similar to the baseline results in Table 6. The reason behind this result is that the Treasury market is quite elastic. Therefore, an increase in demand from the central bank for Treasuries has a modest impact on the Treasury premium. Furthermore, the deposit market is quite inelastic, so a small increase in the Treasury premium does not significantly change depositors' behavior.

Table IA.1: Counterfactual: with Treasury Premium

In this table, we examine how banks' deposits, cost of funding, and other balance sheet variables respond to the introduction of CBDC. Column (1) corresponds to our baseline model in which CBDC is absent from the deposit market; column (2) shows the results in which a non-interest-bearing CBDC is introduced; column (3) shows the results in which a interest-bearing CBDC is introduced. Transaction deposits, savings deposits, and loans are all normalized by the size of the deposit market. Columns (4) and (5) show the sensitivity of each variable of interest to changes in the market share of CBDC for non-interest-bearing and interest-bearing CBDC, respectively.

	Level			Sensitivity	
	No CBDC	No interest	With interest	No interest	With interest
CBDC share	0.000	0.076	0.300	1.000	1.000
Transaction deposits	0.577	0.531	0.416	-0.619	-0.537
Savings deposits	0.293	0.272	0.222	-0.275	-0.236
Loan	1.018	1.007	0.935	-0.144	-0.277
Cash	0.069	0.062	0.047	-0.097	-0.075
Deposit spread (%)	1.120	1.087	0.919	-0.445	-0.669
Loan spread (%)	2.181	2.183	2.207	0.036	0.088
Bank CDS spread (%)	0.063	0.081	0.692	0.237	2.094
Funding cost (%)	1.341	1.406	2.087	0.868	2.485
M/B	1.827	1.813	1.351	-0.182	-1.588

IA.2. Deposit-lending pass-through: comparison with reduced-form evidence

A key purpose of the model is to assess how much of the impact on bank deposits can be transmitted to bank lending. Depending on the design of CBDC and the characteristics of banks in consideration, our model implies a deposit-lending pass-through that ranges from 26 cents to 68 cents of a dollar. We compare our model predictions with the reduced-form evidence in [Khwaja and Mian \(2008\)](#) and [Gilje et al. \(2016\)](#). [Khwaja and Mian \(2008\)](#) exploit a natural experiment in Pakistan in which unanticipated nuclear tests in 1998 prompted large deposit outflows from Palestinian banks. [Khwaja and Mian \(2008\)](#) find a one dollar deposit outflow would lead to a 60 cent decline in lending.¹ [Gilje et al. \(2016\)](#) study bank lending response to exogenous liquidity windfalls from oil and natural gas shale discoveries in the United States. They find that a one dollar deposit inflow would lead to a 51 cent increase in mortgage lending.²

There are a few caveats when comparing our results with the above reduced-form estimates. First, [Khwaja and Mian \(2008\)](#) and [Gilje et al. \(2016\)](#) use cross-bank variation to identify the impact on lending, while our estimate is an aggregate impact. These two estimates could differ because of spillover or substitution effects. Second, the sample banks are different. [Khwaja and Mian \(2008\)](#) study Palestinian banks, which likely face greater external financing frictions. [Gilje et al. \(2016\)](#)' estimate is obtained from an equally weighted regression in a sample of 1,700 banks, most of which are small banks. With these caveats in mind, we find that the deposits-lending pass-through predicted in our model is in a similar order of magnitude as the reduced-form evidence. The average pass-through is around 30 cents of a dollar (Tables 4 and 6), and the pass-through from deposits to

¹See column (1) in Table III of [Khwaja and Mian \(2008\)](#).

²[Gilje et al. \(2016\)](#) find that a 1% increase in the share of branches in boom counties increases deposit growth by 5.67% (Table II, column (1)) and mortgage growth by 6.84% (Table III, column (3)). Since the mortgage to deposit ratio is 0.323/0.827 (Table I, column (3)), we can calculate that a one dollar increase in deposits is associated with around an increase in mortgage lending of 51 cents.

lending is much larger for small banks than big banks (Tables 7: 68 versus 22 cents of a dollar).