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Abstract

Many central banks are considering whether to issue a central bank digital currency (CBDC). The effects of a CBDC on the banking sector, output and welfare depend crucially on the level of competition in the market for bank deposits. We show that when banks have market power in the deposit market, issuing a deposit-like CBDC with a proper interest rate would encourage banks to pay higher interest to keep their customers. As a result, banks would attract more deposits and offer more loans. Hence, issuing a CBDC would not necessarily crowd out private banking. In fact, the CBDC would serve as an outside option for households, thus limiting banks' market power, and improve the efficiency of bank intermediation.

Bank topics: Digital currencies and fintech; Monetary policy; Monetary policy framework; Market structure and pricing

JEL codes: E50, E58

1 Introduction

Many central banks are considering issuing central bank digital currencies (CBDCs), a digital form of central bank money that can be used for retail payments. In the debate around the impact of introducing a CBDC, one frequently raised concern is that, by competing with bank deposits as a payment instrument, a CBDC could increase commercial banks' funding costs and reduce bank deposits and loans, leading to bank disintermediation. For example, Mancini-Griffoli et al. (2018) caution that a CBDC would force banks to increase their deposit interest rates, and banks would respond by increasing lending rates at the cost of loan demand. The 2018 report by the Committee on Payments and Market Infrastructures of the Bank for International Settlements raises the same concern.

This paper develops a general equilibrium model of banking and payments to assess this disintermediation concern, both theoretically and quantitatively. In this model, banks act as intermediaries, issuing loans to entrepreneurs and creating deposits, which households can use as a means of payment to trade consumption goods. Besides deposits, households have access to two other payment instruments: cash and CBDC. Cash and deposits differ in the types of exchange they can facilitate. For example, cash cannot be used in online transactions while deposits can be used via debit/credit cards or electronic transfers. A CBDC, however, is a perfect substitute for deposits in terms of payment functions and bears an interest set by the central bank.

Our main finding is that introducing a CBDC does not necessarily lead to disintermediation if banks have market power in the deposit market. In this case, the impact of a CBDC is non-monotonic in its interest rate. It expands bank intermediation if its interest rate lies in an intermediate range and causes disintermediation only if its interest rate is set too high. The main mechanism through which a CBDC "crowds in" bank intermediation works as follows. In an imperfectly competitive deposit market, banks restrain the deposit supply to keep the deposit interest rate below the level under perfect competition. A CBDC offers an outside option to depositors and sets an interest rate floor for bank deposits. This floor limits the reduction in the deposit rate and reduces commercial banks' incentive to restrain the deposit supply. If the CBDC rate is not too high, banks supply more deposits, reduce the loan rate, and expand lending.

Calibrating our model to the United States economy, we find that a CBDC expands bank intermediation if its interest rate is not too big. At the maximum, it can increase loans and deposits by 1.57%. The CBDC leads to disintermediation, however, if its rate is too big. To break even, banks are forced to raise the lending rate to compensate for the interest paid on deposits. As a result, both loans and deposits decrease.

Our study highlights the role of banks' market power in determining the effects of a CBDC on bank intermediation. The study is closely related to two concurrent papers. Keister and Sanches (2021) focus on the welfare implications of an interest-bearing CBDC when the banking sector is perfectly competitive. They find that, while the CBDC always crowds out bank intermediation, social welfare can still increase when the efficiency in exchange significantly improves, especially when financial frictions are not very severe.[1] In contrast, Andolfatto (2020) studies the effect of a CBDC on banking when there is a monopolistic bank. Using an overlapping generations model, he shows that a CBDC could compel the bank to increase the deposit rate, leading to an increase in bank deposits and financial inclusion. Under the assumption that the central bank offers a lending facility and a deposit facility at the same policy rate, the bank's deposit and loan decisions are made separately. The loan rate and quantity are fully determined by the policy rate and are not affected by the CBDC.

Compared to these papers, our framework is more suitable for quantifying the effects of a CBDC and accommodates various design choices as the payment landscape evolves. First, our model captures a complete spectrum of competitiveness. If the number of banks is one, the banking sector is monopolistic, as in Andolfatto (2020). If this number tends to infinity, the banking sector is perfectly competitive as in Keister and Sanches (2021). We use data to discipline the level of competitiveness, which is crucial for quantifying the effects of a CBDC. Second, we explicitly model cash, deposits and a CBDC as three imperfectly substitutable payment instruments that facilitate different types of transactions. This allows us to discuss the design of a CBDC in terms of its acceptability and its effect when the payment landscape evolves, for example, when the use of cash declines.

The economic literature on CBDCs is just emerging, with several lines of research complementary to our work. A number of studies focus on the role of CBDCs as a monetary policy tool. Barrdear and Kumhof (2021) evaluate the macroeconomic consequences of a CBDC in a dynamic stochastic general equilibrium model. Davoodalhosseini (2021) explores the usage of a CBDC for balance-contingent transfers. Dong and Xiao (2021) examine the effects of CBDC rate when CBDC and deposits are complements. Brunnermeier and Niepelt (2019) and Niepelt (2020) derive conditions under which introducing a CBDC has no effects on macroeconomic outcomes, including bank intermediation. Jiang and Zhu (2021) discuss how the interest on a CBDC and the interest on reserves interact as two separate policy tools. Another line of research studies the financial stability implications of a CBDC such as the risk-taking behavior of banks and bank runs. Recent works by Chiu et al. (2020), Fernández-Villaverde et al. (2020), Schilling et al. (2020), Keister and Monnet (2020), Monnet et al. (2020), and Williamson (2020*b*) have made some important progress. Our paper abstracts from these issues and focuses on the effects of a CBDC on bank intermediation in terms of deposit and loan quantities. For research related to the design of a CBDC, see Agur et al. (2020) and Wang (2020). For policy discussions on CBDCs, see Fung and Halaburda (2016); Engert and Fung (2017); Mancini-Griffoli et al. (2018); Chapman and Wilkins (2019); Davoodalhosseini and Rivadenyra (2020); Davoodalhosseini et al. (2020); and Kahn et al. (2020).[2]

[1] Using a related model, Williamson (2020a) shows that introducing a CBDC to compete with bank deposits can raise welfare by freeing up scarce collateral for banks that are subject to limited commitment.

[2] Our paper is also related to the literature on private digital currencies and currency competition; see Chiu

More broadly, our paper contributes to the monetary theory literature by developing a tractable model with imperfect competition in inside money creation.[3] It is also connected to the literature on how a bank's market power affects monetary policy transmission. Dreschler et al. (2017) provide empirical support for banks' market power in deposit markets and propose a transmission channel accordingly: since a lower nominal interest rate makes cash cheaper to use relative to deposits, banks are compelled to lower the spread between the nominal interest rate and the deposit rate. The effect of a lower nominal interest rate plays a similar role as a higher interest on a CBDC: both policies reduce banks' market power in the deposit market.[4]

The rest of the paper is organized as follows. Section 2 describes the physical environment. Section 3 characterizes the equilibrium. Section 4 calibrates the model and assesses its quantitative implications. Section 5 concludes the paper. The Appendix provides omitted proofs.

2 Environment

Our model is based on the framework of Lagos and Wright (2005). Time is discrete and continues from zero to infinity. There are four types of agents: a continuum of households with measure 2, a continuum of entrepreneurs with measure 1, a finite number of N bankers (each running a bank), and the government. The discount factor from the current period to the next is $\beta \in (0, 1)$. In each period t, agents interact sequentially in two stages: a frictional decentralized market (DM) and a Walrasian centralized market (CM). There are two perishable goods: y in the DM and x in the CM.

Households are divided into two permanent types, buyers and sellers, each with measure 1. In the DM, a buyer randomly meets a seller. The meeting probability is $\Omega \in (0, 1]$ for both buyers and sellers. The buyer wants to consume y, which is produced by the seller. The buyer's utility from consumption is $u(y)$ with $u'(0) = \infty$, $u' > 0$, and $u'' < 0$. The seller's disutility from production is normalized to y. Let y^* be the socially efficient DM consumption, which solves $u'(y^*) = 1$. Households lack commitment and cannot enforce debt repayment. As a result, the DM trade must be quid pro quo and buyers must use a means of payment to exchange for y. We will discuss available means of payment later. The terms of trade are determined by buyers making take-it-or-leave-it offers. In the CM, both buyers and sellers work and consume x. Their labor h is

and Koeppl (2019); Fernández-Villaverde and Sanches (2019); Schilling and Uhlig (2019); Zhu and Hendry (2019); Benigno et al. (2020); Choi and Rocheteau (2020); and Zhou (2020). For a complete introduction to the issues in digital currencies, see Schar and Berentsen (2020).

[3] Berentsen et al. (2008) models banking in the environment of Lagos and Wright (2005). Gu et al. (2018) demonstrate the inherent instability of banking. Dong et al. (2021) study the effects of competition on bank profits and welfare.

[4] Using a variation of the model of Dreschler et al. (2017), Kurlat (2019) shows that banks' market power raises the cost of inflation. Scharfstein and Sunderam (2016) propose a transmission channel based on banks' market power in the loan market. As the nominal interest rate increases, banks reduce their markup due to lower demand for loans. Wang et al. (2020) estimate a structural banking model and show that the effect of banks' market power in monetary policy transmission is sizable and comparable to that of bank capital regulations.

transformed into x one-for-one. The utility from consumption is $U(x)$ with $U'(0) = \infty$, $U' > 0$, and $U'' < 0$.[5] Buyers' and sellers' preferences can be summarized respectively by the period utilities

$$\begin{aligned} \boldsymbol{U}^B(x, y, h) &= u(y) + U(x) - h, \\ \boldsymbol{U}^S(x, y, h) &= -y + U(x) - h. \end{aligned}$$

Young entrepreneurs are born in the current CM and become old and die in the next CM. Entrepreneurs cannot work in the CM and consume only when old. Young entrepreneurs are endowed with an investment opportunity that transforms x current CM goods to $f(x)$ CM goods in the next period, where $f'(0) = \infty$, $f'(\infty) = 0$, $f' > 0$, and $f'' < 0$. Entrepreneurs would like to borrow from households to invest. However, entrepreneurs and households lack commitment and cannot enforce debt repayment, so no credit arrangement among them is viable.

Like entrepreneurs, young bankers are born in the CM, become old and die in the next CM. Bankers cannot work in the CM and consume only when old.[6] Unlike households and entrepreneurs, bankers can commit to repay their liabilities and enforce the repayment of debt from entrepreneurs. Therefore, banks can act as intermediaries between households and entrepreneurs to finance investment projects. A bank can finance its loans by issuing two liabilities: liquid checkable deposits and illiquid time deposits. Checkable deposits can be used as a medium of exchange to facilitate trading between buyers and sellers in the DM. Banks are subject to the reserve requirement that a bank's reserve holdings must cover at least a fraction $\chi \geq 0$ of its checkable deposits.

The government is a combination of monetary and fiscal authorities. The monetary authority, or the central bank, issues three forms of liabilities: physical currency (or cash), central bank reserves, and a CBDC. Currency is a physical token, pays a zero interest rate, and can be used as a means of payment. The reserves are electronic balances that pay a net nominal interest rate $i_r \geq 0$; they can be held only by banks and cannot be used for retail payments. The CBDC is a digital token or electronic entry that can be used for retail payments. It pays a net nominal interest i_e. We focus on stationary monetary policies, where the total liabilities of the central bank (currency, CBDC, and reserves) grow at a constant gross rate $\mu > \beta$ and the central bank stands ready to exchange its three forms of liabilities at par in the CM. We abstract from government purchases. The government collects revenues from the issuance of new liabilities to pay interest on the CBDC and reserves, and the difference finances lump-sum transfers (T) to buyers (a negative T represents lump-sum taxes).

In the DM, buyers use cash, CBDC, and checkable deposits to purchase good y from sellers. We

[5] For the theoretical analysis, $U(x)$ can be simply linear. The more general functional form $U(x)$ allows us to introduce a parameter that affects total CM output to better match the ratio of M1 to GDP in the quantitative analysis.

[6] Infinitely-lived banks complicate expositions, but have little impact on the results. In this model, banks do not have incentives to retain profits for investment because deposit financing is cheaper. Therefore, they behave as if they live for one period.

assume that the two electronic payment methods, CBDC and deposits, are perfect substitutes in terms of payment functions. Sellers are distinguished in three types by the payment methods they accept (Lester et al. 2012; Zhu and Hendry 2019). Type 1 sellers (of measure $\omega_1 > 0$) accept only cash and can be interpreted as local cash-only stores that do not accept electronic payments. Type 2 sellers (of measure $\omega_2 > 0$) accept deposits and CBDC, and can be interpreted as online stores. Type 3 sellers (of measure $\omega_3 = 1 - \omega_1 - \omega_2 \geq 0$) accept all three payment methods and can be interpreted as local stores with point-of-sale machines that accept both cash and electronic payment methods.

3 Equilibrium Characterization

We focus on stationary monetary policies and stationary equilibria where real allocations are constant over time. It takes four steps to solve for the equilibrium. First, characterize the household's problem to derive the demand for cash, CBDC, and bank deposits as functions of the deposit rate. Second, solve the Cournot game for banks, incorporating the household demand for deposits, to derive the aggregate deposit supply and loan supply as functions of the competitive loan rate. Third, derive the aggregate demand for loans from entrepreneurs. Finally, equate the supply and demand for loans to derive the equilibrium loan rate and loan quantity and plug them into the solutions to private agents' problems to obtain other equilibrium objects, such as the rate and quantity of deposits.

3.1 Households

We first present the buyer's problem, and then the seller's problem. Let W and V be the household's value functions in the CM and DM, respectively. We suppress the time subscript and use prime to denote variables in the next period. Define $\vec{a} = (z, e, d, b)$ as the vector of the real value of cash, CBDC, checkable deposits, and time deposits held by an agent. Let $\vec{i} = (i_z, i_e, i_d, i_b)$ be the vector of net nominal returns, and $\vec{R} = (R_z, R_e, R_d, R_b) = (1 + \vec{i})/\mu$ be the vector of real gross returns. For example, the net nominal interest on cash is $i_z = 0$, and its real gross return is $R_z = 1/\mu$. For brevity, we often refer to R_e as the CBDC rate and R_d the (checkable) deposit rate.

In the CM, a buyer chooses consumption x, labor h, and the real asset portfolio $\vec{a}'$ carried to the next DM and measured at the current price. The value function for a buyer holding an asset portfolio $\vec{a}$ is

$$\begin{aligned} W^B(\vec{a}) &= \max_{x,h,\vec{a}'} \left\{ U(x) - h + \beta V^B(\vec{a}') \right\} \\ \text{subject to } x + \vec{1} \cdot \vec{a}' &= T + h + \vec{R} \cdot \vec{a}, \end{aligned}$$

where $\vec{1}$ is the unit vector $(1, 1, 1, 1)$ and "$\cdot$" denotes the inner product of two vectors. The first-order condition with respect to asset portfolio $\vec{a}'$ is

$$\beta \frac{\partial}{\partial a} V^B(\vec{a}') \leq 1, \text{with equality if } a' > 0 \text{ for } a = z, e, d, b. \tag{1}$$

Note that, since the type of the DM meeting is not revealed until the start of the DM, buyers carry a portfolio of cash, CBDC, and bank deposits to the DM. Three standard results of the Lagos-Wright model are $U'(x) = 1$, all buyers choose the same portfolio $\vec{a}'$, and $\partial W^B(\vec{a})/\partial a = R_a$ for $a = z, e, d, b$.

The buyer's DM value function is

$$V^B(\vec{a}) \;=\; \sum_{j=1}^{3} \alpha_j [u(Y(\mathcal{L}_j)) - P(\mathcal{L}_j)] + W^B(\vec{a}), \tag{2}$$

where $\alpha_j = \omega_j \Omega$ is the (unconditional) probability of meeting a seller of type j, and $Y(\mathcal{L})$ and $P(\mathcal{L})$ are the terms of trade and represent the amount of good y being traded and the amount of payment, respectively. The terms of trade in a type j meeting depend on the buyer's usable liquidity $\mathcal{L}_j$, which incorporates the expected return of the asset. Specifically,

$$\mathcal{L}_1 \;=\; R_z z, \tag{3}$$

$$\mathcal{L}_2 \;=\; R_e e + R_d d, \tag{4}$$

$$\mathcal{L}_3 \;=\; R_z z + R_e e + R_d d. \tag{5}$$

Next we turn to the seller's problem. Without loss of generality, we assume that the seller does not take any asset into the DM, or $\vec{a}' = \vec{0}$.[7] Therefore, a type j seller's CM problem is

$$\begin{aligned} W_j^S(\vec{a}) \;&=\; \max_{x,h} \{U(x) - h + \beta V_j^S(\vec{0})\} \\ \text{subject to } x \;&=\; h + \vec{R} \cdot \vec{a}. \end{aligned}$$

The type j seller's DM value function is

$$V_j^S(\vec{0}) \;=\; \Omega[-Y(\tilde{\mathcal{L}}_j) + P(\tilde{\mathcal{L}}_j)] + W^S(\vec{0}),$$

where $\tilde{\mathcal{L}}$ is usable liquidity held by the seller's trading partner.

[7] It can be shown that, if the liquidity premium, defined below, on a liquid asset is positive, then the seller does not take that asset into the DM. The seller is indifferent between holding zero or a positive amount of illiquid time deposits when $R_b = 1/\beta$, which holds in equilibrium as shown below. For simplicity, we assume the seller does not hold time deposits either. Note that a seller enters the CM with positive asset balances ($\vec{a} > 0$) after trading in the previous DM.

The terms of trade in the DM are determined by buyers making take-it-or-leave-it offers and solve

$$\max_{y,p}[u(y) - p] \text{ subject to } p \geq y \text{ and } p \leq \mathcal{L},$$

where the first constraint is the seller's participation constraint and the second is the liquidity constraint. The solution is

$$Y(\mathcal{L}) = P(\mathcal{L}) = \min(y^*, \mathcal{L}). \tag{6}$$

In words, if the buyer has enough payment balances to purchase the optimal amount, then the optimal amount is traded; otherwise, the buyer's liquidity constraint binds and the buyer spends all available payment balances.

Combining (1) to (6), we can characterize the household's solution as follows. First, the demand for time deposits is separable from the demand for liquid assets and is given by $R_b = 1/\beta$. Since time deposits have no liquidity value, their return must compensate for discounting across time. Second, the buyer's demand for payment balances (z, e, d) is determined by

$$\frac{1}{\beta R_z} - 1 = \alpha_1 \lambda(\mathcal{L}_1) + \alpha_3 \lambda(\mathcal{L}_3), \tag{7}$$

$$\frac{1}{\beta R_a} - 1 \geq \alpha_2 \lambda(\mathcal{L}_2) + \alpha_3 \lambda(\mathcal{L}_3) \text{ with equality iff } a > 0, \text{ for } a = e, d, \tag{8}$$

where $\mathcal{L}_j$ is defined by (3) to (5), and $\lambda(\mathcal{L}) = \max\{u'(\mathcal{L}) - 1, 0\}$ is the liquidity premium.

Equation (7) states that the marginal cost of holding cash (left-hand side) equals its marginal benefit (right-hand side). The cost is that the buyer must delay consumption and bear the inflation cost to accumulate cash. The benefit is that more cash allows the buyer to consume more in type 1 and type 3 meetings. Equation (8) is for the CBDC and checkable deposits and has a similar interpretation.

Under the assumptions $u'(0) = \infty$ and $\alpha_1 > 0$, the demand for cash is positive, so (7) holds as an equality. Similarly, if $\alpha_2 > 0$, the demand for total electronic (CBDC plus checkable deposits) balances is also positive. However, because the CBDC and checkable deposits are perfect substitutes, buyers hold only the instrument with the higher rate of return. From (8), if $R_d < R_e$, then the demand for checkable deposits is zero. If $R_d > R_e$, then the demand for the CBDC is zero. If $R_d = R_e$, then the buyer is indifferent between the CBDC and checkable deposits and cares only about the total electronic payment balances.

Equations (7) and (8) define R_d as a function of d, which is the inverse demand function for checkable deposits, denoted as $\mathbf{R}_d(d)$. To derive $\mathbf{R}_d(d)$, it is useful to first obtain the inverse deposit demand without a CBDC. We denote it as $\hat{\mathbf{R}}_d(d)$ (from now on, we will use the accent "ˆ"

to denote variables or functions if there is no CBDC). We can solve $\hat{\mathbf{R}}_d(d)$ from (7) and

$$\frac{1}{\beta R_d} - 1 \quad = \quad \alpha_2 \lambda(\mathcal{L}_2) + \alpha_3 \lambda(\mathcal{L}_3), \tag{9}$$

after imposing $e = 0$. For certain values of d, there may exist multiple values of R_d that solve (7) and (9). This is because although (7) and (9) uniquely determine d given R_d, d may not be monotone in R_d. Intuitively, as R_d increases, there are two opposing effects: the substitution effect implies a higher d and the wealth effect implies a lower d. Throughout this paper, we assume that the substitution effect dominates and d is monotonically increasing in R_d.[8] Then, $\hat{\mathbf{R}}_d(d)$ is well-defined and increasing in d, with $\hat{\mathbf{R}}_d(0) = 0$ and $\hat{\mathbf{R}}_d(d) = 1/\beta$ for $d \geq \beta y^*$. With a CBDC, households hold only the electronic payment instrument that bears a higher rate of return. Therefore,

$$\mathbf{R}_d(d) = \begin{cases} [0, R_e) & \text{if } d = 0, \\ R_e & \text{if } d \in (0, \hat{\mathbf{R}}_d^{-1}(R_e)], \\ \hat{\mathbf{R}}_d(d) & \text{if } d > \hat{\mathbf{R}}_d^{-1}(R_e). \end{cases}$$

Figure 1 illustrates the inverse demand for checkable deposits. The solid line represents the demand with a CBDC, and the dashed line represents the demand without a CBDC. The two functions overlap if $R_d > R_e$. Once R_d is below R_e, the demand for checkable deposits drops to zero.

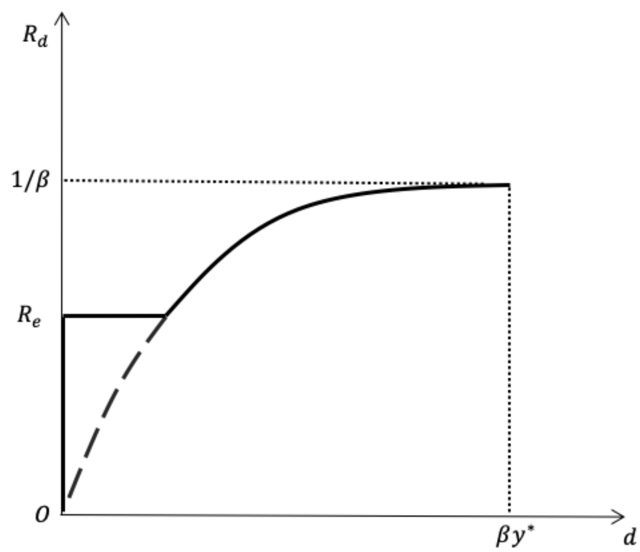


Figure 1: Inverse Demand for Checkable Deposits

Notes. The solid line is the inverse demand for checkable deposits with a CBDC, $\mathbf{R}_d(d)$; and the dashed line is the inverse demand for checkable deposits without a CBDC, $\hat{\mathbf{R}}_d(d)$. The two lines coincide with each other if $R_d > R_e$.

[8] Without this assumption, an equilibrium of the model still exists but may not be unique. A sufficient condition for this assumption is $-yu''(y)/u'(y) \leq 1$.

3.2 Banks

Banks issue two types of deposits, checkable deposits (d) and time deposits (b), and invest in two assets, reserves (r), and loans (ℓ). They do not invest in cash under the assumption $i_r \geq 0$. Bankers maximize consumption in the second period of life, which equals the return from loans and reserves, minus interest payments on deposits. They engage in Cournot competition in the deposit market and perfect competition in the loan market. Formally, banker j chooses $\{r_j, \ell_j, d_j, b_j\}$ to maximize its profit, taking as given the gross real rates for time deposits ($R_b = 1/\beta$), reserves (R_r) and loans (R_ℓ), the inverse demand function for checkable deposits ($\mathbf{R}_d(\cdot)$), and other banks' checkable deposit quantities ($D_{-j} = \sum_{i \neq j} d_i$):

$$\max_{r_j, \ell_j, d_j, b_j} \left\{ R_\ell \ell_j + R_r r_j - \mathbf{R}_d(D_{-j} + d_j) d_j - b_j/\beta \right\} \tag{10}$$
$$\text{subject to} \quad \ell_j + r_j = d_j + b_j, \quad r_j \geq \chi d_j.$$

This problem has two constraints. The first is a balance sheet identity at the end of the banker's first CM. The right-hand side is liabilities, which include checkable and time deposits. The left-hand side is assets, which include reserves and loans. The second is the reserve requirement constraint. We also implicitly impose that d_j, b_j, and ℓ_j are non-negative throughout the paper.

If $R_\ell > 1/\beta$, then the bank can make unlimited profits by issuing time deposits and investing in loans. As a result, $R_\ell \leq 1/\beta$ in equilibrium. From now on, we restrict our attention to $R_\ell \in [0, 1/\beta]$. We also assume $R_r < 1/\beta$. We can separate the bank's problem into two steps. In the first step, the bank chooses funding sources (d_j, b_j):

$$\max_{d_j, b_j} \left\{ [\xi - \mathbf{R}_d(D_{-j} + d_j)] d_j + (\xi_b - 1/\beta) b_j \right\}, \tag{11}$$

where

$$\xi \equiv \max\{R_r, \chi R_r + (1 - \chi) R_\ell\}$$

is the gross return on the bank's checkable deposits, and $\xi_b \equiv \max\{R_r, R_\ell\}$ is the gross return on time deposits. The first term in (11) is the profit from issuing checkable deposits, and the second term is the profit from issuing time deposits. Banks can hold their assets in loans or reserves, and therefore the return on assets is the higher of the two. Note that the return on checkable deposits accounts for the cost of satisfying the reserve requirement, while this consideration is absent for time deposits. Additionally, $b_j = 0$ if $R_\ell < 1/\beta$ and $b_j \in [0, \infty)$ if $R_\ell = 1/\beta$: the bank issues time deposits only if the return on loans is sufficient to cover the return of $1/\beta$ required by households.

In the second step, conditional on the choice in the first step, (d_j, b_j), the bank solves an asset allocation problem. If $R_\ell < 1/\beta$, then the bank issues only checkable deposits. It invests only in reserves if loans have a lower return than reserves, and invests only a fraction χ of assets in reserves to satisfy the reserve requirement if loans have a higher return. If the two assets have the same return, then the bank is indifferent between any allocations that satisfy the reserve requirement. If $R_\ell = 1/\beta$, then the bank starts to issue time deposits and ℓ_j can take any value in $[(1-\chi)d_j, \infty)$.

We focus on a symmetric pure strategy equilibrium in which every bank makes the same choice (r, ℓ, d, b). Denote the equilibrium checkable deposits of the Cournot game as $\mathbf{d}(R_\ell)$ to indicate its dependence on the loan rate R_ℓ. Following the discussion in the above paragraph, conditional on $\mathbf{d}(R_\ell)$, we can express the equilibrium loan supply function $\boldsymbol{\ell}(R_\ell)$ as

$$\boldsymbol{\ell}(R_\ell) = \begin{cases} 0 & \text{if} \quad R_\ell < R_r, \\ [0, (1-\chi)\mathbf{d}(R_\ell)] & \text{if} \quad R_\ell = R_r, \\ (1-\chi)\mathbf{d}(R_\ell) & \text{if} \quad R_r < R_\ell < 1/\beta, \\ [(1-\chi)\mathbf{d}(1/\beta), \infty) & \text{if} \quad R_\ell = 1/\beta. \end{cases} \tag{12}$$

To establish the existence and uniqueness of the equilibrium in the Cournot game, the assumption below, Assumption 1, is maintained throughout the paper.[9] As discussed above, b_j is indeterminate if $R_\ell = 1/\beta$, and ℓ_j is indeterminate for certain values of R_ℓ. We say that the Cournot game has a unique symmetric equilibrium if the symmetric checkable deposit supply is unique.

Assumption 1 *a) For any $D \in [0, \beta y^*)$ and $\zeta \leq 1/\beta$, there exists a unique $d_j \in [0, \beta y^* - D)$ such that $\hat{\mathbf{R}}_d'(D+d)d + \hat{\mathbf{R}}_d(D+d) \lesseqgtr \zeta$ if $d \lesseqgtr d_j$ and $d \in [0, \beta y^* - D)$. b) $\hat{\mathbf{R}}_d'(Nd)d + \hat{\mathbf{R}}_d(Nd)$ increases with d on $[0, \beta y^*/N)$ and is less than R_r if d is sufficiently small.*

In the following, we first characterize the Cournot equilibrium if $R_e = 0$, which is equivalent to the case without a CBDC. It serves as a basis for analyzing the general case where $R_e > 0$. We characterize the Cournot equilibrium by taking the first-order condition of the bank's deposit-issuing problem (11) and imposing symmetry.

Proposition 1 *In the absence of a CBDC, the Cournot game has a generically unique symmetric pure strategy equilibrium, where each bank supplies $\hat{\mathbf{d}}(R_\ell) \in [0, \beta y^*/N)$ checkable deposits. In addition, $\hat{\mathbf{d}}(R_\ell)$ increases with R_ℓ and solves the following equation in d:*[10]

$$\hat{\mathbf{R}}_d'(Nd)d + \hat{\mathbf{R}}_d(Nd) = \xi. \tag{13}$$

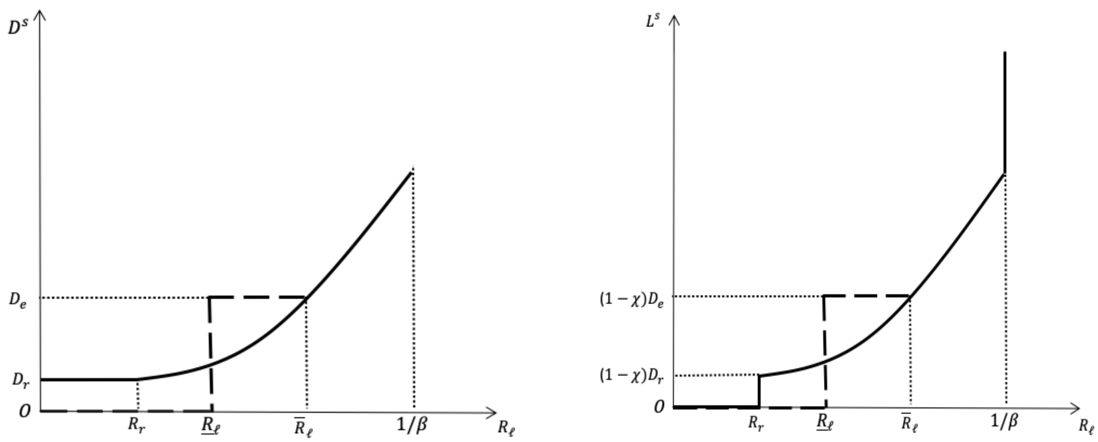
Proof. *See the Appendix.* ■

In Figure 2, we plot the aggregate checkable deposit supply curve $\hat{\mathbf{D}}^s(R_\ell) = N\hat{\mathbf{d}}(R_\ell)$ (solid curve in the left panel) and the loan supply curve $\hat{\mathbf{L}}^s(R_\ell) = N\hat{\boldsymbol{\ell}}(R_\ell)$ (solid curve in the right panel) in the

[9] Part (a) of Assumption 1 guarantees that the symmetric Cournot equilibrium is generically unique. Part (b) guarantees that the equilibrium deposit supply is increasing in R_ℓ and banks issue checkable deposits for any R_ℓ. When $u(y) = y^{1-\sigma}/(1-\sigma)$, Assumption 1 holds if $\sigma < 1$ and R_z is not too small.

[10] The equilibrium is unique unless $R_\ell = 1/\beta$ and $\chi = 0$. In this case, there is one equilibrium where banks make positive profits, and a continuum of equilibria with $d \geq N\beta y^*/(N-1)$ in which banks make zero profits. We select the single positive-profit equilibrium.

absence of a CBDC. Without a CBDC, banks always issue checkable deposits, and the loan supply is positive if $R_\ell \geq R_r$. If $R_\ell < R_r$, banks hold only reserves as assets, the checkable deposit supply is flat and the loan supply is zero. If $R_\ell = R_r$, the loan supply is vertical. Banks are indifferent between loans and reserves as long as the reserve requirement is satisfied. Both checkable deposits and loans strictly increase with R_ℓ if $R_r < R_\ell < 1/\beta$. If $R_\ell = 1/\beta$, then banks start to issue time deposits to finance loans. They are willing to supply any amount of loans that is no less than $(1-\chi)N\hat{\mathbf{d}}(1/\beta)$.



(A) Checkable Deposits

(B) Loans

Figure 2: Effects of a CBDC on the Supply of Checkable Deposits and Loans

Notes. (1) $D_r = N\hat{\mathbf{d}}(R_r)$. (2) The dashed line is the case with a CBDC, and the solid line represents the case without a CBDC. The two curves coincide with each other when $R_\ell \geq \bar{R}_\ell$.

Now we analyze how a CBDC affects the checkable deposit and loan supply. Since the CBDC is a perfect substitute for checkable deposits regarding payment functions, it alters the checkable deposit and loan supply only if the CBDC rate, R_e, exceeds the checkable deposit rate in the Cournot equilibrium without a CBDC, which is denoted by $\hat{\mathbf{R}}_d^*(R_\ell) \equiv \hat{\mathbf{R}}_d(N\hat{\mathbf{d}}(R_\ell))$. From (13) and Assumption 1, $\hat{\mathbf{R}}_d^*(R_\ell)$ is constant if $R_\ell \leq R_r$ and strictly increases in R_ℓ if $R_\ell > R_r$. Intuitively, under Cournot competition, a higher return on assets is partly passed on to the checkable deposit rate. Therefore, for a given CBDC rate R_e, the CBDC tends to alter the checkable deposit and loan supply only for low values of R_ℓ. In the following, we discuss in detail how a CBDC alters the checkable deposit and loan supply. To ease presentation, we focus on the case in which $R_e \in (R_r, \hat{\mathbf{R}}_d^*(1/\beta))$.

If $R_\ell \geq \bar{R}_\ell$, where $\bar{R}_\ell$ solves $\hat{\mathbf{R}}_d^*(\bar{R}_\ell) = R_e$, the CBDC rate is lower than the deposit rate in the Cournot equilibrium without a CBDC, and a CBDC does not affect the deposit and loan supply.[11] If $R_\ell < \underline{R}_\ell$, where $\underline{R}_\ell$ solves $(1-\chi)\underline{R}_\ell + \chi R_r = R_e$, then a bank's return on assets is insufficient to cover the cost of serving deposits, and it stops operating.

[11]The highest deposit rate in the Cournot equilibrium without a CBDC is $\hat{\mathbf{R}}_d^*(1/\beta)$. If $R_e < \hat{\mathbf{R}}_d^*(1/\beta))$, then $\bar{R}_\ell < 1/\beta$.

If $\underline{R}_\ell < R_\ell < \bar{R}_\ell$, then a bank matches the CBDC rate and supplies $d_e = D_e/N$ checkable deposits, where

$$D_e = \hat{\mathbf{R}}_d^{-1}(R_e).$$

Intuitively, if a bank reduces its supply of checkable deposits below d_e, then the checkable deposit rate remains equal to the CBDC rate, because the latter sets a floor for the former. The deviating bank has a strictly lower profit because the marginal return of checkable deposits is higher than the marginal cost, that is, $(1-\chi)R_\ell + \chi R_r > R_e$. Therefore, no bank wants to reduce checkable deposits. On the other hand, no bank wants to increase checkable deposits, because that raises the deposit rate and lowers profits. Notice that a CBDC raises deposit quantity compared to the case without a CBDC, i.e., $d_e > \hat{\mathbf{d}}(R_\ell)$. Without a CBDC, banks restrict deposit supply and pay a deposit rate lower than R_e. With a CBDC, this is no longer possible, because R_e becomes a lower bound for the deposit rate. This reduces banks' incentives to restrict the deposit supply and leads to more deposits.

Finally, if $R_\ell = \underline{R}_\ell$, the bank is indifferent between operating and not, and the deposit supply lies in the interval $[0, d_e]$. Proposition 2 summarizes a bank's checkable deposit supply in the Cournot equilibrium with a CBDC.

Proposition 2 *If $R_e \in (R_r, \hat{\mathbf{R}}_d^*(1/\beta))$, a bank's supply of checkable deposits in the symmetric pure strategy equilibrium of the Cournot game is given by*

$$\mathbf{d}(R_\ell) = \begin{cases} 0 & \text{if} \quad R_\ell < \underline{R}_\ell, \\ [0, d_e] & \text{if} \quad R_\ell = \underline{R}_\ell, \\ d_e > \hat{\mathbf{d}}(R_\ell) & \text{if} \quad \underline{R}_\ell < R_\ell < \bar{R}_\ell, \\ \hat{\mathbf{d}}(R_\ell) & \text{if} \quad \bar{R}_\ell \le R_\ell \le 1/\beta. \end{cases} \tag{14}$$

Proof. *See the Appendix.* ■

Figure 2 illustrates how a CBDC affects the aggregate checkable deposit and loan supply, $\mathbf{D}^s(R_\ell) = N\mathbf{d}(R_\ell)$ and $\mathbf{L}^s(R_\ell) = N\boldsymbol{\ell}(R_\ell)$, graphed in dashed black. If $R_\ell \ge \bar{R}_\ell$, then the deposit rate offered by banks in the absence of a CBDC is higher than the CBDC rate, and the CBDC does not affect the economy. Therefore, the checkable deposit and loan supply curves with and without a CBDC coincide. If $\underline{R}_\ell < R_\ell < \bar{R}_\ell$, then the supply of checkable deposits and loans is dictated by the CBDC rate R_e. The supply of checkable deposits stays at D_e and the supply of loans stays at $(1-\chi)D_e$. This corresponds to the positive horizontal part of the dashed curve. In this interval, the dashed curve is above the solid curve, reflecting that a CBDC can increase the deposit and loan supply. If $R_\ell = \underline{R}_\ell$, banks break even, and the supply of checkable deposits can take any value between zero and D_e, and the supply of loans lies between zero and $(1-\chi)D_e$. This corresponds to the vertical part of the dashed curve. If $R_\ell < \underline{R}_\ell$, banks cannot compete with the CBDC and do not operate.

3.3 Entrepreneurs

Entrepreneurs take the gross loan rate R_ℓ as given and solve

$$\max_{\ell}\{f(\ell) - R_\ell \ell\}.$$

The inverse loan demand for an entrepreneur is $f'(\ell) = R_\ell$, which defines the aggregate loan demand function,

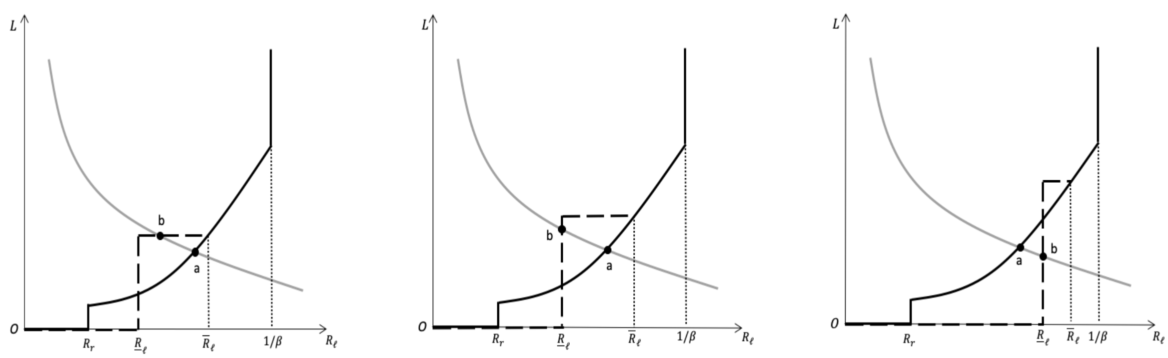
$$\mathbf{L}^d(R_\ell) = f'^{-1}(R_\ell).$$

The loan demand decreases with R_ℓ. It is always positive and approaches zero (infinity) as R_ℓ approaches infinity (zero). Note that the loan demand function is not affected by a CBDC.

3.4 Effects of a CBDC

We now combine the aggregate loan supply curve, $\mathbf{L}^s(R_\ell)$, with the aggregate loan demand curve, $\mathbf{L}^d(R_\ell)$, to determine the equilibrium loan quantity and rate. The loan market equilibrium is unique because the aggregate loan supply curve is non-decreasing. We can then use the equilibrium loan rate to derive the equilibrium quantity and rate of checkable deposits and loans. In the steady state equilibrium, the government budget constraint is $z + e + r = R_z z + R_e e + R_r r + R_z T$, which determines the equilibrium transfer to buyers. Note that the transfer T does not affect the household's demand for real payment balances, so it does not affect the analysis that determines the equilibrium rates and the quantities of deposits and loans.

Figure 3 shows the equilibrium with and without a CBDC. The solid gray curve is the aggregate loan demand and the solid black curve is the aggregate loan supply without a CBDC. They intersect at point a, which corresponds to the equilibrium without a CBDC. Let $\hat{R}_\ell^*$ and $\hat{R}_d^*$ be the rates of loan and checkable deposits, respectively, in this equilibrium.



(A) Regime 1: $R_e \in (\hat{R}_d^*, R_{e1})$ (B) Regime 2: $R_e \in (R_{e1}, R_{e2})$ (C) Regime 3: $R_e \in (R_{e2}, 1/\beta)$

Figure 3: Effects of a CBDC

Notes. The solid gray curve is the aggregate loan demand, the solid black is the aggregate loan supply without a CBDC, and the dashed black curve is the aggregate loan supply with a CBDC. The dashed black curve joins the solid black curve for $R_\ell > \bar{R}_\ell$.

The dashed black curves illustrate the aggregate loan supply under different values of R_e. They intersect with the loan demand at point b, which corresponds to the equilibrium with a CBDC. We focus on the case in which $\hat{R}_\ell^* > R_r$.[12] If $R_e \leq \hat{R}_d^*$, a CBDC does not affect the equilibrium; otherwise, the effect of a CBDC can be distinguished by three regimes as R_e increases from $\hat{R}_d^*$. These regimes are distinguished along two dimensions: the effect of introducing a CBDC (relative to the case without a CBDC), and the comparative statics of deposits and loans with respect to R_e.

Regime 1 is shown in Figure 3(A). Compared with the case without a CBDC, a CBDC raises the deposit rate and the demand for electronic payment balances. If the CBDC had not been introduced, banks would have restricted their supply of checkable deposits and offered a lower deposit rate. However, the CBDC sets a floor for the rate of checkable deposits. Losing the ability to further reduce deposit rate, banks supply D_e checkable deposits to meet all the demand for electronic payment balances at the CBDC rate, because the marginal profit from checkable deposits is positive. In this regime, the CBDC is not used. A bank invests a fraction $1 - \chi$ of its checkable deposits in loans, so the aggregate loan quantity is $L_e = (1 - \chi)D_e$. Now we analyze how the economy responds as the CBDC rate increases. As R_e rises, $\underline{R}_\ell$ and $\bar{R}_\ell$ move to the right and the horizontal part of the loan supply curve rises, because D_e increases. Therefore, the rate and quantity of checkable deposits increase. The loan quantity increases and the loan rate decreases. Banks then have a lower profit margin because of the higher deposit rate and the lower loan rate. If $R_e = R_{e1}$, which solves $R_e = (1-\chi)f'(L_e) + \chi R_r$ as an equation in R_e, the profit margin reaches zero and all banks make a zero profit.

As R_e increases beyond R_{e1}, the economy enters into regime 2, illustrated in Figure 3(B). In this regime, a higher R_e increases the rates of checkable deposits and loans. The marginal profit from checkable deposits is zero and banks behave as if they are perfectly competitive. To stay break-even, banks must increase the loan rate to compensate for a higher deposit rate. This lowers the equilibrium loan quantity. Banks then create fewer checkable deposits to finance loans. However, households increase their electronic payment balances by holding more CBDC. If $R_e < R_{e2} \equiv (1-\chi)\hat{R}_\ell^* + \chi R_r$ (or equivalently, $\underline{R}_\ell = \hat{R}_\ell^*$), a CBDC still leads to more loans and deposits relative to the case without it.

Finally, as R_e increases beyond R_{e2}, regime 3 occurs. It is the same as regime 2, except that the CBDC rate is too high and the quantities of checkable deposits and loans drop below the level without a CBDC. In other words, introducing the CBDC causes disintermediation if and only if $R_e > R_{e2}$. The following proposition summarizes these discussions.

Proposition 3 *There exists a unique steady-state monetary equilibrium with a CBDC. If* $R_e \leq \hat{R}_d^*$,

[12] If the loan demand is sufficiently low, then the intersection a in Figure 3 would lie on the first vertical part of the loan supply curve and $\hat{R}_\ell^* = R_r$. The reserve requirement constraint would be slack and the equilibrium loan rate would be determined by the interest on reserves R_r. In this case, a CBDC can increase deposits without affecting lending, as in Andolfatto (2020).

then a CBDC does not affect the economy. Introducing a CBDC promotes lending relative to the case without a CBDC if $R_e \in (\hat{R}_d^*, R_{e2})$, and reduces lending if $R_e \in [R_{e2}, 1/\beta]$.

Our analysis delivers two important messages. First, introducing a CBDC does not necessarily cause disintermediation or reduce bank loans and deposits. Indeed, the CBDC expands bank intermediation by introducing more competition to the banking sector if its rate falls between $\hat{R}_d^*$ and R_{e2}. Second, one should not judge the effectiveness of the CBDC based on its usage, but, rather, on how much it affects the deposit and lending rates or quantities. Throughout regime 1, the CBDC is not used, but it increases both deposits and loans. In fact, it maximizes lending at $R_e = R_{e1}$, which is the upper bound of regime 1. Here, the CBDC works as a *potential entrant*. It disciplines the off-equilibrium outcome: if banks reduce their deposit rates below the CBDC rate, then buyers would switch to the CBDC.

4 Quantitative Analysis

Theoretically, a CBDC can increase bank lending if its interest rate lies in a certain range. Empirical questions remain as to how large a range this is and how big the effect of a CBDC can be. To answer these questions, we calibrate our model without a CBDC to the United States economy, and conduct a counterfactual analysis to assess the effect of introducing a CBDC.

4.1 Calibration

We introduce two modifications to the model. First, we assume that banks incur a management cost c per unit of deposits. This simply adds the term $-c(d_j + b_j)$ to the profit function in (10). In our model, this cost is equivalent to a variable asset management cost. Second, we allow sellers in the DM to have some market power. Specifically, the DM terms of trade are determined by the Kalai bargaining, with bargaining power θ to the buyer. These modifications do not affect the qualitative results but capture two features in the data: banks have operational costs and sellers have substantial markups. Both features can be quantitatively important.

Consider an annual model and the functional forms $U(x) = B \log x$, $u(y) = [(y + \epsilon)^{1-\sigma} - \epsilon^{1-\sigma}]/(1-\sigma)$, and $f(k) = Ak^\eta$. The parameter ϵ is set to 0.001. This guarantees $u(0) = 0$ so that the Kalai bargaining is well-defined for all σ. It has little effect on our counterfactual analysis. There are 15 parameters to calibrate: $(A, B, N, \Omega, \omega_1, \omega_2, \omega_3, \sigma, c, i_r, \theta, \beta, \eta, \chi, \mu)$. Nine parameters, i_r, c, β, η, μ, χ, and ω_i $(i = 1, 2, 3)$, are set directly. The rest are calibrated internally. We calibrate $\omega_1, \omega_2, \omega_3, c, A, N, i_r, \chi$ and μ using data from 2014 to 2019. The calibration of $(\Omega, B, \sigma, \eta)$ follows the standard approach of matching the money and loan demand curves, which requires the use of longer time series data.

We use four data sets in our calibration exercise: (1) data from the Survey of Consumer Payment Choice (SCPC) and the Diary of Consumer Payment Choice (DCPC) from the Federal Reserve

Bank of Atlanta; (2) call report data from the Federal Financial Institutions Examination Council; (3) new M1 series from Lucas and Nicolini (2015); and (4) several time series on macro variables and reserves from Federal Reserve Economic Data (FRED). In what follows, we briefly discuss the calibration of several key parameters.

We obtain the payment acceptance parameters, the ωs, from the SCPC (Greene and Stavins 2018) and the DCPC (Premo 2018). The SCPC contains information on the fraction of online transactions, and the DCPC contains information on the perceived fraction of point-of-sale transactions that do not accept cash or debit/credit cards. We use data from the 2016 wave, and the numbers are similar in 2015 and 2017. The SCPC documents that an average household makes 67.8 transactions per month. This includes 6.6 automatic bill payments, 5.9 online bill payments, and 4.7 online or electronic non-bill payments. We count these as online transactions and they represent 25.37% of all transactions. We assume that all online transactions accept only deposits. At the point of sale, the DCPC reports that 6.14% of transactions do not accept debit/credit cards and 1.44% of transactions do not accept cash. Then, cash-only transactions are those at points of sale that do not accept cards. This implies $\omega_1 = 6.14\%(1 - 25.37\%) = 4.58\%$. Deposit-only transactions include online transactions and point-of-sale transactions that do not accept cash. Hence, $\omega_2 = 25.37\% + 1.44\%(1 - 25.37)\% = 26.44\%$, and $\omega_3 = 1 - \omega_1 - \omega_2 = 68.98\%$.

We the set $i_r = 1.02\%$ to match the average interest rate on required reserves, c to match average non-interest expenditures, excluding expenditures on premises or rent, per dollar of assets, and η, to match the elasticity of commercial loans with respect to the prime rate, using the time series from FRED. The rest of the parameters are calibrated jointly to match the money demand and several other moments from data. Table 1 summarizes all the parameter values along with their calibration targets.[13]

4.2 Effects of an Interest-Bearing CBDC

Now we conduct counterfactual analysis and introduce an interest-bearing CBDC as a perfect substitute for checkable deposits. We are particularly interested in how the CBDC affects lending and output with different interest rates. Figure 4 shows the results. In all figures, the horizontal axis is the net nominal interest on CBDC i_e. The first row shows the net nominal deposit and loan interest rates and their difference, that is, the spread. All interest rates are in percentages. The second row displays the percentage changes of deposits, loans and total output relative to the equilibrium without a CBDC.

First note that if the interest rate on the CBDC (i_e) is below 0.30%, which is the deposit rate without a CBDC in our calibration, then the CBDC does not affect the economy; this corresponds

[13] The money demand is rather flat during 1987-2008, so σ is larger than one. This result implies that the DM utility has a high curvature and a θ close to one is needed to match the markup. We have also done a calibration using data from 1987 and 2019. This alternative calibration suggests $\sigma = 0.45$ and $\theta = 0.80$, and the effect of a CBDC is larger than the benchmark calibration.

Parameters	Notation	Value	Calibration Targets
Calibrated externally			
Discount factor	β	0.96	Standard in literature
Curvature of production	η	0.66	Elasticity of commercial loans
Reserve requirement	χ	5.60%	2014–19 avg. required reserves/trans. balances
Interest rate on reserves	i_r	1.02%	2014–19 avg. IORR
Cost of handling deposits	c	0.02	Avg. operating cost per dollar asset 2.02%
Gross money growth rate	μ	1.0152	2014–19 avg. annual inflation 1.52%
Frac. of type 1 trades	ω_1	4.58%	SCPC 2016
Frac. of type 2 trades	ω_2	26.44%	SCPC 2016
Frac. of type 3 trades	ω_3	68.98%	SCPC 2016
Calibrated internally			
Prob. of DM trading	Ω	0.56	Money demand 1987-2008
Coeff. on CM consumption	B	2.09	Money demand 1987-2008
Curv. of DM consumption	σ	1.31	Money demand 1987-2008
Total factor productivity	A	1.51	Rate on transaction accounts 0.3049%
Number of banks	N	26	Spread b/w transaction accounts and loans 3.39%
Buyer's bargaining power	θ	0.9923	Retailer markup 20%

Table 1: Calibration Results

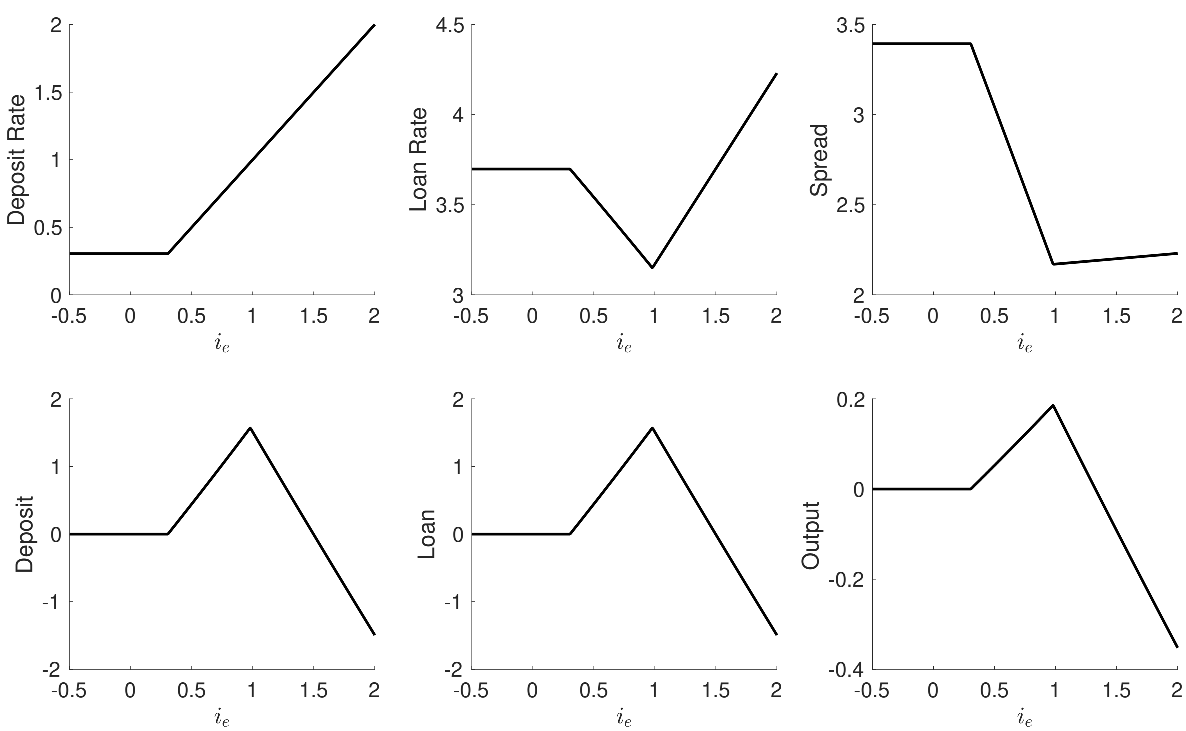


Figure 4: Effects of the Interest Rate on CBDC

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Once i_e exceeds 0.30%, the CBDC rate becomes an effective floor of the deposit rate, and from that point on the deposit rate follows the 45^o line. As i_e and the deposit rate increase, total checkable deposits increase as long as banks make positive profits. At $i_e = 0.98\%$, a bank's profit becomes zero, and the checkable deposits reach their maximum. After that, a further increase in i_e leads to a reduction in checkable deposits. To break even with a higher deposit rate, banks must raise their lending rates, which reduces the loan demand and hence the deposit supply. The effect on loan quantity is the same as the effect on deposits. Because a higher loan supply reduces the loan rate, the loan rate first decreases and then increases with i_e. From Figure 4, if the CBDC rate is between 0.30% and 1.49%, then the CBDC increases both deposits and loans compared to the equilibrium without a CBDC. At the maximum, the CBDC increases checkable deposits and loans by 1.57% and reduces the loan rate to around 3.10% from about 3.70%.

We next focus on the spread. The CBDC competes with checkable deposits, and a higher CBDC rate reduces the spread as long as banks make positive profits. If i_e is sufficiently high, then banks earn zero profits and the spread starts to increase. Intuitively, as the CBDC rate increases, the interest rate on deposits increases. Because of the reserve requirement, a bank can lend only a fraction of its deposits. Therefore, the loan rate must increase even more to compensate for the increase in the deposit rate, explaining the increasing segment of the spread curve.

Lastly, we move to output.[14] The pattern is qualitatively similar to that of loans: as i_e increases, the total output first increases and then decreases. Quantitatively, the expansionary effect on output is more modest relative to lending, because of the diminishing return in production. Introducing a CBDC increases the total output (relative to the case without a CBDC) if $i_e \in (0.30\%, 1.32\%)$. The highest increase in output is 0.19%, which is achieved at $i_e = 0.98\%$.

5 Conclusion

This paper develops a model with imperfect competition in the deposit market to analyze whether introducing a CBDC would cause disintermediation in the banking sector. We show that, contrary to the common wisdom, a CBDC can promote bank intermediation. Intuitively, if banks have market power, they restrict the deposit supply to lower the deposit rate. An interest-bearing

[14]The steady state output aggregates consumption and investment in the DM and the CM:

$$\mathbf{Y} = \sum_{j=1}^{3} \alpha_j P(y_j) + 2B + R_r(D - L) + AL^\eta - R_d D + L.$$

The first two terms are households consumption in the DM and CM, respectively. DM consumption is measured by real payments in terms of CM goods. The third, fourth and fifth terms together measure the CM consumption of old bankers and old entrepreneurs. It equals revenue from reserves (the third term) and production (the fourth term) subtracted by repayment of deposits plus interest (the fifth term). The last term is investment by young entrepreneurs. The net consumption of government is zero.

CBDC introduces more competition, which leads to more deposits and lending, and a lower loan rate. However, greater intermediation arises only if the interest rate on the CBDC lies in some intermediate range. If the CBDC rate is too low, then the CBDC does not affect the equilibrium. If the CBDC rate is too high, disintermediation occurs.

Appendix

Proof of Proposition 1. The bank's choice of checkable deposits solves:

$$\max_{d_j} \left[\xi - \hat{\mathbf{R}}_d(D_{-j} + d_j)\right] d_j.$$

First, suppose $\xi < 1/\beta$, which occurs if $\chi > 1$ or $R_\ell < 1/\beta$. Focus the case where $D_{-j} + d_j < \beta y^*$ because banks make negative profit otherwise. By Assumption 1(a), this problem has a unique solution. It satisfies $\hat{\mathbf{R}}_d'(D_{-j} + d_j)\, d_j + \hat{\mathbf{R}}_d(D_{-j} + d_j) = \xi$. Then the symmetric pure strategy Nash equilibrium d must satisfy (13). Because $\hat{\mathbf{R}}_d'$ is positive and $\hat{\mathbf{R}}_d(\beta y^*) = 1/\beta > \xi$, $\hat{\mathbf{R}}_d'(Nd)\, d + \hat{\mathbf{R}}_d(Nd) > \xi$ if d is slightly smaller than $\beta y^*/N$. By Assumption 1, equation (13) has a unique solution, which is increasing in ξ and hence increasing in R_ℓ. Next, we show that there is a solution to (13) on $[0, \beta y^*)$ if $\xi = 1/\beta$. Let ξ_n be an increasing sequence that converges to $1/\beta$ and d_n be the solution to (13) if $\xi = \xi_n$. Then d_n is the Cournot equilibrium supply of checkable deposits if $\xi = \xi_n$. Let $\tilde{d} = \lim_n d_n \le \beta y^*/N$. We show that $\tilde{d} < \beta y^*/N$ and therefore solves (13) under $\xi = 1/\beta$ by continuity. Suppose towards contradiction $\tilde{d} = \beta y^*/N$. Then a bank's profit under ξ_n is $[\xi_n - \hat{\mathbf{R}}_d(Nd_n)]d_n$, which converges to 0 because d_n converges to $\beta y^*/N$ and ξ_n converges to $1/\beta$. But if a bank unilaterally deviate to $d_n/2$, its profit is $[\xi_n - \hat{\mathbf{R}}((N-1/2)d_n)]d_n$, which converges to $[1/\beta - \hat{\mathbf{R}}((N-1/2)\beta y^*/N)]y^*/2N > 0$. This implies that for n sufficiently large, a bank can choose $d_n/2$ and gets a higher profit. Therefore, d_n cannot be an equilibrium. This leads to a contradiction. As a result, $\tilde{d} < \beta y^*/N$ and solves (13) if $\xi = 1/\beta$. ■

Proof of Proposition 2. We only prove the third branch of (14), which says $\mathbf{d}(R_\ell) = d_e > \hat{\mathbf{d}}(R_\ell)$ if $\underline{R}_\ell < R_\ell < \bar{R}_\ell$. The other branches are obvious. First, if the total supply of checkable deposits D is lower than $Nd_e = D_e$, then increasing d_j does not change the real gross rate of deposits, which is fixed at R_e. The first-order derivative of (11) with respect to d_j is $\xi - R_e$, which is positive if $R_\ell > \underline{R}_\ell$ by the definition of $\underline{R}_\ell$. Therefore, bank j can always increase its profit by increasing d_j. Second, by the definition of $\bar{R}_\ell$, if $R_\ell = \bar{R}_\ell$, then $\hat{\mathbf{R}}_d(D_e) + \hat{\mathbf{R}}_d'(D_e)\frac{D_e}{N} = \xi$. Therefore, by Assumption 1, the marginal profit of a bank $\xi - \hat{\mathbf{R}}_d(D) - \hat{\mathbf{R}}_d'(D)\frac{D}{N} < 0$ for all $D > D_e$ and $R_\ell < \bar{R}_\ell$. It is profitable for a bank to reduce its supply of deposit if $D > D_e$. Combining both arguments, banks supply D_e checkable deposits in total and $\mathbf{d}(R_\ell) = d_e$ by symmetry. ■

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