Central Bank Digital Currency: Will Banks Survive?*

Sergey Sarkisyan†

August 27, 2022

Abstract

Will an introduction of CBDC cause disintermediation? I provide empirical and theoretical evidence that CBDC will not necessarily crowd out bank deposits in economies with significant demand for currency. I estimate the model for the US using data on households' payment choices and find that non-interest-bearing CBDC will lead instead to an inflow of deposits caused by cash substitution. Banks then lower deposit rates and lend more. Similarly, banks will not contract lending if CBDC is intermediated even if they experience an outflow of deposits. Finally, I show that CBDC can lead to disintermediation when it is interest-bearing.

Keywords: Central bank digital currency, demand for currency, intermediation, financial stability

JEL Codes: E41, E51, E58, G21

1 Introduction

Central Bank Digital Currency (CBDC) is a digital form of fiat currency available to general public that is currently being considered by 90% central banks in the world.[1] The goal is to make cash payments more efficient, enhance inclusivity, and re-establish the role of central bank money in the era of diminishing demand for cash. The main concern

*I am grateful for outstanding guidance and support from my advisors João Gomes and Yao Zeng. I thank Mike Schwert for extremely insightful discussions and advice. I thank Sylvain Catherine, Winston Dou, Vadim Elenev, Jesús Fernández-Villaverde, Itay Goldstein, Urban Jermann, Tim Landvoigt, Marco Di Maggio, Abdou Ndiaye, Chisom Onyishi, Cameron Peng, Tom Sargent, and Luke Taylor for helpful suggestions.

†Department of Finance, Wharton School, University of Pennsylvania.
E-mail address: sesar@wharton.upenn.edu

[1] See https://cbdctracker.org

remains financial stability – the introduction of CBDC may lead to disintermediation. In this paper, I explore conditions under which CBDC leads to an outflow of deposits and consequent contraction in lending. I provide both theoretical and empirical evidence that CBDC should not necessarily lead to disintermediation in economies with existing demand for cash (such as the US).

I first describe the proposed designs of CBDC and the current state of policy research. Digital currency can in theory pay interest. It will then act as a narrow bank – deposits parked at the central bank. The primary advantage then is the possibility of negative interest rates. However, most policymakers suggest that CBDC will not pay any interest to prevent significant crowding-out of bank deposits. CBDC can be wholesale (i.e., available to financial institutions only) or retail (i.e., available to households). In this paper, I will focus on the retail CBDC. Finally, CBDC can be direct (i.e., directly delivered to households by the central bank) or intermediated (i.e., delivered through commercial banks). In the case of intermediated CBDC, the main advantage of CBDC compared to deposits is 100% insurance.

I start by showing that the CBDC introduction has not caused disintermediation in countries where it is already used. I hand-collect banking and financial data from Nigeria and the Bahamas. The countries introduced CBDC in 2020 and 2021, respectively. The Bahamian CBDC (Sand Dollar) is direct and non-interest-bearing. The Nigerian digital currency (e-Naira) is intermediated and non-interest-bearing. I provide descriptive evidence that there wasn't any outflow of deposits in both countries. In fact, for Nigerian banks, the deposits-to-assets ratio significantly increased since the CBDC was introduced. It is important to mention that both Nigeria and the Bahamas are developing countries with high demand for cash. The effects can be dramatically different in cash-less economies such as Sweden because the only legal tender that households can substitute for there is bank deposits.

Next, I propose a three-period general equilibrium model to study how the introduction of CBDC impacts deposit demand, deposit and loan rates, and lending. Households derive utility from consumption and money, i.e., cash and deposits. Each period they choose how much to consume and how much to invest in three assets – cash, deposits, and government bonds. Deposits and bonds pay interest, but cash is more convenient. Moreover, every period there is a probability that households will need cash. The conversion of deposits to cash incurs costs. For example, if you end up in a store that only accepts cash (a common thing in the US), you will need to find ATM and withdraw cash. Banks operate in monopolistically competitive deposit markets, so they choose deposit rates, loan amounts, reserves, and equity issuance subject to deposit demand, balance sheet, reserve requirement, and occasionally binding leverage constraint. Finally, loan rates are determined in the perfectly competitive market where non-financial firms borrow to finance their investments.

CBDC is introduced in the second period. I define an introduction of CBDC as a change in two parameters – the convenience of cash and costs of conversion. First, digital currency makes cash (both physical and digital) more convenient since it is not only widely accepted but also stored digitally. Second, it is less costly to convert deposits to CBDC than to physical currency. For example, in Nigeria and the Bahamas, bank accounts are directly connected to the CBDC wallet and conversion takes a few seconds on the phone. If CBDC is intermediated, the conversion costs are the lowest – it happens directly through the mobile bank.

I find that the increase in convenience leads to an outflow of deposits but the decline in conversion costs leads to an inflow of deposits. If the latter effect dominates, the CBDC introduction will lead have a crowding-in effect. The conversion channel is likely to dominate in countries with significant demand for cash. The United States is one example of such countries. In countries like Sweden, the convenience of cash is low, and cards are accepted everywhere, hence, the convenience channel will dominate.

In response to an outflow of deposits, banks increase deposit rates. However, the pass-through to the loan rates is not complete. If equity issuance costs are low and leverage constraint is non-binding, monopolistic banks will choose to issue more equity to compensate for the loss in deposits. I find that after a certain point, banks stop issuing equity and contract lending thus causing loan rates to rise. Hence, even if the CBDC introduction leads to an outflow of deposits, banks do not experience losses if they are not financially constrained, have deposit market power, and equity issuance costs are low. If an introduction of CBDC leads to an inflow of deposits, financially unconstrained banks decrease interest rates and lend more. Financially constrained banks do the same unless equity issuance costs are too large. This is because according to Basel leverage regulations, a reduction in deposit rates makes banks more leveraged – hence, they might need to expand assets and compensate them by issuing more equity.

Finally, if CBDC pays interest, it leads to an outflow of deposits through the convenience channel. It is especially relevant in the current state because major banks in the US keep deposit rates close to zero. Hence, even low CBDC rates would make banks increase deposit rates significantly to compensate households for the inconvenience and maintain deposit demand. This is in line with the Fed's concerns regarding the idea of the Narrow Bank (TNB) and the Chicago plan.

The three-period model provides a clear economic intuition on how an introduction of CBDC can change intermediation. However, financial constraints do not matter when the number of periods is so small. I extend the model to a full dynamic stochastic general equilibrium model. The solution is complicated by the presence of the occasionally binding leverage constraint. I use the Guerrieri and Iacoviello (2015) method to obtain a local solution. I estimate and calibrate the model using survey data on the US households' payment preferences and macroeconomic data on currency and checking deposits circulation and consumption.

I confirm that the introduction of CBDC has a two-fold effect on deposits. On the one hand, the increased attractiveness of cash makes households demand fewer deposits. On the other hand, households do not need to have cash if costs of conversion are low. The latter effect dominates the former in most calibration scenarios if the probability of needing cash is high. Specifically, for the US estimation and calibration, I find that

CBDC leads to an inflow of deposits. I also show that following an outflow of deposits, banks issue more equity. Hence, the impact of loans is not as dramatic as it could be if banks could not issue equity.

To illustrate that the concerns of policymakers are relevant, I consider two extreme cases – the 'Sweden' case of low cash demand and the high equity issuance cost case. I show that in Sweden, the introduction of CBDC will likely lead to an outflow of deposits because households almost do not use cash. With high equity issuance, banks are not able to issue more equity to compensate for an outflow of deposits, so loan contraction is larger.

Overall, I provide both empirical and theoretical evidence that CBDC can lead to an inflow of deposits in economies with existing demand for cash including the United States. Moreover, I show that even if CBDC leads to an outflow of deposits, lending and investments do not need to shrink dramatically if banks have deposit market power, equity issuance costs are low, and banks are not financially constrained. I also consider two extensions. First, I show that if CBDC pays interest, the crowding-out effect is stronger. The reason is that interest-bearing CBDC has an additional advantage – it increases households' income. Hence, policymakers' suggestions to pay interest on CBDC might lead to an elevated fragility. Second, I show that if CBDC is intermediated, i.e., delivered through banks, lending does not decline at all. This is because banks pariticipate in delivering CBDC and thus acquire additional funds to finance lending.

I contribute to the growing literature on CBDC. Keister and Sanches (2019) claims that an introduction of CBDC can lead to an outflow of deposits but it can be mitigated if CBDC could be targeted to be either cash-like or deposit-like. Andolfatto (2020) shows that CBDC should not necessarily lead to disintermediation but banks will sacrifice their monopoly power. Brunnermeier and Niepelt (2019) claim the irrelevance between public and private money because central banks can always bail banks out. Whited et al. (2022) shows that an outflow of deposits should not necessarily lead to a contraction in lending in frictionless economies, but it does if wholesale funding is associated with default risks. Schilling et al. (2021) show that when central banks that introduce CBDC set goals to avoid bank runs, achieve an efficient allocation, and keep prices stable, they can achieve the utmost two goals. Agur et al. (2022); Chiu et al. (2019) come close to my questions and show how the impact of CBDC will be different if the design is cash-like or deposit-like, but the former paper focuses on anonymity and security and the latter one focuses on interest-bearing CBDC designs. Finally, several papers show that CBDC introduction will have consequences for monetary policy (Garratt et al. (2022)), cross-border payments (Ferrari Minesso et al. (2022)), and stablecoins (Cong and Mayer (2022)). The advantage of my paper is two-fold. First, I introduce cash and do not assume that it is costless to convert deposits to cash. Second, I consider an interaction between market power, equity issuance, and occasionally binding leverage constraints and show that banks can partly finance their loans by equity when they lose deposits.

The paper also contributes to the literature on the impact of central bank policy on banks. Monetary policy transmits to lending and investments through different banking channels, including reserves, capital, and deposits (Bernanke and Blinder (1988, 1992); Kashyap and Stein (2000); Bolton and Freixas (2000); Brunnermeier and Sannikov (2014); Drechsler et al. (2017, 2021); Sarkisyan and Viratyosin (2022)). Central banks can also impact banks and hence, welfare through capital and leverage regulations (Van den Heuvel (2008); Begenau (2020); Elenev et al. (2021); Begenau and Landvoigt (2022)). I show that central bank can have an immense role on the economy and welfare by introducing its digital currency.

Finally, the paper contributes to the general equilibrium models. I use local perturbation methods applied to the model with occasionally binding constraints, similar as in Guerrieri and Iacoviello (2015, 2017). This is more tractable, although less precise, than global methods such as used by Elenev et al. (2021). Moreover, I estimate households' side of the model using US data on payment choices to make predictions about the United States. Strutural estimation of the banking CBDC model has also been made in Whited et al. (2022) – I contribute by estimating the household side of the model and showing that the assumption of crowding out effect is at least uncertain.

The rest of the paper proceeds as follows. Section 2 describes the institutional background and provided details on important definitions and milestones. I provide empirical evidence from Nigeria and the Bahamas in Section 3. Section 4 sets up the three-period general equilibrium model and shows its main results. Section 5 extends the model to the fully dynamic case and shows simulation results. Section 6 considers important extensions. Finally, Section 7 concludes.

2 Institutional background

The role of cash is declining. Since 2000 households in most developed countries contracted their demand for cash. See Figure INSERT. In certain countries, cash demand has become very close to zero (e.g. Sweden and Denmark). That is why most central banks in the world seek to develop a digital analog of cash – Central Bank Digital Currency (CBDC).

CBDC is supposed to be a legal tender and has similar properties to cash. It will also share certain properties with dollar-denominated stablecoins such as USDT. For example, according to technical reports (Duffie et al. (2021)), CBDC will operate on distributed ledger technology (DLT). One possibility is the Ethereum blockchain – it does not belong to the government, but it provides full anonymity. Another possibility is to use other private blockchain technologies. For example, R3 Corda provided the technology for the Canadian CBDC pilot *Jasper*. Finally, governments can create their own blockchains or simply distribute CBDC as deposits parked at the central bank, but Fed acknowledges that it is not feasible.[2]

Policymakers argue that CBDC may pay interest, i.e. be *interest-bearing*. In that case, CBDC will be analogous to the *narrow bank*. The narrow banking idea is not new, and it has been proposed in 1933 – the Chicago plan. The narrow bank operates as other

[2]For the full Fed paper, see https://www.federalreserve.gov/publications/files/money-and-payments-20220120.pdf

commercial banks but with one important difference – 100% of its assets are central bank reserves. In other words, narrow banking provides households an opportunity to deposit funds directly in the central bank. The last narrow banking proposal in the US has failed and resulted in The Narrow Bank (TNB) suing Fed. Fed in turn announced that they would not pay interest in TNB reserves.[3] The main concern is that narrow banking would lead to an outflow of deposits. Hence, the opponents of the interest-bearing CBDC share analogous concerns.

Nevertheless, interest-bearing CBDC may allow breaking the zero-lower bound (ZLB). With physical cash or non-interest-bearing CBDC, it is not possible. If Fed decides to reduce interest rates to negative 3%, households will choose to hold cash that pays 0%. Then, the demand for deposits will shrink and interest rates will rise back to 0%. However, multiple papers show that it is inefficient because ZLB forces central banks to conduct unconventional monetary policy which might be less efficient (Kuttner (2001); Gurkaynak et al. (2005); Inoue and Rossi (2021).

CBDC can be wholesale or retail. Wholesale CBDC is available only to financial institutions. The goal is to simplify cross-border and inter-bank payments. However, in the US wholesale CBDC would not add a lot of value since technologies like Fedwire and FedNOW are actively developing. France and Canada have tested wholesale CBDC and claimed that it is welfare-improving for their economies. Retail CBDC is accessible to households. In this paper, I focus only on the retail CBDC.

Finally, CBDC design should specify how it is delivered. One possibility is to deliver it directly to households. Central banks should either develop or partner with applications that allow households to set up digital wallets. Then households can make payments using the wallet. For example, the Bahamas launched a direct non-interest-bearing CBDC – Sand Dollar. The main advantage is financial inclusion – it is possible to use even if you do not have a Bahamian bank account. Unbanked users have a daily limit of $500 but otherwise, all functions are available.

[3]See https://www.federalreserve.gov/newsevents/pressreleases/bcreg20190306a.htm

CBDC can be intermediated. It means that households can access CBDC through their bank accounts. It is still possible for unbanked people to use CBDC but they would need to contact a bank anyway. Commercial banks have a relative advantage in intermediating funds; hence, it should be more efficient for the central bank to delegate the function to the banks. The disadvantage is the data. In the case of the intermediated CBDC, the data are collected by the commercial banks – similar to the current reserve-deposits intermediation. However, a *hybrid* CBDC is proposed, so banks act as conduits to deliver CBDC but the data are collected by the central bank.

An intermediated non-interest-bearing CBDC has been launched in Nigeria – e-Naira. Households need to download the application, register through their bank, and then pay using the QR code. Given that banks directly participate in the CBDC introduction, the effects are different from the ones in the Bahamas. I will examine both countries in the next section.

3 Empirical evidence

Most central banks have not yet developed their CBDC. Only two countries have launched one. The Bahamas became the first country to make its CBDC a legal tender in 2021. The second country is Nigeria. Several East Caribbean countries have launched CBDC in 2022. A few countries, including Uruguay, Canada, and China have developed CBDC pilots and conducted stress tests. Other countries are still at either the research or proof of concept stage. Hence, we still have very few data points to analyze the consequences of the introduction of CBDC. In this section, I provide a survey, graphical, and statistical evidence on how CBDC impacted economies and household behavior in the Bahamas and Nigeria. I first describe the data collection process, then present the findings.

3.1 Data

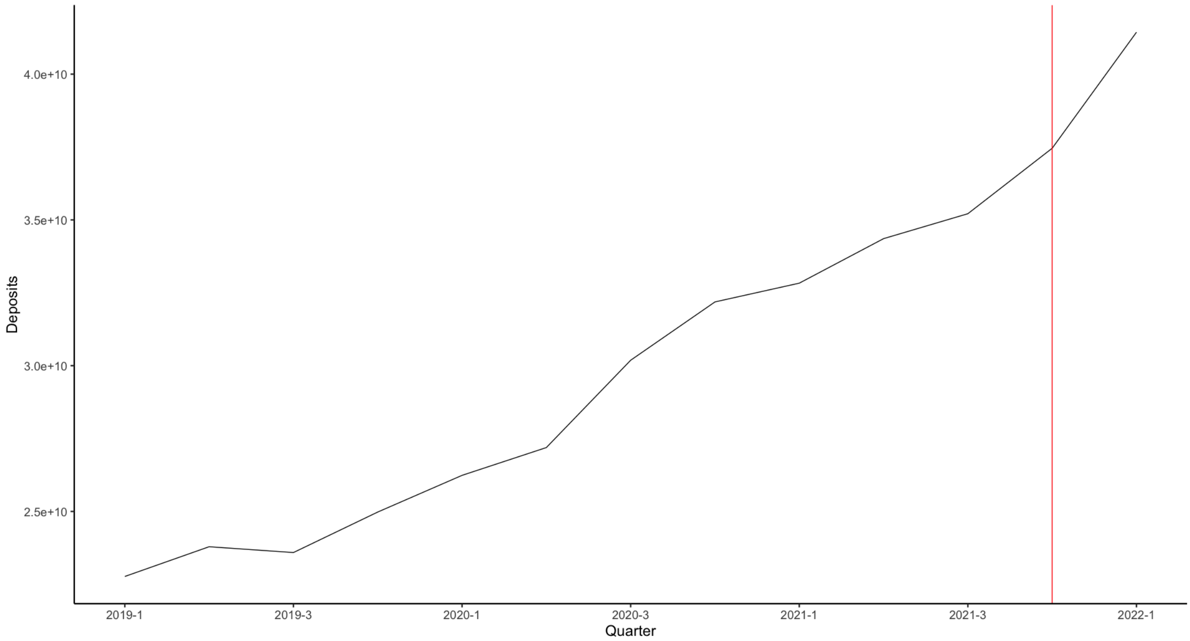
I hand-collect banking data from Nigeria and the Bahamas. Nigeria has 20 commercial banks, and all of them distribute CBDC. There are quarterly financial reports available for the post-CBDC period for 9 of them – Access Bank, Ecobank Nigeria, Fidelity Bank, Guarantee Trust Bank, Stanbic IBTC, Union Bank of Nigeria, United Bank for Africa, Wema Bank, and Zenith Bank. I collect assets, deposits, loans, retained earnings, derivative holdings, cash, reserves, and investment securities from 2018 to current. I do the same data collection for the Bahamas. The Bahamian sample covers 6 commercial banks.

In Nigeria, using CBDC is straightforward. The Central Bank of Nigeria (CBN) launched the wallet app to hold e-Naira. Customers should register through their bank. It is also possible to register as a merchant to accept CBDC in the store. Unbanked customers can use e-Naira as well but they have daily limits depending on their credit score. To accept e-Naira in stores it is enough to have the app installed and connected to the bank account. As CBDC is distributed through banks and banks get fees from the government for transmitting it, they have incentives to advertise e-Naira.

In the Bahamas, CBDC is direct. It is transmitted through authorized applications such as SunCash and IslandPay. As of now, it is only possible to pay with Sand Dollar if the receiver also has one of the authorized applications. Hence, the process in the Bahamas is not centralized. It is also costly for unbanked users since they can only open accounts in some of the apps and only by physically going to the ATM. However, IslandPay is going to issue Sand dollar debit cards. They will work as standard debit cards but with Sand dollars instead of checking deposits. It is not clear yet if the government will assume liability for commission fees charged by Visa and MasterCard.

In addition to the banking data, I conduct a small-scale field survey in the Bahamas to collect data on households' perceptions of the CBDC. I asked people if they have ever heard of the 'sand dollar', 'digital dollar', or 'CBDC'. If yes, I asked if they are using it. If yes, I asked if they started using sand dollars instead of cash or deposits. I also

Figure 1: Deposits in Nigerian Banks



Note: Source: data is from the financial reports of 9 commercial banks operating in Nigeria.

surveyed 10 merchants in different districts (both touristic and non-touristic) in the two largest cities in the Bahamas – Nassau and Freeport. I asked them if they accepted sand dollars. If they do, I asked how I can pay with it.

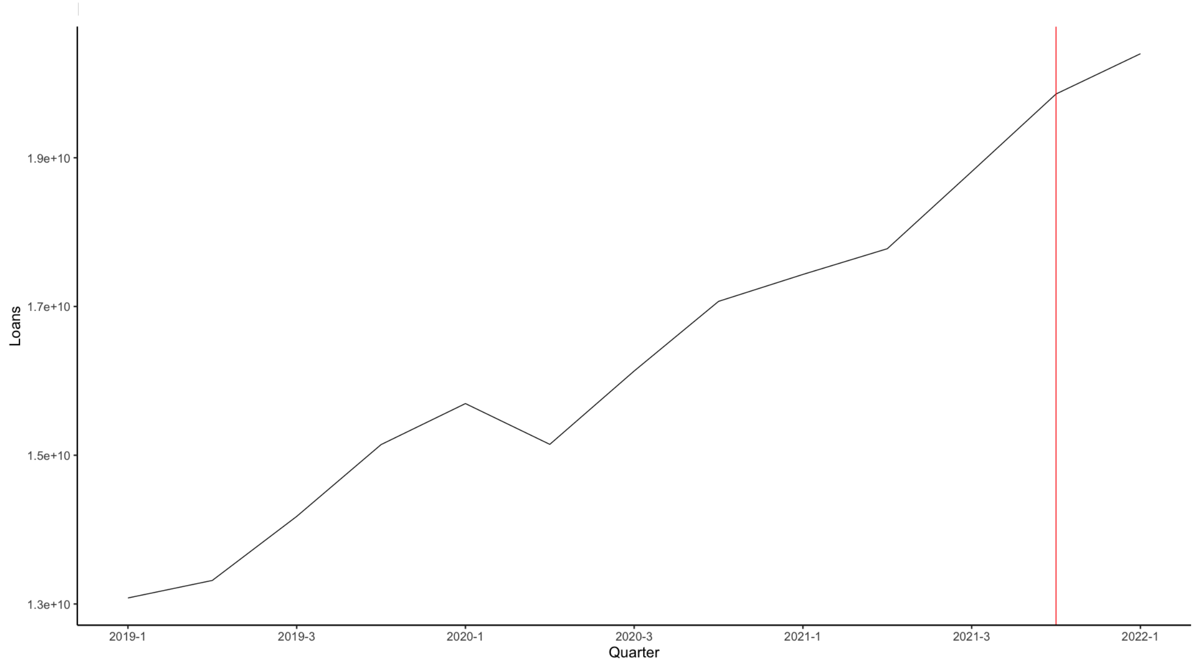
Finally, I look at Google searched in the Bahamas and Nigeria. Specifically, I use Google Trends to see how many times the words 'CBDC', 'digital currency', 'sand dollar', and 'e-Naira' have been searched online in the Bahamas and Nigeria. Two countries are comparable – not rich and with emerging economies. Nigeria is more advanced in terms of IT, but the Bahamas attracts more tourists and immigrants.

3.2 Results

Nigerian e-Naira has been launched in October 2021. Sand Dollar was introduced in October 2020. I analyze deposits, loans, and deposits-to-assets ratios in Nigerian and Bahamian banks before and after October 2021 and 2020, respectively.

Figure 1 shows deposits in Nigerian commercial banks from 2019 till current. It

Figure 2: Loans in Nigerian Banks



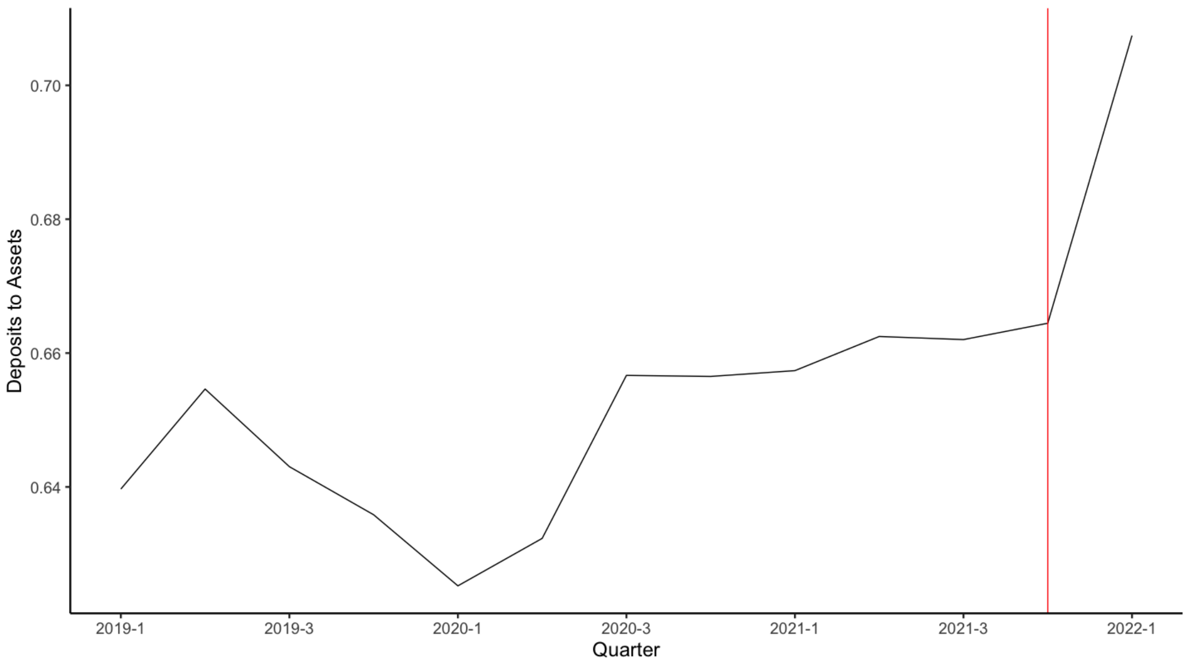
Note: Source: data is from the financial reports of 9 commercial banks operating in Nigeria.

is clear that deposits didn't shrink. Moreover, deposit growth increased. The mean after October 2021 is significantly higher than the mean before. The most worrisome consequence of an outflow of deposits is a contraction in lending. Figure 2 shows that there has not been any contraction in lending in Nigeria.

One can worry that an increase in deposits is explained by high levels of inflation in Nigeria – In 2021 it peaked at 20%. First, inflation since June 2021 has been steadily declining. It cannot be explained by changing interest rates either – the CBN policy rate did not change in 2021. Finally, even if inflation has caused movements in deposits, it should not impact the deposits-to-assets ratio. Figure 3 shows that deposits spiked relative to assets of commercial banks. Regressions also confirm that the deposit-to-asset ratio in commercial banks has increased since October 2021.

I acknowledge that it is hard to provide causal evidence since little time has passed. Also, Nigeria and the Bahamas are countries with a low financial literacy ratio. Both countries are hard to compare to the US or Europe. This is a serious external validity

Figure 3: Deposits-to-assets in Nigerian Banks



Note: Source: data is from the financial reports of 9 commercial banks operating in Nigeria.

concern. However, the analysis above shows that the slow introduction of non-interest-bearing CBDC, preferably through banks doesn't lead to an outflow of deposits.

I also collect field survey data from the two largest cities in the Bahamas – Nassau and Freeport. When I asked people if they knew about the Sand Dollar, 50% of respondents said 'yes'. 90% of people in the high-income group (based on occupation) knew about the Sand Dollar. Among those who said 'yes', less than 10% used the Sand Dollar. All of them used it for work – to receive payments in the restaurant or for delivery. None of the respondents claimed to liquidate deposits to use CBDC. Among the reasons not to use CBDC, people mentioned that it was new and not widely accepted and that they trusted banks and cash more. Some people heard about the Sand Dollar but did not know that it has already been launched. It indicated that poor promotion might be the main reason for CBDC's unpopularity.

Finally, I surveyed 10 merchants in Nassau and Freeport. They include restaurants, hotels, taxis, delivery services, airports, and grocery stores. 8 out of 10 merchants do not accept CBDC payments. The Nassau Airport and online delivery service accepted CBDC. Overall, CBDC is not yet popular in the Bahamas. It is not widely accepted, and most people do not know about it or have never used it. The results are consistent with the banking data – there was no impact on deposits or deposit-to-assets ratio in the Bahamas after the introduction of CBDC.

The evidence above is consistent with the Google searches. In the Bahamas, people searched CBDC online only around the time when it was introduced. Since then, Google searches are as low as before. The situation is dramatically different in Nigeria – since the CBDC has been introduced, people google it a lot. Hence, I hypothesize that the intermediated CBDC is easier to promote than the direct one.

The evidence in this section suggests that CBDC should not necessarily lead to an outflow of deposits in economies with significant demand for cash. If it is intermediated, it incentivizes people (especially unbanked) to increase their deposit demand to use CBDC. In developing countries, CBDC may not cause any changes to the deposit demand since it becomes popular slowly. I aim to capture several of the facts in the dynamic general equilibrium model in the next two sections.

4 Three-period model

The model has 4 agents – households, banks, firms, and the central bank. The model has three periods. In period $t = 0$ households are born with an initial endowment. They decide on their portfolio and consumption. Monopolistic banks in turn decide on deposit rates, loans, reserves, and equity. In $t = 1$ CBDC is introduced. In $t = 2$ households consume the rest of their holdings including banks' and firms' profits and die. I describe the problems of households and banks in detail. Firms and the central bank are trivial and required to pin down loan demand and bond issuance.

4.1 Households

There is a representative household that decides on consumption and its portfolio holdings. The portfolio consists of bank deposits, cash (or broadly public money including CBDC), and bonds. Every period households derive the utility

$$U_t = \log C_t + \omega \log M_t \tag{1}$$

where M_t is a stock of monetary goods that households hold:

$$M_t = [\theta Cash_t^{\rho} + D_t^{\rho}]^{1/\rho} \tag{2}$$

where D_t is deposits and θ shows the attractiveness of cash. Cash can be more attractive because it is safer and more widely accepted. The only inconvenience of cash is that it is usually not digital. Hence, if CBDC is introduced, θ increases. Households discount future utilities at the rate δ.

I relax two important assumptions made in the literature. First, it is not possible to pay with deposits ubiquitously. Each period, there is a probability η that households need cash. In the US η is non-zero but not high. In Sweden $\eta = 0$. In most developing countries η is high. This is the key parameter of the model. If households need cash, they have to withdraw deposits. Therefore, the second assumption that I relax is about the costs of converting deposits into cash. In the real economy, they are non-zero, since it at least requires finding ATM. I denote the share of deposits that households keep after conversion by ξ. It means that if households withdraw \$1 of deposits, they end up with \$$\xi$ of cash. Households also own firms and banks and earn interest on sovereign bonds and deposits. Their budget constraint in $t = 0, 1$ is

$$C_t + Cash_{t+1} + D_{t+1} + B_{t+1} = Y_t + Cash_t + D_t(1 + r_t^d)(1 - \eta(1 - \xi)) + B_t(1 + r_t^f) \tag{3}$$

where B_t is a sovereign bond holding, r_t^f is a risk-free rate, and Y_t is the rest of households' income, i.e., profits from firms and banks. In the terminal period, households consume the rest of their holdings.

In $t = 1$ CBDC is introduced. CBDC makes cash more attractive and more efficient at the same time. The latter means that it is cheaper to convert deposits into cash. This assumption is motivated by the policy papers describing how CBDC will work and by the experience of Nigeria and the Bahamas. In the model, CBDC introduction implies an increase in θ and an increase in ξ. When CBDC is intermediated, θ is the same as in the case with the direct CBDC, but ξ increases to reach 1.

I solve the model backwards using dynamic programming techniques. I start by solving for consumption at $t = 2$. It is straightforward since households consume everything that is left. I then use the solution to $t = 2$ and Euler equation to solve for $t = 1$ consumption and portfolio. I repeat the step to find the solution for $t = 0$. I do not provide full technical details with proofs here and leave them in the Online Appendix.

First, I use FOCs to derive cash-to-deposit and deposit-to-consumption ratios for $t = 1, 2$. Note that cash and deposits for $t = 2$ are decided at $t = 1$. I obtain the following ratios:

$$\frac{Cash_{t+1}}{D_{t+1}} = \theta^{\frac{1}{1-\rho}} \left(\frac{(r^f_{t+1} - r^d_{t+1}) + (1 + r^d_{t+1})\eta(1-\xi)}{r^f_{t+1}} \right)^{\frac{1}{1-\rho}} = \Gamma_{t+1} \tag{4}$$

$$\frac{D_{t+1}}{C_{t+1}} = \frac{\omega\theta}{r^f_{t+1}(\theta\Gamma_{t+1} + \Gamma^{1-\rho}_{t+1})} = \Theta_{t+1} \tag{5}$$

The choice between cash and deposits in the model trades off convenience, conversion costs, and interest rate. When deposit rates increase, the cash-to-deposit ratio declines, because deposits become more attractive. Similarly, when η increases, i.e., when it becomes harder or less convenient to pay with deposits, the cash-to-deposit ratio increases. The effects of the introduction of CBDC on cash-to-deposit ratio, deposit-to-consumption ratio, cash-to-consumption ratio, and bond demand are summarized in the Propositions 1 and 2.[4]

[4]Proofs of all propositions are in the Online Appendix that is available upon request.

Proposition 1 *Consider an introduction of CBDC at* $t = 1$ *that increases* θ*. Then, unconditionally, the following is true:*

1. *Cash-to-deposit ratio increases.*
2. *Cash-to-consumption ratio increases.*
3. *Deposit-to-consumption ratio decreases.*
4. *Bond demand decreases.*

Proposition 2 *Consider an introduction of CBDC at* $t = 1$ *that increases* ξ*. Then, unconditionally, the following is true:*

1. *Cash-to-deposit ratio decreases.*
2. *Cash-to-consumption ratio decreases.*
3. *Deposit-to-consumption ratio increases.*
4. *Bond demand increases.*

Proposition 1 shows that CBDC can lead to a decline in the demand for deposits relative to cash and consumption because public money becomes more convenient. It is the main banking-related concern regarding CBDC. However, the existence of cash in the model and frictions associated with its conversion lead to Proposition 1. It shows that CBDC can also lead to an increase in deposit demand relative to cash and consumption because it makes cash efficient. Without CBDC, households decide to hold cash because they may need it, and converting it from deposits is costly. With CBDC, converting is cheap, so households keep money in deposits to earn interest and if needed, they easily withdraw deposits to use cash.

To proceed further to monopolistic banks, we need to establish what is happening to deposits and consumption levels. The results are stated in Proposition 3.

Proposition 3 *Consider an introduction of CBDC at $t = 1$. Define the following variables:*

$$\Pi_2 = 1 - \Gamma_2\Theta_2 - \Theta_2 \tag{6}$$

$$I_{1,2} = (1 - \Gamma_1\Theta_1 - \Theta_1(1 + r_1^d)(1 - \eta(1 - \xi)))\frac{1}{\delta}\frac{1}{1 + r_2^f} + \Gamma_2\Theta_2 + \Theta_2 \tag{7}$$

Then, if

$$I_{1,2}(1 + r_2^f) + \Pi_2 < 0 \tag{8}$$

the following holds

1. *Increase in θ leads to a decrease in consumption and deposits.*

2. *Increase in ξ leads to an increase in consumption and deposits.*

Proposition 3 states the condition under which the introduction of CBDC can lead to both inflow and outflow of deposits. However, notice that the drop in consumption when θ increases are not counter-intuitive. Although households consume less, they derive more utility from monetary goods. Hence, they are still better off.

Condition (8) is not straightforward to interpret, so it is useful to analyze its comparative statics. For example, higher risk-free rates make the condition more likely to be satisfied. It is because of the decreasing marginal utility – for higher risk-free rates, households prefer bonds to consumption, so changes to preferences have a greater effect. Higher ω makes the condition less likely to be satisfied. It is because households value monetary goods more and when they want to increase either cash or deposit holdings, they will do it by reducing their bond demand. The condition also depends on other parameters of the model, but their impact is ambiguous. I discuss the sensitivity of the results to parameters in detail in Section 5.

An important question is which effect dominates. It depends on the calibration and is clearer in the dynamic model but some economic intuition can be discussed here. Let's consider Nigeria – economy with high η and potentially low ξ. In that economy, households initially hold more cash. Hence, decreasing marginal utility makes cash more substitutable. When ξ increases, households increase their deposit demand relative to cash more than they decrease it when θ increases, conditional on similar magnitudes. In other words, in economies like Nigeria, the crowding-in effect dominates. Now let us consider Sweden – the economy with $\eta = 0$. There ξ has no impact on portfolio allocations. Therefore, the introduction of CBDC inevitably leads to an outflow of deposits. Most papers in the literature abstract from either cash or cash frictions, hence, they consider Sweden, not Nigeria. The United States clearly has non-zero η (although lower than in Nigeria).[5] Hence, it is interesting to calibrate the model to the United States and see which effect dominates there. I elaborate more on this in Section 5.

The evidence in this subsection sheds new light on the impact of CBDC on deposit demand. When taking cash into account the introduction of CBDC may lead to an increase in deposit demand, because the costs of converting interest-bearing deposits into public money are low. Households then prefer to keep their money in deposits to earn interest and they withdraw at low costs when they need to pay in cash. The shortcoming of the model is assuming that CBDC and cash are equivalent except CBDC is more efficient. For example, it implies that CBDC is widely accepted. While it is unlikely to be true initially, CBDC doesn't require any complicated technologies and is not subject to surcharges. Hence, accepting CBDC should not be costly for merchants, especially in developed economies. I also assume that CBDC does not pay interest. I relax this assumption in Section 6.

4.2 Monopolistic banks

An important shortcoming of parts of the CBDC literature is assuming that banks are engaged in perfect competition. This inevitably makes them want more deposits to match leverage constraints. Their profits then shrink unless they are equal to zero. In this paper,

[5] According to San Francisco Fed 19% of transactions in the US in 2021 were done in cash. This is considering the COVID-19 pandemic that significantly reduced the usage of cash.

I model monopolistic banks to avoid this problem. To do that I follow Piazzesi et al. (2022) and Elenev et al. (2021). There is a representative 'retail' bank in the economy and a continuum $[0, 1]$ of 'wholesale' banks.[6] The retail bank takes deposits of wholesale banks as inputs and outputs aggregate deposits following Dixit-Stiglitz technology:

$$D_t = \left(\int_0^1 \left(D_t^i \right)^{1-1/\epsilon} \right)^{\frac{1}{1-1/\epsilon}} \tag{9}$$

The retail bank then sells deposits to households at interest r_d. The costs for households are alternatives – investing in bonds. Then, the demand for deposits of wholesale bank i is

$$D_t^i = \left(\frac{r_t^f - r_t^{di}}{r_t^f - r_t^d} \right)^{-\varepsilon} D_t \tag{10}$$

where $\varepsilon > 0$ is market power, r^{di} is a deposit rate set by bank i.

Each bank i sells one-period deposits to households at interest r^{di}, lends to firms at interest r^{ℓ}, and holds reserves that pay a risk-free rate. Banks also issue costly equity. Each period bank i's utility is

$$V_t = \psi(L_t + R_t - D_t^i) - E_t \tag{11}$$

where L_t is the amount lent, R_t are reserves, E_t is equity, and ψ is the share of profits that is paid to shareholders, i.e. to households.

Banks discount future profits at a rate δ. They choose a loan amount, reserves, and deposit rates for the next period and current equity to maximize their profits subject to (10) and three constraints below:

$$\begin{aligned} &(1-\psi)(L_t + R_t - D_t^i) + E_t - \Psi(E_t) \\ &\geq \frac{1}{1+r_{t+1}^{\ell}} L_{t+1} + \frac{1}{1+r_{t+1}^{f}} R_{t+1} - \frac{1}{1+r_{t+1}^{di}} D_{t+1}^i \end{aligned} \tag{12}$$

[6] I take 'retail' and 'wholesale' in quotes because an analogy with non-financial firms is not accurate. However, this way to model monopolistic banks is convenient.

$$\frac{1}{1+r^{di}_{t+1}}D^i_{t+1} \leq \xi^d \frac{1}{1+r^{\ell}_{t+1}}L_{t+1} \tag{13}$$

$$R_{t+1} \geq \xi^r D^i_{t+1} \tag{14}$$

where $\Psi(E_t)$ are quadratic equity issuance costs with parameter $\varphi_e > 0$.

Constraint (12) is a budget constraint of banks. It always binds in equilibrium. I denote the Lagrange multiplier for that constraint by λ_t. Constraint (13) is a Basel-type leverage constraint. It restricts the amount the banks can borrow. Pre-multiplying by prices is an accepted way to include risk weights to the constraint. Removing risk weights only strengthens all results of this paper. Notice that this constraint does not have to bind since banks do not choose deposits. It complicates the dynamic model in Section 5 but does not significantly change the three-period model. I denote the Lagrange multiplier by γ_t. The final constraint (14) is a standard reserve constraint. For this paper, I assume that this constraint always binds. I relax this assumption in 6. The Lagrange multiplier for this constraint is μ_t. For (13) we also have a complementarity slackness condition.

I solve banks' model backwards since in the last period they only issue equity. I consider two cases inherited from the households' problem. In equilibrium, all wholesale banks choose the same deposit rate, and hence, they end up getting the same number of deposits. Let's first consider the case when deposit demand declines after CBDC is introduced, i.e. D_2 drops. Then, regardless of whether the leverage constraint was binding before, it does not bind now. Hence, $\gamma = 0$. The following proposition states the main results:

Proposition 4 *Consider the case when the introduction of CBDC leads to an outflow of deposits. If equity issuance costs are not too high, i.e. if the following condition is satisfied*

$$(1-\varphi_e E_1)^2 > \frac{\varphi_e}{1+r_d} \tag{15}$$

then an outflow of deposits leads to

1. *An increase in deposit rates,*

2. *Increase in equity issuance as long as* (15) *is satisfied,*

3. *Decrease in lending but less than if* (15) *is not satisfied,*

4. *Increase in loan rates.*

Proposition 4 shows that the outflow of deposits does not need to lead to a dramatic contraction in lending if equity issuance costs are low. This is because banks do not like to contract lending since it would reduce profits. If they can find alternative funds to finance loans, they do it. This is reminiscent of Whited et al. (2022). They show similar results but instead of equity, they consider wholesale funds.

The outflow of deposits leads to an increase in deposit rates but only if equity issuance costs are not too high. If they are, banks would have to compensate for decreased risk on the balance sheet by contracting lending more. However, this is just a sufficient condition, not necessary. Equity issuance itself makes deposit rates increase through an elevated Lagrange multiplier. Increased deposit rates imply higher costs of funds. Hence, banks have to contract lending, and loan rates increase. This is the main concern associated with the introduction of CBDC. I show that the concern is justified but potentially exaggerated.

The results above rely on three important features of the model. The first is monopolistic competition. Banks choose rates, not deposits, so they do not have incentives to be fully leveraged. They also make monopolistic profits, so the pricing does not happen according to the zero-profit condition. The second is occasionally binding leverage constraint. Banks do not need to adjust risk-weighted loans to be equal to risk-weighted deposits. Finally, the third is equity issuance. If alternative sources of financing are ignored, banks would have to contract lending.

The second case has not yet been considered in the CBDC literature – inflow of deposits. Although it is not as worrisome as an outflow, it makes banks more leveraged and hence, riskier. The next proposition shows the results.

Proposition 5 *Consider the case when the introduction of CBDC leads to an inflow of deposits. If leverage constraint still does not bind,*

1. *Deposit rates decline,*

2. *Lending increases or stays unchanged,*

3. *Loan rates decline or stay unchanged,*

4. *Equity declines or stays unchanged*

If leverage constraint binds and equity issuance costs are not too high, i.e. if the following condition is satisfied

$$\frac{(1-\varphi_e E_1)^2}{\varphi_e} \cdot \frac{\lambda_1 - \gamma_1}{\lambda_1} \cdot \frac{(1+r^\ell)\xi^d}{1-(1+r^\ell)\xi^d} > \frac{1/\xi^d - 1}{1+r_d} \tag{16}$$

then an inflow of deposits leads to

1. *A decline in deposit rates,*

2. *Decrease in equity issuance as long as* (16) *is satisfied,*

3. *Increase in lending but less than if* (16) *is not satisfied,*

4. *Decline in loan rates.*

The facts above hold unconditionally if prices are not included in leverage constraints.

Proposition 5 shows the reverse of the case with deposit outflow but in this case, results are less dependent on the equity issuance costs. The condition (16) is also very likely to be satisfied since $\xi^d > 0.9$ in the US data. I elaborate more on the calibration in the next section.

The model also implicitly assumes that r^f is constant. I relax it in the next section by introducing the central bank. I also assume the lending demand function without loss of generality to draw conclusions regarding loan rates:

$$L_t = 1/(1+r_t^\ell)^2 \tag{17}$$

The three-period model in this section sheds new light on the introduction of CBDC and its impact on deposits and lending. Specifically, I show that CBDC does not have to lead to an outflow of deposits. It can result in an inflow of deposits in economies with significant demand for cash (such as the US). Even if CBDC does lead to an outflow of deposits, as long as equity issuance costs are low, banks can substitute lost funds with equity, and they do not have to contract lending. The three-period model is useful to understand the crucial economic mechanisms, but it is not enough to evaluate and quantify the long-term impact of CBDC introduction. I address this issue by proposing and solving a fully dynamic model in the next section.

5 Dynamic model

The three-period model nicely shows that CBDC does not need to lead to an outflow of deposits. The second result of the model is that even if banks lose deposits, they do not need to contract lending as long as they can issue equity instead. Three-period model by definition cannot show what happens to equity and lending in later periods. The full dynamic model allows doing that. Moreover, with many periods it is possible to introduce CBDC slowly to see how two effects on cash preferences and efficiency interact.

5.1 Model setup

The general equilibrium model is fully dynamic and stochastic. Main assumptions of the three-period model are held here as well. Namely, there are households, monopolistic banks, firms, and the government. There are two shocks in the economy – TFP and real interest rate. In addition to stochastic processes, there are two parameters, θ and ξ that change their values when CBDC is introduced.

5.1.1 Households

There is a representative household that chooses consumption C_t, deposits D_{t+1}, cash $Cash_{t+1}$, and bonds B_{t+1} to maximize its lifetime utility:

$$\max_{C_t, Cash_{t+1}, D_{t+1}, B_{t+1}} \sum_{s=0}^{\infty} \delta^s [\log C_{t+s} + \omega \log M_{t+s}] \tag{18}$$

where M_{t+1} is monetary good defined in (2). As before, households can use both deposits and cash to pay but there is a probability η that they are hit by the shock that requires them to pay in cash. If they need to pay in cash, they convert deposits into cash which incurs a cost $1-\xi$. Households' budget constraint is then

$$C_t + Cash_{t+1} + D_{t+1} + B_{t+1} = Y_t + Cash_t + D_t(1+r_t^d)(1-\eta(1-\xi)) + B_t(1+r_t^f) \tag{19}$$

where Y_t includes production by the firms' and bank's dividends.

The household side of the model is complicated because agents can invest in three assets. To simplify the problem, I normalize all variables including those from the banks' problem by bond level B_t. I define variable x_t as $\frac{X_t}{B_t}$. Then equation (18) can be rewritten as

$$c_t + cash_{t+1}b_{t+1} + d_{t+1}b_{t+1} + b_{t+1} = y_t + cash_t + d_t(1+r_t^d)(1-\eta(1-\xi)) + (1+r_t^f) \tag{20}$$

where $b_{t+1} = \frac{B_{t+1}}{B_t}$.

5.1.2 Monopolistic banks

Banking problem is fairly similar to the one in Section 4. To recall, there is a representative 'retail' bank in the economy and a continuum $[0,1]$ of 'wholesale' banks. The retail bank takes deposits of wholesale banks as inputs and outputs aggregate deposits following Dixit-Stiglitz technology:

$$D_t = \left(\int_0^1 \left(D_t^i \right)^{1-1/\epsilon} \right)^{\frac{1}{1-1/\epsilon}} \tag{21}$$

The retail bank then sells deposits to households at interest r_d. The costs for households are alternatives – investing in bonds. Then, the demand for deposits of wholesale bank i is

$$D_t^i = \left(\frac{r_t^f - r_t^{di}}{r_t^f - r_t^d} \right)^{-\varepsilon} D_t \tag{22}$$

where $\varepsilon > 0$ is market power, r^{di} is a deposit rate set by bank i.

Each bank i sells one-period deposits to households at interest r^{di}, lends to firms at interest r^{ℓ}, and holds reserves that pay a risk-free rate. Banks also issue costly equity. The Bellman equation for the wholesale bank is

$$v_t = \max_{\ell_{t+1}, e_t, r_{t+1}, r_{t+1}^{di}} \psi(\ell_t + r_t - d_t^i) - e_t + \delta \mathbb{E}_t v_{t+1} \tag{23}$$

Banks maximize their value subject to (22) and the following constraints:

$$\begin{aligned} &(1-\psi)(\ell_t + r_t - d_t^i) + e_t - \Psi(e_t) \\ &\geq \frac{1}{1+r_{t+1}^{\ell}} \ell_{t+1} + \frac{1}{1+r_{t+1}^{f}} r_{t+1} - \frac{1}{1+r_{t+1}^{di}} d_{t+1}^i \end{aligned} \tag{24}$$

$$\frac{1}{1+r_{t+1}^{di}} d_{t+1}^i \leq \xi^d \frac{1}{1+r_{t+1}^{\ell}} \ell_{t+1} \tag{25}$$

$$r_{t+1} \geq \xi^r d_{t+1}^i \tag{26}$$

where all parameters and functions are defined in Section 4. As before, constraints (24) and (25) do not have to bind.[7] I assume that the reserve constraint is always binding and relax this assumption in Section 6.

[7] Note that (24) always binds in equilibrium.

5.1.3 Firms and government

Non-financial firms in the model are trivial. They borrow from banks in the perfectly competitive market and use loans to produce. The loan demand function is (17). Firms' production[8] is

$$z_t = A_t \ell_t \tag{27}$$

where A_t is the aggregate total factor productivity that follows AR(1) process:

$$\log(A_t) = \rho_a \log(A_{t-1}) + \sigma_a \epsilon_t \tag{28}$$

where ϵ_t is standard normal TFP shock.

The central bank decides on the bond issuance. I assume that the risk-free rate follows the feedback rule that depends on bond growth:

$$\log(1 + r_t^f) = (1 - \rho_f) \log(1/\delta) + \rho_f \log(1 + r_{t-1}^f) + \log(b_t) + \sigma_f u_t \tag{29}$$

where u_t is a standard normal monetary shock.

5.2 Solution technique and calibration

I aim to solve the model locally around deterministic steady-state. The local solution is significantly complicated by the presence of an occasionally binding constraint (25). Since it does not bind in all states of the world but binds in a steady-state the local approximation is not smooth. Perturbation methods require smooth behavior around steady-state, so it is not possible to use them.

To understand the problem better let us consider the example. Assume we are in the deterministic steady-state and leverage constraint binds. Also, assume that the introduction of CBDC leads to an outflow of deposits.[9] To make sure that Blanchard and Kahn

[8]Households' income is then $y_t = z_t + \psi n_t$ where $n_t = \ell_t + r_t - d_t$.

[9]Inflow is not problematic since the increase in deposits does not relax the constraint.

(1980) conditions are satisfied, we need to assume that the constraint keeps being binding. Otherwise, the derivative around the kink or discontinuity does not exist and log-linearization is not possible. Hence, banks have to contract lending to match deposits. In reality, banks have alternative sources of financing, and the three-period model shows that banks use equity to finance loans. Therefore, leverage constraint does not always bind.

Also, note that using Chebyshev polynomials to fit policy functions is possible but not great. They help because global methods do not rely on linearization. However, polynomials cannot fit occasionally binding constraints well enough because of the kink. To achieve the desired approximation, I need to fit leverage constraints using piecewise linear functions.

The goal is to solve the model around steady-state but fitting occasionally binding constraints using a piecewise linear function. To do it, I use the Guerrieri and Iacoviello (2015) method.[10] It treats the constraint as two regimes – one when it binds and one when it does not. Therefore, in the first case, the Lagrange multiplier is pinned down by the leverage constraint and in the second case, it is equal to zero (Kuhn-Tucker condition). The method relies on two assumptions. We still start in the steady-state when the constraint binds. Shocks can lead to a switch in the regime, but they must be unanticipated and last for a limited number of periods.

The second assumption is not problematic. Issuing equity is costly for banks and they try to get back to the deposit financing as soon as possible. The first assumption states that agents in state i do not expect to move to state j in the future. While this assumption is likely violated in the case of CBDC, it is necessary to make it to solve the model.

Most parameters of the model are calibrated to the US data. I set the discount rate $\delta = 0.98$ to reflect the mean risk-free rate in the US from 1974 to 2014. I choose $\rho_a = \rho_f = 0.95$ and $\sigma_a = \sigma_f = 0.007$ following Gomes et al. (2016). I set bank dividend

[10] For applications and discussions of the method see Ajello (2016); Guerrieri and Iacoviello (2017); Leeper et al. (2017); Garriga et al. (2017).

rate $\psi = 0.07$ which is equal to the average bank dividends in the US. I choose $\xi^d = 0.93$ and $\xi^r = 0.15$ as in Basel and Fed regulations, respectively. I set $\varepsilon = 7$ to reflect the concentration on deposit markets in the US (Drechsler et al. (2017); Piazzesi et al. (2022); Sarkisyan and Viratyosin (2022)). I also set $\rho = 0.5$ assuming equal weights for cash and deposits in the liquidity function. I set $\omega = 0.03$ to match cash to deposit ratio in the data. Finally, I set $\phi_e = 0.2$ to match key banking moments.

To calibrate η, I use the Survey of Consumer Payment Choices that is conducted annually by Atlanta Fed. Specifically, I consider responses to two questions from 2020. The first questions is how likely are debit cards accepted for payment? The second question is how costly is it to pay by card? I assign equal weights to both responses. Both questions have answer scale from 1 to 5 where 5 is the easiest, and 1 is the worst. I assume that cash is widely accepted and not costly, hence I divide the score of debit cards by 5. The number I get is $1 - \eta = 0.868$.

5.2.1 Data and estimation

I estimate the main household parameters – ξ and θ using two moment conditions – (4) and (5). Hence, the model is just-identified. Cash-to-deposits ratio varies when θ changes because cash becomes more or less convenient for households. Same logic applies to the second moment. When ξ increases, households become richer and consume more. Hence, the model is identified.

I estimate the model using two-step Generalized Method of Moments (GMM). I get most of the data for the empirical moments from the FRED database maintained by St. Louis Fed. For cash I use currency in circulation that is used to compute monetary base. For deposits, I obtain checkable deposits. For consumption, I obtain personal consumption expenditures. I use 3-month T-Bills as a rate of return on government bonds. Finally, I obtain average bank deposit rates from S&P Global RateWatch.

Estimated values are $\xi = 0.982$ and $\theta = 0.929$. Standard errors are 0.011 and 0.001, respectively. It means that costs of converting deposits to cash in the US are approximately 2%, and cash is slightly less convenient than deposits. Estimates indicate that the US is mainly digital but is still dependent on cash. I show in the next section that this is enough to revert the crowding out effect of CBDC on deposits.

5.3 Simulation results

After solving the model, I run the experiment of CBDC introduction. Specifically, I assume that we start at period $t = 0$ in the steady-state without CBDC where $T = 5000$.[11] At time $t = 1000$ CBDC is introduced. I assume that the first effect it has is an increase in θ by 0.02. At $t = 2000$ ξ increases by 0.02. There is no economic reason why I treat them separately – the goal is to see how both shocks impact outcomes. Since the model is perfect foresight, the effects would simply add up if I switched them on simultaneously.

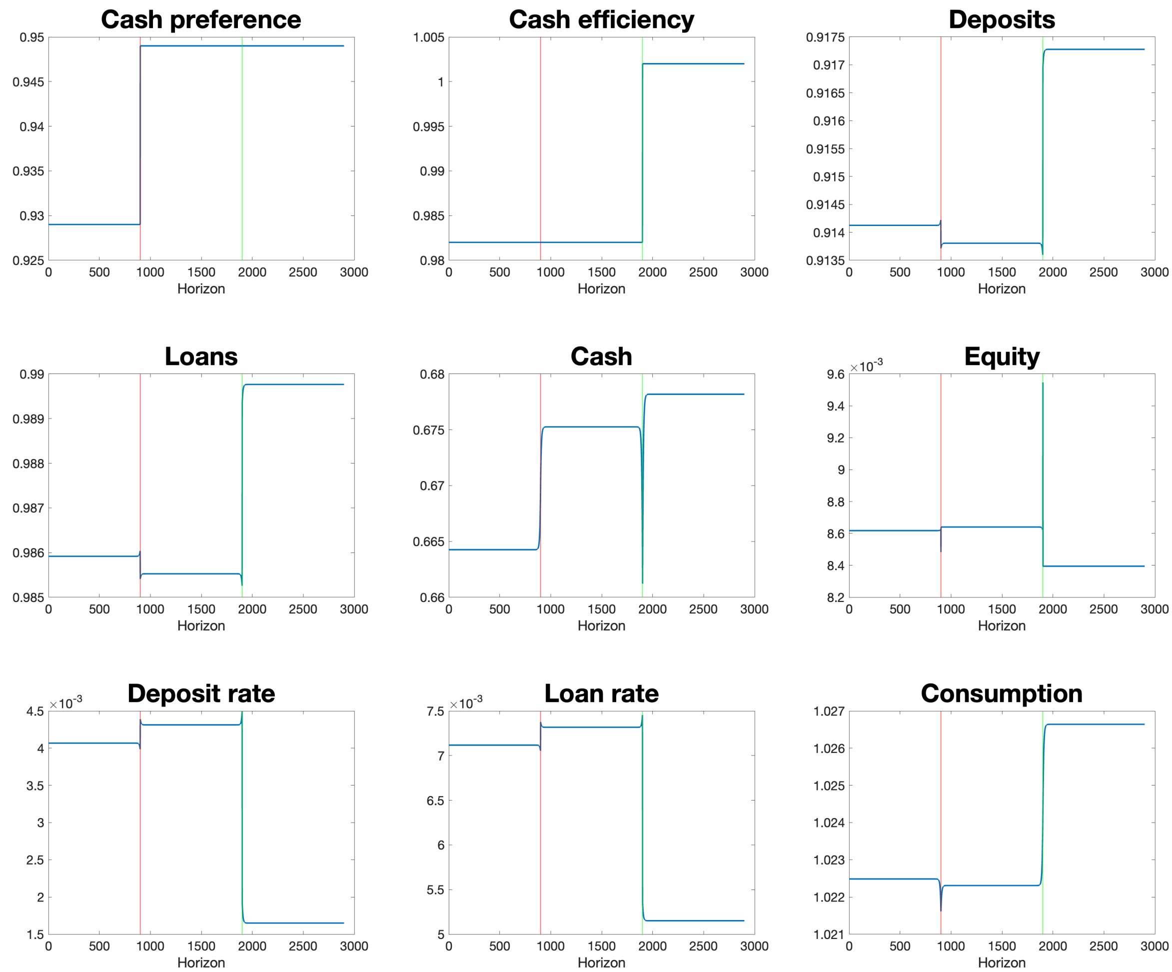
I consider three main cases. The first case is a benchmark – with the calibration and estimation using the US data described in Section 5.2. The second case is a 'Sweden case' – with $\eta = 0$, i.e. when cash is not used in the economy.[12] Finally, to evaluate Propositions 4 and 5 I consider the case with high equity issuance costs, i.e. $\phi_e = 8$ to better understand the role of equity in CBDC introduction.

5.3.1 Benchmark case

The results from the benchmark case are presented in Figure 4. The first two graphs illustrate the policy experiment. Specifically, cash becomes more convenient at $t = 1000$, and more efficient at $t = 2000$. As in the three-period model, an increase in θ leads to an outflow of deposits. This is the main concern regarding the introduction of CBDC. CBDC is a more convenient analog of cash, and it should be widely accepted since it does not require any surcharges or commission fees. Then households might prefer CBDC to deposits. Consequently, deposit and loan rates increase. Cash increases initially but then

[11] I drop first 100 periods of the simulation.
[12] Note that this is virtually the case that is considered in most CBDC papers.

Figure 4: Impact of the Introduction of CBDC: Benchmark Simulation



Note: The figure presents the results from simulations for the first 3000 periods out of 5000 of the model solved using the Guerrieri-Iacoviello method with the US calibration and estimation. The red line corresponds to the period when θ increases by 0.02. The green line corresponds to the period when ξ increases by 0.02. Both changes are persistent.

starts to decline again because deposit rates rise. Loans contract but equity also grows. This shows that parts of an outflow of deposits are compensated by the equity issuance. Finally, consumption falls as a result of the introduction of CBDC because banks lose profits and contract lending.

When cash becomes more efficient, i.e., less costly to withdraw from deposits, deposits and loans rise, deposit and loan rates fall, and consumption grows. It means that the introduction of CBDC can have a positive impact on banking because there are fewer incentives to hoard cash. Moreover, the overall effect of the introduction of CBDC is positive – deposits rise because the calibration assumes a significant demand for cash in the economy.

5.3.2 Sweden case

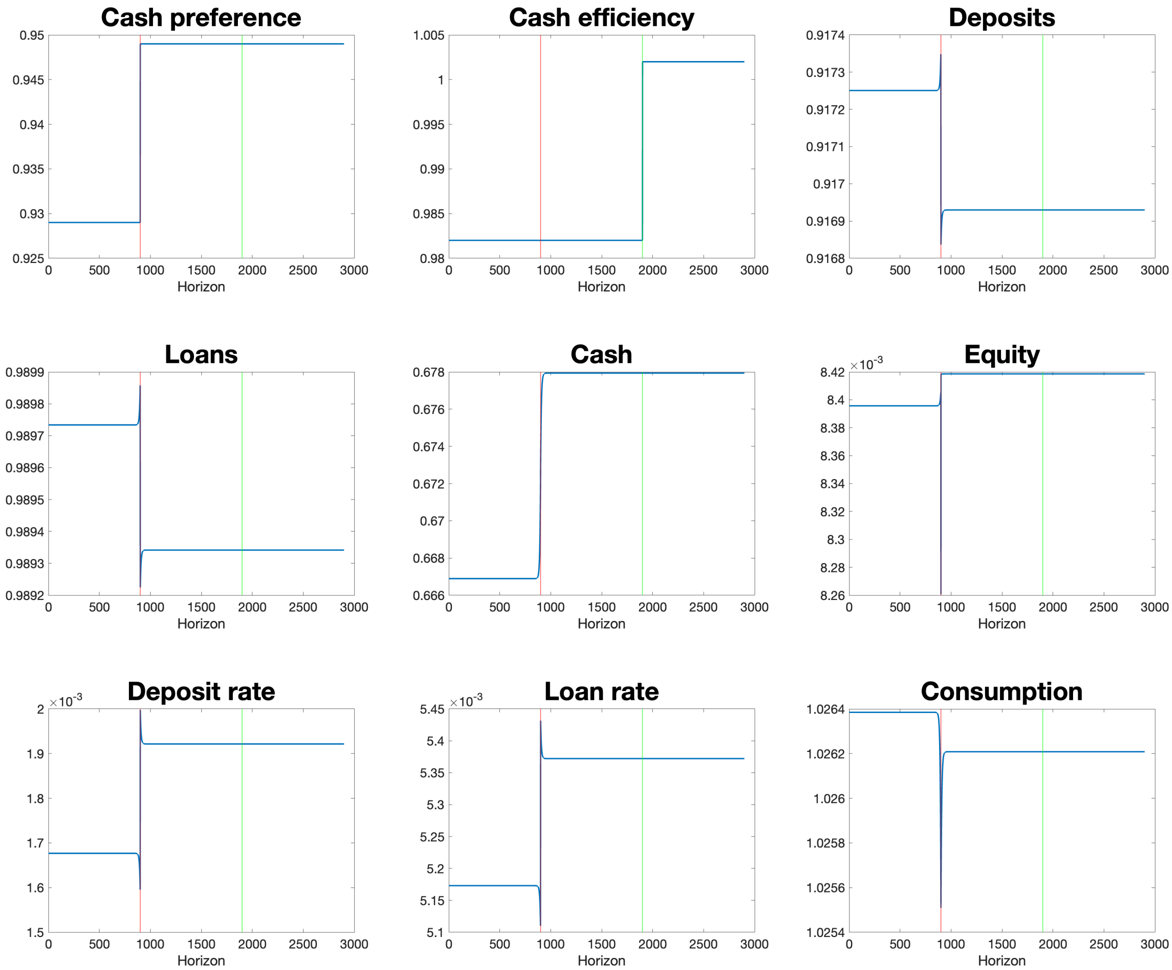
The reason why CBDC has a positive impact on banking is a high demand for cash. However, many developed countries abstract from cash. The most prominent example is Sweden, where cash virtually does not exist anymore. Cards are ubiquitously accepted and paying with cash is possible only in pharmacies and a few grocery stores. Hence, when CBDC is introduced in Sweden, the only legal tender asset to substitute from will be deposited. I illustrate the result in Figure 5. CBDC leads to an outflow of deposits and contraction in lending. As before, the contraction in lending is not as dramatic, because banks issue equity. Households in Sweden use very little cash, so when CBDC is introduced, they increase cash holding. Consumption decreases due to losses in banks' monopoly profits.

The Sweden case shows that policymakers' and economists' concerns are relevant – in countries where cash is not used, CBDC introduction will lead to an outflow of deposits. As long as banks have alternative sources of financing that are not very costly to raise, the contraction in lending will not be dramatic. The central bank and government have power over the costs of raising new funds, so they can mitigate the impact of the introduction of CBDC on banking. I discuss some of the potential policy solutions in Section 6.

5.3.3 Costly equity issuance case

Even if banks experience an outflow of deposits, I show that they can issue more equity to finance parts of their loans. This relies on the assumption that equity issuance costs are low. The same argument follows for other sources of financing, e.g. wholesale funds (Whited et al. (2022)). In this Section, I consider the case with high equity issuance costs. The simulation results are presented in Figure 6.

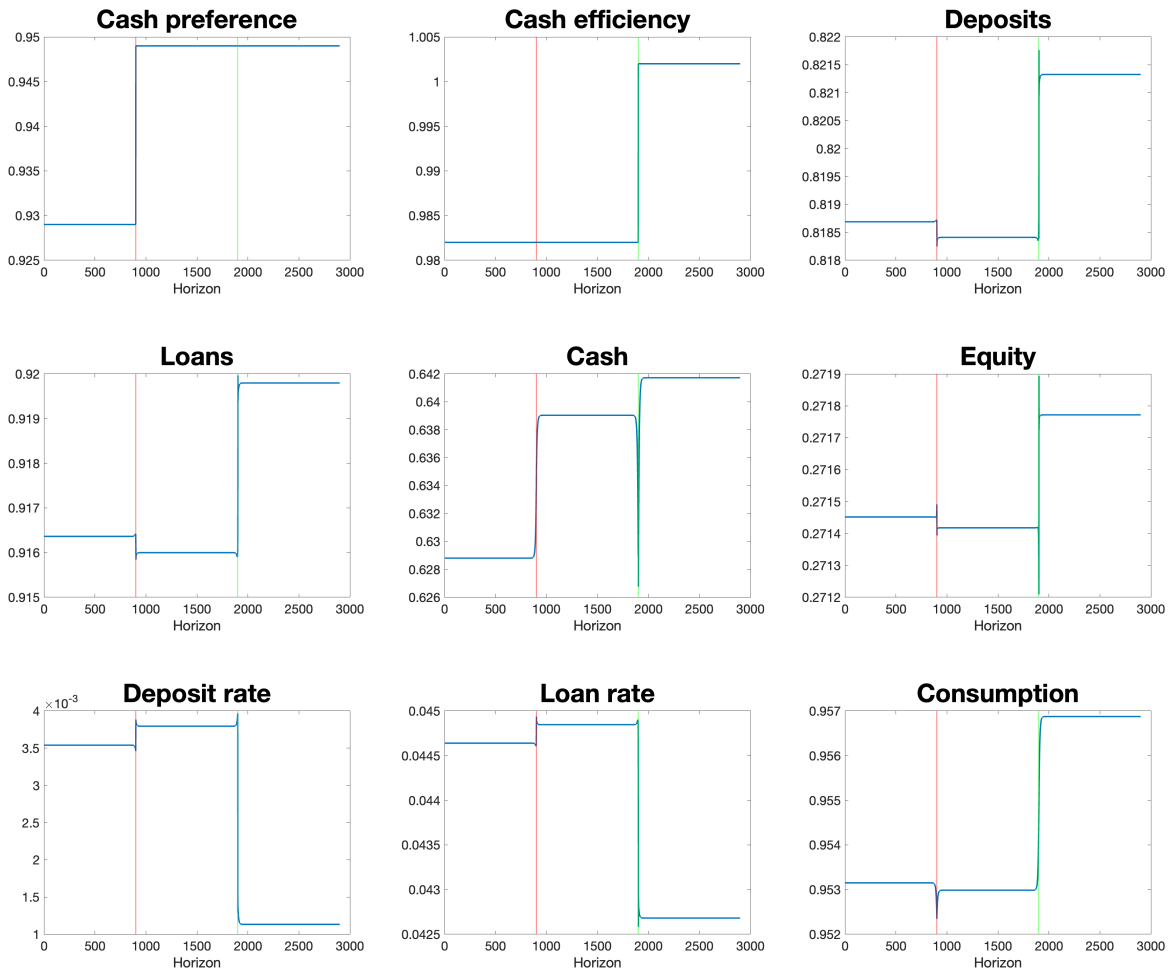
Figure 5: Impact of the Introduction of CBDC: Sweden Simulation



Note: The figure presents the results from simulations for the first 3000 periods out of 5000 of the model solved using the Guerrieri-Iacoviello method with the Sweden calibration, i.e. with $\eta = 0$. The red line corresponds to the period when θ increases by 0.02. The green line corresponds to the period when ξ increases by 0.02. Both changes are persistent.

In this case, banks do not issue more equity because it is costly. Hence, loan contraction is not compensated, so loans follow the leverage constraint. Even in this case, consumption increases. Other results also stay the same. Equity issuance costs regulations (or in the case of wholesale funds, insuring it) are not the only policy that can mitigate the impact of the introduction of CBDC. I consider two important extensions – intermediated CBDC and the potential for paying interest on CBDC in the next Section.

Figure 6: Impact of the Introduction of CBDC: High Equity Issuance Cost Simulation



Note: The figure presents the results from simulations for the first 3000 periods out of 5000 of the model solved using the Guerrieri-Iacoviello method with the high equity issuance cost calibration, i.e. with $\eta = 0$, and US estimation. The red line corresponds to the period when θ increases by 0.02. The green line corresponds to the period when ξ increases by 0.02. Both changes are persistent.

6 Extensions

In the main part of the paper, I considered the direct CBDC that does not pay any interest. However, central banks discuss the possibility to pay interest on CBDC accounts. The main concern is that CBDC will become even more attractive if it pays interest and will crowd out more deposits. The second extension is intermediated CBDC, i.e. delivered through commercial banks. For example, the Nigerian CBDC is intermediated. I next solve and simulate the model for two proposed extensions.

6.1 *Interest-bearing CBDC*

Policymakers consider paying interest on CBDC to be able to break the zero-lower bound. Without CBDC it is not possible for the following reason. Assume the central bank decreases interest rates to negative values. Households will react by selling deposits and bonds to keep money in non-interest-bearing cash. It will force interest rates to rise back to zero. If the central bank pays interest on cash, then it can adjust the rate accordingly and break the ZLB. In this version of the paper, I do not consider the central bank's problem and I focus only on the costs of paying interest on CBDC.

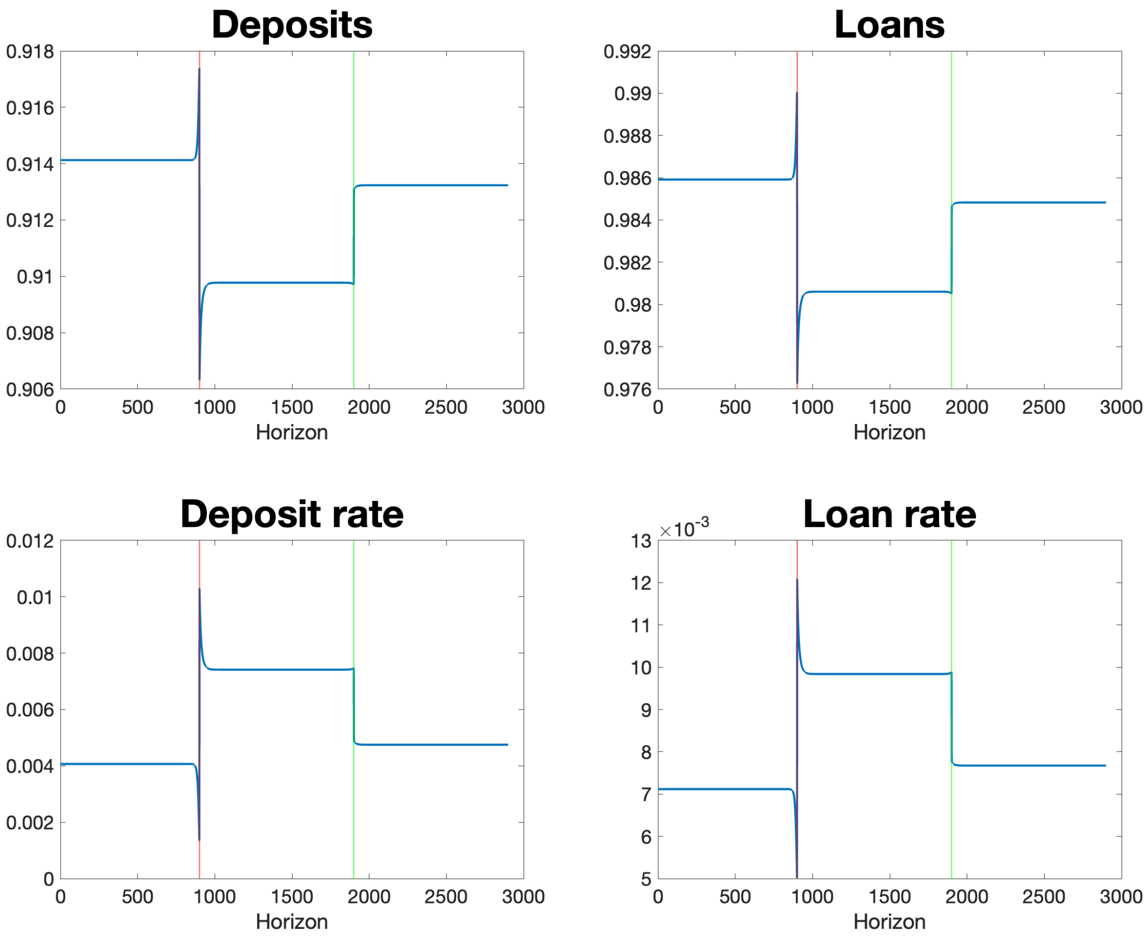
If CBDC pays interest, it adds a new benefit of holding cash. Previously it was convenience and acceptability. With the third benefit, it is possible that CBDC can crowd out deposits. To test it, I conduct the experiment. I assume that once CBDC is introduced, the central bank pays interest on it. I fix the interest to be 0.9%. The results of simulations are presented in Figure 7.

When interest-bearing CBDC is introduced, deposits drop. They soar later when ξ increases but compared to Figure 4 the overall increase in deposits is much smaller. Consequently, loans contract more, deposits, and loan rates rise more. Hence, when CBDC pays interest, the crowding-out effect is stronger. Hence, if central banks decide to pay interest on CBDC, they should make sure it is not high enough to crowd out deposits. Alternatively, they might pay only negative interest to accomplish monetary policy goals but when the interest rates in the economy are positive, pay zero.

Interest-bearing CBDC is analogous to the narrow banking proposal. The main advantage is that households can open deposits at the central bank. The first proposal was the Chicago Plan and the last was The Narrow Bank (TNB). So far there haven't been any successful implementations of narrow banking in the US.[13] The reason is that it can crowd-out deposits. Same concerns are often applied to CBDC but they are significantly mitigated if CBDC does not pay interest.

[13] Two European countries have narrow banks. England has National Savings and Investments. Norway has The Safe Deposit Bank of Norway established in 2015.

Figure 7: Impact of the Introduction of Interest-Bearing CBDC: Simulation



Note: The figure presents the results from simulations for the first 3000 periods out of 5000 of the model solved using the Guerrieri-Iacoviello method. The red line corresponds to the period when θ increases by 0.02 and CBDC starts paying 0.9% interest. The green line corresponds to the period when ξ increases by 0.02. All changes are persistent.

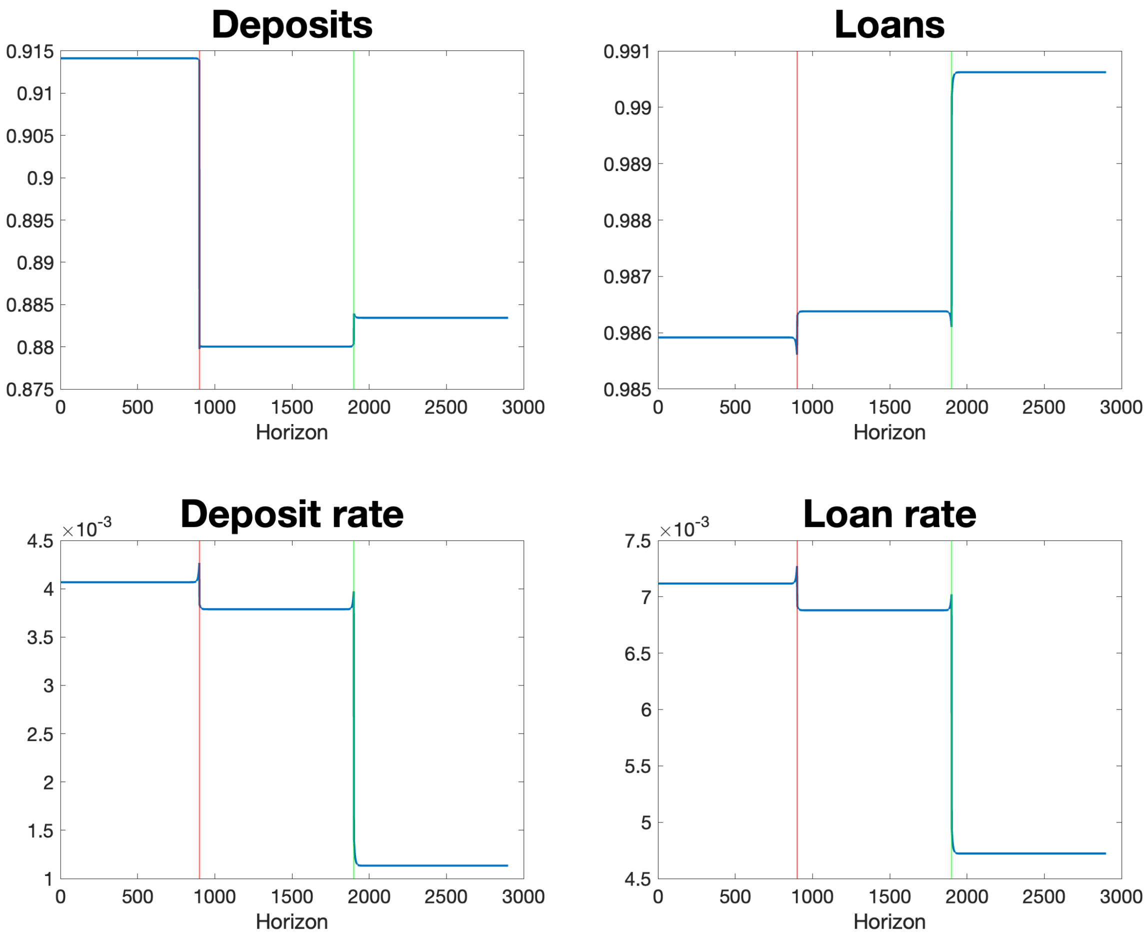
6.2 Intermediated CBDC

One proposed measure to mitigate crowding-out effects is to intermediate CBDC. If banks participate in the distribution of CBDC, they will have more reserves and more funds to finance loans. In terms of the equations of the model, the leverage and reserve constraints are now the following:

$$\frac{1}{1+r_{t+1}^{di}} d_{t+1}^{i} + cbdc_{t+1} \leq \xi^{d} \frac{1}{1+r_{t+1}^{\ell}} \ell_{t+1} \tag{30}$$

$$r_{t+1} \geq \xi^{r} (d_{t+1}^{i} + cbdc_{t+1}) \tag{31}$$

Figure 8: Impact of the Introduction of Intermediated CBDC: Simulation



Note: The figure presents the results from simulations for the first 3000 periods out of 5000 of the model solved using the Guerrieri-Iacoviello method. The red line corresponds to the period when θ increases by 0.02 and 5% of CBDC is intermediated. The green line corresponds to the period when ξ increases by 0.02. All changes are persistent.

where $cbdc_{t+1}$ is the amount of CBDC that central bank delivers through banks. I assume the intermediated fraction to be fixed to 5% when CBDC is introduced. The results of the simulation are presented in Figure 8.

The graph shows that even though banks lose deposits after the introduction of CBDC, they do not contract loans. This is because banks directly participate in CBDC distribution. Nigerian CBDC is intermediated. Figure 2 shows that loans in Nigeria did not decline despite introduction of CBDC. This is consistent with the simulations of the economy with the intermediated CBDC.

7 Conclusion

In this paper, I analyze both empirically and theoretically how CBDC introduction impacts banking. I show that CBDC does not need to crowd out deposits if there is a significant demand for cash in the economy. The reason is that CBDC is very efficient and costless to convert from deposits. Even if CBDC leads to an outflow of deposits, I show that banks do not contract lending dramatically if they can issue equity to finance loans. I also argue in favor of the intermediated non-interest-bearing CBDC to mitigate potential detrimental effects on deposits and lending.

A general problem with the CBDC research is the lack of data. Even though I provide evidence for Nigeria and the Bahamas, I acknowledge that those countries are not developed and the impact there should not necessarily hold for the US or other developed countries. Hence, all conclusions in any CBDC papers are sensitive to assumptions. In this paper, I use central bank papers and technical reports to make sure that my assumptions are close to the ones mentioned there. The hope is that developed countries will start introducing their CBDC to generate data for the researchers. Many countries including Canada, Sweden, and China are close to issuing their CBDC.

An important shortcoming of this paper is that I ignore private digital currency. Stablecoins develop fast and can potentially be used as means of payment. In that case, CBDC will compete with them. The advantage of stablecoins is privacy and anonymity. For CBDC, that is not guaranteed but on the other hand, CBDC is safer – there is no risk of debasement or default on it. This trade-off and other questions related to private coins and CBDC should be addressed in future research.

References

Agur, I., A. Ari, and G. Dell'Ariccia (2022). Designing Central Bank Digital Currencies. *Journal of Monetary Economics 125*, 62–79.

Ajello, A. (2016). Financial Intermediation, Investment Dynamics, and Business Cycle Fluctuations. *American Economic Review 106*(8), 2256–2303.

Andolfatto, D. (2020). Assessing the Impact of Central Bank Digital Currency on Private Banks. *Federal Reserve Bank of St. Louis, Working Paper 2018-026*.

Begenau, J. (2020). Capital Requirements, Risk Choice, and Liquidity Provision in a Business-Cycle Model. *Journal of Financial Economics 136*(2), 355–378.

Begenau, J. and T. Landvoigt (2022). Financial Regulation in a Quantitative Model of the Modern Banking System. *The Review of Economic Studies 89*(4), 1748–1784.

Bernanke, B. and A. Blinder (1988). Credit, Money, and Aggregate Demand. *American Economic Review 78*(2), 435–439.

Bernanke, B. and A. Blinder (1992). The Federal Funds Rate and the Channels of Monetary Transmission. *American Economic Review 82*(4), 901–921.

Blanchard, O. J. and C. M. Kahn (1980). The Solution of Linear Difference Models under Rational Expectations. *Econometrica 48*(5), 1305–1311.

Bolton, P. and X. Freixas (2000). Equity, Bonds, and Bank Debt: Capital Structure and Financial Market Equilibrium under Asymmetric Information. *Journal of Political Economy 108*(2), 324–351.

Brunnermeier, M. K. and D. Niepelt (2019). On the Equivalence of Private and Public Money. *Journal of Monetary Economics 106*, 27–41.

Brunnermeier, M. K. and Y. Sannikov (2014). A Macroeconomic Model with a Financial Sector. *American Economic Review 104*(2), 379–421.

Chiu, J., S. M. Davoodalhosseini, J. Hua Jiang, and Y. Zhu (2019). Bank Market Power and Central Bank Digital Currency: Theory and Quantitative Assessment. *Ssrn*.

Cong, L. and S. Mayer (2022). The Coming Battle of Digital Currencies. *SSRN Electronic Journal*.

Drechsler, I., A. Savov, and P. Schnabl (2017). The Deposits Channel of Monetary Policy. *The Quarterly Journal of Economics 132*(4), 1819–1876.

Drechsler, I., A. Savov, and P. Schnabl (2021). Banking on Deposits: Maturity Transformation without Interest Rate Risk. *Journal of Finance LXXVI*(3).

Duffie, J. D., K. Mathieson, and D. Pilav (2021). Central Bank Digital Currency: Principles for Technical Implementation. *SSRN Electronic Journal*, 1–17.

Elenev, V., T. Landvoigt, and S. Van Nieuwerburgh (2021). A Macroeconomic Model With Financially Constrained Producers and Intermediaries. *Econometrica 89*(3), 1361–1418.

Ferrari Minesso, M., A. Mehl, and L. Stracca (2022). Central Bank Digital Currency in an Open Economy. *Journal of Monetary Economics 127*, 54–68.

Garratt, R., J. Yu, and H. Zhu (2022). How Central Bank Digital Currency Design Choices Impact Monetary Policy Pass-Through and Market Composition. *SSRN Electronic Journal*.

Garriga, C., F. Kydland, and R. Sustek (2017). Mortgages and Monetary Policy. *Review of Financial Studies 30*(10), 3337–3375.

Gomes, J., U. Jermann, and L. Schmid (2016). Sticky Leverage. *American Economic Review 106*(12), 3800–3828.

Guerrieri, L. and M. Iacoviello (2015). OccBin: A Toolkit for Solving Dynamic Models with Cccasionally Binding Constraints Easily. *Journal of Monetary Economics 70*, 22–38.

Guerrieri, L. and M. Iacoviello (2017). Collateral Constraints and Macroeconomic Asymmetries. *Journal of Monetary Economics 90*, 38–49.

Gurkaynak, R., B. Sack, and E. T. Swanson (2005). The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models. *American Economic Review 95*(1), 425–436.

Inoue, A. and B. Rossi (2021). A New Approach to Measuring Economic Policy Shocks, with an Application to Conventional and Unconventional Monetary Policy. *Quantitative Economics 12*(4), 1085–1138.

Kashyap, A. K. and J. C. Stein (2000). What Do a Million Observations on Banks Say about the Transmission of Monetary Policy? *American Economic Review 90*(3), 407–428.

Keister, T. and D. Sanches (2019). Should Central Banks Issue Digital Currency? *FRB of Philadelphia Working Paper* (19-26), 1–37.

Kuttner, K. N. (2001). Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Market. *Journal of Monetary Economics 47*(3), 523–544.

Leeper, E., N. Traum, and T. Walker (2017). Clearing up the Fiscal Multiplier Morass. *American Economic Review 107*(8), 2409–2454.

Piazzesi, M., C. Rogers, and M. Schneider (2022). Money and Banking in a New Keynesian Model. *Working Paper*.

Sarkisyan, S. and T. Viratyosin (2022). The Impact of the Deposit Channel on the International Transmission of Monetary Shocks. *SSRN Electronic Journal*.

Schilling, L., J. Fernandez-Villaverde, and H. Uhlig (2021). Central Bank Digital Currency: When Price and Bank Stability Collide. *SSRN Electronic Journal*.

Van den Heuvel, S. (2008). The Welfare Cost of Bank Capital Requirements. *Journal of Monetary Economics 55*(2), 298–320.

Whited, T. M., Y. Wu, and K. Xiao (2022). Central Bank Digital Currency and Banks.