Hungarian DOI: 10.14754/CEU.2024.06

Essays in Financial Intermediation

by

András Kollarik

Submitted to

Central European University

Department of Economics and Business

In partial fulfillment of the requirements for the degree

Doctor of Philosophy in Economics

Supervisor: Ádám Zawadowski

Budapest - Vienna,

2024

Hungarian DOI: 10.14754/CEU.2024.06

Copyright notice

Author: András Kollarik

Title: Essays in Financial Intermediation

Degree: Ph.D.

Dated: June, 2024

Signature of the author: Kollarik András

Hungarian DOI: 10.14754/CEU.2024.06

Abstracts

The thesis consists of three single-authored chapters. The first chapter compares central bank digital currency (CBDC) with the current monetary system without CBDC but with deposit insurance. The second chapter is a step towards a theory of commercial bank money creation. The last chapter gives some empirical evidence for this theory.

The thesis topics are at the boundaries of Financial Economics (Financial Intermediation) and Macroeconomics (Monetary Economics). Money, which is a liability of a bank, is the central concept throughout the thesis. All chapters deal to some extent both with central bank money (monetary base, high-powered money) and with commercial bank money (deposit money). In the first chapter, central bank money is represented by CBDC, while in the other two chapters I concentrate on commercial banks' reserves held with the central bank. I regard commercial bank money as deposits held by the non-financial private sector with commercial banks.

The first and second chapters are theoretical ones, however, in the first, there are real world applications too. In contrast, the third chapter is about empirical evidence based on a panel database of US commercial banks between 1994-2021. Moreover, the first chapter on CBDC is related to the other two on commercial bank money creation. As issuing CBDC can impair the liquidity creation ability of commercial banks, I assume there are no deposits at all in a hypothetical economy with CBDC in which deposit insurance is abolished.

The individual chapters are summarised in the following abstracts.

Chapter 1: Central Bank Digital Currency versus Deposit Insurance

This paper compares Central Bank Digital Currency (CBDC) with deposit insurance (DI) in a moral hazard setting. The relevant agents' utilities are the same in the two systems when either the deposit insurance fee is paid ex post or the deposit insurance fund (DIF) bears the risk-free market interest rate. If the DIF's return is lower than the risk-free market rate, then CBDC yields higher welfare than DI. As in reality the DIF mainly invests in claims on the government, CBDC and DI can be regarded equivalent in practice. However, in old times of metallic standard the DIF could have invested primarily in non-interest bearing metal, which is in line with the fact that early central banks issued demand deposits to the non-bank private sector.

Hungarian DOI: 10.14754/CEU.2024.06

Chapter 2: Creative Banks: A Theory

This paper addresses the questions: What does liquidity creation of a commercial bank depend on? What is the reaction of the deposit market to a loan demand shock of the bank's borrowers? I unify existing theories of commercial bank money creation in an asset-liability management model. A liquidity creation ability parameter determines the co-movement of deposits and loans. I show that the ability plays a liquidity risk hedging role for the bank: the larger the ability, the smaller the bank's liquid asset holding and the greater the bank's liquidity creation. I also show a conjecture according to which the bank's deposit demand increases in its borrower's loan demand, and this effect is larger for banks with worse money creation ability.

Chapter 3: Creative Banks: Evidence

This paper gives some empirical evidence for the theory of Chapter 2. Using a quarterly panel of US commercial banks from 1994 to 2021, I show that the correlation between deposit and loan shocks is typically positive, around 1/2. The correlation decreased over time, especially for larger banks. However, it is not necessarily a sign of worsening money creation ability, due to a regime change after the Great Financial Crisis. I also find some evidence that a rise in the deposit-loan correlation is associated with a drop in banks' liquidity holding. In addition, deposit demand co-moves with loan demand, especially for institutions with less money creation ability.

Hungarian DOI: 10.14754/CEU.2024.06

Acknowledgements

I wish to express my heartfelt thanks to those who have supported me throughout my doctoral journey.

First of all, I would like to thank my advisor, Ádám Zawadowski for his guidance. His ideas, insights, questions and suggestions had a profound impact on this thesis. Moreover, he helped me obtain and did the aggregation of the US banking data too.

I appreciate the valuable and thorough feedback provided by the examiners of the thesis, David Pothier and Ibolya Schindele.

I thank other members of the CEU faculty, who provided much help during various research seminars. I would especially thank Marc Kaufmann, Soomin Lee, Róbert Lieli, Sergey Lychagin and Arieda Muço for their comments and advice.

I had the opportunity to consult Zoltán Barabás, Zsófia Bárány, Bruno Biais, András Danis, Marc Kaufmann, Luc Laeven, Soomin Lee, Róbert Lieli, Thomas Philippon, Attila Rátfai, Ibolya Schindele, Ádám Szeidl and Paul Voss, for which I am grateful. Special thanks to András Danis without whom I would not have had access to the banking data, and who read thoroughly the first version of the third chapter.

I am grateful to the participants and organisers of the 2021 Annual Financial Market Liquidity Conference, particularly to Dr. Zsolt Bihary, who discussed my first chapter.

I also thank Csaba Balogh, Róbert Lieli and Dirk Veestraeten for giving me a recommendation for my PhD studies.

I would also like to express my gratitude to Judit Lafferthon, Lilla Nagy, Veronika Orosz, Katalin Szimler and their colleagues for their help with administrative issues.

I also want to acknowledge my PhD peers, especially Ákos Aczél and Ceyda Üstün, with whom we share interest in financial topics. Ákos helped me a lot with rehearsals of my presentations. The same applies to my father, with whom I could discuss my topics at home too.

I would like to express my gratitude to my bosses at the MNB as well, who let me go on an unpaid leave. They are Csaba Balogh, Balázs Kóczián, Zsolt Kuti, Kristóf Lehmann, Márton Nagy and Barnabás Virág.

I am grateful to my friends outside CEU for giving opportunity to relax sometimes. I thank

Hungarian DOI: 10.14754/CEU.2024.06

András Veres, my yoga teacher for supporting me in spirit.

I thank my family for giving me a solid background throughout my studies.

Contents

Hungarian DOI: 10.14754/CEU.2024.06

List of Tables

 Hungarian DOI: 10.14754/CEU.2024.06

List of Figures

Hungarian DOI: 10.14754/CEU.2024.06

Hungarian DOI: 10.14754/CEU.2024.06

1 Chapter 1: Central Bank Digital Currency versus Deposit Insurance

1.1 Introduction

An account based central bank digital currency (CBDC) is a demand deposit held by the general public with the central bank. It is a type of money which is similar to currency (or cash) as both are issued by the central bank, so it is free of credit risk. But it also resembles commercial bank deposits because it is intangible, non-physical money. CBDC is convenient to hold, unlike cash, which can be lost and/or stolen more easily. It is also more convenient to pay in CBDC than in currency as there are no indivisibilities of denomination. In addition, CBDC can pay an interest to the owner. Essentially, CBDC is nearly the same as commercial banks' reserves at the central bank. But while reserves are only accessible by commercial banks, all private agents can hold CBDC. Table 1.1 shows the different money types according to issuer, accessibility and tangibility.

Table 1.1: Traditional types of money

	Central bank issued		Commercial bank issued
	For banks	For all	For all
Physical	-	Cash	-
Digital	Reserves	CBDC	Deposit

Note: By traditional type of money I mean money which is liability of a bank. Physical money is tangible, digital is intangible.

CBDC is an old-new topic in central banking. Early central banks in the 19th century used to maintain current accounts for the non-bank private sector, that is to firms and households. However, after a while paper bookkeeping became burdensome, and a two-tier banking system emerged in which nationalised central banks are responsible for monetary policy and financial stability. Non-bank private agents can have money in non-physical form only with commercial banks but not with the central bank. However, in the 21st century information technology has developed to a level at which it is possible to issue CBDC at low cost.

The question naturally arises whether there is point in issuing CBDC or not. What is the advantage of CBDC relative to commercial bank deposits? Both are intangible (digital), convenient to hold and use, and potentially interest-bearing. One may say that CBDC is central bank issued, therefore it is a safe asset. In contrast, deposits are risky assets because banks can go bankrupt. The problem with this argument is that deposits are also safe due to deposit insurance (DI) supported by the government.

This paper argues that a CBDC system and DI system are similar from the viewpoint of all the relevant agents. From the investors' point of view, both CBDC and insured deposits are risk-free assets due to the unlimited taxation capacity and willingness of the government. From the government's point of view, both a CBDC system and a DI system involve taking on default risk of commercial banks. On the one hand, in a CBDC system the central bank lends funds to commercial banks directly to replace outflowing deposits. On the other hand, in a DI system the exposure is indirect through insurance. From the commercial banks' point of view, both a CBDC system and a DI system entail a compensation paid to the government. In the CBDC system they pay a risk premium on the loan taken from the central bank[1] while in the DI system they pay an insurance premium to the deposit insurance corporation.

My question is whether there is a difference between CBDC and DI systems. On the one hand, I search for conditions under which the two systems are equivalent in terms of money supply and social welfare. On the other hand, I aim to quantify the differences if they are not equivalent. I also compare the model with the real world and give a potential explanation for the existence of CBDC in old days and the creation of DI after abandoning the gold standard.

I build a microeconomic model with a Banker, an Investor and the Government. There are two periods, $t = 0, 1$. At $t = 1$, there are two states of the world, a good and a bad one. The Banker owns a good and a bad risky project, the latter gives her some private benefit. There is moral hazard as her project choice is unverifiable. She needs outside funding from the Investor. The Investor has a demand for risk-free claim, which is regarded as money. He is also subject to taxes and transfers. The Government has unlimited liability and operates with zero expected net taxes. That is how it can create risk-free claims.

There are two versions of the model, one for CBDC and one for DI. I model CBDC as government debt. In the CBDC version, the Banker pays a compensation to the Government at

[1]There is a risk premium especially in the case of lender of last resort (LoLR) loans, at least according to Bagehot's Dictum (Bagehot, 1873). Goodhart, 1999 interprets Bagehot's main proposals as to 1. lend freely, 2. at a high rate of interest, 3. on good banking securities.

$t = 1$ in the good state in the form of a risk premium on the loan taken from the Government. In the DI version, there is a parameter which governs the share of deposit insurance fee paid for sure at $t = 0$ (ex ante fee). The remainder is paid at $t = 1$ in the good state (ex post fee). There is another parameter for the return of the deposit insurance fund (DIF). I focus on cases in which the good project is chosen in equilibrium. In both versions I also restrict the analysis to interior solutions, in which the investment is funded both by equity and debt (debt = money).

However, I calculate a first best solution too. In this version there is no information problem. There is a first best both for CBDC and DI, and in DI, the social planner can choose the ex ante share of the fee optimally. The overall first best out of CBDC and DI first bests is the regime which yields higher utilitarian welfare.

My results both for the first best and the decentralised equilibria are the following.

1. In the benchmark first best solution the project is financed fully by debt as there is no need to incentivise the Banker. The CBDC and DI first bests give the same money stock and welfare. In DI, if the DIF's return is lower than the discount rate, then the optimal ex ante share is zero. Otherwise the ex ante share is arbitrary.

2. If all the deposit insurance fee is to be paid ex post, then the decentralised CBDC and DI systems are equivalent both in terms of money stock and utilities. It is because the compensation is paid at the same time ($t = 1$) in the same (good) state by the Banker to the Government.

3. If there is some ex ante insurance fee but the DIF's return is equal to the risk-free market interest rate (= return on money), then more money is created in DI than in CBDC but utilities are the same. As the ex ante insurance fee increases, the ex post fee decreases, so there is more room for debt repayment at $t = 1$ in the good state. Also, higher debt repayment is equivalent to higher initial debt (= money stock) due to the constant money interest rate. As the difference in money stocks is just equal to the ex ante part of the insurance fee, the Banker has to invest the same amount of funds at $t = 0$ in the two regimes. That is why welfare is the same in the two systems.

4. If there is some ex ante insurance fee and the DIF's return is lower than the safe market

interest rate, then, although money stock in DI is higher than that in CBDC, welfare is higher in CBDC than in DI. The welfare difference increases in the ex ante share of the fee, and decreases in the success probability of the Bank's good project and in the convenience yield. In this case the welfare loss of the foregone interest income of the DIF outweighs the welfare gain of savings on the Banker's capital cost due to higher money stock in DI. This is equivalent to a larger initial investment by the Banker in DI than in CBDC. Or alternatively, the net present value of the $t = 0$ DIF investment is negative, even taking into account that this is a risk-free investment. If the DIF's return is above the risk-free market rate, then the opposite is true: welfare under DI is higher than under CBDC.

I compare the model with the reality of both current and old times. Nowadays the Federal Deposit Insurance Corporation (FDIC) in the United States (US) collects deposit insurance fees at least de jure ex ante. But as the DIF is invested in obligations of the US government, the conditions of result 2) hold. Moreover, as risk-free interest rates are relatively low nowadays, the convenience yield is relatively high. Furthermore, we can infer a relatively high project success probability of banks from the low Designated Reserve Ratio (DRR) of the FDIC, which is only 2 percent (relative to insured deposits). So, even if we assumed a DIF return different from the market risk-free rate, CBDC and DI systems would be more or less equivalent in terms of money and welfare.

In contrast, in early days of central banking, before the introduction of DI, the general public used to hold deposits ("CBDC") at several central banks (Bordo and Levin, 2017, Fernández-Villaverde et al., 2020, see also Appendix A.1). We can assume that in these times, under metallic standard, if there had been DI, then the DIF would have invested a non-negligible share in precious metal, which bears no interest. In addition, as safe real interest rates were higher than nowadays (Schmelzing, 2020), the foregone interest income could have been substantial. As a result, in those times CBDC could provide higher welfare than DI. This could be a reason for introducing DI only after abandoning the gold standard.[2]

Related literature. There is a growing literature on CBDC. But, to the best of my knowledge, no paper focuses explicitly on the comparison of CBDC and DI in detail. Carapella and

[2]The FDIC, the first explicit national deposit insurer in the world, was founded in 1933, the same year when the US went off the gold standard (Demirgüç-Kunt and Kane, 2001).

Flemming, 2020, Auer et al., 2021, Hoang et al., 2023 and Chapman et al., 2023 are comprehensive literature reviews of CBDC.

Tobin, 1985 and Tobin, 1987 are the firsts to propose CBDC (”deposited currency accounts” as Tobin calls) as a substitute for DI, but without a formal model. Tobin, 1985 says DI is inefficient, as it diminishes banks’ incentives to assess and limit risks and depositors’ incentives to assess the riskiness of banks. Moreover, it is an extension and delegation of the government’s monetary fiat because if a big bank fails, then the Congress appropriates additional funds to the DIF. According to Tobin, 1987, there is moral hazard in DI, as the sounder and luckier banks pay higher DI premiums to salvage the depositors of failed banks. The problem appeared with the deregulation of deposit interest rates, since when banks have attracted deposits to finance risky assets. Risk-based DI premia could help, but it is not possible to gauge risk in advance. In contrast, in my model moral hazard is similar in a DI and in a CBDC system, but both are managed by insurance/risk premium.

I model money as a risk-free claim in the spirit of Gorton and Pennacchi, 1990.[3] According to their paper, safe debt, which is insensitive to asymmetric information, is an appropriate medium of exchange when there is an adverse selection problem on securities markets between uninformed traders and informed traders. Gorton and Pennacchi also analyse government debt (which is similar to CBDC) and DI. Both types of government intervention restore the full-information case, and hence, they are deemed very similar. However, they assume different financial frictions than I do, there is no moral hazard in their model. Moreover, when government debt is issued, the proceeds are invested in capital directly, unlike in my approach in which the government lends funds to the bank. This pass-through policy seems to be more realistic as whenever a depositor transfers money from his deposit account to his CBDC account, the central bank lends reserves to the bank automatically. Lastly, they assume ex post funding of the DIF, while I allow for ex ante and ex post funding too.

Brunnermeier and Niepelt, 2019 shows that an appropriate central bank swap of private and public money, coupled with a pass-through policy would not change the equilibrium allocation. By pass-through policy Brunnermeier and Niepelt mean that the central bank becomes an intermediary between households and banks, and lends funds to banks at the same conditions as

[3]Money is modelled as risk-free claim in Kiyotaki and Moore, 2002 and Stein, 2012 too.

that of the deposit funding prior to the swap. Brunnermeier and Niepelt also mention that if there was DI in the initial equilibrium and CBDC was risk-free as well, then the swap would not change payoffs and no government transfers would be needed. However, their paper does not analyse DI in detail. My approach is different from that of Brunnermeier and Niepelt as they do not define an exact policy rule: their aim is to replicate the equilibrium with private money. In contrast, in my model policy is the same across the two systems and my aim is to compare the outcomes. Moreover, Brunnermeier and Niepelt do not do normative analysis explicitly, while I calculate utilitarian social welfare.

Böser and Gersbach, 2020 finds, among many other results, that if there is bank solvency risk, then the welfare comparison of CBDC and DI depends on the depositors' cost of switching between deposits and CBDC, and also on commercial banks' collateral requirements set by the central bank. When switching costs are high, depositors accept a bail-in and do not transfer funds to the central bank in the CBDC system, so welfare is the same in the two systems. If switching costs are low, then the comparison is dependent on collateral requirements. If tight collateral requirements are optimal, then CBDC is better, because tight requirements improve banks' monitoring activity, and this productivity gain outweighs the costs of monitoring, of defaults and of switching. But if loose collateral requirements are optimal, then DI is better when there are some switching costs. However, if there are no switching costs at all and requirements are loose (akin to my model), then the two regimes are equivalent again. Nevertheless, Böser and Gersbach do not go into more details, and do not calculate with the deposit insurance fee.

Williamson, 2022 compares, among other regimes, both CBDC and DI with a baseline economy in which there is physical currency and deposits, but no CBDC or DI. He finds that, compared to the baseline, DI discourages banking panics and increases welfare because it reduces payoffs from panicking and eliminates the disruptive effects of bank failures on payments. CBDC, in contrast, encourages banking panics relative to the baseline, as CBDC is a more attractive safe harbour than physical currency, it is more useful in transactions. However, in the CBDC regime, panic equilibria are better than no-panic equilibria because CBDC is less disruptive of retail payments in a panic than cash. Nonetheless, Williamson do not compare CBDC with DI explicitly, and do not introduce a deposit insurance fund into his model.

There are empirical papers which analyse the effect of DI on deposit stocks in the presence of CBDC like accounts, and the effect of DI on money flows to "CBDC" in the case of shocks. Davison and Ramirez, 2016 examines two schemes operating in the US during the 1920s: the Postal Savings System (which I think is similar to CBDC), and DI that some states adopted. By comparing cities located along the borders of states that did and did not have DI, they find that, after a bank suspension within a 10-mile radius, "CBDC" in the non-DI state increased by 16 percent more than "CBDC" in the DI state. By comparing pairs of counties straddling the DI-non-DI state borders, they also show that county level deposits at state banks were 56 percent higher with DI. Schuster et al., 2019 shows that postal savings deposits were a safe haven during the Great Depression, but the rapid rise halted after the establishment of the FDIC. Then, the demand for "CBDC" depended primarily on the interest rates of other savings mechanisms. Both papers imply that in the absence of DI, money flows to "CBDC", which is in line with my modelling assumption.

The structure of the paper is the following. In Section 1.2, I present the model both for CBDC and DI. In Section 1.3, I discuss the question of risk-taking. Then in Section 1.4, I attempt to broadly calibrate the model both to current and to old monetary regimes. In Section 1.5, I conclude. The Appendix A contains further figures, proofs and a glossary of notations.

1.2 Model

1.2.1 Setup

1.2.1.1 General setup There are three agents in the model.

1. Banker. Based on Tirole, 2006 Ch. 3.2, she has two production technologies, a good and a bad one. Both involve an indivisible, fixed investment $I > 0$ of the unique storeable good of the economy at $t = 0$. At $t = 1$, both projects yield a return $R > I$ in the good state of the world and 0 in the bad state of the world. The ex ante probability of the good state is $p_H \in (0, 1)$ and $p_L \in (0, p_H)$ for the good and bad projects, respectively. She can invest only in one of the projects. The Banker's project choice is unverifiable. She owns an endowment $A_B \in (0, I)$. If she wants to undertake one of the projects, she needs outside funding from the Investor. To get access to funding, she can set up a Bank with limited liability. The Banker cannot divert funds. But, the bad project yields some private benefit

$\mathcal{B} > 0$ to the Banker. She is risk neutral with the following lifetime utility:

$$U_{B,j} = C_{B,0} + \mathbb{1}_{j=b}\mathcal{B} + \beta\mathbb{E}(C_{B,1}) \tag{1.1}$$

where $C_{B,t} \geq 0$ is her consumption at t, $\beta \in (0,1)$ is the subjective discount factor, and p_j is the success probability of project j.

2. Investor. There is an ex ante identical unit mass of deep pocketed Investors, who own an endowment of $A_{I,0} \geq I$. In addition, they get a non-pledgeable endowment of $A_{I,1} \geq \frac{I}{\beta+\gamma}$ at $t = 1$. They are subject to taxes and transfers unconditional on their behaviour. Moreover, they have a demand for safe asset (money). I take an Investor's lifetime utility function from Stein, 2012.
$$U_I = C_{I,0} + \beta\mathbb{E}(C_{I,1}) + \gamma R_M \tag{1.2}$$
where $C_{I,t} \geq 0$ is his time t consumption, $R_M \geq 0$ is his money stock measured in $t = 1$ consumption good, and $\gamma > 0$ is his convenience yield (liquidity premium). Also, $\beta + \gamma < 1$, that is he still discounts money.

3. Government. It is penniless, it does not consume, but has unlimited liability and taxation capacity: its intertemporal budget is balanced by net lump sum taxes τ imposed on the Investors. That is taxes are equal to the loss of the Government on the CBDC or DI business. That is how it can create safe asset: in the bad state of the world, it taxes Investors' $t = 1$ endowment, and repays debt from the proceeds. As taxes are unconditional on Investor behaviour, Investors are willing to buy such debt. The Government breaks even in expectation (actuarially fair pricing).

The net present value of the bad project (NPV_b) is negative. Moreover, the social surplus of the project financed fully by money ($NPV_b^{'}$) is also negative.[4] The net present value of the

[4]This rules out the bad project in equilibrium. The motivation of the assumption is that the relationship of CBDC and DI is the same in the case of the good project and in the case of the bad project, at least for interior solutions.

good project (NPV_g) is positive.

$$NPV_b^{'} = \beta(p_L R - \frac{I}{\beta+\gamma}) + \mathcal{B} = \underbrace{\beta p_L R - I + \mathcal{B}}_{NPV_b} + \frac{\gamma}{\beta+\gamma} I < 0 < \beta p_H R - I = NPV_g \tag{1.3}$$

There are two further assumptions in order to have meaningful results.

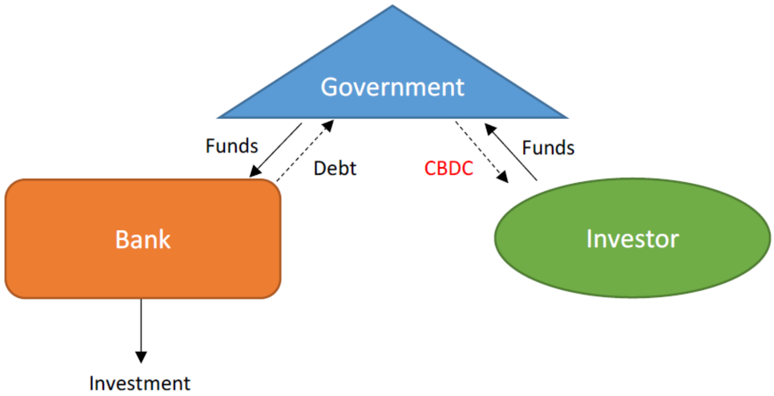
$$0 < \underbrace{R - \frac{\mathcal{B}}{\beta \Delta p}}_{\mathcal{P}} < \frac{I}{\beta+\gamma} \tag{1.4}$$

where $\Delta p = p_H - p_L$ and $\mathcal{P}$ is the Banker's pledgeable income. The left hand side means that the good project is not ruled out completely. Owing to the right hand side, there is an interior solution: the good project cannot be financed fully by (safe) debt, there is a need for Bank equity. Assumption (1.3) and the left hand side of (1.4) limit $\mathcal{B}$, or the degree of asymmetric information, from above, while the right hand side of assumption (1.4) puts a lower bound on $\mathcal{B}$.

1.2.1.2 CBDC setup The Government works as a central bank, it intermediates funds from the Investors to the Banker. At $t = 0$, the Banker may set up the Bank. If she does so, then she gives a take-it-or-leave-it ("tioli") borrowing offer to the Government. The offer consists of a loan amount $L \in (0, I]$ and a promised repayment $R_L \geq 0$. If the Government accepts the offer, then it gives a tioli borrowing offer to the Investors. This offer includes $M = L$ amount of CBDC and $R_M \geq 0$ repayment. If an Investor accepts the offer, then his funds are channelled to the Bank. If the total mass of Investors accept, then the Bank can operate. The Banker may need to complement M with own funds $a \in [0, A_B]$. The Banker chooses one of the projects to undertake only afterwards. Lastly, $t = 0$ consumption takes place. At $t = 1$, payoffs are realised. Net taxes are also paid, and $t = 1$ consumption comes last. Figure 1.1 presents the $t = 0$ flows.

1.2.1.3 DI setup At $t = 0$, the Government sets the ex ante and ex post deposit insurance premia $h_0 \geq 0$ and $h_1 \geq 0$, respectively, paid by the Bank to the Government on unit of deposit. An exogenous $\alpha \in [0, 1]$ share of the fee is paid ex ante, and $1 - \alpha$ ex post. Then, the Banker may set up a Bank. If she does so, then she gives a tioli borrowing offer to the Investors. The offer consists of a deposit amount $M \in (0, I]$ and a promised repayment $R_M \geq 0$. If an Investor

Figure 1.1: Central Bank Digital Currency system



Note: The Government is an intermediary between the Bank and the Investor, and issues its own money. The figure shows $t = 0$ flows. Solid lines represent real flows and dashed lines are for financial contracts.

accepts the offer, then he deposits funds with the Bank. If the total mass of Investors accept, then the Bank can operate. The Banker may need to complement M with own funds $a \in [0, A_B]$, and the Banker also has to pay $h_0 M$ ex ante insurance fee to the Government. The Government invests the DIF at $R_G \in [1, \frac{1}{\beta}]$ safe gross return, which is an exogenous variable. The Banker chooses the project to undertake only afterwards. Lastly, $t = 0$ consumption takes place. At $t = 1$, payoffs are realised. In the good state, the Banker pays $h_1 M$ ex post insurance fee too. Net taxes are also paid, and $t = 1$ consumption comes last. Figure 1.2 shows the $t = 0$ flows.

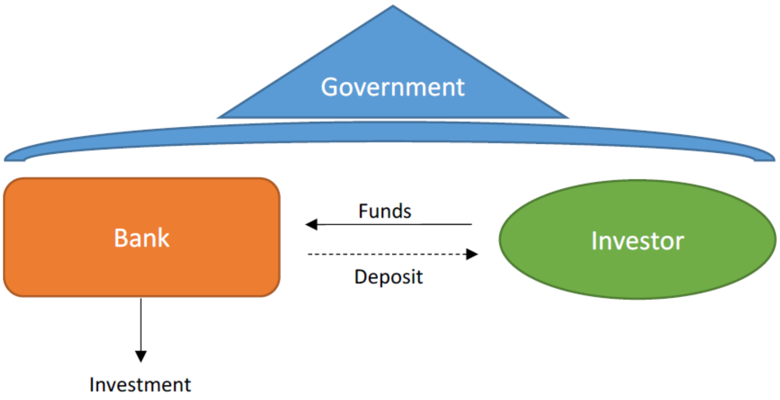
A further assumption is needed so as to have meaningful results.

$$p_H > \frac{1-(\beta + \gamma)}{1-\beta} \tag{1.5}$$

so that Bank equity is minimised.

1.2.1.4 First best In the first best setup, there is no incentive problem. That is the Government can enforce the good project at no cost. Otherwise the problems are the same. There is a first best for the CBDC and the DI versions too. In addition, I allow for endogenous α in the DI first best. The overall first best is that of the CBDC and DI first best allocations which gives larger utilitarian social welfare.

Figure 1.2: Deposit Insurance system



Note: The Government guarantee scheme is a safety net that makes commercial bank money creation possible. The figure shows $t = 0$ flows (with ex ante share $\alpha = 0$). The solid line represents a real flow and the dashed line is for a financial contract.

1.2.2 Solution

1.2.2.1 First best

CBDC first best By backward induction. Suppose there is a candidate equilibrium in which all the other Investors invest in the Government. An Investor buys CBDC if and only if it is individually rational, given L, R_L, M, R_M and the behaviour of other Investors. The Government's CBDC offer (M, R_M) ensures that the Government breaks even, given L, R_L and the balance sheet constraint of the Government. The Banker chooses a borrowing offer (L, R_L) by maximising her lifetime utility, given the above constraints, her equity constraint, her repayment constraint, her balance sheet constraint and her individually rational constraint.

The Banker's problem is the following.

$$\begin{aligned}
\max_{L,R_L,M,R_M,a} \quad & U_{B,g} = A_B - a + \beta p_H(R - R_L) \\
\text{s.t.} \quad & 0 \leq a \leq A_B && \text{(equity constraint)}, \\
& 0 \leq R_L \leq R && \text{(repayment constraint)}, \\
& I = a + L && \text{(Bank's balance sheet)}, \\
& L = M && \text{(Government's balance sheet)}, \\
& R_M \geq \frac{M}{\beta+\gamma} && (IR_I), \\
& R_M = p_H R_L && (ZP_{G,g}), \\
& R_L \leq \frac{NPV_g + M}{\beta p_H} && (IR_{B,g})
\end{aligned} \tag{1.6}$$

The constraints are the following. The first is the equity constraint, the second is the repayment constraint, the third is the Bank's balance sheet and the fourth is the Government's balance sheet. IR_I is the Investor's individually rational constraint, which binds.[5] $ZP_{G,g}$ is the Government's zero profit constraint for the good project. Finally, $IR_{B,g}$ is the Banker's IR constraint for the good project. If IR_I binds, then it holds. The derivation of the constraints is in Appendix A.2.

Proposition 1.1 (First best CBDC solution)**.** *Let M^o_{CBDC}, $U^o_{B,CBDC}$ and W^o_{CBDC} denote the first best CBDC stock, Banker net utility and net utilitarian welfare (above endowments), respectively.*

1. $M^o_{CBDC} = I$.

2. $W^o_{CBDC} = U^o_{B,CBDC} = NPV_g + \frac{\gamma}{\beta+\gamma} I$.

Proof. In Appendix A.2. ■

As the good project is enforced anyhow, there is no role for Bank equity, so the project is funded by full debt. Net welfare is just equal to the Banker's net utility, as she bids down the Investor's net utility to zero. This net welfare comes from two sources: the NPV of the good

[5] IR_I would be the same if taxes were conditional (only those Investors were liable to taxes/transfers who actually invest). In such a case we could allow for $A_{I,1} = 0$. Also, IR_I would be unchanged if instead of money repayment, the minimum $t = 1$ consumption was multiplied by γ in the Investor's utility function: $U_I = C_{I,0} + \beta \mathbb{E}(C_{I,1}) + \gamma \min_s \{C_{I,1,s}\}$. This is similar to a mean-variance utility. I show these in Appendix A.2.

project, and the Investor's utility from holding money γR_M. Although the latter is positive, due to the tioli offer it eventually raises the Banker's utility. It is a saving on capital cost of equity funding.

DI first best Suppose there is a candidate equilibrium in which all the other Investors invest in the Bank. The Investor places deposits if and only if it is individually rational, given h_0, h_1, M, R_M and the behaviour of other Investors. The Government sets the insurance policy (h_0, h_1) so that it breaks even, given M, R_M. The Banker chooses a potential borrowing offer (M, R_M) by maximising her lifetime utility, given h_0, h_1, the above constraints, her equity constraint, her repayment constraint, her balance sheet constraint and her individually rational constraint. Lastly, the Government chooses the ex ante share α optimally.

The Banker solves the following problem.

$$
\begin{aligned}
\underset{M,R_M,a,h_0,h_1}{max} \quad & U_{B,g} = A_B - a - h_0 M + \beta p_H [R - (R_M + h_1 M)] & & \\
\text{s.t.} \quad & 0 \le a \le A_B - h_0 M & & \text{(equity constraint)},\\
& 0 \le R_M \le R - h_1 M & & \text{(repayment constraint)},\\
& I = a + M & & \text{(Bank's balance sheet)},\\
& h_0 = \alpha \frac{1-p_H}{R_G}\frac{R_M}{M} & & (ZP_{G,g,0}),\\
& h_1 = (1-\alpha)\frac{1-p_H}{p_H}\frac{R_M}{M} & & (ZP_{G,g,1}),\\
& R_M \ge \frac{M}{\beta+\gamma} & & (IR_I),\\
& R_M \le \frac{NPV_g + (1 - h_0 - \beta p_H h_1)M}{\beta p_H} & & (IR_{B,g})
\end{aligned}
\tag{1.7}
$$

The constraints are the following. The first is the equity constraint, the second is the repayment constraint and the third is the Bank's balance sheet. $ZP_{G,g,0}$ and $ZP_{G,g,1}$ are results of the Government's zero profit constraint for the good project for $t = 0, 1$ and of the assumption that α share of the insurance fee is paid ex ante. IR_I is the Investor's individually rational constraint, which binds. Finally, $IR_{B,g}$ is the Banker's IR constraint for the good project. If IR_I binds, then it holds. The derivation of the constraints is in Appendix A.2.

 Hungarian DOI: 10.14754/CEU.2024.06

Proposition 1.2 (First best DI solution)**.** *Let M^o_{DI}, $U^o_{B,DI}$, W^o_{DI} and α^o denote the first best deposit stock, Banker net utility, net utilitarian welfare (above endowments) and ex ante share of insurance fee, respectively.*

1. $M^o_{DI} = I$.
2. $W^o_{DI} = U^o_{B,DI} = NPV_g + \frac{\gamma}{\beta+\gamma} I$.
3. *If* $R_G < \frac{1}{\beta}$, *then* $\alpha^o = 0$, *otherwise* $\alpha^o \in [0,1]$ *arbitrary.*

Proof. In Appendix A.2. ■

Money stock and welfare are the same as in the CBDC first best, with the same reasoning. In principle, there is another factor affecting welfare: the potential foregone interest income $(1-\beta R_G)h_0 M$ of investing in the DIF ex ante. However, it ends up being zero. If $R_G < \frac{1}{\beta}$, then there is no point in choosing a positive ex ante share. Otherwise ($R_G = \frac{1}{\beta}$) the NPV of the DIF investment is zero, so the ex ante share is not important.

Overall first best In the first best there is no difference between CBDC and DI neither in terms of money stock nor in terms of welfare. So, the social planner is indifferent to the two.

1.2.2.2 CBDC solution The solution is similar to the CBDC first best. The only difference is the appearance of the Banker's incentive compatibility constraint due to the information asymmetry. In principle, this constraint does not need to hold, so the Banker could choose the bad project too. Then the Banker would compare the optimal borrowing offer for the good project and the optimal borrowing offer for the bad project. However, given assumption (1.3), I disregard the bad project.

The Banker's problem to solve is the following.

$$\begin{aligned}
\max_{L,R_L,M,R_M,a} \quad & U_{B,g} = A_B - a + \beta p_H (R - R_L) && \\
\text{s.t.} \quad & 0 \leq a \leq A_B && \text{(equity constraint)}, \\
& 0 \leq R_L \leq R && \text{(repayment constraint)}, \\
& I = a + L && \text{(Bank's balance sheet)}, \\
& L = M && \text{(Government's balance sheet)}, \\
& R_L \leq R - \frac{\mathcal{B}}{\beta \Delta p} = \mathcal{P} && (IC_{B,g}), \\
& R_M \geq \frac{M}{\beta + \gamma} && (IR_I), \\
& R_M = p_H R_L && (ZP_{G,g}), \\
& R_L \leq \frac{NPV_g + M}{\beta p_H} && (IR_{B,g})
\end{aligned} \tag{1.8}$$

The constraints are the same as in the CBDC first best, except for $IC_{B,g}$, which is the Banker's incentive compatibility constraint for the good project. It says the repayment on the loan taken from the government must not exceed the pledgeable income. That is, in order to incentivise the Banker to choose the good project, she must be left with enough income in the good outcome $(R - R_L)$ to outweigh the advantage of the bad project $(\frac{\mathcal{B}}{\beta \Delta p})$. The derivation of the constraints is in Appendix A.2.

Proposition 1.3 (CBDC solution)**.** *Let M^*_{CBDC}, $U^*_{B,CBDC}$ and W^*_{CBDC} denote equilibrium CBDC stock, Banker net utility and net utilitarian welfare (above endowments), respectively.*

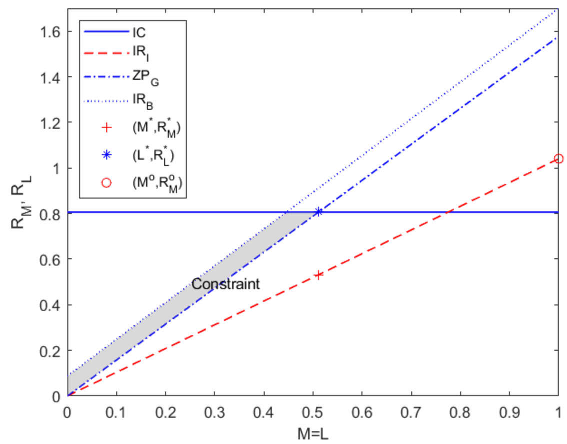
1. $M^*_{CBDC} = (\beta + \gamma) p_H \mathcal{P}$. *If $M^*_{CBDC} < I - A_B$, then there is credit rationing.*

2. $W^*_{CBDC} = U^*_{B,CBDC} = NPV_g + \gamma p_H \mathcal{P}$.

Proof. In Appendix A.2. ■

Since the Banker minimises equity, R_L, the repayment on the loan from the Government, is equal to $\mathcal{P}$, the Banker's pledgeable income. As a result, R_M, the repayment on money, is $p_H \mathcal{P}$ or the *expected* pledgeable income. Therefore, the money stock is equal to the present value of the expected pledgeable income. Welfare comes from the NPV of the good project, and from the Banker's savings on capital cost of equity funding γR_M. Welfare is just the Banker's utility because IR_I binds.

Figure 1.3: CBDC constraints and solutions



Note: The figure shows the constraints faced by the Banker in CBDC, the equilibrium and the first best. IC is the incentive compatibility, IR_I is the Investor's individually rational, ZP_G is the Government's zero profit and IR_B is the Banker's individually rational constraint. (M^*, R_M^*) is the equilibrium CBDC stock and repayment on money. (L^*, R_L^*) is the equilibrium lending to the Bank and its repayment. (M^o, R_M^o) is the first best CBDC stock and repayment on money. The grey shaded area is the intersection of the constraints. $I = 1$ (investment), $R = 1.7$ (return in good state), $p_L = 0.46$ (success probability of bad project), $p_H = 0.66$ (success probability of good project), $\beta = 0.94$ (discount factor), $\gamma = 0.021$ (convenience yield), $\mathcal{B} = 0.168$ (private benefit). I assume A_B (Banker's endowment) is high enough to implement the project.

Figure 1.3 shows the problem of the Banker in CBDC. She chooses (L, R_L) between the area delimited by IR_B and ZP_G. But as she maximises profits, her choice lies on ZP_G (or equivalently, (M, R_M) lies on IR_I). Also, due to the positive convenience yield, she maximises money. As a result, in the first best, she chooses full money funding. While in the decentralised equilibrium, she maximises money such that (L, R_L) is in the grey shaded area ("Constraint").

1.2.2.3 DI solution The solution is again similar to the DI first best. The only difference is the appearance of the Banker's incentive compatibility constraint. In principle, this constraint does not need to hold in this case either. However, given assumption (1.3), I disregard the bad project.

I present the Banker's problem below.

$$
\begin{aligned}
\max_{M,R_M,a,h_0,h_1} \quad & U_{B,g} = A_B - a - h_0 M + \beta p_H [R - (R_M + h_1 M)] \\
\text{s.t.} \quad & 0 \le a \le A_B - h_0 M && \text{(equity constraint)}, \\
& 0 \le R_M \le R - h_1 M && \text{(repayment constraint)}, \\
& I = a + M && \text{(Bank's balance sheet)}, \\
& R_M \le R - \frac{\mathcal{B}}{\beta \Delta p} - h_1 M = \mathcal{P} - h_1 M && (IC_{B,g}), \\
& h_0 = \alpha \frac{1-p_H}{R_G} \frac{R_M}{M} && (ZP_{G,g,0}), \\
& h_1 = (1-\alpha) \frac{1-p_H}{p_H} \frac{R_M}{M} && (ZP_{G,g,1}), \\
& R_M \ge \frac{M}{\beta + \gamma} && (IR_I), \\
& R_M \le \frac{NPV_g + (1 - h_0 - \beta p_H h_1) M}{\beta p_H} && (IR_{B,g})
\end{aligned}
\tag{1.9}
$$

The constraints are the same as in the DI first best, except for $IC_{B,g}$, which is the Banker's incentive compatibility constraint for the good project. Here again, so as to incentivise the Banker to choose the good project, she must get at least as much income in the good state $(R-(R_M+h_1M))$ as the advantage of the bad project is $(\frac{\mathcal{B}}{\beta\Delta p})$. The derivation of the constraints is in Appendix A.2.

Proposition 1.4 (DI solution)**.** *Let M^*_{DI}, $U^*_{B,DI}$ and W^*_{DI} denote equilibrium deposit stock, Banker net utility and net utilitarian welfare (above endowments), respectively.*

1. $M^*_{DI} = (\beta+\gamma)\frac{p_H}{\alpha p_H + 1 - \alpha}\mathcal{P}$. *If* $M^*_{DI} < \frac{(\beta+\gamma)R_G(I-A_B)}{(\beta+\gamma)R_G - \alpha(1-p_H)}$, *then there is credit rationing.*

2. $W^*_{DI} = U^*_{B,DI} = NPV_g + \frac{\gamma R_G - \alpha(1-p_H)(1-\beta R_G)}{R_G}\frac{p_H}{\alpha p_H + 1 - \alpha}\mathcal{P}$.

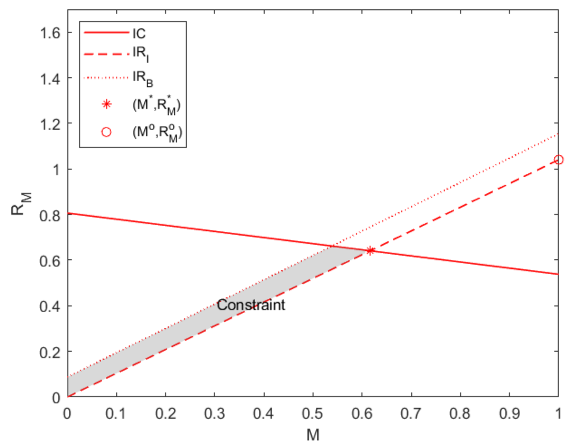
Proof. In Appendix A.2. ■

Since the Banker minimises equity, $R_M + h_1 M$, the repayment on money plus the ex post fee, is equal to $\mathcal{P}$, the Banker's pledgeable income. As a result, R_M, the repayment on money, is $\frac{p_H}{\alpha p_H+1-\alpha}\mathcal{P}$. Now R_M is the *harmonic mean* of the pledgeable income and the expected pledgeable income with weights α and $1-\alpha$.[6] Therefore, the money stock is equal to the present value

[6] $\frac{p_H}{\alpha p_H+1-\alpha} = \frac{1}{\frac{\alpha}{1}+\frac{1-\alpha}{p_H}}$

of the harmonic mean of the pledgeable income and the expected pledgeable income. Welfare comes from three sources: (1) the NPV of the good project, (2) the Banker's savings on capital cost of equity funding γR_M, and (3) the Banker's loss due to the foregone interest income of the DIF $(1-\beta R_G)h_0 M$. Welfare is just the Banker's utility because IR_I binds.

Figure 1.4: DI constraints and solutions



Note: The figure shows the constraints faced by the Banker in DI, the equilibrium and the first best. IC is the incentive compatibility, IR_I is the Investor's individually rational and IR_B is the Banker's individually rational constraint. (M^*, R_M^*) and (M^o, R_M^o) are the equilibrium and first best deposit stocks and repayments on money, respectively. The grey shaded area is the intersection of the constraints. $I = 1$ (investment), $R = 1.7$ (return in good state), $p_L = 0.46$ (success probability of bad project), $p_H = 0.66$ (success probability of good project), $\beta = 0.94$ (discount factor), $\gamma = 0.021$ (convenience yield), $\mathcal{B} = 0.168$ (private benefit), $\alpha = 0.5$ (ex ante share), $R_G = 1.031$ (DIF return). I assume A_B (Banker's endowment) is high enough to implement the project.

Figure 1.4 shows the problem of the Banker in DI. She chooses (M, R_M) between the area delimited by IR_B and IR_I. But as she maximises profits, her choice lies on IR_I. Also, due to assumption (1.5), she maximises money. As a result, in the first best, she chooses full money funding. In contrast, in the decentralised equilibrium, she maximises money such that (M, R_M) is in the grey shaded area ("Constraint").

1.2.2.4 Comparison of CBDC and DI

Proposition 1.5 (Comparison of CBDC and DI)**.** *Let W^{n*} denote equilibrium net welfare above endowments and the NPV of the good project ($W^{n*} = W^* - NPV_g$).*

1. *Money*

(a) $M^*_{DI} - M^*_{CBDC} = (\beta + \gamma)\frac{\alpha p_H(1-p_H)}{1-\alpha(1-p_H)}\mathcal{P} \geq 0$

(b) $\frac{M^*_{DI} - M^*_{CBDC}}{M^*_{CBDC}} = \frac{\alpha(1-p_H)}{1-\alpha(1-p_H)} \in [0, \frac{1-p_H}{p_H}]$.

(c) $M^*_{DI} = M^*_{CBDC}$ *if and only if* $\alpha = 0$.

2. *Welfare*

(a) $W^*_{DI} - W^*_{CBDC} = \frac{(\beta+\gamma)R_G - 1}{R_G}\frac{\alpha p_H(1-p_H)}{1-\alpha(1-p_H)}\mathcal{P}$

(b) $\frac{W^{n*}_{DI} - W^{n*}_{CBDC}}{W^{n*}_{CBDC}} = \frac{\alpha(1-p_H)}{1-\alpha(1-p_H)}[1 - \frac{1-\beta R_G}{\gamma R_G}] \in [-\frac{1-(\beta+\gamma)}{\gamma}\frac{1-p_H}{p_H}, \frac{1-p_H}{p_H}]$.

(c) $W^*_{DI} = W^*_{CBDC}$ *if and only if* $\alpha = 0$ *or* $R_G = \frac{1}{\beta+\gamma}$.

(d) $W^*_{DI} < W^*_{CBDC}$ *if and only if* $\alpha > 0$ *and* $R_G < \frac{1}{\beta+\gamma}$.

Proof. From Proposition 1.3 and Proposition 1.4. I use $\alpha \in [0, 1]$ and $R_G \in [1, \frac{1}{\beta}]$ for the calculation of the intervals. ∎

Whenever there is only ex post insurance fee ($\alpha = 0$), the two systems are equivalent both in terms of money and welfare. As in both cases the Investor gets a tioli offer, he ends up with zero net utility. The Government also breaks even in expectation, due to the policy rule. So only the Banker's payoff is interesting, and in such a case the Banker pays the compensation to the Government at the same time ($t = 1$) in the same (good) state.

When there is some ex ante fee ($\alpha > 0$), then more money is created in DI than in CBDC. One can see in Figure 1.3 that in CBDC, ZP_G is above IR_I, reducing money. However, Figure 1.4 shows that in DI, IC is downward-sloping, again reducing money. Overall there is less reduction in DI than in CBDC. The Banker's cash outflow in the good state is just the pledgeable income both in CBDC and in DI:

$$R_L = \mathcal{P} = R_{M,DI} + h_1 M_{DI} = (\frac{1}{\beta + \gamma} + h_1)M_{DI} \tag{1.10}$$

As α grows, the ex post premium h_1 decreases, which creates a room for higher debt repayment $R_{M,DI}$. This leads to a larger money stock M_{DI} too as the safe market interest rate is a constant. Meanwhile, the CBDC stock is unaffected by α, so money in DI is larger than in CBDC. Precisely, the difference in monies is[7]

$$M_{DI} - M_{CBDC} = (\beta + \gamma) R_G h_0 M_{DI} \tag{1.11}$$

which is the present valued repayment of the $t = 0$ investment in the DIF from the Investor's perspective. Paying the same taxes in CBDC and DI state-by-state enables as much larger money repayment in DI than in CBDC as the future value of the DIF investment ($R_G h_0 M_{DI}$), because this future value is a fixed income for the Investor. In other words, safe asset is a result of taxes, and in CBDC only the Investor is taxed at $t = 1$, while in DI the Banker is also taxed at $t = 0$ (above the risk/insurance premium paid in the good state). This creates more safe asset in DI. The Investor's extra utils from larger money repayment is $(\beta + \gamma) R_G h_0 M_{DI}$, which is taken by the Banker in the form of larger initial money stock.

If $\alpha > 0$, then the key question is whether R_G, the return of the DIF, reaches the safe market interest rate $\frac{1}{\beta+\gamma}$ or not. The difference in welfare is

$$W_{DI} - W_{CBDC} = \gamma(R_{M,DI} - R_{M,CBDC}) - (1 - \beta R_G) h_0 M_{DI} \tag{1.12}$$

in which the first term is DI's (present valued) extra savings on capital cost compared to CBDC, and the second is the (present valued) foregone interest income of the DIF. If we denote the Bank's *gross* equity, that is the equity plus the ex ante insurance fee, with $a^g (= a + h_0 M)$, then the welfare difference is further equal to[8]

$$W_{DI} - W_{CBDC} = a_{CBDC} - a^g_{DI} = [(\beta + \gamma) R_G - 1] h_0 M_{DI} \tag{1.13}$$

So, on the one hand, the welfare gain of DI to CBDC is as much as less gross equity has to be invested in DI than in CBDC. On the other hand, it is equal to the net present value of the $t = 0$ investment in the DIF from the Investor's perspective. The intuition is that, as it has

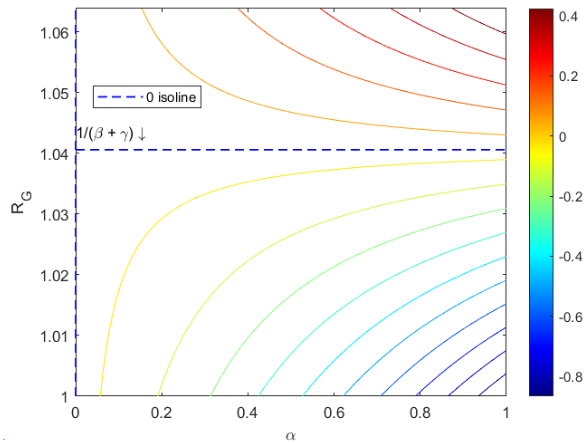
[7] $M_{DI} - M_{CBDC} = (\beta + \gamma)(R_{M,DI} - R_{M,CBDC})$ and $R_{M,DI} - R_{M,CBDC} = (\frac{p_H}{\alpha p_H + 1 - \alpha} - p_H)\mathcal{P} = [1 - (\alpha p_H + 1 - \alpha)] \frac{p_H}{\alpha p_H + 1 - \alpha} \mathcal{P} = \alpha(1 - p_H) R_{M,DI} = R_G h_0 M_{DI}$.

[8] $W_{DI} - W_{CBDC} = \gamma(R_{M,DI} - R_{M,CBDC}) - (1 - \beta R_G) h_0 M_{DI} = (\beta + \gamma)(R_{M,DI} - R_{M,CBDC}) - \beta(R_{M,DI} - R_{M,CBDC}) - (1 - \beta R_G) h_0 M_{DI}$ where $R_{M,DI} - R_{M,CBDC} = R_G h_0 M_{DI}$. So, $W_{DI} - W_{CBDC} = (\beta + \gamma)(R_{M,DI} - R_{M,CBDC}) - h_0 M_{DI} = M_{DI} - M_{CBDC} - h_0 M_{DI}$. On the one hand, this is equal to $(I - a^g_{DI}) - (I - a_{CBDC}) = a_{CBDC} - a^g_{DI}$, and on the other hand, it is equal to $[(\beta + \gamma) R_G - 1] h_0 M_{DI}$, using (1.11).

been shown, the extra utils in DI come from the larger money stock $(\beta+\gamma)R_G h_0 M_{DI}$. To get this, the Banker has to invest the ex ante insurance fee $h_0 M_{DI}$. The net of the two gives the welfare difference. Put differently, the $t=0$ extra tax burden of the Banker has to be compared with the money value of this tax burden. Or, we may argue that if the Investor paid the ex ante fee and he got the repayment, then he would calculate the NPV as $[(\beta+\gamma)R_G - 1]h_0 M_{DI}$. The difference in gross equities $a_{CBDC} - a^g_{DI}$ is also a difference in net monies for the Investor $(1-h_0)M_{DI} - M_{CBDC}$, which is valuable for him.

The sign of the welfare difference is merely dependent on the relationship of R_G and $\frac{1}{\beta+\gamma}$. In other words, R_G is a sufficient statistic. Whenever the DIF's return is lower than the market risk-free rate, CBDC yields higher welfare. As in such a case gross equity is lower with CBDC than with DI, the equity constraint is more likely to bind with DI than with CBDC. That is credit rationing is more of a problem with DI than with CBDC. When $R_G > \frac{1}{\beta+\gamma}$, the opposite is true.

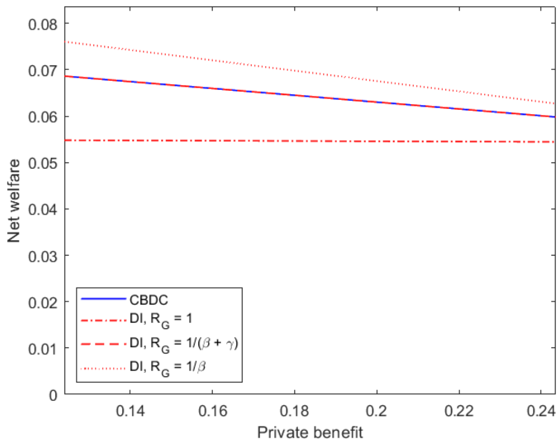
Figure 1.5: Contour plot of relative net welfare surplus of DI to CBDC



Note: The figure shows the contours of $\frac{W^{n*}_{DI} - W^{n*}_{CBDC}}{W^{n*}_{CBDC}}$ (relative net welfare difference above endowments and NPV of the good project) in the (α, R_G) plane (α is ex ante share of the insurance fee, R_G is the DIF's return). $I=1$ (investment), $R=1.7$ (return in good state), $p_L=0.46$ (success probability of bad project), $p_H=0.66$ (success probability of good project), $\beta=0.94$ (discount factor), $\gamma=0.021$ (convenience yield), $\mathcal{B}=0.168$ (private benefit). I assume A_B (Banker's endowment) is high enough to implement the project.

Figure 1.5 shows the isolines of the relative welfare surplus of DI to CBDC as a function of the ex ante share of the insurance fee and of the return of the DIF. If $\alpha=0$ or $R_G = \frac{1}{\beta+\gamma}$, then welfare levels are the same. As α grows or as R_G moves away from $\frac{1}{\beta+\gamma}$, the absolute value of the relative welfare difference increases. The maximum relative welfare difference is $\frac{1-p_H}{p_H}$ at $(\alpha, R_G) = (1, \frac{1}{\beta})$. The minimum is $-\frac{1-(\beta+\gamma)}{\Delta\beta+\gamma}\frac{1-p_H}{p_H}$ at $(\alpha, R_G) = (1, 1)$.

Figure 1.6: Net welfare in CBDC and DI for different DIF returns as a function of the private benefit



Note: Net welfare is above endowments. The private benefit $\mathcal{B}$ is in the range defined by assumptions (1.3) and (1.4). $I = 1$ (investment), $R = 1.7$ (return in good state), $p_L = 0.46$ (success probability of bad project), $p_H = 0.66$ (success probability of good project), $\beta = 0.94$ (discount factor), $\gamma = 0.021$ (convenience yield), $\alpha = 1$ (ex ante share of insurance fee). I assume A_B (Banker's endowment) is high enough to implement the project.

Figure 1.6 plots net welfare above endowments as a function of the private benefit $\mathcal{B}$ both for CBDC and for DI, using three different values for the DIF return R_G. I set α to 1 to magnify the differences. As earlier, we can see the equivalence in the case of $R_G = \frac{1}{\beta+\gamma}$, and that DI welfare increases in R_G. It is also visible that welfare decreases in $\mathcal{B}$ or the degree of asymmetric information.

1.2.2.5 Comparison of decentralised equilibria with first best

Proposition 1.6 (Comparison of decentralised equilibria with first best). *Let M^*, M^o, W^{n*} and W^{no} denote money stock and net welfare (above endowments and the NPV of the good project) in the decentralised equilibrium and in the first best, respectively ($W^n = W - NPV_g$).*

1. $0 < M^*_{CBDC} \leq M^*_{DI} < M^o$

2. $0 < \min_{\alpha, R_G} W_{DI}^{n*} < W_{CBDC}^{n*} < \max_{\alpha, R_G} W_{DI}^{n*} < W^{no}$

Proof. In Appendix A.2. ■

There is less money supplied in the decentralised equilibria than in the first best, as in the former there is a need to incentivise the Banker, so there is need for equity. For the same reason, even the best of decentralised equilibria (DI with $\alpha = 1$ and $R_G = \frac{1}{\beta}$) yields less welfare than the first best. However, the worst of decentralised equilibria (DI with $\alpha = 1$ and $R_G = 1$) is still better than a world without money, due to assumption (1.5).

1.3 Discussion on risk-taking

The two regimes seem to be similar even if risk-taking is taken into account. Although by Assumption 1.3 I exclude the bad project choice in equilibrium, it is worth discussing the question of risk-taking. Firstly, I consider banks' risk-taking in reality, then I turn to the model.

1.3.1 Risk-taking in reality

1.3.1.1 Demandable debt According to Tirole, 2006 Ch. 8.4, demandable debt is a monitoring tool. As demand deposit holders can withdraw their deposit at any time, the issuer bank is disciplined to behave well. Unless it runs a safe business, and remains liquid and solvent, depositors may run on the bank.[9]

But by introducing deposit insurance, depositors' such incentive to monitor is reduced, if not eliminated. It is because in the case of bank failure, depositors are salvaged by the government, whereby the government is most likely to finance this operation by unconditional taxes. So, depositors are indifferent to leave their deposits with the bank or to withdraw it. In other words, "no questions are asked" by depositors (Gorton, 2020). As a result, bank risk-taking can increase. This is a reason why bank regulation and supervision is important: instead of depositors, the government does the monitoring.

In a CBDC system in which all deposits flow to the central bank which refinances commercial banks, supervision is also important. In such a system, the central bank is the only lender of

[9]This is a bit more complicated. A review of banking panics is found for example, in Calomiris and Gorton, 1991.

commercial banks. If we allow for short-term loans, then we end up with demandable debt again. Although normally the central bank does not want to make a commercial bank go bankrupt (due to bankruptcy costs),[10] the central bank is also interested in financing good projects by the commercial bank, and perhaps in its own profits. So, the central bank may withdraw demandable refinancing if it fears the borrower bank will not be able to repay its debt. To assess the creditworthiness of the commercial bank, the central bank may rely on supervisory information.

1.3.1.2 Risk premium In the US DI system, insurance premia are to be paid ex ante (at least de jure). That is, all banks have to pay some fee in every period, not just those banks which survive a potential crisis (ex post funding). The reason for ex ante payment is that ex post fees give bad incentives to banks (Tobin, 1987). If the sounder (or luckier) banks have to pay fees to salvage depositors of the riskier (or unlucky) banks, then banks in general may behave badly. Ex ante funding also entails a larger deposit insurance fund, that is, less taxes and less tax distortion. However, the larger DIF may result in more foregone interest income too, especially if it was invested in cash.

Tobin, 1987 also writes that it is impossible to set risk-based insurance premia in advance of failure. Authorities are able to assess the risk profiles of banks when the crisis hits, but it is too late. I understand his point, but again would like to emphasize the importance of proper supervision, based on which insurance premia could be determined.

In a CBDC system, the problem is similar. Banks pay interest rate premia on their loan taken from the central bank in every period. Thus, in case of a failure, all banks (the failed institution included) indemnify the central bank. The central bank usually invests the proceeds in a conservative manner. Although the interest premium is uniform throughout the banking system (the Fed's primary credit rate is the same for all institutions), the amount of refinancing is based on the value of eligible collateral, so it is determined somewhat according to the risk profile of commercial banks.

[10]In the case of CBDC, bankruptcy costs are likely to be smaller than in DI because the electronic payment system is not disrupted (Williamson, 2022).

1.3.2 Risk-taking in the model

DI and CBDC still seem to be similar systems when controlling for the bad project. If I allowed for the bad project to be chosen in equilibrium, then I would need to modify Assumption 1.3 such that $NPV_g < NPV_b'$. That is, a fully debt-financed bad project would yield higher surplus than a fully equity-financed good project.

In such a case, in DI, the bank would have to choose between two potential equilibria:

- Good project: the incentive compatibility constraint and the individually rational constraint of investors both bind so that there is small amount of debt. This is the solution I present in the paper ((M^*, R_M^*) in Figure 1.4).
- Bad project: the incentive compatibility constraint does not hold but the individually rational constraint of investors bind, and there is full debt (no equity). This is point (M^o, R_M^o) in Figure 1.4 (but with the bad project in this case).

It may happen that the bank chooses the bad project. But this is welfare-improving, as all utils go to the banker. In other words, the private benefit should be considered too in welfare comparisons, and this private benefit is so large that it overcompensates the low success probability. There is no risk-shifting in the model either. The banker cannot promise to choose the good project with 0 equity, and later deviate to the bad one, because everybody knows she will invest in the bad one without equity.

The situation is similar with CBDC. The two potential equilibira are:

- Good project: the incentive compatibility constraint and the individually rational constraint of investors both bind, together with the zero profit constraint of the government (the latter for the good project), so that there is small amount of debt. This is the solution I present in the paper ((M^*, R_M^*) in Figure 1.3).
- Bad project: the incentive compatibility constraint does not hold but the individually rational constraint of investors bind, together with the zero profit constraint of the government (the latter for the bad project), and there is full debt. (This point is not in Figure 1.3.)

Again, the bank could choose the bad project. However, this is welfare-improving, given the fact that the private benefit is part of welfare. Moreover, there is no risk shifting because the banker cannot deceive investors and the government.

1.4 Historical outlook

In this section, I try to bring the model to the real world, both to nowadays and to older times. As the model is quite simple, I cannot give sharp values to the parameters. Therefore, we ought not to focus on the exact numbers but on the orders of magnitude and on the comparison of current versus old times. Moreover, as differences between CBDC and DI regimes are driven by a reduced form parameter (R_G), the Lucas critique suggests that the model cannot be used to draw robust welfare implications about the trade-offs between the two regimes (Lucas, 1976). In the exercise I pay attention to assumptions (1.3), (1.4) and (1.5).

1.4.1 Common parameters

First I present the parameters which are common throughout the centuries. I set the investment I as a scaling variable to 1, and I assume the repayment of the project in the good outcome R is 1.1. I use $\Delta p = 0.2$ difference in success probabilities. According to the examples of Stein, 2012, the discount factor β is 0.96, which is quite standard in the literature (see Dejong and Dave, 2011 for example).

As a baseline, I consider a fully ex ante financed DIF, that is $\alpha = 1$. The reason behind is that the FDIC claims to be funded ex ante (Ellis, 2013). Nevertheless, I also experiment with $\alpha = 0.5$, as ex ante funding is smooth over time in reality (when there are more than 2 periods). Also, we can argue that funding is at least partially ex post because the FDIC has not yet reached the 2 percent DRR even though it was first set in 2011.[11]

1.4.2 Nowadays

Since the beginning, the FDIC has invested its funds mainly in government securities. In 1934, the share of Treasury securities in total assets was 94 percent, while in 2020, the same ratio was 92 percent (FDIC, 1935, FDIC, 2021a). As a result, we can infer that the DIF bears the safe

[11] See Historical Designated Reserve Ratio. The actual reserve ratio as of 31 March 2021 was 1.25 percent (FDIC, 2021b).

market return, that is $R_G = \frac{1}{\beta+\gamma}$. Therefore, given Proposition 1.5, CBDC and DI are equivalent nowadays.

However, a potentially better candidate for R_G is the return on the assets of the *consolidated* government, which is difficult to estimate. In the following, I assume in a conservative manner that this alternative R_G is 1. That is the government does not achieve a positive net return on its assets.

To calibrate γ, the convenience yield of safe assets, I use the data of Schmelzing, 2020. He calculates global advanced economy safe real interest rates for every year between 1314-2018. From these I calculate $\gamma = \frac{1}{1+\text{safe rate}} - \beta$. In the 1998-2018 period, the safe rate was around 1.5 percent on average. γ fluctuated between 0.004 and 0.044, with an average of 0.025. This is similar to the 0.03 value in the examples of Stein, 2012.

Then, I use the 2 percent DRR of the FDIC to calibrate p_H, the success probability of the good project. If there are $T \geq 2$ periods, if default can only occur at $t = T-1$ (the last period), if there is no discounting ($R_G = \beta = 1$ and $\gamma = 0$), and if the deposit insurance premium is the same h in every period, then the Government's zero profit condition is

$$(T-1)hM = (1-p_H)R_M \tag{1.14}$$

If the DRR is achieved at $t = T-2$, then $DRR = (T-1)h = (1-p_H)\frac{R_M}{M} = 1-p_H$ as there is no discounting. By using a 2 percent DRR, I get $p_H = 0.98$ and $p_L = 0.78$. A crucial assumption I use is that the DIF insures all deposits even in the case of a system-wide bank failure. Otherwise, the DRR would need to be higher to guarantee all deposits at all times, leading to a lower success probability.

Lastly, I use a private benefit $\mathcal{B} = 0.08$. This value is in the middle of the range defined by assumptions (1.3) and (1.4).

Altogether, with $I = 1$, $R = 1.1$, $p_L = 0.78$, $p_H = 0.98$, $\beta = 0.96$, $\gamma = 0.025$, $\mathcal{B} = 0.08$, $\alpha = 1$ and $R_G = 1$, the relative welfare difference of DI to CBDC $\frac{W^n_{DI} - W^n_{CBDC}}{W^n_{CBDC}}$ is -0.012 (or -1.2 percent). Thus, even in an extreme case of fully ex ante funding and no interest income of the DIF, the welfare loss of DI relative to CBDC is negligible.

1.4.3 Old times: 18th, 19th centuries

Some centuries ago, privately-owned central banks used to be competitors of commercial banks. For example, Bordo and Levin, 2017 writes that in early years of central banking, individuals and non-financial firms used to hold bank accounts at the Sveriges Riksbank and the Bank of England. Also, according to Fernández-Villaverde et al., 2020, the First and Second Banks of the United States,[12] and the Banco de España engaged in commercial banking activities on the borrowing and credit markets. Later, central banks abandoned issuing CBDC-like liabilities as paper-based account management had become more and more impractical. In the following, I focus on the 1830s-1840s USA, just after the era of the First and Second Banks of the US (1791-1836), at the beginning of the Free Banking Era (1837-62). My choice is motivated by data availability: the first capital ratio data I have found are from this period.

I calculate the convenience yield γ in the same way as in Subsection 1.4.2. I look at the period of 1830-50. During these decades, the average safe real interest rate was around 4.1 percent. γ fluctuated between -0.095 and 0.133, the average was 0.001.

In old ages, the monetary system was based on precious metal. In the period analysed, the US was also on a metallic standard. Stevens, 1971 determines four kinds of monetary instruments: federal coin and uncoined specie, foreign coin, bank notes and deposits, and state and private scrip. Between 1842-50, the ratio of bank-issued notes and deposits to specie held by non-banks was between 1.5-3. The proportion of notes and deposits to specie held by banks was around 3-5. Thus, 1/4 to 1/2 of specie was held by banks. I assume that in such a regime, if there had been a federal DI system, then it would have invested much of its funds in specie, which bears no interest. Precisely, I assume the DIF would have had a specie ratio equal to that of banks, 1/3-1/5, resulting in $R_G - 1 = (2/3 - 4/5) \times \text{safe rate} = 2.7 - 3.3\%$.[13]

To calibrate the success probability p_H, I use assumption (1.5), according to which $p_H > 0.985$. As this is a very high lower bound, my guess for p_H is simply 0.985. Thus, p_L is 0.785.

Then I can calibrate the private benefit $\mathcal{B}$ by modifying the model somewhat. In a free banking system, the amount of deposits would be $\beta p_H \mathcal{P}$.[14] This entails $\mathcal{P} = \frac{\text{Deposit}}{\beta p_H}$. Berger

[12]There was a 1/5 stake of the Government in the (Second) Bank of the US. Early central banks had a dual mandate of profitability and social responsibility (Calomiris, 2011).

[13]I have not found data on the assets of early state-level DI schemes.

[14]The proof is similar to that of Propositions 1.3 and 1.4. The gross repayment on deposit is $\mathcal{P}$, the pledgeable

et al., 1995 writes that the capital ratio of US banks in 1840 was as high as 50 percent. Then I estimate the deposit ratio as the remaining 50 percent. As a result, I get an estimate of 0.53 for $\mathcal{P}$, from which the guess for the benefit $\mathcal{B}$ is 0.11.

All in all, with $I = 1$, $R = 1.1$, $p_L = 0.785$, $p_H = 0.985$, $\beta = 0.96$, $\gamma = 0.001$, $\mathcal{B} = 0.11$, $\alpha = 1$ and $R_G = 1.03$, the relative welfare difference of DI to CBDC $\frac{W^n_{DI} - W^n_{CBDC}}{W^n_{CBDC}}$ is -0.23 (or -23 percent). This seems to be economically significant.

I summarise the baseline parameter values in Table 1.2.

Table 1.2: Baseline parameters

Variable	Notation	Nowadays	Old times
Investment	I	1	
Project outcome in good state	R	1.1	
Discount factor	β	0.96	
Ex ante share of insurance fee	α	1	
Success probability of bad project	p_L	0.78	0.785
Success probability of good project	p_H	0.98	0.985
Private benefit	$\mathcal{B}$	0.08	0.11
Convenience yield	γ	0.025	0.001
DIF's gross return	R_G	1.015	1.03

Note: The values above the line are common.

1.4.4 Comparison of current and old times

The relative welfare loss of DI to CBDC was probably higher in old times than nowadays. The difference in the relative welfare measures originates from two (or potentially three) parameters: R_G, γ (and p_H).

1. R_G: the change from metallic to fiat standard could lead to a higher return on the DIF. The banks are no longer obliged to pay specie to the bearer on demand but their demand deposits are based on central bank money. The central bank can create fiat money out of thin air, unlike silver or gold. Therefore, the FDIC can afford to hold government claims, which bear interest.

income. As the deposit is risky, the Investor is interested in the *expected* pledgeable income, or $p_H\mathcal{P}$. Its present value is $\beta p_H \mathcal{P}$.

 Hungarian DOI: 10.14754/CEU.2024.06

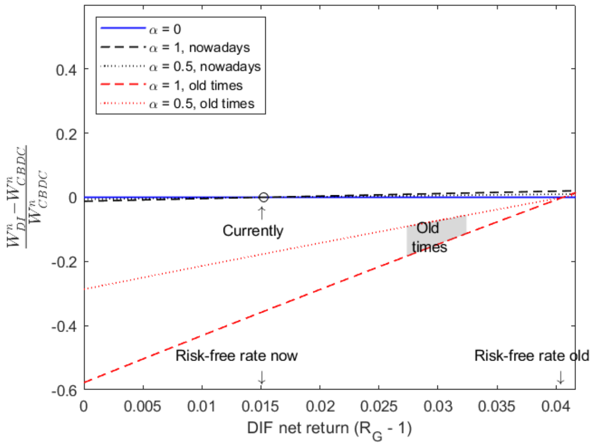
2. γ: I show an increasing γ over time. Krishnamurthy and Vissing-Jorgensen, 2012 gives a more sophisticated measure of the convenience yield between 1919-2008 (see Appendix A.1). Krishnamurthy and Vissing-Jorgensen claim their estimate is conservative, so the true convenience yield could be higher. That is, it could be closer to my estimate of γ. This might give support to my numbers, and therefore, to my finding that γ increased throughout the last two centuries. Del Negro et al., 2017 finds that the premium for safety and liquidity has increased since the late 1990s, and it is in line with the literature on the shortage of safe assets.

3. p_H: The success probability of the bank's assets could have also increased over time (this is outside of my calibration). In the 1830s-1850s there were frequent banking panics and many bank failures in the USA (see for example, Calomiris and Gorton, 1991, Calomiris, 2011). In those times, the US banking system was mainly based on unit banking (geographically isolated single-office banks). These banks could not diversify investments across the country (and sectors). Moreover, as there were a large number of banks, they could not cooperate easily to manage adverse shocks. In contrast, nowadays there is branch banking in the US.[15] In addition, information technology is much more advanced nowadays than before, and computers help banks assess the creditworthiness of their customers. Lastly, the mere fact that banks' capital ratio has declined over time can be a sign that they have become safer, resulting in a lower capital requirement by the public (Berger et al., 1995).

Figure 1.7 shows the relative welfare surplus of DI to CBDC nowadays and in old times. For a hypothetical $\alpha = 0$, the two systems are equivalent. Nowadays, if I assume the DIF net return $R_G - 1$ is just the market risk-free rate, then there is no difference between DI and CBDC either. Moreover, even if $\alpha = 1$ and $R_G - 1 = 0$, then the two regimes are still observationally the same due to the currently high convenience yield γ (and high success probability p_H). However, in old times the market safe rate was higher but the DIF return could have fallen short of it. Then, with $\alpha \in [0.5, 1]$ and with a lower γ (and potentially lower p_H), DI could have underperformed CBDC.

[15] The Riegle-Neal Interstate Banking and Branching Efficiency Act of 1994 made branch banking possible in the whole country.

Figure 1.7: Relative welfare surplus of DI to CBDC - then and now



Note: The figure shows the relative net welfare surplus of DI to CBDC above endowments and the NPV of the good project as a function of the DIF's net return $R_G - 1$ for different α's (ex ante share of insurance fee), both for current and old times. Nowadays the market risk-free rate is 1.5 percent, while it was 4.1 percent in the past. $\beta = 0.96$ (discount factor), $p_{H,now} = 0.98$ (success probability of good project now), $p_{H,old} = 0.985$ (success probability of good project then), $\gamma_{now} = 0.025$ (convenience yield now), $\gamma_{old} = 0.001$ (convenience yield then). I assume $\alpha \in [0.5, 1]$. $R_{G,now} - 1$ is the risk-free market rate, while $R_{G,old}$ was only $2/3 - 4/5$ times the risk-free rate.

1.5 Conclusion

As Central Bank Digital Currency and deposit insurance seem to be equivalent systems nowadays, it is not necessarily reasonable to introduce CBDC. We live in a world of DI, and central banks consider issuing CBDC. I have shown that, if my model assumptions hold, the two solutions to create safe asset lead to the same outcome. The equivalence is a result of the investment strategy of the DIF, and more generally of the fiat monetary regime.

However, my approach is clearly limited. It is a microeconomic model without a price level and there is no possibility of bank runs. Thus, we cannot draw either monetary policy or financial stability conclusions. This is a scope for further research.

Hungarian DOI: 10.14754/CEU.2024.06

2 Chapter 2: Creative Banks: A Theory

2.1 Introduction

Banks have a special relationship with liquidity. On the one hand, unlike other firms, banks create liquidity to their customers in the form of deposits. Deposits are monetary liabilities of banks, the non-bank sector uses them as money. On the other hand, similarly to other firms, banks hold liquid assets, like cash reserves or securities. While non-financial firms mainly hold these assets to cope with revenue shortfalls, banks' motives are threefold (Stulz et al., 2022).

- Transaction motive: customers can pay deposits to customers of other banks, and the bank has to settle these flows in central bank money (reserves).
- Precautionary motive: the bank has to prepare for a potential massive outflow of deposits (bank run) or drawdown on credit lines.
- Investment motive: a bank as a financial intermediary has a portfolio of financial assets, and the composition of the portfolio depends on the risk-adjusted returns of the assets. Thus, a bank can hold interest-bearing reserves for portfolio reasons as well.

The money supply process is still a black box. Although there exists a standard measure of bank liquidity creation, there is no benchmark theory of liquidity provision by banks (D. W. Diamond and Kashyap, 2016). Berger and Bouwman, 2009 measures bank liquidity creation based on the liquidity of all the on- and off-balance sheet items of intermediaries. However, up to my knowledge, there is no underlying theory which governs the value of this metric. We can distinguish at least three theories of banking and money creation (Werner, 2016). I call them financial intermediation, aggregate money creation and individual money creation theories. The financial intermediation theory neglects the money supplier role of commercial banks, it only concentrates on deposit-taking and lending. The aggregate money creation theory says that commercial banks on the aggregate create money in a chain of depositing, lending, redepositing. According to the individual money creation theory, however, banks can create money individually by lending. As this paper deals with banks' role played in the money supply mechanism, hereinafter I focus on the latter two theories.

This paper proposes a measure of money creation ability of a bank. When the bank lends to a borrower, it disburses the loan in newly created deposit money. The borrower then may use this money to pay his/her purchases on the market, thereby the deposit starts to circulate in the economy. If the circulating deposit remains with the bank, then it could create money. But if the deposit leaves for another bank, then the first bank is unable to create (and retain) (commercial bank) money as it has to pay off the other bank in central bank money. So, the suggested money creation ability is the reaction of depositors' supply of new deposits to borrowers' demand for new loans. It grabs the spillover effect of lending on deposit-taking, that is, on money creation. In my theory, this spillover effect is a parameter θ which lies between 0 and 1. The larger the θ, the better is the bank's ability to create liquidity. That is how I unify the aggregate and the individual creation theories: for lower θ the bank is an aggregate creator of money, and for larger θ it is an individual creator.

I connect this parameter with a simplified version of the standard liquidity creation measure. Instead of the complex Berger-Bouwman metric, I look at the reserves-to-deposits ratio, which is the reciprocal of the money multiplier of an individual bank. I show that the reserve ratio decreases in θ, that is, actual money creation indeed increases in the creation ability. Or, we might say that a bank's liquidity holding is inversely related to its liquidity creation ability.

I also show that the correlation of deposits and loans is increasing in θ. It holds even if the relationship between deposit-taking and lending is endogenous. That is, if there is a omitted confounder, or if deposit-taking and lending are simultaneously determined, or lending is measured with an error, then the correlation is still larger with larger θ. As a result, money creation ability can be approximated by the deposit-loan correlation. Therefore, a bank's liquid asset holding is not only a negative function of money creation ability but also of deposit-loan correlation.

Lastly, I address the question how the deposit market reacts to loan demand shocks overall, depending on the ability to create money. Above the connection between borrowers' loan demand and depositors' deposit supply, what is the relationship between borrowers' loan demand and the bank's deposit demand? I modify my model somewhat to answer this question, but as I could not solve it, I only show a graphical exposition. According to this, I conjecture that deposit demand increases in loan demand, and this increase is larger for banks which can create money less, that is, for aggregate creators.

I build a model of bank asset-liability management. The bank, subject to minimum reserve requirement, has market power both in the deposit and loan markets. Deposit and loan contracts are short-term, but interest rates are fixed for long-term. As the future deposit supply and loan demand curves are uncertain, the bank faces liquidity risk due to the sticky prices. For example, if depositors decrease their deposit supply in the future, the bank cannot adjust and increase the interest rates to preserve its liquidity position. Therefore, it can breach the reserve requirement. The probability of illiquidity is a parameter, subject to which the bank maximises profits. In addition, the deposit shock comes from two sources: there is the spillover effect of loan shocks, and there is a residual deposit supply shock. The spillover effect seizes the bank's money creation ability, and, to handle potential endogeneity, the residual shock can be correlated with the loan shock. In an extension I allow for interest rate adjustment costs, that is, prices are only partially sticky to obtain a downward-sloping deposit demand curve. I use this extension to show graphically the effect of loan demand on deposit demand.

The intuition for the main result is that if the bank finances loan shocks by new deposits rather than by using reserves, then it needs to hold less reserves ex ante. We can also say that the variability of reserves is smaller when the money creation ability is larger. As a consequence, for a given level of reserves, there is less probability of becoming illiquid. Or vice versa, for a given probability of illiquidity, a lower level of reserves is sufficient. This highlights the liquidity risk hedging role of the ability to create money.

The intuition behind the conjecture of the effect of loan demand on deposit demand is the following. For aggregate money creators (with small θ and large reserves), an increase in loan demand must be accompanied by a larger increase in deposit demand than in the case of individual creators (with large θ and small reserves) due to two reasons. On the one hand, due to large reserves, which are assumed to be complements of loans, at least on the medium run, an increase in loans also entails a rise in reserves, both of which must be financed by deposits. On the other hand, due to the small θ, deposit supply does not increase. So, deposit demand must go up substantially.

My findings may have policy implications. Financial stability relies partly on the adequate stock of bank liquid assets. If the regulator does not want to penalise individual creator banks, who would want to hold less liquidity, with a one-size-fits-all liquidity requirement, or if the regulator wants to avoid the risk that aggregate creators, who should hold more liquidity, accommodate to such a uniform requirement, then the regulator may introduce individual requirements. If banks know their money creation ability better than the regulator, then an optional liquidity requirement system can be considered.[16] But if for some reason the regulator knows θ better, then it may set requirements bank-by-bank.

The conjecture of the relationship between loan demand and the deposit market implies a more volatile deposit interest rate for aggregate creators than for individual creators. This may weaken the monetary transmission mechanism. However, government backstop facilities, such as lender of last resort (LoLR), deposit insurance or bailout, which may improve banks' money creation ability, might reduce the sensitivity of deposit rates to loan demand shocks, contributing to a more efficient transmission mechanism.

Social welfare does not necessarily increase in individual banks' ability to create liquidity. A larger θ contributes to larger bank profits through smaller liquidity ratios. The more efficient liquidity management, nonetheless, can reduce central bank profits (seigniorage) and may affect government finances adversely.

Related literature. The first strand of related literature is about liquid asset holdings of banks. In Freixas and Rochet, 2008 Ch. 8.2 there is a reserve management model with deposit uncertainty and penalty of liquidity shortage. The optimal amount of reserves is that for which the marginal opportunity cost of holding reserves equals the expected cost of liquidity shortage. In the monopolistic version of the model, based on Prisman et al., 1986, asset and liability decisions become interdependent, interest rates increase in the penalty rate, and the volume of credit decreases in the variance of the deposit shock. Duttweiler, 2009 uses the concept Liquidity-at-Risk which I build on. Other relevant papers deal with the determinants of bank liquid asset ratio (Stulz et al., 2022), with liquidity requirements, liquidity choice, and financial stability (D. W. Diamond and Kashyap, 2016), with accumulating reserves during the Great Financial Crisis (GFC) of 2008-9 (Keister and McAndrews, 2009, Chang et al., 2014), or with the potential adverse effect of quantitative easing on lending (Acharya and Rajan, 2022, W. F. Diamond et al., 2022). My contribution is introducing correlated liquidity shocks on both sides of the balance

[16] There was an optional reserve requirement system in place in Hungary between 2010 and 2015, and between 2022 and 2023 (MNB website).

sheet.

The second strand of literature deals with money creation of commercial banks. The debate on how commercial banks create money has a long history (Werner, 2016). In the 19th-20th centuries representatives of the financial intermediation theory were, for example, von Mises, 1912, Gurley and Shaw, 1960, Tobin, 1963, D. W. Diamond and Dybvig, 1983 or Holmström and Tirole, 1997. Economists arguing for aggregate creation were Marshall, 1890, Phillips, 1920 or Samuelson, 1948. Others, such as Wicksell, 1898, Schumpeter, 1912, or Fisher, 1935, were proponents of individual creation. In the 21st century, the financial intermediation theory still dominates (for instance, Gertler and Kiyotaki, 2015, Boissay et al., 2016). Among those who take money creation into account, Mankiw, 2016 supports aggregate creation, while CORE, 2017 presents individual creation. The Bank of England and the Deutsche Bundesbank have also published papers in favour of individual creation (McLeay et al., 2014a, McLeay et al., 2014b, Bundesbank, 2017).

Li et al., 2023 analyses the network structure of money multiplier. According to this paper, the dual role of deposits as funding for banks and means of payment for non-banks implies liquidity spillover effects of bank lending. The authors model a game of bank lending on a random graph of payment flows. They find that network topology determines the money multiplier, and network externalities distort the money-multiplier mechanism. Kashyap et al., 2002 analyses the relationship between loan commitments and demand deposits in a discrete world, and points out the potential for diversification across both sides of a bank's balance sheet. They say that the cost of holding liquid assets can be shared by the deposit-taking and the loan commitment activities as long as deposit withdrawals and credit drawdowns are not perfectly positively correlated. Berger and Bouwman, 2009 defines a measure of bank liquidity creation, which is a generalisation of the metric of Deep and Schaefer, 2004. Also, Jakab and Kumhof, 2019 compares two macroeconomic models, one with intermediation of loanable funds, and one with financing through money creation. I contribute to this strand by assuming joint normally distributed deposit and loan shocks, and by introducing a measure of money creation ability, which can be represented by the correlation of deposit and loan shocks.

Thirdly, the literature on the bank lending channel (of monetary transmission) is related too. This strand of literature deals with the effect of bank liabilities on bank loans (in the case of monetary policy shocks). Bernanke, 1983, 1988, Bernanke and Blinder, 1988, Kashyap and Stein, 1994, J. Stiglitz and Greenwald, 2003 emphasize the importance of bank credit for the macroeconomy, along with money. Stein, 1998 and Hanson et al., 2015 highlight the special role of deposits in bank funding, according to which the bank lending channel operates through deposits. Drechsler et al., 2017 builds on this approach too. Disyatat, 2011, however, builds a new framework in which market-based funding enhances the importance of the channel. My paper connects to this literature in the sense that I change the direction of analysis: I am interested in the effect of loans on deposits, and not of deposits on loans.

The rest of the paper is organised as follows. In Section 2.2 I summarise the textbook theories of money creation. In Section 2.3, I build my theoretical liquidity management model and solve it. In Section 2.4, I extend the model with interest rate adjustment costs, and draw my conjectures. Lastly, I conclude in Section 2.5. In Appendix B, I show model versions with explicit endogeneity, and I present another, potentially more realistic but more complicated version of the model.

2.2 Aggregate versus individual money creation

2.2.1 Textbook presentation

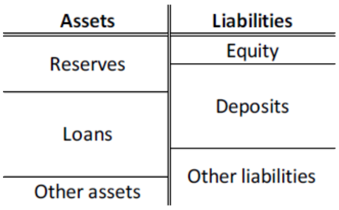
Figure 2.1 shows the stylised balance sheet of a commercial bank. As a financial intermediary, loans are its most important assets and deposits are the most important liabilities. However, on the asset side, there are also liquid assets, such as central bank money (cash and balances at the central bank) and securities.[17] The bank can manage liquidity risk by holding liquid assets. For example, if deposits flow out from the bank, then it pays these deposits in cash. Similarly, on the liability side there is equity, which can absorb potential losses. For instance, if some borrowers default on their loan, then the bank charges off their obligation from the loans and from its equity. Examples for other assets and liabilities are wholesale (interbank) claims and obligations, physical capital, or debt securities issued.

Figure 2.2 presents the aggregate money creation view, based on Mankiw, 2016 Ch. 4-2. According to this approach, in order to engage in lending, a bank first has to collect deposits. First, depositors deposit cash with the bank by which its balance sheet increases: it gets reserves,

[17]For the sake of simplicity, I call liquid assets reserves in the paper. However, normally reserves mean central bank money only, while liquid assets is a broader concept.

 Hungarian DOI: 10.14754/CEU.2024.06

Figure 2.1: Stylised bank balance sheet

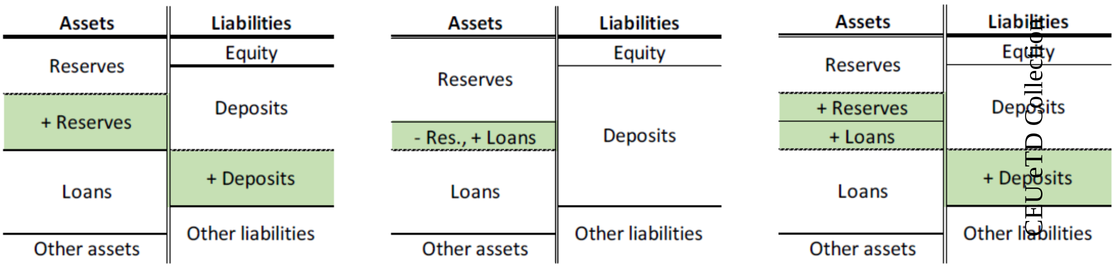


Note: In this figure reserves constitute of cash and liquid securities.

which are funded by new deposits. Then, the bank keeps some part of the reserves to comply with reserve requirements set by authorities and potentially by the bank itself. The bank is able to lend out the remaining part of reserves (free reserves) to potential borrowers. This view assumes the bank lends cash to borrowers. The cash that leaves the bank is later deposited with another bank (not in the figure), which does the same. And so on, the process goes till infinity. During the process, central bank money is multiplied as new deposits are created. Deposits, especially demand deposits, are also a form of money, we call them commercial bank money.

Figure 2.2: Aggregate money creation (Mankiw, 2016)

(a) Depositing (b) Lending (c) Together



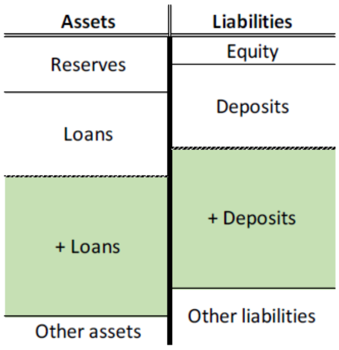
Note: The three figures together show one round in the infinite money multiplication process. In panel 2.2(a) depositors deposit cash (central bank money) with the bank. In panel 2.2(b) the bank lends out part of this cash to borrowers and keeps the remaining as reserves. Panel 2.2(c) shows the two steps together.

Figure 2.3 depicts the individual money creation view, based on CORE, 2017 Ch. 10.8.[18] According to this approach, if a bank wants to lend to potential borrowers, it needs much less reserves. The bank lends out not cash but newly created deposits. Whenever a borrower is granted a loan, (s)he gets commercial bank money and not central bank money. The bank writes

[18] McLeay et al., 2014a and Bundesbank, 2017 contain similar figures.

the amount of money on the deposit account of the borrower. As the new deposit finances the new loan, the bank can multiply its free reserves in one step, there is no infinite long money multiplication process.

Figure 2.3: Individual money creation (CORE, 2017)



Note: The borrower receives a deposit (commercial bank money) in exchange for his/her indebtedness to the bank. The bank increases its balance sheet directly by lending, which is financed by the newly created deposit.

There are several factors which provide commercial bank money with purchasing power, although as a digital token it lacks intrinsic value. Firstly, the loan in the books of the bank is a backing behind the deposit (for example, McAndrews and Roberds, 1999, Donaldson et al., 2018). There will be demand for deposit money at the time of loan redemption because the bank accepts the deposit for loan redemption (otherwise the bank seizes collateral, for example real estate). So, essentially, real estate could be bought by deposit in the future, generating purchasing power today. Secondly, deposit money is a claim on cash as cash can be withdrawn from a deposit account (Donaldson and Piacentino, 2019). Cash has purchasing power because it is legal tender, it is mandatory to accept it in exchange of goods and services. In addition, the purchasing power of cash (or inversely, the price level) is influenced by monetary policy, which is generally explicitly in charge of price stability. The first two factors are related to the safeness of the deposit (Gorton and Pennacchi, 1990). Thirdly, a bubble value can also be attributed both to cash and deposit (for instance, Kareken and Wallace, 1981, Moinas and Pouget, 2013, Brunnermeier and Niepelt, 2019). Money is accepted as means of payment by one agent simply because (s)he expects others to accept it in the future.

2.2.2 Combining the theories

In my view, the two theories can be generalised into one common approach. It is known that when a bank gives a loan to a borrower, it does not hand over cash but it disburses the loan in digital money. This digital money is typically held on a deposit account at the same bank. So, the bank credits the borrower's deposit account while it does not debit the deposit account of anyone else. This is an evidence for money creation: the loan is financed by a new deposit.

But, the newly created deposit can leave the bank. Net deposit flows are interesting in this respect. If the borrower pays to someone with a deposit account at another bank, then there is a gross deposit outflow. Meanwhile, other banks' customers can pay to the first banks' customers, which results in a gross deposit inflow. There can be intrabank transfers too among the customers of the first bank. The bank has to pay out net outflows in central bank money, which consumes liquid assets.

In my interpretation, the key difference between individual and aggregate money creation is about the afterlife of the newly created deposit. Individual creation means the deposit remains at the bank, while aggregate creation implies the deposit leaves the bank. That is how I introduce the money creation ability parameter θ. It connects the asset and liability sides of the bank through the behaviour of its customers. If the bank lends some amount λ to borrowers in the form of deposits on account of a loan demand shock of borrowers, then immediately appears λ deposits in the bank. Then, due to changes in depositors' deposit supply, by the end of the period (day, week), a proportion θ of deposits remain with the bank, and $1 - \theta$ leaves it. Furthermore, I allow for a residual deposit supply shock. So, essentially θ is a linear regression coefficient of deposit change on loan change.

The liquidity creation ability parameter θ can capture different organisational and institutional characteristics. If the bank is a monopoly in the deposit market, then it should have larger ability, as there is no other bank to which deposits could flow out. On the one hand, larger banks could have larger θ. On the other hand, smaller banks which are locally active could also possess a better ability. Both types of banks could have market power. Also, if banks are similar, if they tend to expand their balance sheets by lending at the same time and same size, and if deposits tend to spread across the system in a uniform manner, then bank level deposit-loan correlations are likely to be large for all banks. Government backstop facilities, such as LoLR, deposit insurance or bailout are institutional arrangements which help the commercial banking system create deposits too, as they prevent deposits from fleeing to cash.

2.3 Model

2.3.1 Framework

There are three periods, $t = 0, 1, 2$. The only agent who optimises is the bank, which is active in the deposit (D) and loan (L) markets. It has market power, that is it faces an upward sloping deposit supply curve and a downward-sloping loan demand curve. Drechsler et al., 2017 and Whited et al., 2021 provides evidence for deposit market power, while for example, Degryse and Ongena, 2005 shows arguments for loan market power. Deposit and loan contracts last for one period. As there is no credit risk or information asymmetry in the model, the bank only uses external funds, so the book value of equity is 0. In reality, banks operate with high leverage indeed, the average equity-to-asset ratio in my database is 10 percent.

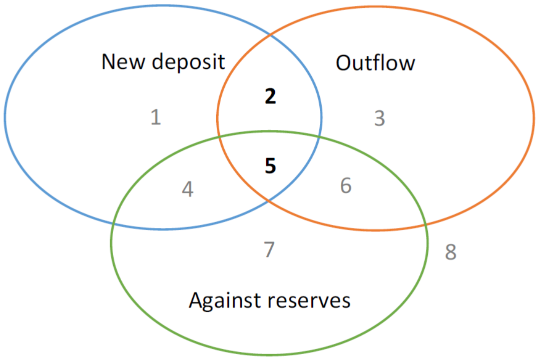
The bank also holds reserves (R) paying an exogenous interest rate r, and faces reserve requirements set at 0 which it has meet at all times. In reality, central banks usually also require banks to hold non-negative amount of reserves at all times, at least at the end of the day.[19] If we consider reserves in the model as high quality liquid assets (HQLA) in reality, then, since the Liquidity Coverage Ratio (LCR) requirement of Basel III regulation, the model reserve requirement could be positive. However, HQLA can be used in liquidity stress situations, so at least the ex post zero reserve requirement in the model seems to be justified (BIS LCR website). The bank maximises profits with respect to the deposit and loan interest rates (r_D and r_L, respectively).

Interest rates are set at $t = 0$ and are fixed for two periods. I justify this assumption with deposit interest rates' slow adjustment to shocks documented in the literature (see Drechsler et al., 2017 and its references). Moreover, I assume the three periods (two time intervals) together correspond to only one quarter in reality, which can still be regarded as short run. At $t = 1$ the

[19] Even though in Canada there has been a zero averaging system in which negative reserve balances are allowed, these are essentially collateralised overdrafts with a penalty rate (Clinton, 1997). In the USA, there is possibility of uncollateralised daylight overdraft, but not overnight credit (Fed intraday credit website, Fed discount window website).

bank faces liquidity shocks δ and λ coming from the deposit supply and the loan demand curves, respectively. These shocks are correlated: a fraction θ of the loan shock appears as new deposit funding (plus there is the residual deposit shock ε, which can also be correlated with the lending shock). So, θ stands for the ability to create liquidity to customers. A larger θ means the bank can finance new loans by new deposits to a greater extent.

Figure 2.4: Venn diagram of deposit flows



Note: The figure shows a typology of deposit flows from a commercial bank's perspective (bank A). The blue ellipse refers to the source of the deposit (newly created by lending or old). The orange ellipse is about the direction of the flow (out- or inflow). The green ellipse says if the flow is against electronic central bank reserves (interbank transfer) or against cash (deposit withdrawal/placement). $\theta\lambda$, the spillover effect of lending, applies to types 2 and 5, while ε, the residual deposit shock, to all the other types.

Figure 2.4 presents a Venn diagram of deposit flows. δ is decomposed into two parts. The spillover effect $\theta\lambda$ (represented by types 2 and 5 in the figure) is directly related to λ. Till the end of the period, θ fraction of deposits which are newly created by lending remains with the bank. In reality, the fraction is 1 at the time of lending and converges to 0 as time goes to infinity. All other types of shocks are included in ε, the residual deposit shock. The flows represented by the numbers are the following:

1. Another bank (bank B) lends, creates new deposit, the deposit is withdrawn to cash, and the cash is deposited with bank A.
2. Bank A lends, creates new deposit, the deposit is withdrawn to cash.
3. Old deposit of bank A is withdrawn to cash.
4. Bank B lends, creates new deposit, the deposit is transferred to bank A.

5. Bank A lends, creates new deposit, the deposit is transferred to bank B.

6. Old deposit of bank A is transferred to bank B.

7. Old deposit of bank B is transferred to bank A.

8. Old deposit of bank B is withdrawn to cash, the cash is deposited with bank A.

2.3.2 Reduced-form borrowers and depositors

Equation (2.1) shows the reduced-form behaviour of borrowers and depositors. The upward-sloping deposit supply and the downward-sloping loan demand curves are linear ($a, b, c, d > 0$). Due to the fixed interest rates the shocks to the loan and deposit stocks are equivalent to shocks to the intercepts of the $t = 0$ curves. The residual deposit supply shock ε and the loan demand shock λ have a joint normal distribution with 0 mean, standard deviations σ_ε and σ_λ, respectively, and correlation ρ. $\theta \in [0, 1]$ is the money creation ability parameter. I use joint normal distribution so that I can calculate the optimal reserve level of the bank easily. I allow for a non-zero ρ in order to have a more general model which can account for potential endogeneity. There are three examples of explicit endogeneity in Appendix B.1.

$$L_0 = a - br_L \qquad (t = 0 \text{ loan demand}) \tag{2.1a}$$

$$D_0 = c + dr_D \qquad (t = 0 \text{ deposit supply}) \tag{2.1b}$$

$$L_1 = L_0 + \lambda \qquad (t = 1 \text{ loan demand}) \tag{2.1c}$$

$$D_1 = D_0 + \theta\lambda + \varepsilon \qquad (t = 1 \text{ deposit supply}) \tag{2.1d}$$

$$\begin{bmatrix} \varepsilon \\ \lambda \end{bmatrix} \sim \mathcal{N}(\mathbf{0}, \begin{bmatrix} \sigma_\varepsilon^2 & \rho\sigma_\varepsilon\sigma_\lambda \\ \rho\sigma_\varepsilon\sigma_\lambda & \sigma_\lambda^2 \end{bmatrix}) \qquad (\text{distribution of shocks}) \tag{2.1e}$$

The net liquidity outflow shock is $(1-\theta)\lambda - \varepsilon$. Lending reduces liquidity by λ, while deposit-taking raises it by ε. Moreover, the spillover effect of loans on deposits $\theta\lambda$ mitigates the negative effect of lending. The net shock follows a normal distribution with 0 mean and standard deviation

$\sigma_{(1-\theta)\lambda-\varepsilon}$:[20]

$$\sigma_{(1-\theta)\lambda-\varepsilon} = \sqrt{\sigma_\varepsilon^2 - 2(1-\theta)\rho\sigma_\varepsilon\sigma_\lambda + (1-\theta)^2\sigma_\lambda^2} \tag{2.2}$$

2.3.3 Problem of the bank

The bank maximises profits with respect to non-negative interest rates, subject to liquidity constraints (and taking into account borrower and depositor behaviour).

$$\begin{aligned}
&\max_{r_D, r_L \geq 0} && \overbrace{r_L L_0 + r R_0 - r_D D_0}^{t=0 \text{ profit}} + \beta \mathbb{E}(\overbrace{r_L L_1 + r R_1 - r_D D_1}^{t=1 \text{ profit}}) \\
&\text{s.t.} && R_0 = D_0 - L_0 \geq 0, \qquad \text{(non-negative liquidity constraint)}, \\
& && \mathbb{P}(R_1 < 0) = \mathbb{P}(D_1 < L_1) \leq p, \quad \text{(Liquidity-at-Risk constraint)}
\end{aligned} \tag{2.3}$$

Equation (2.3) presents the bank's problem. The bank pays out the entire profit to shareholders as a dividend. $\beta \in (0,1)$ is the subjective discount factor, and parameter $p \in (0, 1/2)$ is the highest probability allowed of becoming illiquid. Owing to the normal distribution, illiquidity cannot be excluded, but I assume a Liquidity-at-Risk (LaR) constraint (Duttweiler, 2009). This is similar to value-at-risk (VaR) in the case of credit risk (Jorion, 2007, Gourieroux and Jasiak, 2010). In the normal course of business, in a worst case scenario the bank becomes illiquid with probability p. The minimum reserves it has to hold at $t = 0$, which is the LaR, can be derived from p and the distribution of the shocks.

LaR is a shortcut for a more realistic model version in which a penalty must be paid in case of illiquidity. Freixas and Rochet, 2008 Ch. 8.2 presents such a model. For instance, if deposits flow out, or if borrowers draw down on credit lines en masse, then the zero reserve requirement can be breached. In such a situation, the bank may want to turn to wholesale funding, but this is difficult to get when the bank is in trouble. So, the bank can make use of the central bank's LoLR function. Emergency lending is, however, costly (see for example, Bagehot's Dictum (Bagehot, 1873)).

LaR is somewhat similar to the LCR of Basel III. Both metrics are based on the net liquidity outflow in an adverse situation. But while LaR is more focused on normal course of business,

[20] The linear combination of two correlated (and therefore not independent) normal random variables is not necessarily normal, unless the two random variables are jointly normal. That is why I need joint normality of ε and λ.

LCR explicitly targets a stress scenario. On the one hand, the philosophy of LaR is that of VaR: it is a quantile of the net outflow distribution. For example, $p = 0.01$ refers to the upper 1st percentile, or (lower) 99 percentile. On the other hand, the philosophy of LCR is more of that of expected shortfall (ES). ES_q captures the expected loss of a portfolio in the worst q percent of cases (Andersen et al., 2013). That is, ES is the conditional VaR, or expected tail loss. ES is larger than VaR, it is more sensitive to the tail of the distribution. According to the LCR, a bank must hold HQLA (ex ante) at least as much as its net liquidity outflow in a stress situation. This is essentially ES.

2.3.4 The importance of the reserve ratio

In this simple model, the reserves-to-assets ratio is an invertible function of a standard bank liquidity creation measure. Berger and Bouwman, 2009 writes that the "liquidity transformation gap" or "LT gap" measure of Deep and Schaefer, 2004 is a special case of one of the four Berger-Bouwman liquidity creation measures. If all assets and liabilities are classified as either liquid or illiquid, and if we disregard off-balance sheet items, then the Berger-Bouwman (BB) "mat nonfat" measure is the same as the LT gap. The larger this value is, the more liquidity a bank creates.

$$\text{BB mat nonfat} = \text{LT gap} = \frac{\text{Liquid liabilities} - \text{Liquid assets}}{\text{Total assets}} \tag{2.4}$$

In my simple model, in which all liabilities are deposits, which are liquid (means of payment), and reserves are the unique liquid assets, the LT gap is the inverse of the reserve ratio.

$$\text{LT gap} = \frac{\text{Liquid liabilities} - \text{Liquid assets}}{\text{Total assets}} = \frac{D - R}{D} = 1 - \frac{R}{D} = 1 - \alpha \tag{2.5}$$

where $\alpha \in [0, 1]$ denotes the reserve ratio. That is why in the paper I focus on the reserve ratio.

 Hungarian DOI: 10.14754/CEU.2024.06

2.3.5 Solution

I focus my attention to the positive territory of interest rates. In order to be out of the zero lower bound on nominal interest rates, I assume the following.

$$c < \min\{\frac{ad}{b+2d}, \frac{a(2b+d)}{b}\} \tag{2.6}$$

Assumption (2.6) says the autonomous deposit supply is not so large that it pushes interest rates down to zero. For instance, if the interest sensitivities are the same ($b = d$), then (2.6) simplifies to $c < a/3$, meaning that at 0 interest rate, there is at least 3 times as large loan demand than deposit supply.

Proposition 2.1 (Interest rates). *Let $\Phi_{(\mu,\sigma)}$ denote the (standard) normal cumulative distribution function (CDF). Then there exists a cutoff interest on reserves $\hat{r} = \frac{a-c-2\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p)}{b+d}$ such that*

1. *If $r \leq \hat{r}$, then*
   - *the Liquidity-at-Risk constraint binds: $R^*_{0,bind} = -\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p) > 0$,*
   - *the deposit interest rate: $r^*_{D,bind} = \frac{ad-bc-2cd-2d\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p)}{2d(b+d)}$,*
   - *the loan interest rate: $r^*_{L,bind} = \frac{ad-bc+2ab-2b\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p)}{2b(b+d)}$.*
2. *If $r > \hat{r}$, then*
   - *the Liquidity-at-Risk constraint is slack: $R^*_{0,slack} = \frac{(b+d)r-(a-c)}{2} > R^*_{0,bind}$,*
   - *the deposit interest rate: $r^*_{D,slack} = \frac{dr-c}{2d}$,*
   - *the loan interest rate: $r^*_{L,slack} = \frac{a+br}{2b}$.*

Proof. From equation (2.1), the balance sheet constraint and the properties of the normal distribution, the LaR constraint is:

$$p \geq \mathbb{P}(D_1 < L_1) = \mathbb{P}(R_0 < (1-\theta)\lambda - \varepsilon) = 1 - \Phi_{0,\sigma_{(1-\theta)\lambda-\varepsilon}}(R_0) = 1 - \Phi(\frac{R_0}{\sigma_{(1-\theta)\lambda-\varepsilon}}) \tag{2.7a}$$

$$\text{So, } R_0 \geq \sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(1-p) = -\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p) = R^*_{0,bind} > 0 \tag{2.7b}$$

Due to zero-mean shocks, the expected $t = 1$ stocks are just their $t = 0$ values. So, by plugging in equation (2.1) into the objective function, the Lagrangian is:

$$\mathcal{L}(r_D, r_L, \mu) = (1+\beta)[(r_L - r)(a - br_L) + (r - r_D)(c + dr_D)] + \mu\{[(c+dr_D) - (a - br_L)] - R^*_{0,bind}\} \tag{2.8}$$

Focusing on interior solutions (positive interest rates), the F.O.C.'s are:

$$\frac{\partial \mathcal{L}}{\partial r_D} = (1+\beta)(dr - c - 2dr^*_D) + d\mu^* = 0 \tag{2.9a}$$

$$\frac{\partial \mathcal{L}}{\partial r_L} = (1+\beta)(a + br - 2br^*_L) + b\mu^* = 0 \tag{2.9b}$$

If the constraint binds ($\mu^* > 0$), then by solving the system of F.O.C.'s, we get

$$r^*_{D,bind} = \frac{ad - bc - 2cd + 2dR^*_{0,bind}}{2d(b+d)} = \frac{ad - bc - 2cd - 2d\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p)}{2d(b+d)} \tag{2.10a}$$

$$r^*_{L,bind} = \frac{ad - bc + 2ab + 2bR^*_{0,bind}}{2b(b+d)} = \frac{ad - bc + 2ab - 2b\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p)}{2b(b+d)} \tag{2.10b}$$

If the constraint is slack ($\mu^* = 0$), then by solving the system of F.O.C.'s, we get

$$r^*_{D,slack} = \frac{dr - c}{2d} \tag{2.11a}$$

$$r^*_{L,slack} = \frac{a + br}{2b} \tag{2.11b}$$

The slack reserve level is:

$$R^*_{0,bind} < R^*_{0,slack} = D^*_{0,slack} - L^*_{0,slack} = (c + dr^*_{D,slack}) - (a - br^*_{L,slack}) = \frac{(b+d)r - (a-c)}{2} \tag{2.12a}$$

$$\text{iff } r > \frac{a - c + 2R^*_{0,bind}}{b+d} = \frac{a - c - 2\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p)}{b+d} = \hat{r} \tag{2.12b}$$

Furthermore, it can be shown that the sum of the present value of profits in the slack case is weakly greater than that of the binding case iff

$$0 \leq [(b+d)r-(a-c)]^2+(2R^*_{0,bind})^2-4[(b+d)r-(a-c)]R^*_{0,bind} = [(b+d)r-(a-c)-2R^*_{0,bind}]^2 \tag{2.13}$$

which is true. That is the bank chooses the slack solution whenever it is possible. ■

The bank holds a positive amount of reserves to prepare for an adverse liquidity shock. The distribution of the net liquidity outflow $(1-\theta)\lambda-\varepsilon$ and the maximum probability of illiquidity p determines the minimum LaR, $R^*_{0,bind}$. It is a product of the level of uncertainty and the inverse of the standard normal CDF, just as in the case of VaR. In this simple case, $R^*_{0,bind}$ does not depend on loan demand or deposit supply.[21] The desired liquidity is naturally a positive function of the interest on reserves r, however, it must not go below $R^*_{0,bind}$. There is also a positive relationship between reserves and the interest rates set by the bank: higher interest rates result in more deposits and less loans, and thus more reserves.

To illustrate the results, let us assume $b=d$. In this case, the interest rates are the following.

$$r^*_{D,bind} = \frac{a-3c+2R^*_{0,bind}}{4b} \tag{2.14a}$$

$$r^*_{L,bind} = \frac{3a-c+2R^*_{0,bind}}{4b} \tag{2.14b}$$

$$r^*_{D,slack} = \frac{br-c}{2b} \tag{2.14c}$$

$$r^*_{L,slack} = \frac{a+br}{2b} \tag{2.14d}$$

$$\hat{r} = \frac{a-c+2R^*_{0,bind}}{2b} = \frac{r^*_{D,bind}+r^*_{L,bind}}{2} + \frac{R^*_{0,bind}}{2b} \tag{2.14e}$$

Then the interest margins are

$$r^*_{L,bind}-r^*_{D,bind} = r^*_{L,slack}-r^*_{D,slack} = \frac{a+c}{2b} \tag{2.15a}$$

$$r-r^*_{D,slack} = \frac{c+br}{2b} \tag{2.15b}$$

$$r^*_{L,slack}-r = \frac{a-br}{2b} \tag{2.15c}$$

[21]For a version of the model in which $R^*_{0,bind}$ is dependent on loan demand and deposit supply, see Appendix B.2.

This means the loan-deposit margin is positive and independent of r. Moreover, the threshold $\hat{r}$ is somewhat higher than the mean of the deposit and loan rates. Although the slack deposit and loan rates increase in r, the marginal effect is lower than 1 (it is 1/2).

Proposition 2.2 (Reserve ratio). *1. If $r \leq \hat{r}$, then $\alpha^*_{0,bind} = -\frac{2(b+d)\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p)}{ad+bc-2d\sigma_{(1-\theta)\lambda-\varepsilon}\Phi^{-1}(p)} > 0$.*

2. If $r > \hat{r}$, then $\alpha^*_{0,slack} = \frac{(b+d)r-(a-c)}{c+dr} > \alpha^*_{0,bind}$.

Proof. This is direct consequence of Proposition 2.1 by dividing R^* by D^*. ■

$\hat{r}$ is a threshold policy rate not only for the absolute but also for the relative level of reserves. The reserve ratio depends on the interest on reserves r only in the slack regime.

Proposition 2.3 (Reserve ratio - partial derivatives). *1. If $r \leq \hat{r}$, then the reserve ratio $\alpha^*_{0,bind}$*

- *decreases in θ if and only if $\rho < \frac{(1-\theta)\sigma_\lambda}{\sigma_\varepsilon}$,*
- *decreases in ρ,*
- *increases in σ_ε if and only if $\rho < \frac{\sigma_\varepsilon}{(1-\theta)\sigma_\lambda}$,*
- *increases in σ_λ if and only if $\rho < \frac{(1-\theta)\sigma_\lambda}{\sigma_\varepsilon}$.*

2. If $r > \hat{r}$, then the reserve ratio $\alpha^*_{0,slack}$ increases in r.

Proof. Given equation 2.2, it can be shown that the marginal effect of money creation ability on the binding reserve ratio is:

$$\frac{\partial \alpha^*_{0,bind}}{\partial \theta} = \frac{2(b+d)(ad+bc)\sigma_\lambda[\rho\sigma_\varepsilon - (1-\theta)\sigma_\lambda]R^*_{0,bind}}{\sigma^2_{(1-\theta)\lambda-\varepsilon}(ad+bc+2dR^*_{0,bind})^2} \tag{2.16}$$

the sign of which is equal to that of $\rho\sigma_\varepsilon - (1-\theta)\sigma_\lambda$, so it is negative iff $\rho < \frac{(1-\theta)\sigma_\lambda}{\sigma_\varepsilon}$.
The effect of correlation is:

$$\frac{\partial \alpha^*_{0,bind}}{\partial \rho} = -\frac{2(b+d)(ad+bc)(1-\theta)\sigma_\varepsilon\sigma_\lambda R^*_{0,bind}}{\sigma^2_{(1-\theta)\lambda-\varepsilon}(ad+bc+2dR^*_{0,bind})^2} \leq 0 \tag{2.17}$$

The effect of residual deposit uncertainty is:

$$\frac{\partial \alpha^*_{0,bind}}{\partial \sigma_\varepsilon} = \frac{2(b+d)(ad+bc)[\sigma_\varepsilon - (1-\theta)\rho\sigma_\lambda]R^*_{0,bind}}{\sigma^2_{(1-\theta)\lambda-\varepsilon}(ad+bc+2dR^*_{0,bind})^2} \tag{2.18}$$

the sign of which is equal to that of $\sigma_\varepsilon - (1-\theta)\rho\sigma_\lambda$, so it is positive iff $\rho < \frac{\sigma_\varepsilon}{(1-\theta)\sigma_\lambda}$.

The effect of loan uncertainty is:

$$\frac{\partial \alpha^*_{0,bind}}{\partial \sigma_\lambda} = \frac{2(b+d)(ad+bc)(1-\theta)[(1-\theta)\sigma_\lambda - \rho\sigma_\varepsilon]R^*_{0,bind}}{\sigma^2_{(1-\theta)\lambda-\varepsilon}(ad+bc+2dR^*_{0,bind})^2} \tag{2.19}$$

and its sign is equal to that of $(1-\theta)\sigma_\lambda - \rho\sigma_\varepsilon$, so it is positive iff $\rho < \frac{(1-\theta)\sigma_\lambda}{\sigma_\varepsilon}$ (and $\theta < 1$).

The effect of the interest on reserves on the slack reserve ratio is:

$$\frac{\partial \alpha^*_{0,slack}}{\partial r} = \frac{ad+bc}{(c+dr)^2} > 0 \tag{2.20}$$

■

When the correlation is not too large, the money creation ability and the correlation behave similarly, and the effect of the uncertainty parameters are also similar to each other. The larger the uncertainty of the net liquidity shock $\sigma_{(1-\theta)\lambda-\varepsilon}$, the larger the reserve level and reserve ratio in the binding case. According to equation (2.2), in general the standard deviation of the net liquidity shock increases in the standard deviations of the residual deposit and of the loan shocks. The correlation has a risk management role: if a negative deposit shock is accompanied by a negative loan shock, then there is less usage of reserves, the two shocks finance each other. Therefore, the need for reserve buffer is smaller. As only $1-\theta$ part of the loan shock influences reserves, the money creation ability θ mitigates the effect of the loan shock variability. That is, they behave inversely, the money creation ability reduces reserves. Lastly, due to an investment motive, the reserve ratio increases in the interest on reserves in the slack regime.

Proposition 2.4 (Standard deviation and correlation of stocks)**.** *Let $\sigma_\delta = \sigma_{\theta\lambda+\varepsilon}$ denote the standard deviation of the total deposit shock.*

1. *The standard deviation of D_1^* increases in σ_ε if and only if $\rho > -\frac{\sigma_\varepsilon}{\theta\sigma_\lambda}$.*

2. *The correlation of D_1^* and L_1^* is $\frac{\theta\sigma_\lambda+\rho\sigma_\varepsilon}{\sigma_\delta}$.*

3. *This correlation is increasing in θ (if $|\rho| < 1$).*

Proof. As D_0^* is deterministic,

$$Std(D_1^*) = \sigma_\delta = \sigma_{\theta\lambda+\varepsilon} = \sqrt{\sigma_\varepsilon^2 + 2\theta\rho\sigma_\varepsilon\sigma_\lambda + \theta^2\sigma_\lambda^2} \tag{2.21}$$

It can be shown that the marginal effect of the standard deviation of residual deposit supply shock on that of the deposit stock is:

$$\frac{\partial Std(D_1^*)}{\partial\sigma_\varepsilon} = 2(\sigma_\varepsilon + \theta\rho\sigma_\lambda) \tag{2.22}$$

which is positive iff $\rho > -\frac{\sigma_\varepsilon}{\theta\sigma_\lambda}$.
As L_0^* is also deterministic,

$$Corr(D_1^*, L_1^*) = Corr(\delta, \lambda) = Corr(\theta\lambda + \varepsilon, \lambda) = \frac{Cov(\theta\lambda + \varepsilon, \lambda)}{\sigma_{\theta\lambda+\varepsilon}\sigma_\lambda} = \frac{\theta\sigma_\lambda^2 + \rho\sigma_\varepsilon\sigma_\lambda}{\sigma_{\theta\lambda+\varepsilon}\sigma_\lambda} = \frac{\theta\sigma_\lambda + \rho\sigma_\varepsilon}{\sigma_\delta} \tag{2.23}$$

Then it can be shown that the marginal effect of money creation ability on the correlation is:

$$\frac{\partial Corr(D_1^*, L_1^*)}{\partial\theta} = \frac{(1-\rho^2)\sigma_\varepsilon^2\sigma_\lambda}{\sigma_\delta^3} \geq 0 \tag{2.24}$$

■

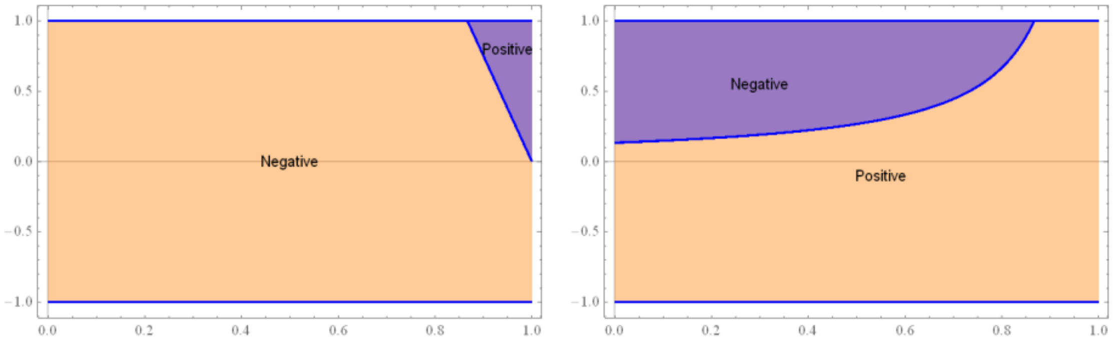
If the correlation of loan demand and residual deposit supply is not too small, then deposit uncertainty increases in residual deposit uncertainty. This holds for instance, if the loan shock is exogenous to the deposit shock, that is, if $\rho = 0$. Then the residual deposit uncertainty can be approximated by total deposit uncertainty. Moreover, if a bank can create liquidity more easily, then its deposits and loans are more correlated. Therefore, we can approximate θ by the deposit-loan correlation. I use these results in Chapter 3.

2.3.6 Illustration of results

In Figure 2.5 I depict the signs of the partial derivatives of the reserve ratio with respect to the money creation ability and with respect to the deposit standard deviation, for a given set of parameters. I choose the parameters to get realistic levels of interest rates: the deposit rate is around 3 percent and the lending rate is around 8 percent, which correspond to average rates in the USA before the GFC. It is visible that for most of the (θ, ρ) combinations, the conditions of Proposition 2.3 hold: $\rho < \min\{\frac{(1-\theta)\sigma_\lambda}{\sigma_\varepsilon}, \frac{\sigma_\varepsilon}{(1-\theta)\sigma_\lambda}\}$.

Figure 2.5: Signs of partial derivatives of the reserve ratio in the (θ, ρ) plane w.r.t....

(a) ...money creation ability (θ) (b) ...residual deposit uncertainty (σ_ε)



Note: The left and right panel show $sgn(\frac{\partial \alpha^*_{0,bind}}{\partial \theta})$ and $sgn(\frac{\partial \alpha^*_{0,bind}}{\partial \sigma_\varepsilon})$, respectively, as a function of θ (horizontal axis) and ρ (vertical axis), where $\alpha^*_{0,bind}$ is the binding reserve ratio, θ is the money creation ability, σ_ε is the standard deviation of the residual deposit shock and ρ is the correlation of the loan and residual deposit shocks. $\sigma_\varepsilon = 0.1$, $\sigma_\lambda = 0.75$ (the latter is the standard deviation of the loan shock).

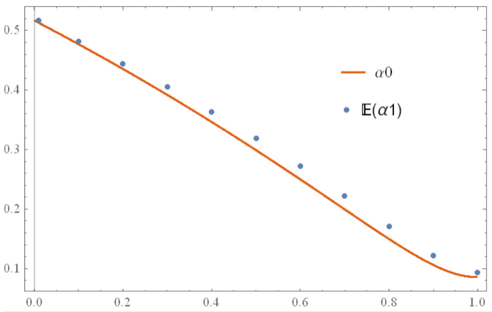
Figure 2.6 shows the reserve ratio as a function of different parameters, by using the above parameter values. I graph both the initial and the expected post-shock reserves-to-assets ratio, but the latter I could only approximate numerically due to the difficulty of calculating the expectation of a quotient of random variables. Generally the pre- and post-shock values are similar, and the figures confirm the analytical results of Proposition 2.3.

Figure 2.7 presents similar figures for the deposit and loan interest rates. As the reserve ratio is an increasing function of interest rates, the slopes of the curves are similar to those of Figure 2.6. By bidding down interest rates, the supplied amount of deposits shrinks while the demanded quantity for loans increases, as a result, reserves and the reserve ratio are both reduced.

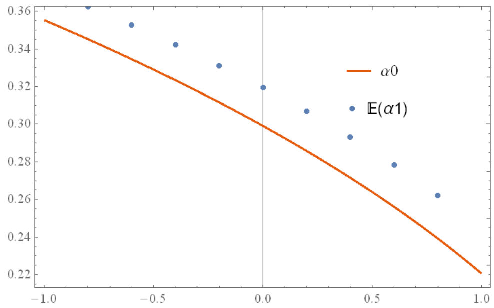
Figure 2.8 is about the return on assets as a function of the same parameters. As interest margins are more or less constant, ROA mainly depends on the reserve ratio. A larger reserve ratio is a drag on profits, as reserves earn less return than loans. As a consequence, the slopes are the reverse of those of the reserve ratio. Only the case of the interest on reserves is different

Figure 2.6: Reserve ratio as a function of...

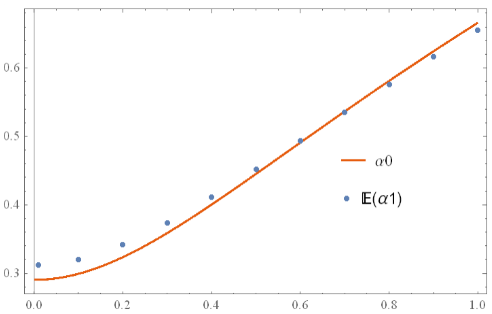
(a) ...money creation ability (θ)



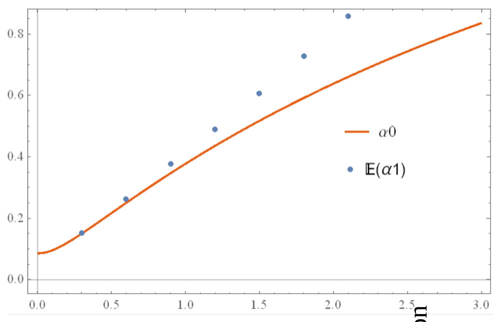
(b) ...correlation (ρ)



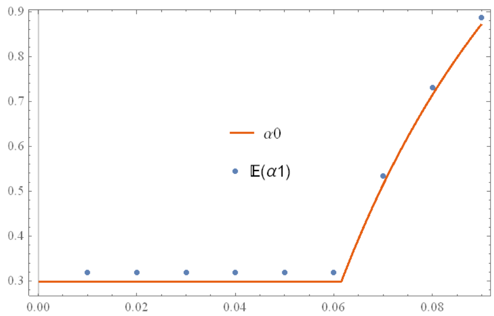
(c) ...residual deposit uncertainty (σ_ε)



(d) ...loan uncertainty (σ_λ)



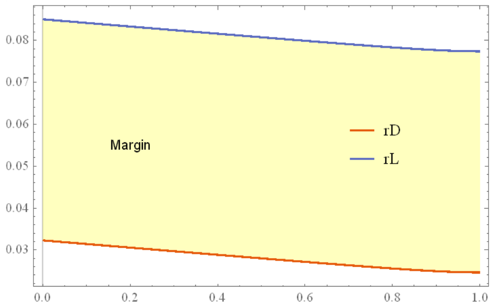
(e) ...interest on reserves (r)



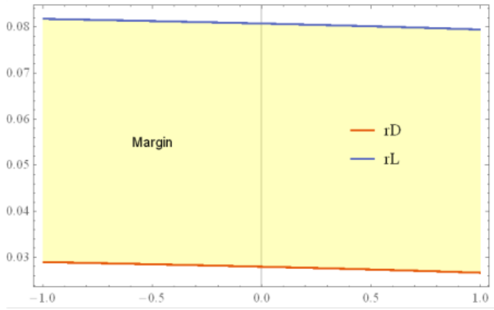
Note: α_0 is the $t = 0$ reserve ratio, $\mathbb{E}(\alpha_1)$ is the (numerically solved) expected $t = 1$ reserve ratio. The loan demand and deposit supply parameters: $a = 11$, $b = 110$, $c = 0.5$, $d = 90$. $p = 0.01$ (maximum probability of illiquidity), $r = 0.05$ (interest on reserves), $\beta = 0.995$ (subjective discount factor), $\sigma_\varepsilon = 0.1$ (residual deposit standard deviation), $\sigma_\lambda = 0.75$ (loan standard deviation), $\rho = 0$ (correlation), $\theta = 0.5$ (money creation ability).

Figure 2.7: Interest rates as a function of...

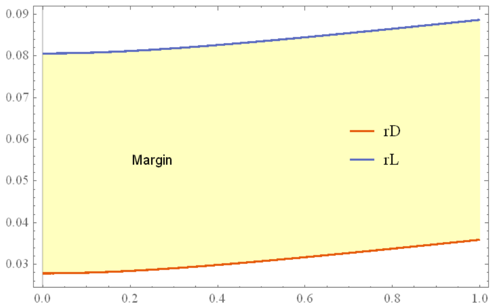
(a) ...money creation ability (θ)



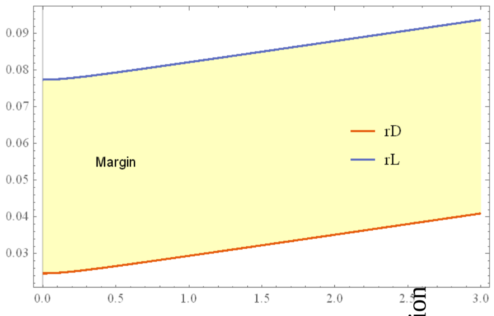
(b) ...correlation (ρ)



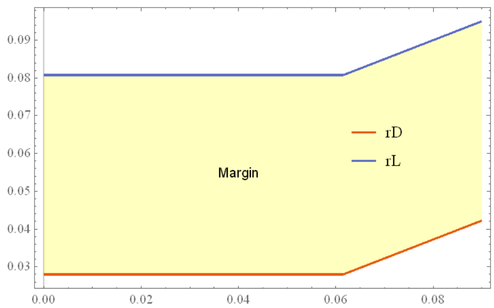
(c) ...residual deposit uncertainty (σ_ε)



(d) ...loan uncertainty (σ_λ)



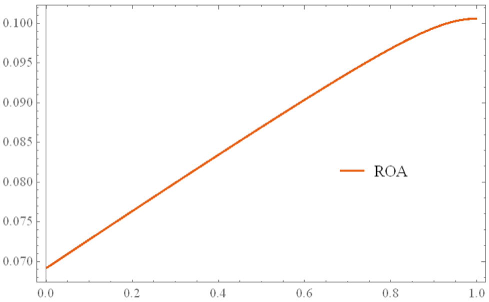
(e) ...interest on reserves (r)



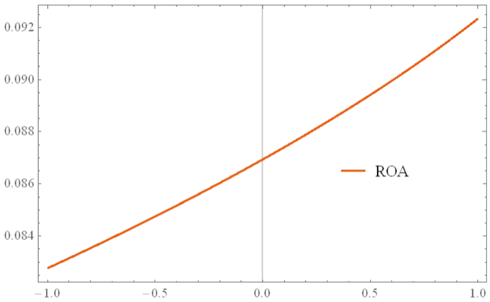
Note: r_D and r_L are deposit and lending rates, respectively. The loan demand and deposit supply parameters: $a = 11$, $b = 110$, $c = 0.5$, $d = 90$. $p = 0.01$ (maximum probability of illiquidity), $r = 0.05$ (interest on reserves), $\beta = 0.995$ (subjective discount factor), $\sigma_\varepsilon = 0.1$ (residual deposit standard deviation), $\sigma_\lambda = 0.75$ (loan standard deviation), $\rho = 0$ (correlation), $\theta = 0.5$ (money creation ability).

Figure 2.8: Return on assets as a function of...

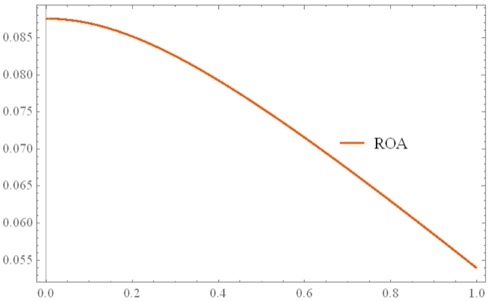
(a) ...money creation ability (θ)



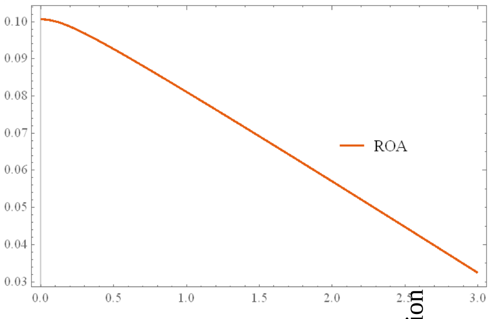
(b) ...correlation (ρ)



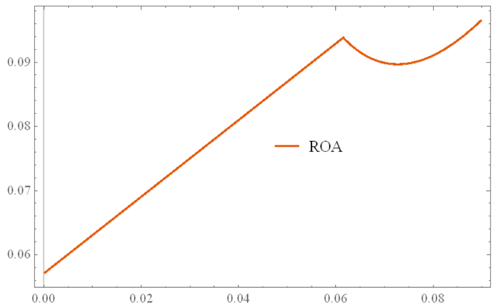
(c) ...residual deposit uncertainty (σ_ε)



(d) ...loan uncertainty (σ_λ)



(e) ...interest on reserves (r)



Note: ROA is the sum of present valued expected profits, divided by $t = 0$ deposits. The loan demand and deposit supply parameters: $a = 11$, $b = 110$, $c = 0.5$, $d = 90$. $p = 0.01$ (maximum probability of illiquidity), $r = 0.05$ (interest on reserves), $\beta = 0.995$ (subjective discount factor), $\sigma_\varepsilon = 0.1$ (residual deposit standard deviation), $\sigma_\lambda = 0.75$ (loan standard deviation), $\rho = 0$ (correlation), $\theta = 0.5$ (money creation ability).

in Figure 2.8(e). A larger interest on reserves per se contributes to larger profits up to the breakeven interest rate $\hat{r}$ (which is around 6.2 percent in the figure). Then, above the threshold rate, the two effects co-determine profits and ROA: by increasing the interest rate on reserves, (1) there is a larger interest income on reserves, but (2) in this slack regime the reserve ratio also rises, pulling down profits. As the sensitivity of deposit and loan interest rates is constant and lower than 1, the loan spread decreases and the deposit spread increases in r. So, the first effect becomes stronger after a while.

2.4 Extended model with adjustable interest rates

2.4.1 Problem of the bank

In the modified model, the bank is able to adjust deposit and loan interest rates after the shock at $t = 1$. However, there is a convex adjustment cost to interest rates. That is why prices are partially sticky. The behaviour of borrowers and depositors is the same as in the original model.

$$\max_{r_{Dt}, r_{Lt} \geq 0} \overbrace{r_{L0}L_0 + rR_0 - r_{D0}D_0}^{t=0 \text{ profit}} + \beta\mathbb{E}(\overbrace{r_{L1}L_1 + rR_1 - r_{D1}D_1 - \underbrace{[\frac{\gamma_D}{2}(r_{D1} - r_{D0})^2 + \frac{\gamma_L}{2}(r_{L1} - r_{L0})^2]}_{\text{adjustment cost}})}^{t=1 \text{ profit}}$$

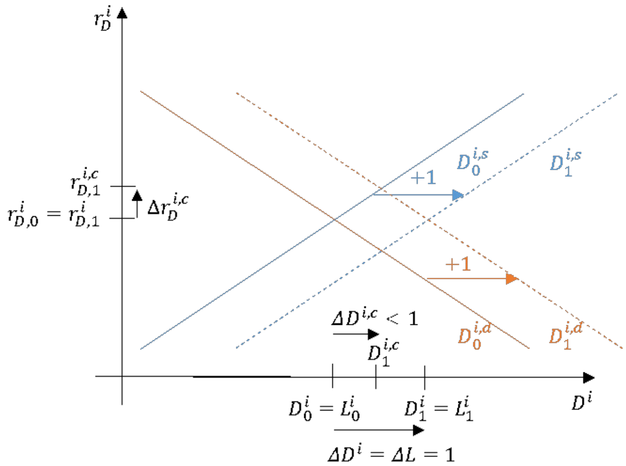
$$\begin{aligned} \text{s.t.} \qquad & R_0 = D_0 - L_0 \geq 0, && \text{(non-negative liquidity constraint)}, \\ & \mathbb{P}(R_1 < 0) = \mathbb{P}(D_1 < L_1) \leq p, && \text{(Liquidity-at-Risk constraint)} \end{aligned} \tag{2.25}$$

γ_D and γ_L are positive adjustment cost parameters for the deposit and loan rates, respectively. Adjustment costs are needed because in the absence of such costs, with flexible interest rates, the bank can always adjust to shocks and there is no point in holding reserves ex ante.

2.4.2 Conjecture

As I could not solve the model even with the help of the computer, I only show a vague conjecture of the reaction of the deposit market to a demand shock on the loan market. Let us assume there is a USD 1 loan demand shock, which translates to an increase in loan stock by the same amount. This is a simplification, in this case I do not take into account the likely upward-sloping nature of the bank's loan supply curve. I am interested in the effect of such a shock on the deposit market, especially on the bank's deposit demand curve.

Figure 2.9: Reaction of the deposit market to a unit loan demand shock: individual creator bank

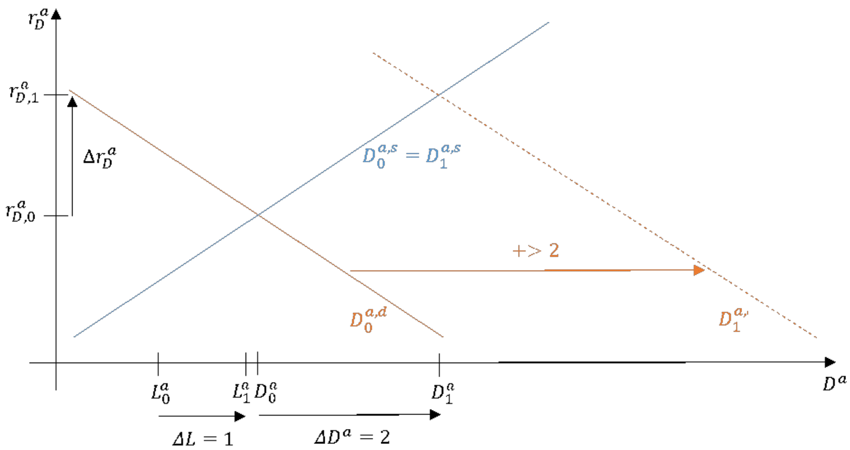


Note: D is deposit stock while r_D is deposit interest rate. The orange D^d is the demand curve and the blue D^s is the supply curve. Curves at $t = 0$ are solid lines while curves of $t = 1$ are dashed. The i superscript stands for individual creator and Δ is time change. c superscript denotes variables in the case when I control for the change in deposit supply, that is, the outcomes of the intersection of D_0^s and D_1^d. I assume money creation ability $\theta = 1$ and reserve ratio $\alpha = 0$.

Figure 2.9 presents my guess for a fully individual creator bank with money creation ability $\theta = 1$ and reserve ratio $\alpha = 0$. As loans increase by USD 1, deposits increase by the same amount as there are no reserves. Also, deposit supply must shift to the right by the same amount due to full ability to create money. As a result, deposit demand also shifts to the right by USD 1, and the interest rate is unchanged. When I control for the upward-sloping deposit supply, the increase in stock is smaller but the price moves upward.

Figure 2.10 shows my conjecture for a fully aggregate creator bank with money creation ability $\theta = 0$ and reserve ratio $\alpha = 1/2$. As there is no money creation ability, the deposit supply curve is constant. However, on the medium run, the bank may want to hold the 1/2 reserve ratio, so deposits must increase by USD 2 in order to finance not only the extra lending but also an increase in reserves. As a result, owing to the upward-sloping nature of the supply curve, the deposit demand curve shifts to the right by even more than 2 units. This also entails a large increase in the deposit rate.

Figure 2.10: Reaction of the deposit market to a unit loan demand shock: aggregate creator bank



Note: D is deposit stock while r_D is deposit interest rate. The orange D^d is the demand curve and the blue D^s is the supply curve. Curves at $t = 0$ are solid lines while curves of $t = 1$ are dashed. The a superscript stands for aggregate creator and Δ is time change. I assume money creation ability $\theta = 0$ and reserve ratio $\alpha = 1/2$. D_0 is equal to that of the individual creator in Figure 2.9.

2.5 Conclusion

My results might have implications for central bank policies, such as payment system and financial system stability, or monetary policy. The health of the payment system, financial stability and the transmission of the policy interest rate to interbank rates are based in part on the appropriate stock of bank liquid assets. If there is (ex ante) liquidity regulation in place which does not take into account varying money creation abilities, then individual creators may end up with a larger requirement than the amount of liquidity they would otherwise hold (ex ante). In contrast, aggregate creators may face a looser requirement than their optimal choice under a laissez-faire regime. Therefore, such a one-size-fits-all regulation may reduce profits of individual creators and may incentivise aggregate creators to take on more risk. So as to avoid such a case, the regulator may apply individual (ex ante) liquidity requirements, which could be implemented in different ways. If banks have better knowledge about their money creation ability than the regulator, then an optional liquidity requirement system can be considered. Nevertheless, if the regulator knows the ability better (for example, if it can estimate θ somehow even in the case of endogeneity), then it may set requirements bank-by-bank.

 Hungarian DOI: 10.14754/CEU.2024.06

I show a guess according to which the sensitivity of deposit demand to loan demand shocks is larger for aggregate creators than for individual creators. As a result, if there is no correlation between loan demand shocks and liquidity creation ability, deposit interest rates are more uncertain for aggregate creators. That is, monetary policy transmission to deposit rates could be weaker for aggregate creators. And if, for example, banks are risk averse, then greater variability in deposit rates can result in higher cost of insurance, or term premium, for aggregate creators. This may hold on the level of the banking system as well. For instance, in case of a financial crisis, when loan demand is likely to rise and money creation ability is likely to drop in general, interest rates probably jump. Government backstop facilities, which contribute to a better liquidity creation ability of banks, may mitigate these effects, implying a more efficient monetary transmission.

Although bank profits are larger with a better creation ability, and although monetary transmission may be stronger with banks which can create money individually, the impact of θ on social welfare is ambiguous. The better the creation ability, the less is the liquid asset holding, but liquid assets are typically issued by the consolidated government (central bank reserves, government securities). Therefore, less bank demand for liquid assets may decrease seigniorage, that is, the revenue of the central bank, and may make government debt financing harder.

I argue that money creation ability helps hedge bank liquidity risk, resulting in lower liquidity buffers, but my model could be extended by some more realistic features. For instance, the (ex ante) required liquidity level could be a parameter in the model, not necessarily 0. Moreover, the probability of illiquidity could be endogenised by introducing a penalty in case of liquidity falling behind the required level. I could introduce wholesale assets and liabilities into the model as well, to create a role for the Fed funds rate (which is not necessarily the same as the interest on reserve balances). Last but not least, the money creation ability parameter θ is also worth modelling. For example, greater market power could lead to larger θ. These indicate further research directions.

Hungarian DOI: 10.14754/CEU.2024.06

3 Chapter 3: Creative Banks: Evidence

3.1 Introduction

This is a supplementary chapter of Chapter 2. In Chapter 2, I distinguish individual and aggregate money creator banks based on their ability to create money: the ability grabs the spillover effect of new loans on new deposits. I show that the correlation of a bank's deposits and loans is an increasing function of its ability. I also find that bank liquidity creation increases in this ability. Or equivalently, the liquid asset ratio is a decreasing function of the liquidity creation ability. Lastly, I show a conjecture that a bank's demand for deposits increases in its borrowers' demand for loans, and the smaller is the money creation ability, the larger is this effect.

In the current chapter I search for empirical evidence for my theoretical results of Chapter 2. I am interested in the actual values of money creation ability, measured by the deposit-loan correlation. Otherwise, I ask if the findings of Chapter 2 hold in reality. Does the liquid asset ratio decrease in the deposit-loan correlation? Does deposit demand increase in loan demand, and is this effect larger for aggregate money creators? To answer the questions, I build a panel data set based on US commercial banks' Reports of Condition and Income (Call Reports) from 1994 to 2021.

I show that US banks' deposit-loan correlations are typically positive with a central tendency around 1/2. This correlation decreased over time, nevertheless, at the end of the time series, during the Covid-19 crisis, it jumped. The decreasing trend in correlation is more pronounced for larger banks, which can be due to a regime change after the Great Financial Crisis (GFC) of 2008-9. Several factors could contribute to the drop in correlation, such as, for example, hitting the zero lower bound (ZLB) on nominal interest rates, changes in requlatory liquidity and capital requirements, or an increase in competition in the banking system.

I find some evidence that lower levels of banks' liquidity holding are associated with larger correlation between deposit and loan shocks. I measure liquidity holding by the reserves-to-assets ratio (reserve ratio) or by the reserves-and-securities-to-assets ratio (liquidity ratio). I regress liquidity holding on the correlation and standard deviations of deposit and loan shocks in the previous 5 years, and I include time fixed effects. Focusing on the pre-GFC period, the regression coefficient of the correlation ranges from -0.02 (reserve ratio) to -0.08 (liquidity ratio). This means a unit increase in the correlation is associated with 2 (or 8) percentage points decrease in the reserve ratio (or liquidity ratio). These numbers are significant both statistically and economically. However, if I also add bank fixed effects to my regressions, then the regression coefficient of the correlation drops in absolute value to an insignificant level. This is likely due to the fact that deposit-loan correlation is persistent for banks.

I also find evidence that deposit demand co-moves with loan demand, especially for aggregate money creators. I identify deposit and loan demand and supply shifts by quantity and price changes: when quantity and price move in the same direction, there is a demand shift, whereas if they move in the opposite direction, there is a supply shift. I regress changes in deposit quantity and in deposit price on changes in loan demand, on the lagged liquid asset ratio (as a proxy for the inability to create money), and on the product of the two. I control for aggregate movements too by subtracting the industry average from the differenced variables. The regression coefficients both for deposit quantity and price, and both for loan demand and liquidity x loan demand, are positive and statistically significant. For fully individual creators (with 0 liquid assets), 1 dollar increase in loan demand comes with 64 cents increase in deposits (relative to the industry mean), and 1 percentage point increase in loan demand is associated with 2 basis points increase in the deposit interest rate (relative to the industry mean). The same numbers for fully aggregate creators (with a lagged liquidity ratio of 1) are 173 cents and 6 basis points. That is, aggregate creators seem to search for deposits more than individual creators.

Related literature. The first strand of literature I relate to consists of empirical papers on liquid asset holdings of banks. Stulz et al., 2022 presents a comprehensive research on US banks' liquid asset holdings. They find that the liquid asset ratio of a bank increases in demand deposits-to-assets, and decreases in the logarithm of total assets, in loans-to-assets, in equity-to-assets and in trading assets. I build on their paper and use a very similar database, moreover, I supplement their analysis with deposit-loan correlations. Other papers, for instance, analyse the accumulation of bank and thrift reserves during the GFC (Chang et al., 2014), or find an adverse effect of the Fed's quantitative easing (QE) on bank lending (W. F. Diamond et al., 2022, Kuang et al., 2023).

The second set of empirical literature deals with commercial banks' money creation. Werner, 2016 presents an experiment in which the researcher asks for a test loan from a German cooperative bank. The bank books the loan on the asset side and there is an equal increase in customer deposits on the liability side. Werner interprets this as an evidence for individual creation ("credit creation" theory). But as it is only a test loan, he cannot trace the afterlife of the created money. So, it is still a question whether it would remain at the bank or flow out to another bank, resulting in a drop in liquidity. In contrast, my paper has a broader view with live data of several banks over a longer period, and with deposit in- and outflows.

Jakab and Kumhof, 2019 builds a macroeconomic model and calibrates it to the US economy. Aggregate data supports individual creation ("financing" model) as opposed to the "loanable funds" model, because there are large and fast changes in lending and great real effects of financial shocks. Aggregate balance sheets show very high volatility, which can only be explained by individual creation. In contrast to Jakab and Kumhof, I use bank level data to analyse the question, and I allow for variation in money creation ability.

Kashyap et al., 2002 finds that US banks diversify liquidity risk across both sides of the balance sheet. They also look at Call Report data, and estimate positive regression coefficients both for liquid assets on demand deposits, and for loan commitments on demand deposits. My paper, however, directly deals with the relationship between deposit-loan correlation and liquid assets, and is not particularly focused on loan commitments.

Li et al., 2023 considers the network structure of money multiplier. The authors use transaction-level data from Fedwire Funds Service, which is the real-time gross settlement system of US banks. According to their finding, the level of aggregate credit supply decreases by 9 percent and the volatility increases by 20 percent due to network externalities. In addition, a small subset of banks are systematically important regarding credit supply.

Berger and Bouwman, 2009 proposes four different measures of bank liquidity creation. They apply these to US banks from 1993 to 2003, and conclude that liquidity creation increased in every year. The preferred "cat fat" measure shows liquidity creation of 39 percent of total assets in 2003, or 4.56 times the overall level of equity capital. Liquidity creation is positively correlated with bank value. Instead of their complex measure, I only use the liquid asset ratio, which is negatively related to bank liquidity creation.

The third strand of related papers is about the bank lending channel of monetary policy. Bernanke and Blinder, 1992 presents through vector autoregressions (VARs) that monetary policy works not only through money but also through credit. Kashyap and Stein, 1995, 2000 use disaggregated data on bank balance sheets and finds evidence for the lending view of monetary policy transmission. Moreover, various funding shocks in different countries have been shown to impact bank lending (see Plosser, 2014 and its references). However, my approach is different from this literature, as I look at the co-movement of deposit demand and loan demand, unlike these papers which focus on the effect of deposit supply on loan supply.

I also build on Cohen et al., 2007. This paper presents a unique identification strategy to isolate demand and supply shifts in the stock shorting market. They find that shorting demand is an important predictor of future stock returns. I apply their identification method to loan and deposit markets.

The rest of the paper is organised as follows. In Section 3.2, I show my data, descriptive statistics and aggregate time series. In Section 3.3, I present my empirical analysis for the relationship of deposit-loan correlation and liquidity holding. Then in Section 3.4 I analyse the co-movement of loan demand and deposit demand. I discuss the post-GFC period in Section 3.5, and I conclude in Section 3.6. There are further figures and regression results in Appendix C.

3.2 Data

3.2.1 Construction of the panel

I use Reports of Condition and Income (Call Reports) of US banks. These are quarterly reports which include balance sheets and income statements. The source of the panel database is Wharton Research Data Services (WRDS). The time frame spreads from the first quarter of 1994 to the second quarter of 2021. In addition, I use consumer price index data (from the Federal Reserve Economic Data, FRED, of the St. Louis Fed) to calculate the real value of assets. Interest rate data (from the FRED) include the Federal funds target rate, the interest on reserve balances and the market yield on five-year maturity Treasury securities. I also download the consolidated balance sheet data of US depository institutions (Enhanced Financial Accounts, EFA, from the Federal Reserve). Lastly, I use Federal Financial Institutions Examination Council (FFIEC) data on relationships among banks to find the ultimate parent of every entity.

I try to replicate the Stulz et al., 2022 database with some modifications. I only look at commercial banks (bank charter code = 200), but contrary to the authors, I aggregate entities of the same banking group.[22] I ignore banks which are twice-born, that is which cease to provide data for some time but later resume to do so. I only use observations which have all the data I need. I retain observations with non-negative equity and non-negative loan interest income. I analyse those banking group-quarter pairs which have total assets of at least USD 2 billion (in 2018 US dollars). I end up with 868 banking groups (between 205-381 in each quarter), which is less than 1282 (between 288-405 in each quarter) of Stulz et al., 2022, mainly owing to aggregation.

I calculate implied interest rates and winsorize all my variables at 1 percent to control for outliers. The implied rate of a balance sheet item (for example, transaction deposits) is equal to the income flow divided by the mean of the current and the one-quarter lagged balance sheet item, multiplied by 4 (annualised). I winsorize balance sheet ratios (for example, transaction deposits-to-assets) and implied interest rates by each quarter. Then, I impute the balance sheet items (for example, winsorized transaction deposits). Lastly, I also winsorize changes in these variables.

3.2.2 Descriptive statistics

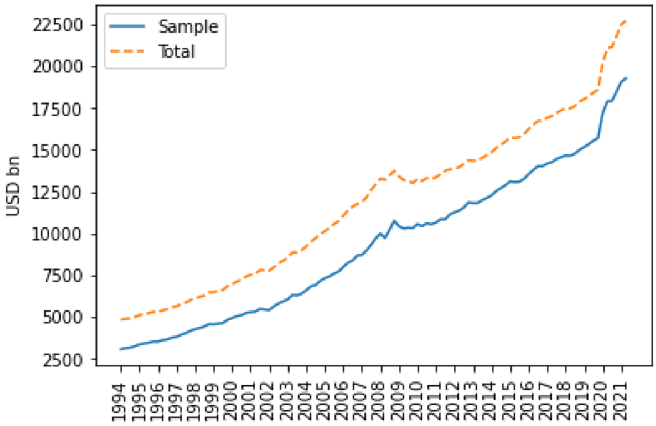
My sample covers the majority of US depository institutions' assets (Figure 3.1). At the end of the time series, the sum of sample banks' assets is around 9/10 of total EFA assets. But at the beginning it is only around 1/2 because I use a fixed lower bound for real assets although real assets are growing over time.

Table 3.1 shows that the distribution of assets is skewed. The minimum level (in nominal terms) is USD 1 billion, while at the end of the time series, JPMorgan Chase & Co. has USD 3200 billion.

The reserves-to-assets ratio is also skewed, the mean is greater than the median. I call cash and balances held at other depository institutions (the Fed included) as reserves. While on average only the 1/20 of assets are held in reserves, the typical securities-to-assets ratio reaches 1/5. The securities ratio nearly spans all possibilities (from 0 to above 9/10). In the following,

[22] This is aggregation, not consolidation, as I do not have data on the counterparty of the different balance sheet items. Special thanks to Ádám Zawadowski for the aggregation.

Figure 3.1: Total assets of banks



Note: Sample is what I use, Total is EFA data.

Table 3.1: Descriptive statistics of balance sheets and interest rates

	N	Mean	Std	Min	Median	Max
Assets (USD bn)	29,633	34.36	161.49	1.18	4.29	3207.52
Asset side:						
Reserve ratio (%)	29,633	5.72	5.87	0.03	3.86	53.46
Securities ratio (%)	29,633	21.60	13.01	0.00	19.54	93.02
Loan ratio (%)	29,633	63.56	14.39	0.55	66.10	96.65
Liability side:						
Deposit ratio (%)	29,633	76.17	11.86	0.18	78.77	96.40
Equity ratio (%)	29,633	10.43	3.22	2.44	9.80	47.03
Interest rates:						
Lending rate (%)	29,487	6.43	2.29	1.59	5.90	25.18
Deposit rate (%)	29,527	1.69	1.44	0.00	1.24	9.49

Note: N is the number of observations (banking group-quarter pairs). Mean is the unweighted average, Std is the standard deviation, Min is the minimum, Max is the maximum. Reserves are cash and balances with other depository institutions (the Fed included). I use all types of securities not held for trading (equity securities, and held-to-maturity and available-for-sale debt securities). Loans are computed as loans and leases net of unearned income and allowance. Deposits include transaction and nontransaction accounts in domestic offices, and deposits in foreign offices (both transaction and nontransaction accounts). Equity is total bank equity capital plus noncontrolling (minority) interests in consolidated subsidiaries. The ratios are in terms of total assets. The interest rates are implied rates from income flows divided by balance sheet items.

I refer to the reserves-and-securities-to-assets ratio as liquidity ratio. As not all securities are eligible collateral for the Fed's discount window facility,[23] the true liquidity of the bank(ing group) is likely to be in between the reserve ratio and the liquidity ratio. The largest liquidity ratio is nearly 1, pertaining to TD Bank in 2001, which implies that this entity was operating as a narrow bank at that time.[24]

Around 2/3 of assets are loans on average, but the loan ratio also spreads from essentially no loans to almost full lending. Deposits are even more important as the average deposit ratio is around 3/4. This also entails a large leverage, the equity-to-assets ratio is only 1/10 on average. The deposit ratio has a wide spread as well, from 0 to almost 1. Household Bank (Nevada) has the minimum deposit ratio in 1999, this entity financed its operations with wholesale funds and equity. The typical implied interest rates on loans is around 6 percent, and somewhat below 2 percent on deposits.

Figure 3.2 shows the key items in the balance sheets over time. Since the GFC, liquid assets and deposits have increased, substituting other assets and other liabilities (for example, wholesale funding). The typical liquidity ratio grew post-crisis in line with loose monetary and fiscal policies.

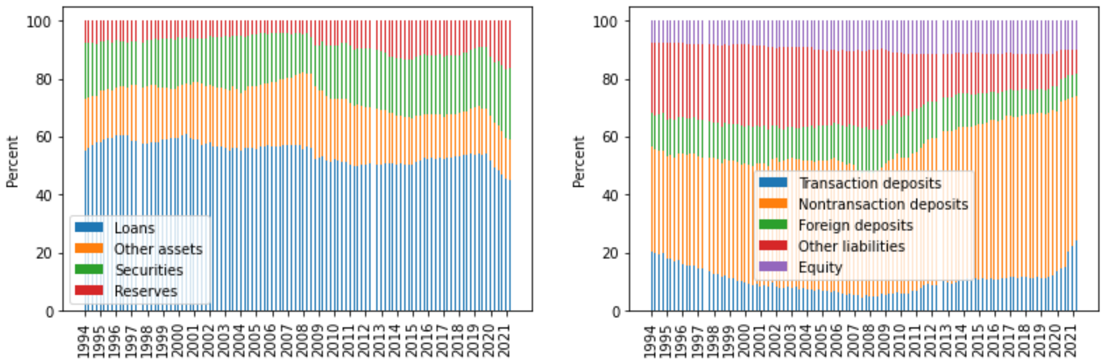
The liquid asset ratio has a broad distribution, ranging from 0 to 1 (Figure 3.3). Although the distribution has not changed markedly after the GFC, the ratio of banks with zero liquidity has decreased. A switch between smaller and larger banks is also visible from the histograms. While before the GFC, larger banks tended to have lower liquidity than smaller ones, post-crisis the opposite holds. The reserve ratio naturally has a smaller spread, ranging from 0 to 1/2. Post-GFC, its distribution has shifted to the right, especially in the case of larger banks. I show figures of similar histograms for time series means of banks in Appendix C.1.

In Figure 3.4 we can look at cross-sectional average interest rates over time. Government bond yields seem to be more important in pricing than the Fed funds rate. Lending rates more or less follow Treasury yields, and there is a more or less constant interest margin between lending and deposit rates.[25] However, the ZLB on deposit rates became more binding after the GFC, resulting in a declining interest rate margin. Among deposits, those held in foreign offices seem

[23]Own obligations and equity securities are not eligible collateral (Fed collateral eligibility).
[24]Narrow banks invest all their deposit liabilities in assets of very high quality (Bossone, 2001; Pennacchi, 2012).
[25]Drechsler et al., 2021 also show a constant net interest margin for US banks over an even longer period.

Figure 3.2: Asset and liability composition of banks

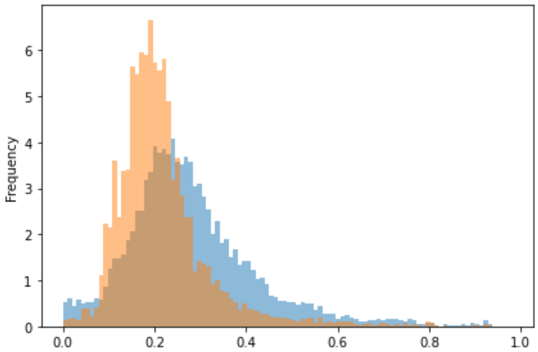
(a) Assets (b) Liabilities



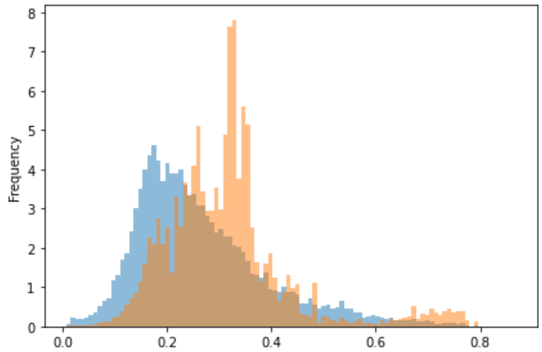
Note: Loans are computed as loans and leases net of unearned income and allowance. Other assets include, for example, allowance for loan and lease losses, and wholesale assets. I use all types of securities not held for trading (equity securities, and held-to-maturity and available-for-sale debt securities). Reserves are cash and balances with other depository institutions (the Fed included). Transaction and nontransaction deposits are in domestic offices. The former include demand deposits, while the latter include savings and time deposits, among others. Foreign deposits are deposits in foreign offices (both transaction and nontransaction accounts). Other liabilities include wholesale liabilities, among others. Equity is total bank equity capital plus noncontrolling (minority) interests in consolidated subsidiaries. I compute the ratios by summing the given item across banks and then I divide it by the sum of total assets across banks.

Figure 3.3: Histograms of liquidity

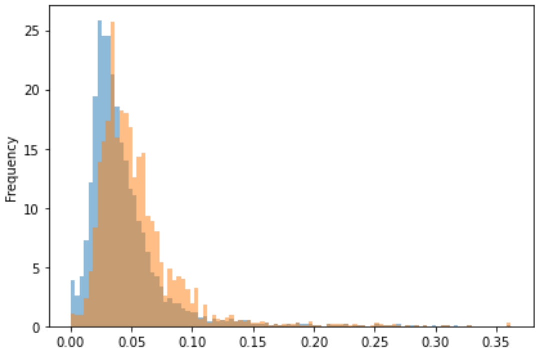
(a) Liquidity ratio pre-2008



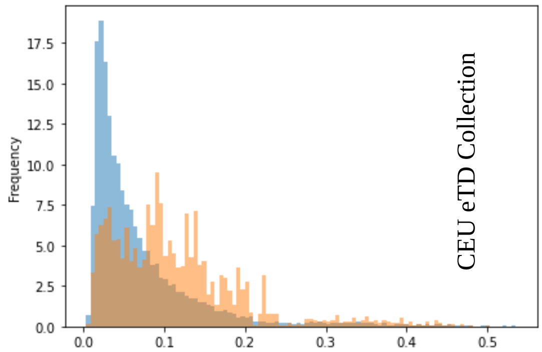
(b) Liquidity ratio post-2008



(c) Reserve ratio pre-2008



(d) Reserve ratio post-2008



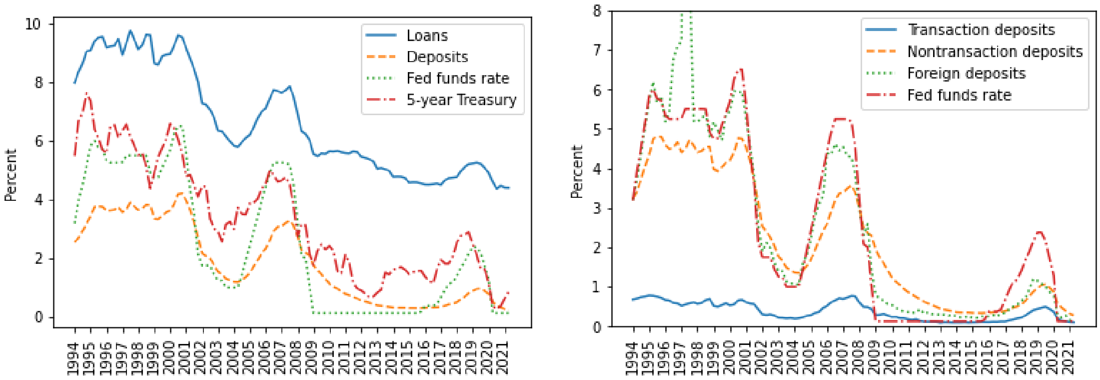
Note: One observation is a bank-quarter pair. Blue histograms are unweighted, orange ones are asset-weighted. Liquidity ratio is (reserves + securities)-to-assets, reserve ratio is reserves-to-assets.

to follow the policy rate the most, and transaction deposits (for example, demand deposits) the least. Nontransaction deposits (for example, savings and time deposits) are in between.

Figure 3.4: Implied loan and deposit interest rates

(a) Loan and deposit

(b) Deposit types

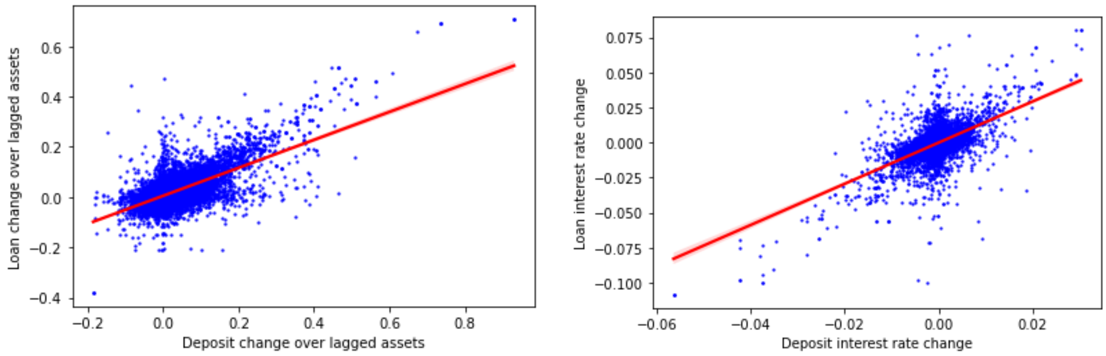


Note: Loan and deposit rates are implied rates calculated from income flows and balance sheets. I present unweighted averages across banks. Transaction and nontransaction deposits are in domestic offices. The former include demand deposits, while the latter include savings and time deposits, among others. Foreign deposits are deposits in foreign offices (both transaction and nontransaction accounts). The Federal funds rate is the quarterly average Fed funds target rate (or midpoint of the target range). 5-year Treasury is the market yield on U.S. Treasury securities at 5-year constant maturity, quoted on an investment basis.

Deposit-taking and lending co-move, just like deposit and loan interest rates (Figure 3.5). By running an OLS regression of loan change on deposit change, we get a coefficient of 0.56. The same coefficient for the change in lending rate on the change in deposit rate is 1.47. There are some banks which, in a given quarter, only collect deposits or only grant loans. This may be because they are aggregate creators: first they gather deposits, and only later they give out loans. But using wholesale funding can also lead to a similar pattern. In some other cases there is a one-to-one relationship between depositing and lending, which is more in line with individual creation. Lending rates have a greater variability than deposit rates, which can be a result of the ZLB. There are similar bin scatter plots in Appendix C.1.

Figure 3.5: Scatter plots of deposits and loans

(a) Quantities (b) Prices



Note: Quarterly changes, measured as scalars. All bank-quarter pairs. The line is a pooled OLS regression line.

3.3 Deposit-loan correlation and liquidity

3.3.1 Identifying shocks and their (co)movements

When bringing the model of Chapter 2 to the data, I assume that the 3 model periods (2 time intervals) together form only 1 quarter. That is, period 0 is the 1st day of the quarter, period 1 is in the middle of the quarter, and period 3 is the first day of the next quarter. Then I observe only the shocked (end-quarter) variables. My other assumption is that the beginning-quarter implicit stocks are equal to the previous end-quarter explicit stocks. That is, in the baseline version, I estimate the δ deposit (supply) shock and λ loan (demand) shock as changes in stocks (normalised by lagged assets):

$$\hat{\delta}_t = \frac{D_t - D_{t-1}}{\text{assets}_{t-1}} \tag{3.1a}$$

$$\hat{\lambda}_t = \frac{L_t - L_{t-1}}{\text{assets}_{t-1}} \tag{3.1b}$$

where D_t and L_t are observed end-quarter deposit and loan stocks.

In an alternative version the beginning quarter implicit stocks are approximated by the trend of the stocks. That is, I estimate δ and λ as deviations of stocks from trend (normalised by lagged assets):

$$\hat{\delta}_t = \frac{D_t - trend(D_t)}{\text{assets}_{t-1}} \tag{3.2a}$$

$$\hat{\lambda}_t = \frac{L_t - trend(L_t)}{\text{assets}_{t-1}} \tag{3.2b}$$

I use central 5-quarter moving average trends.

In Table 3.2 we can see the descriptive statistics of the estimated shocks. The baseline shocks have positive mean due to the upward trend in deposit and loan stocks. In contrast, the average alternative shocks are closer to zero because of detrending. All the variables have positive skewness, which is in line with the mean being larger than the median.

Table 3.2: Descriptive statistics of deposit and loan shocks

	N	Mean	Std	Min	Median	Max	Skew
Baseline depo shock	28,809	0.0199	0.0510	-0.1851	0.0113	0.9301	3.7884
Baseline loan shock	28,809	0.0163	0.0425	-0.3800	0.0102	0.7074	3.9913
Alternative depo shock	26,202	0.0009	0.0338	-0.2983	-0.0003	0.5004	1.4622
Alternative loan shock	26,202	0.0015	0.0281	-0.2315	0.0002	0.4612	2.0907

Note: N is the number of observations (banking group-quarter pairs). Mean is the unweighted average, Std is the standard deviation, Min is the minimum, Max is the maximum, Skew is the skewness. Baseline shocks are changes divided by lagged assets. Alternative shocks are detrended stocks divided by lagged assets.

I estimate the standard deviations σ_δ and σ_λ from the estimated shocks. For every entity-quarter pair, I calculate the standard deviation of the previous 5 years of the same entity (with a minimum periods of 8 quarters). Furthermore, as in theory the money creation ability θ of Chapter 2 behaves similarly to the correlation, I calculate the correlation of the deposit and loan shocks. This is also a backward-looking rolling 5-year correlation with a minimum of 8 periods.

Table 3.3 presents the descriptive statistics of standard deviations and correlations. The standard deviation of deposit change is around 4 percentage points while that of loan change is around 3 percentage points. The larger variability of deposits not only suggests a larger uncertainty but is also consequence of the larger balance sheet ratio. The typical correlation is positive, around 1/2, but there are nearly all kind of values between -4/5 and 1. The standard deviation of the correlation is much larger, around 15 times as that of the standard deviations. If I calculate shocks in the alternative way, by detrending, then the standard deviations are smaller

Table 3.3: Descriptive statistics of standard deviations and correlations

	N	Mean	Std	Min	Median	Max
Baseline depo stdev	27,806	0.0412	0.0274	0.0009	0.0331	0.3239
Baseline loan stdev	27,806	0.0318	0.0250	0.0032	0.0238	0.2486
Baseline correlation	27,806	0.4610	0.3860	-0.7848	0.5009	0.9969
Alternative depo stdev	25,706	0.0280	0.0205	0.0020	0.0213	0.2348
Alternative loan stdev	25,706	0.0213	0.0194	0.0015	0.0146	0.2108
Alternative correlation	25,706	0.4424	0.4150	-0.8600	0.4966	0.9976

Note: N is the number of observations (banking group-quarter pairs). Mean is the unweighted average, Std is the standard deviation, Min is the minimum, Max is the maximum. Baseline shocks are changes divided by lagged assets. Alternative shocks are detrended stocks divided by lagged assets. Stdev is backward-looking rolling 5-year standard deviation for each observation (from the time series of the banking group). Correlation is the backward-looking 5-year correlation of deposit and loan shocks. The minimum number of quarters to calculate the statistics is 8.

but the correlation is similar to the baseline.

In Figure 3.6 we find the time series of standard deviations and correlation. The standard deviations are more or less stable over time, but there is a rise after the turbulent Great Financial and the Covid-19 crises. There is an increase in the 1990s too, perhaps due to the Asian and Russian financial crises of 1997 and 1998. The aggregate measure is most likely to be determined by larger institutions. As a result, the observation that the (unweighted) mean is larger than the aggregate, implies that larger entities have smaller standard deviations. This suggests that the ability to diversify deposit/loan shocks improves with bank size. Another reason why aggregate variation is lower than the mean is that idiosyncratic shocks do not affect the former.

The correlation diminishes over time, but partially reversed during the Covid-19 period.[26] If the correlation grasps money creation ability well, then we can say the typical banking group's such ability decreased over time. It may refer to an increasing competition in the banking system, which is supported by some literature.[27] As the decrease in correlation is most spectacular for the aggregate measure, which is probably led by larger banks, we might conjecture that correlation dropped in the case of large intermediaries in the first place.

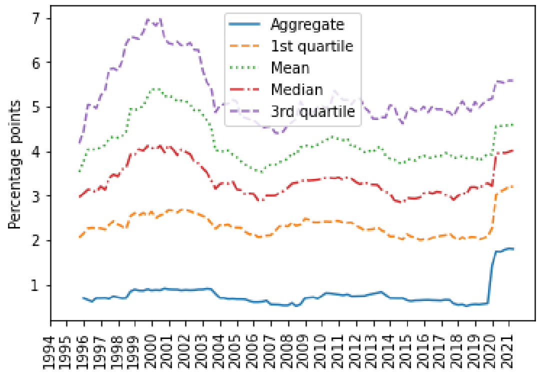
Figure 3.7 supports this view. It shows the distribution of correlation for all the entity-time pairs, both unweighted and asset-weighted. We can observe quite large correlations before the

[26]The rise in correlation at the end of the time series is in line with Strahan and Zhang, 2020, according to which firms drew down on credit lines in early-2020, and coincidentally, cash inflows arrived from depositors.

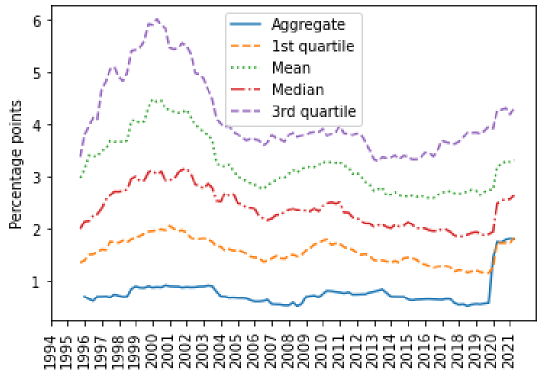
[27]Erler et al., 2017 shows that bank Lerner indices have dropped since 2004, and according to Covas and Calem, 2022, concentration has decreased in the banking system since the GFC.

Figure 3.6: Overall standard deviations and correlation

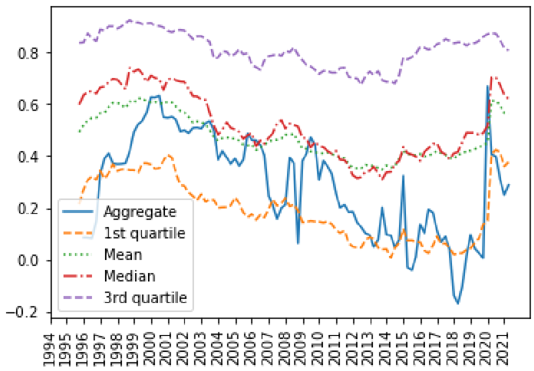
(a) Standard deviations of deposit change



(b) Standard deviations of loan change



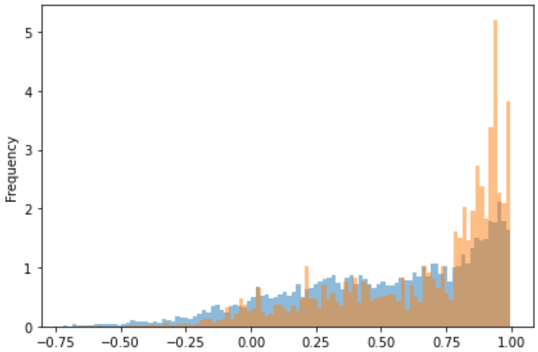
(c) Correlation of deposit and loan changes

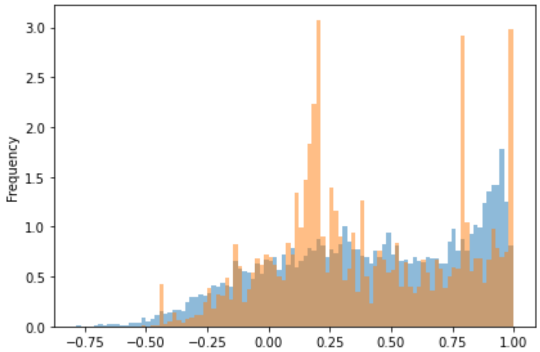


Note: Standard deviation is backward-looking rolling 5-year standard deviation for each observation (from the time series of the banking group). Correlation is the backward-looking 5-year correlation of deposit and loan shocks. The minimum number of quarters to calculate the statistics is 8. Aggregate time series is calculated from system wide EFA data. Mean is the unweighted cross-sectional average of standard deviations and correlations. Cross-sectional quartiles are also presented.

Figure 3.7: Histograms of correlation of deposit and loan changes

(a) Pre-2008 (b) Post-2008





Note: One observation is a bank-quarter pair. Blue histograms are unweighted, orange ones are asset-weighted. Correlation is the backward-looking 5-year correlation of deposit and loan shocks. The minimum number of quarters to calculate the statistic is 8.

GFC, especially for large banks. Post-GFC, however, the distribution has shifted to the left, and this is most visible for larger institutions. In Section 3.5, I discuss the potential effects of the regime switch after 2008 on correlations.

3.3.2 Regression of liquidity on correlation

In order to verify my theoretical model, I estimate the following regression:

$$\alpha_{it} = \beta_0 + \beta_1 Corr_{it} + \beta_2 \sigma_{\delta_{it}} + \beta_3 \sigma_{\lambda_{it}}$$
$$(+\beta_4 Post_t \times Large(>250bn)_i + \beta_5 Post_t \times Large(50-250bn)_i) + \beta_6' X_{i,t-1} + FE_t (+FE_i) + \varepsilon_{it} \quad (3.3)$$

α_{it} is the reserves-to-assets or the (reserves+securities)-to-assets ratio held by banking group i at the end of quarter t. $Corr_{it}$ is the backward-looking 5-year correlation of deposit and loan changes. $\sigma_{\delta_{it}}$ and $\sigma_{\lambda_{it}}$ stand for the deposit and loan standard deviations (of the past 5 years), respectively. My way of controlling for the LCR is adopted from Stulz et al., 2022. $Post_t$ is an indicator variable equal to 1 starting in 2013, the year from which large banks started to prepare for the LCR regulation. $Large(>250bn)_i$ is an indicator variable if assets are above

USD 250 billion at end-2011 (these banks are mostly affected by the LCR). $Large(50 - 250bn)_i$ is an indicator variable if assets are between USD 50 billion and USD 250 billion at end-2011 (these institutions are also affected by the LCR). $X_{i,t-1}$ are control variables, such as lagged logarithm of total assets and lagged equity ratio. FE_t is a time fixed effect to filter out time trend, and FE_i is individual fixed effect. Lastly, ε_{it} is a disturbance term. In the default version I do not use the LCR controls and the individual fixed effect. I estimate the regression with ordinary least squares (panel OLS).

According to the results of Chapter 2, I hypothesise that $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 > 0$. That is, the correlation is a hedge for the bank, while the uncertainty in deposits and loans absorbs liquidity. $\beta_4 > 0$ and $\beta_5 > 0$ is also expected, so that the LCR requirement incentivises banks to hold more liquidity.

The regression results are in Table 3.4, separately for reserve ratio and liquidity ratio, and for full sample, pre- and post-GFC subsamples. The signs of the coefficients are in line with my theory only in part. Correlation reduces liquidity holding, and deposit variability increases it indeed. Nevertheless, loan variability has a negative impact on liquidity held.

The coefficients are significant both statistically and economically. The interpretation of the numbers is the following: focusing on the more reliable pre-GFC sample, by increasing correlation by one standard deviation (0.37), the reserve ratio changes by $-0.02 \times 0.37 \times 100 \approx -0.7$ percentage points. The similar effect of deposit standard deviation is $0.29 \times 0.029 \times 100 \approx 0.9$ percentage points, and for loan standard deviation is $-0.31 \times 0.028 \times 100 \approx -0.9$ percentage points. The effects on the liquidity ratio are larger: -2.9, 5.7 and -6.2 percentage points, respectively, which suggests that reserves and securities are complements rather than substitutes (in the cross-section).[28] The most visible difference is in the effect of loan uncertainty, implying that securities are quite sensitive to loan variability.

The pre- and post-GFC estimates of the coefficient of correlation behave differently for the reserve ratio and the liquidity ratio. In the case of reserve ratio there is a larger effect post-GFC than pre-GFC, but regarding the liquidity ratio the larger effect is pre-GFC. This may be related

[28]This may be true over time too because flooding the banking system with reserves after 2008 did not result in a drop in securities.

Table 3.4: Regression results: liquidity on correlation (baseline shocks, time fixed effect)

	Reserve ratio			Liquidity ratio		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
Correlation	-0.03***	-0.02***	-0.04***	-0.07***	-0.08***	-0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Deposit stdev	0.92***	0.29***	1.49***	2.16***	1.95***	2.45***
	(0.19)	(0.09)	(0.28)	(0.26)	(0.35)	(0.34)
Loan stdev	-0.72***	-0.31***	-1.09***	-2.60***	-2.23***	-2.97***
	(0.16)	(0.08)	(0.26)	(0.28)	(0.38)	(0.35)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Invididual FE	No	No	No	No	No	No
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	23455	10374	13081	23455	10374	13081
Entities	649	441	449	649	441	449
Time periods	103	52	51	103	52	51
R^2	0.15	0.11	0.20	0.19	0.19	0.22
Within R^2	-0.02	-0.13	-0.10	-0.04	-0.03	-0.13

Note: Standard errors clustered at entity level are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Reserve ratio is reserves-to-assets, liquidity ratio is reserves-and-securities-to-assets. Full sample: 1994Q1-2021Q2, Pre-GFC: 1994Q1-2008Q3, Post-GFC: 2008Q4-2021Q2. Stdev is backward-looking 5-year rolling standard deviation of shocks. Correlation is backward-looking 5-year rolling correlation of deposit and loan shocks. Shocks are represented by changes, divided by lagged assets. Controls are lagged log assets and lagged equity-to-assets ratio.

to the fact that reserves started to pay interest in October 2008, so banks can rely on reserves as a liquidity management tool better post-GFC. Before 2008, they could focus more on securities.

When I include individual fixed effects too, then the significance of the coefficients decreases in general. The signs are unchanged but the absolute values are smaller. The coefficient of correlation drops virtually to zero. This might be because the variables of the regression are slowly moving, so it is difficult to estimate the parameters from changes over time. By the way, using only time fixed effects without individual fixed effects is not without precedent in the related literature. For example, Plosser, 2014 uses the same strategy to emphasize cross-sectional differences. Including the LCR indicators does not change the results markedly, and the coefficients of such variables are generally positive. If I use the alternative shocks (detrended variables) instead of the baseline, then I still have similar results. For all these robustness checks see Appendix C.2.

A potential explanation for the negative coefficient of the loan uncertainty is the phenomenon of credit rationing. One can argue that if there is an increase in loan demand, then the bank can intervene and limit the amount of loans disbursed, if needed (J. E. Stiglitz and Weiss, 1981). However, it cannot really push borrowers to take up loans when loan demand is weak.[29] As a result, the distribution of lending would be negatively skewed. In such a case, an increase in loan volatility would mainly affect the downside of the lending distribution. That is, by increasing uncertainty, the mean of the right-truncated distribution would drop, resulting in less loans and a better liquidity position. This could entail a lower demand for liquid assets (ex ante). My data do not support this explanation, however. As Table 3.2 shows, the lending distribution is positively skewed, not negatively.

Nevertheless, I find sign of asymmetric relationship between positive and negative loan changes from one side, and liquidity from the other, which can entail an alternative explanation. I estimate the following regression:

$$y_{it} = \beta_0 + \beta_1\delta_{it} + \beta_2\delta^-_{it} + \beta_3\lambda_{it} + \beta_4\lambda^-_{it} + \beta_5^{'}X_{i,t-1} + FE_t(+FE_i) + \varepsilon_{it} \tag{3.4}$$

y_{it} is the quarterly change in reserves (or liquidity) over lagged assets. δ_{it} and λ_{it} are deposit and loan changes over lagged assets. The negative superscript refers to a negative change.

Table 3.5 shows the results. A rise in liquidity is mechanically associated with an increase in deposit change and a decrease in loan change. The coefficients are larger post-GFC, which suggests that pre-GFC, loans were mainly financed by deposits, not from liquid assets. This is in line with the decreasing deposit-loan correlation over time. The result is also in harmony with the fact the impacts of standard deviations on liquidity are larger post-2008.

But most importantly, negative changes have magnified effects on liquidity, at least after the GFC. That is, a drop in loans is associated with an increase in liquidity more than how a rise in loans is associated with a reduction in liquidity. As a result, greater loan variability co-moves with an increase in expected liquidity. If a bank is more concerned with the mean of liquidity than its variance, then the expected increase in liquidity makes a lower ex ante liquidity holding possible. The opposite holds for deposit changes: as negative changes are more important, by increasing the standard deviation, a fall in liquidity is expected. Thus, the entity may want to

[29] As Friedman, 1968 puts in a somewhat similar context: "You could lead a horse to water but you could not make him drink." (p.1)

Table 3.5: Regression results: asymmetric effects (time fixed effect)

	Reserve change over lagged assets			Liquidity change over lagged assets		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
Depo change	0.25***	0.08***	0.44***	0.51***	0.39***	0.65***
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
Negative depo change	0.15***	0.05***	0.18***	0.05*	-0.09***	0.12***
	(0.03)	(0.02)	(0.05)	(0.03)	(0.03)	(0.04)
Loan change	-0.17***	-0.01*	-0.35***	-0.26***	-0.12***	-0.44***
	(0.02)	(0.01)	(0.03)	(0.02)	(0.02)	(0.03)
Negative loan change	-0.06**	-0.02	-0.20***	-0.12***	-0.08*	-0.24***
	(0.03)	(0.02)	(0.05)	(0.04)	(0.05)	(0.04)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Invididual FE	No	No	No	No	No	No
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	28809	13878	14931	28594	13663	14931
Entities	825	539	560	821	535	560
Time periods	110	59	51	109	58	51
R^2	0.21	0.11	0.35	0.37	0.27	0.53
Within R^2	0.24	0.11	0.39	0.39	0.27	0.55

Note: Standard errors clustered at entity level are in parentheses. $^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Liquidity is reserves+securities. Full sample: 1994Q1-2021Q2, Pre-GFC: 1994Q1-2008Q3, Post-GFC: 2008Q4-2021Q2. Changes are quarterly changes for a banking group. Changes are divided by lagged assets. Negative changes are changes which have a negative sign. Controls are lagged log assets and lagged equity-to-assets ratio.

hold more liquidity ex ante. The asymmetry in deposit changes may reflect that the bank cannot really fight against large outflows, but can disincentivise large inflows by cutting deposit rates.

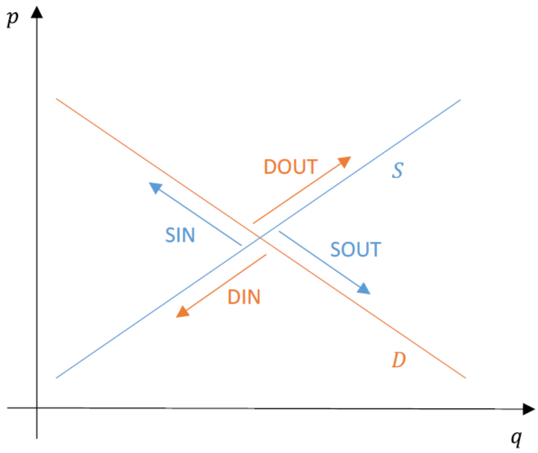
3.4 Loan demand and deposit demand

3.4.1 Empirical strategy

My aim in this section is to estimate the effect of borrowers' loan demand on banks' deposit demand, depending on the liquidity creation ability. In order to have external validity of the analysis, I use a 27 years long time frame with entities covering most of the US banking system. This macroeconomic approach comes with the cost of being difficult to find a variable which is exogenous in theory. That is why I do not search for an instrumental variable but I use another identification scheme. In fact, I show only correlations which should not be interpreted as causality.

I build on Cohen et al., 2007 to identify deposit and loan demand and supply shifts (Figure 3.8). Whenever quantities (for example, deposits) and prices (for example, deposit interest rates) move in the same direction from one quarter to the next (for example, both increase), then there is a demand shift (in this case, deposit demand outward shift, or DDOUT). If, however, quantities and prices move in the opposite direction, then I identify a supply shift (for example, loan supply inward shift, or LSIN). In fact, these movements imply at least one such shift, as other demand or supply shocks can also occur. But if, for example, both the quantity and the price increase, there must be at least a demand outward shift. In this way I can isolate DDIN, DDOUT, DSIN, DSOUT, and LDIN, LDOUT, LSIN, LSOUT.[30]

Figure 3.8: Demand and supply shifts in theory



Note: p is price, q is quantity, D is demand, S is supply. IN is inward shift, OUT is outward shift.

I try to control for aggregate movements in demand and supply. To this aim, in every period, I compute the between transformed changes in quantities and prices. That is, I subtract the cross-sectional mean of these changes for every quarter. Then comes the identification of demand and supply shifts - relative to the industry average. That is how I create indicator variables. I also combine in- and outward shifts to get deposit demand (DD), deposit supply (DS), loan demand (LD) and loan supply (LS) indicator variables.

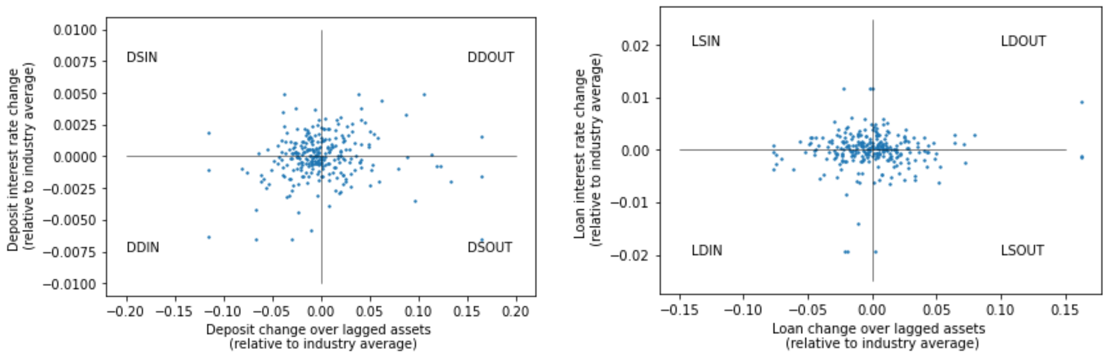
Figure 3.9 shows these demand and supply shifts in the data for a specific point in time. By construction, due to demeaning, observations are centered around the origin. We can see that quantity changes (relative to lagged assets) are frequently larger than price changes. In addition, in the deposit market, the observations are closer to the horizontal axis than in the loan market.

[30]My method is similar to vector autoregressions (VARs) with sign restrictions.

This is in line with the fact we have already seen that changes in lending rates are larger than changes in deposit rates.

Figure 3.9: Demand and supply shifts in the data (2008Q2)

(a) Deposit market (b) Loan market



Note: Quarterly changes, measured as scalars. All bank-quarter pairs. DDIN = deposit demand in, DDOUT = deposit demand out, DSIN = deposit supply in, DSOUT = deposit supply out, LDIN = loan demand in, LDOUT = loan demand out, LSIN = loan supply in, LSOUT = loan supply out.

In Figure 3.10 we can see the weights of the different demand/supply shifts over time. In other words, for example in the deposit market, it shows how many banks undergo DDIN, DDOUT, DSIN and DSOUT in a given quarter, relative to the number of banks in that quarter. These ratios are not necessarily 1/4 because the distribution of quantity and price changes is not necessarily symmetric. That is, larger changes in the case of some banks can distort the industry average, leading to for example, a mean greater than the median, and thus to more inward shifts.

3.4.2 Regressions of deposit indicators on loan demand

In order to analyse the relationship between deposit demand and loan demand I estimate the following regressions.

$$\tilde{y}_{ist} = \beta_0 + \mathbb{1}_{LD,ist}(\beta_1 \tilde{L}_{ist} + \beta_2 \alpha_{is,t-1} \tilde{L}_{ist}) + \beta_3 \alpha_{is,t-1} + \beta_4' X_{ist}(+FE_{is} + FE_{st}) + \varepsilon_{ist} \quad (3.5)$$

A banking group is indicated by i, the US state in which it is located by s, and a quarter by t. Tilde means quarterly change relative to the industry average. I use two different left-hand

Figure 3.10: Ratios of banks with demand/supply shifts over time

(a) Deposit market (b) Loan market

Note: The figure shows the number of banks with the given change in a given period, divided by the total number of banks in that period.

side variables.

1. Deposit quantity: $\tilde{y}_{ist} = \frac{D_{ist} - D_{is,t-1}}{\text{assets}_{is,t-1}} - \frac{\sum_{i=1}^{N_t} \frac{D_{ist} - D_{is,t-1}}{\text{assets}_{is,t-1}}}{N_t}$, in which D is deposit stock and N_t is the number of banks in quarter t.

2. Deposit price: $\tilde{y}_{ist} = (r_{D_{ist}} - r_{D_{is,t-1}}) - \frac{\sum_{i=1}^{N_t} r_{D_{ist}} - r_{D_{is,t-1}}}{N_t}$, in which r_D is the implied deposit interest rate.

$\mathbb{1}_{LD,ist}$ is an indicator variable taking the value of 1 if there is loan demand shift for that bank-quarter pair, and 0 otherwise. $\tilde{L}_{ist} = \frac{L_{ist} - L_{is,t-1}}{\text{assets}_{is,t-1}} - \frac{\sum_{i=1}^{N_t} \frac{L_{ist} - L_{is,t-1}}{\text{assets}_{is,t-1}}}{N_t}$, where L is the loan stock. $\alpha_{is,t-1}$ is the lagged liquidity ratio, which approximates the inability to create money. X_{ist} are control variables such as lagged log assets, lagged equity-to-assets ratio, change in the Fed funds rate, and change in the interest paid on reserves. FE_{is} is individual fixed effect and FE_{st} is state-time fixed effect. The latter is a control for local economic developments that can influence deposit supply. Lastly, ε_{ist} is a disturbance term.

I estimate the regressions with ordinary least squares (panel OLS). In the default there are no individual fixed effects because I am mostly interested in cross-sectional variability in money creation potential. However, including such effects gives similar result. There are no time fixed effects either because of the between transformation of the left-hand side variables (that is, due to subtracting the cross-sectional mean, which is similar to detrending). In the default I do not use state-time fixed effects either to show the full co-movement of deposits and loan demand, not just the deposit demand and loan demand. But, when I include such fixed effects, I get similar estimates. I cluster standard errors at the bank level. Regressions are run on the full sample from 1994 to 2021, and also on the sample before Q4 2008, and starting from Q4 2008.[31] Tables with fixed effects and with the reserve ratio instead of the liquidity ratio are in Appendix C.2.

According to the results of Chapter 2, I hypothesise that $\beta_1 > 0$ and $\beta_2 > 0$, both for deposit quantity and price. That is, deposit demand increases in loan demand, especially for aggregate money creators. I only expect $\beta_1 = 0$ for the deposit interest rate when there is no control for deposit supply (no state-time fixed effect). In such a case my conjecture says that fully individual creators' deposit demand and supply react one-for-one to loan a demand shift, therefore the interest rate is unchanged.

The results of the default estimates are in Table 3.6. The signs of the estimated coefficients are more or less in line with my hypotheses. In the pre-GFC sample, the numbers of which are more reliable, both loan demand and lagged liquidity x loan demand have positive and statistically significant coefficients, both for quantity and price changes. So, deposit demand positively co-moves with loan demand, and this relationship is stronger for banks with larger liquidity ratio, that is, for aggregate money creators. That its, if a bank is more of an aggregate creator, it tries to collect deposits more heavily when it faces a loan demand outward shift. However, the positive coefficient of loan demand on the deposit interest rate is counter to my 0 conjecture. It may be because I identify loan demand shifts by quantity-price changes, so I ab ovo assume an increasing lending rate, which may entail an upward movement in the deposit rate too.

The interpretation of the numbers is as follows. For fully individual creators (with 0 liquid assets), 1 dollar increase in loan demand (relative to the industry mean) comes with 64 cents increase in deposits (relative to the industry mean), and 1 percentage point increase in such loan demand is associated with 2 basis points increase in the deposit interest rate (relative to the industry average). The same numbers for fully aggregate creators (with a lagged liquidity ratio

[31] Note that after the GFC, by reaching the ZLB, my identification scheme can fail. In such a situation, the deposit market could clear at rates below zero. Therefore, (smaller) shifts in demand and supply are invisible as they leave the price unchanged. That is why I do not compare pre- and post-GFC results explicitly.

Table 3.6: Regression results: deposit quantity and price on loan demand and liquidity (with lagged liquidity, no fixed effect)

	Deposit change			Deposit interest rate change		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
Loan demand	0.721***	0.635***	0.868***	0.010***	0.019***	0.001
	(0.065)	(0.093)	(0.053)	(0.003)	(0.004)	(0.001)
Lagged liq. x Loan demand	0.766***	1.091***	0.178	0.034***	0.044***	0.007*
	(0.228)	(0.327)	(0.203)	(0.011)	(0.016)	(0.004)
Lagged liquidity	0.002	0.002	0.001	0.000***	0.000*	0.000***
	(0.004)	(0.006)	(0.004)	(0.000)	(0.000)	(0.000)
Constant	0.004	0.014**	-0.002	-0.000***	-0.000	-0.000***
	(0.003)	(0.006)	(0.005)	(0.000)	(0.000)	(0.000)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Invididual FE	No	No	No	No	No	No
State-time FE	No	No	No	No	No	No
Obs	28468	13588	14880	28468	13588	14880
Entities	817	534	557	817	534	557
Time periods	109	58	51	109	58	51
R^2	0.340	0.389	0.290	0.079	0.125	0.015
Within R^2	0.332	0.383	0.278	0.083	0.133	0.012

Note: Standard errors clustered at entity level are in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Deposit and deposit interest rate changes are relative changes compared to the cross-sectional average. In the case of deposit change, there is a division by lagged assets. Full sample: 1994Q1-2021Q2, Pre-GFC: 1994Q1-2008Q3, Post-GFC: 2008Q4-2021Q2. Liquidity is reserves plus securities divided by assets. Loan demand is relative lending compared to the cross-sectional mean, divided by lagged assets, and multiplied by a loan demand shift indicator variable. Controls are lagged log assets, lagged equity-to-assets ratio, change in the Fed funds rate, and change in the interest paid on reserves.

 Hungarian DOI: 10.14754/CEU.2024.06

of 1) are 64+109=173 cents and 2+4=6 basis points. The coefficients on deposit quantity seem to be more significant economically than those on deposit price.

3.5 Discussion of the post-GFC period

I consider the pre-GFC numbers more reliable because post-GFC there are several factors which bias the deposit-loan correlation and the liquidity ratio. These effects mainly influence larger banks. The following discussion relies on Stulz et al., 2022.

1. ZLB: due to the decline in aggregate demand, the zero lower bound on nominal interest rates became binding after 2008. With zero Fed funds rate and zero interest on reserves, the cost of holding liquidity decreased. This could increase banks's demand for reserves.

2. QE: due to the ZLB, the Fed started large-scale asset purchases to bring down longer-term yields. This resulted in a lengthening of commercial bank balance sheets: the Fed supplied reserves to banks, who financed these assets by new deposits.

3. IORB: owing to QE, the Fed introduced the interest on reserve balances (IORB) as a monetary policy tool. As reserves became interest-bearing (effectively between 2016 and 2020), the system could approach the "slack" liquidity regime of my model in Chapter 2, in which the reserve ratio does not depend on the money creation ability θ.

4. LCR: the key Basel III liquidity requirement could also contribute to a larger demand for liquid assets in the case of larger banks.

5. Capital requirements: post-GFC, risk-based capital requirements increased, mainly for larger institutions. This made holding loans more expensive and holding risk-free liquid assets more favourable.

6. Capital depletion: mainly big banks held mortgage related securities that suffered losses during the GFC. So, they could become capital constrained, and therefore, interested in switching loans to liquid assets.

7. Deposit inflow: some big banks enjoyed large deposit inflows during the GFC because of flight to quality, which again contributed to an increase in liquidity.

8. Derivatives: big banks have larger (off-balance sheet) derivative exposure, which, according to the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010, requires more collateral than before. Collateral is placed in liquid assets, thus their demand for liquid assets could increase.

All the above factors could contribute to a larger liquidity ratio (mainly for larger banks). Moreover, they could reduce the deposit-loan correlation: if deposits and reserves increase simultaneously without lending, then the relationship between deposits and loans could weaken. The same holds if reserves crowd out loans without a change in deposits. Therefore, we can conclude that the post-GFC lower correlation and larger liquidity ratio is not necessarily a sign of weaker money creation ability.

3.6 Conclusion

This paper is a contribution to the old debate on the mechanics of money supply by commercial banks. Nevertheless, some caveats hold. It would be interesting to look at not only the consequences but also the causes of being an individual or aggregate creator. More importantly, my empirical strategy is not necessarily best fit for the purpose of this paper as I do not use an exogenous variables (instruments). In Section 3.3 I use the deposit-loan correlation instead of the deposit-loan regression coefficient (θ), because estimating θ would probably need an instrument. In Section 3.4 although I separate demand and supply shifts on the deposit and loan markets, I do not separate these across the markets. In theory, loan demand and deposit demand could be explained by the same variable, leading to endogeneity problem in the estimation. However, I use control variables, which may solve some of this problem. Altogether, another analysis with some instruments seems to be promising.

References

Acharya, V. V., & Rajan, R. (2022). Liquidity, liquidity everywhere, not a drop to use - why flooding banks with central bank reserves may not expand liquidity. *NBER Working Paper*, (29680).

Andersen, T. G., Bollerslev, T., Christoffersen, P. F., & Diebold, F. X. (2013). Financial risk measurement for financial risk management. In G. M. Constantinides, M. Harris, & R. Stulz (Eds.), *Handbook of the economics of finance* (pp. 1127–1220). Elsevier B.V.

Auer, R., Frost, J., Gambacorta, L., Monnet, C., Rice, T., & Shin, H. S. (2021). Central bank digital currencies: Motives, economic implications and the research frontier. *BIS Working Papers*, (976).

Bagehot, W. (1873). *Lombard street: A description of the money market* (1st ed.). Scribner, Armstrong & Co.

Berger, A. N., & Bouwman, C. H. S. (2009). Bank liquidity creation. *The Review of Financial Studies*, *22*(9), 3779–3837.

Berger, A. N., Herring, R. J., & Szegö, G. P. (1995). The role of capital in financial institutions. *Journal of Banking & Finance*, *19*(3–4), 393–430.

Bernanke, B. S. (1983). Nonmonetary effects of the financial crisis in the propagation of the great depression. *The American Economic Review*, *73*(3), 257–276.

Bernanke, B. S. (1988). Monetary policy transmission: Through money or credit? *Federal Reserve Bank of Philadelphia Business Review*, (November/December), 3–11.

Bernanke, B. S., & Blinder, A. S. (1988). Credit, money, and aggregate demand. *The American Economic Review*, *78*(2), 435–439.

Bernanke, B. S., & Blinder, A. S. (1992). The federal funds rate and the channels of monetary transmission. *The American Economic Review*, *82*(4), 901–921.

Boissay, F., Collard, F., & Smets, F. (2016). Booms and banking crises. *Journal of Political Economy*, *124*(2), 489–538.

Bordo, M. D., & Levin, A. T. (2017). Central bank digital currency and the future of monetary policy. *NBER Working Paper*, (23711).

Böser, F., & Gersbach, H. (2020). Monetary policy with a central bank digital currency: The short and the long term. *CEPR Discussion Paper*, (DP15322).

Bossone, B. (2001). Should banks be narrowed? *IMF Working Paper*, (01/159).

Brunnermeier, M. K., & Niepelt, D. (2019). On the equivalence of private and public money. *Journal of Monetary Economics*, *106*, 27–41.

Bundesbank, D. (2017). The role of banks, non-banks and the central bank in the money creation process. *Monthly Report*, (April 2017).

Calomiris, C. W. (2011). Banking crises and the rules of the game. In G. Wood, T. Mills, & N. Crafts (Eds.), *Monetary and banking history: Essays in honour of forrest capie* (pp. 88–132). Routledge.

Calomiris, C. W., & Gorton, G. (1991). The origins of banking panics: Models, facts, and bank regulation. In R. G. Hubbard (Ed.), *Financial markets and financial crises* (pp. 109–174). University of Chicago Press.

Carapella, F., & Flemming, J. (2020). Central bank digital currency: A literature review [FEDS Notes. 9 November 2020]. https://www.federalreserve.gov/econres/notes/feds-notes/central-bank-digital-currency-a-literature-review-20201109.htm

Chang, S.-H., Contessi, S., & Francis, J. L. (2014). Understanding the accumulation of bank and thrift reserves during the u.s. financial crisis. *Journal of Economic Dynamics & Control*, *43*, 78–106.

Chapman, J., Chiu, J., Davoodalhosseini, M., Jiang, J., Rivadeneyra, F., & Zhu, Y. (2023). Central bank digital currencies and banking: Literature review and new questions. *Bank of Canada Staff Discussion Paper*, (2023-4).

Clinton, K. (1997). Implementation of monetary policy in a regime with zero reserve requirements. *Bank of Canada Working Paper*, (97-8).

Cohen, L., Diether, K. B., & Malloy, C. J. (2007). Supply and demand shifts in the shorting market. *Journal of Finance*, *62*(5), 2061–2096.

CORE. (2017). *The economy*. https://core-econ.org/the-economy/v1/en/

Covas, F., & Calem, P. (2022). Five important facts about the competitiveness of the u.s. banking industry [24 February 2022]. https://bpi.com/five-important-facts-about-the-competitiveness-of-the-u-s-banking-industry/

Davison, L. K., & Ramirez, C. D. (2016). Does deposit insurance promote financial depth? evidence from the postal savings system during the 1920s. *FDIC Center for Financial Research Working Paper*, (2017-02).

Deep, A., & Schaefer, G. K. (2004). Are banks liquidity transformers? *Harvard University, KSG Working Paper*, (RWP04-022).

Degryse, H., & Ongena, S. (2005). Distance, lending relationships, and competition. *The Journal of Finance*, *60*(1), 231–266.

Dejong, D. N., & Dave, C. (2011). Structural macroeconometrics. Princeton University Press.

Del Negro, M., Giannoni, M. P., Giannone, D., & Tambalotti, A. (2017). Safety, liquidity, and the natural rate of interest. *Brookings Papers on Economic Activity*, 235–316.

Demirgüç-Kunt, A., & Kane, E. J. (2001). Deposit insurance around the globe: Where does it work? *World Bank Policy Research Working Paper*, (2679).

Diamond, D. W., & Dybvig, P. H. (1983). Bank runs, deposit insurance, and liquidity. *The Journal of Political Economy*, *91*(3), 401–419.

Diamond, D. W., & Kashyap, A. K. (2016). Liquidity requirements, liquidity choice, and financial stability. In J. B. Taylor & H. Uhlig (Eds.), *Handbook of macroeconomics* (pp. 2263–2303, Vol. 2B). Elsevier B.V.

Diamond, W. F., Jiang, Z., & Ma, Y. (2022). The reserve supply channel of unconventional monetary policy. *NBER Working Paper*, (31693).

Disyatat, P. (2011). The bank lending channel revisited. *Journal of Money, Credit and Banking*, *43*(4), 711–734.

Donaldson, J. R., & Piacentino, G. (2019). Money runs. *NBER Working Paper*, (26298).

Donaldson, J. R., Piacentino, G., & Thakor, A. (2018). Warehouse banking. *Journal of Financial Economics*, *129*, 250–267.

Drechsler, I., Savov, A., & Schnabl, P. (2017). The deposits channel of monetary policy. *The Quarterly Journal of Economics*, *132*(4), 1819–1876.

Drechsler, I., Savov, A., & Schnabl, P. (2021). Banking on deposits: Maturity transformation without interest rate risk. *Journal of Finance*, *76*(3), 1091–1143.

Duttweiler, R. (2009). *Managing liquidity in banks: A top down approach.* Wiley.

Ellis, D. (2013). Deposit insurance funding: Assuring confidence. *FDIC Staff Paper.*

Erler, A., Gischer, H., & Herz, B. (2017). Regional competition in us banking - trends and determinants. *Universität Magdeburg Working Paper*, (8).

FDIC. (1935). Annual report of the federal deposit insurance corporation for the year ending december 31, 1934.

FDIC. (2021a). 2020 annual report.

FDIC. (2021b). Quarterly banking profile. *15*(2).

Fernández-Villaverde, J., Sanches, D., Schilling, L., & Uhlig, H. (2020). Central bank digital currency: Central banking for all? *NBER Working Paper*, (26753).

Fisher, I. (1935). *100% money*. The Adelphi Company.

Freixas, X., & Rochet, J.-C. (2008). *Microeconomics of banking*. The MIT Press.

Friedman, M. (1968). The role of monetary policy. *The American Economic Review*, *58*(1), 1–17.

Gertler, M., & Kiyotaki, N. (2015). Banking, liquidity, and bank runs in an infinite horizon economy. *The American Economic Review*, *105*(7), 2011–2043.

Goodhart, C. A. E. (1999). Myths about the lender of last resort. *International Finance*, *2*(3), 339–360.

Gorton, G. (2020). The regulation of private money. *Journal of Money, Credit and Banking, Supplement to*, *52*(S1), 21–42.

Gorton, G., & Pennacchi, G. (1990). Financial intermediaries and liquidity creation. *The Journal of Finance*, *45*(1), 49–71.

Gourieroux, C., & Jasiak, J. (2010). Value at risk. In W. T. Ziemba (Ed.), *Handbook of financial econometrics* (pp. 553–615). Elsevier B.V.

Gurley, J. G., & Shaw, E. S. (1960). *Money in a theory of finance*. Brookings Institution.

Hanson, S., Shleifer, A., Stein, J. C., & Vishny, R. W. (2015). Banks as patient fixed-income investors. *Journal of Financial Economics*, (117), 449–469.

Hoang, Y. H., Ngo, V. M., & Vu, N. B. (2023). Central bank digital currency: A systematic literature review using text mining approach. *Research in International Business and Finance*, *64*(101889), 1–20.

Holmström, B., & Tirole, J. (1997). Financial intermediation, loanable funds, and the real sector. *The Quarterly Journal of Economics*, *112*(3), 663–691.

Jakab, Z., & Kumhof, M. (2019). Banks are not intermediaries of loanable funds — facts, theory and evidence. *Bank of England Staff Working Paper*, (761).

Jobst, C., & Scheiber, T. (2014). South-eastern european monetary and economic statistics from the nineteenth century to world war ii (austria-hungary: From 1863 to 1914). Bank of Greece, Bulgarian National Bank, National Bank of Romania, Oesterreichische Nationalbank.

Jorion, P. (2007). *Value at risk: The new benchmark for managing financial risk* (Vol. 3). McGraw-Hill.

Kareken, J., & Wallace, N. (1981). On the indeterminacy of equilibrium exchange rates. *The Quarterly Journal of Economics*, *96*(2), 207–222.

Kashyap, A. K., Rajan, R., & Stein, J. C. (2002). Banks as liquidity providers: An explanation for the coexistence of lending and deposit-taking. *The Journal of Finance*, *57*(1), 33–73.

Kashyap, A. K., & Stein, J. C. (1994). Monetary policy and bank lending. In N. G. Mankiw (Ed.), *Monetary policy* (pp. 221–261). The University of Chicago Press.

Kashyap, A. K., & Stein, J. C. (1995). The impact of monetary policy on bank balance sheets. *Carnegie-Rochester Conference Series on Public Policy*, *42*, 151–195.

Kashyap, A. K., & Stein, J. C. (2000). What do a million observations on banks say about the transmission of monetary policy? *The American Economic Review*, *90*(3), 407–428.

Keister, T., & McAndrews, J. J. (2009). Why are banks holding so many excess reserves? *Federal Reserve Bank of New York Current Issues in Economics and Finance*, *15*(8), 1–10.

Kiyotaki, N., & Moore, J. (2002). Evil is the root of all money [Papers and Proceedings of the One Hundred Fourteenth Annual Meeting of the American Economic Association (May, 2002)]. *The American Economic Review*, *92*(2), 62–66.

Krishnamurthy, A., & Vissing-Jorgensen, A. (2012). The aggregate demand for treasury debt. *Journal of Political Economy*, *120*(2), 233–267.

Kuang, C., Yang, J., & Zhu, W. (2023). Reserve holding and bank lending [November 2023]. https://ssrn.com/abstract=4400455

Li, Y., Li, Y., & Sun, H. (2023). The network structure of money multiplier. *Columbia Business School Research Paper*. https://ssrn.com/abstract=3998037

Lucas, R. (1976). Econometric policy evaluation: A critique. In K. Brunner & A. H. Meltzer (Eds.), *The phillips curve and labor markets. carnegie-rochester conference series on public policy* (pp. 19–46, Vol. 1). American Elsevier.

Mankiw, N. G. (2016). *Macroeconomics, 9th edition*. Worth Publishers.

Marshall, A. (1890). *Principles of economics*. Macmillan.

McAndrews, J., & Roberds, W. (1999). Payment intermediation and the origins of banking. *Federal Reserve Bank of Atlanta Working Paper*, (99-11).

McLeay, M., Radia, A., & Thomas, R. (2014a). Money creation in the modern economy. *Bank of England Quarterly Bulletin*, (2014 Q1).

McLeay, M., Radia, A., & Thomas, R. (2014b). Money in the modern economy: An introduction. *Bank of England Quarterly Bulletin*, (2014 Q1).

Moinas, S., & Pouget, S. (2013). The bubble game: An experimental study of speculation. *Econometrica*, *81*(4), 1507–1539.

Pennacchi, G. (2012). Narrow banking. *Annual Review of Financial Economics*, *4*(0), 1–36.

Phillips, C. A. (1920). *Bank credit*. Macmillan.

Plosser, M. C. (2014). Bank heterogeneity and capital allocation: Evidence from 'fracking' shocks. *Federal Reserve Bank of New York Staff Report*, (693).

Prisman, E. Z., Slovin, M. B., & Sushka, M. E. (1986). A general model of the banking firm under conditions of monopoly, uncertainty, and recourse. *Journal of Monetary Economics*, *17*(2), 293–304.

Samuelson, P. A. (1948). *Economics*. McGraw-Hill.

Schmelzing, P. (2020). Eight centuries of global real interest rates, r-g, and the 'suprasecular' decline, 1311-2018. *Bank of England Staff Working Paper*, (845).

Schumpeter, J. A. (1912). *Die theorie der wirtschaftlichen entwicklung*. Duncker und Humblot.

Schuster, S. S., Jaremski, M., & Perlman, E. R. (2019). An empirical history of the united states postal savings system. *NBER Working Paper*, (25812).

Stein, J. C. (1998). An adverse-selection model of bank asset and liability management with implications for the transmission of monetary policy. *RAND Journal of Economics*, (29), 466–486.

Stein, J. C. (2012). Monetary policy as financial stability regulation. *The Quarterly Journal of Economics*, *127*, 57–95.

Stevens, E. J. (1971). Composition of the money stock prior to the civil war. *Journal of Money, Credit and Banking*, *3*(1), 84–101.

Stiglitz, J., & Greenwald, B. (2003). *Towards a new paradigm in monetary economics*. Cambridge University Press.

Stiglitz, J. E., & Weiss, A. (1981). Credit rationing in markets with imperfect information. *The American Economic Review*, *71*(3), 393–410.

Strahan, P. E., & Zhang, S. (2020). Banks as lenders of first resort: Evidence from the covid-19 crisis. *The Review of Corporate Finance Studies*, (9), 472–500.

Stulz, R. M., Taboada, A. G., & van Dijk, M. A. (2022). The determinants of bank liquid asset holdings. *NBER Working Paper*, (30340).

Tirole, J. (2006). *The theory of corporate finance*. Princeton University Press.

Tobin, J. (1963). Commercial banks as creators of "money". *Cowles Foundation Discussion Paper*, (159).

Tobin, J. (1985). Financial innovation and deregulation in perspective. *BoJ Monetary and Economic Studies*, *3*(2), 19–29.

Tobin, J. (1987). A case for preserving regulatory distinctions. *Challenge*, *30*(5), 10–17.

von Mises, L. (1912). *Theorie des geldes und der umlaufsmittel*. Duncker; Humblot.

Werner, R. A. (2016). A lost century in economics: Three theories of banking and the conclusive evidence. *International Review of Financial Analysis*, *46*, 361–379.

Whited, T. M., Wu, Y., & Xiao, K. (2021). Low interest rates and risk incentives for banks with market power. *Journal of Monetary Economics*, *121*(100), 155–174.

Wicksell, J. G. K. (1898). *Geldzins und güterpreise*. Fischer.

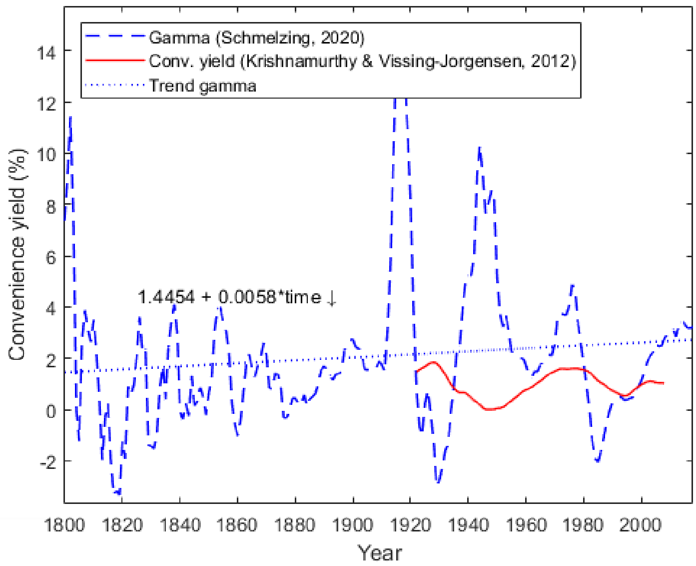
Williamson, S. D. (2022). Central bank digital currency and flight to safety. *Journal of Economic Dynamics & Control*, *142*(104146), 1–25.

Hungarian DOI: 10.14754/CEU.2024.06

A Appendix for Chapter 1

A.1 Supplementary figures

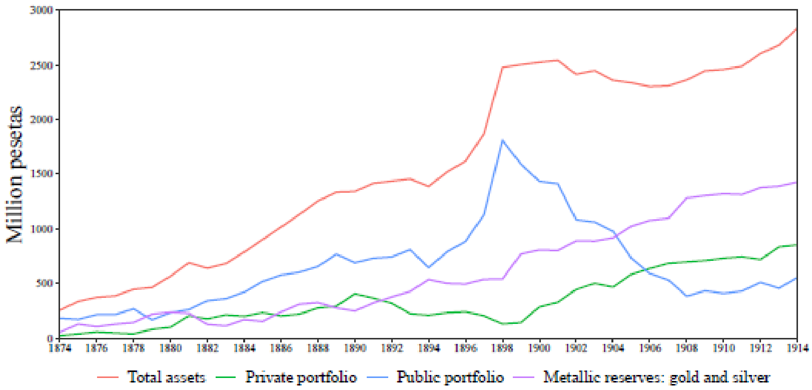
Figure A.1: Convenience yields based on different methodologies



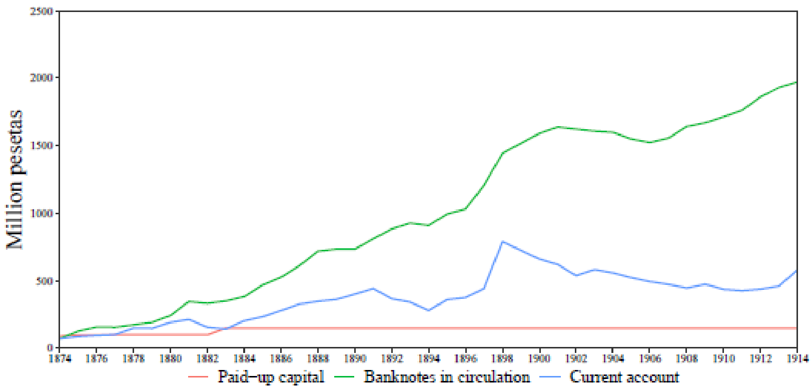
Note: The figure shows γ as calculated from the data of Schmelzing, 2020, and the convenience yield as computed from the data of Krishnamurthy and Vissing-Jorgensen, 2012. I calculate γ from "safe asset provider real interest rates" by assuming $\beta = 0.96$. I compute the convenience yield from Table 3 column (3) of Krishnamurthy and Vissing-Jorgensen, 2012. It is a piecewise linear function of Treasury supply in which the parameters are from a regression of BAA-Treasury spread on Treasury supply for 1919-2008. Krishnamurthy and Vissing-Jorgensen claim their estimate is conservative, so the true convenience yield could be higher. In both cases, I use seven-year moving averages. I also plot the linear trend of γ.

 Hungarian DOI: 10.14754/CEU.2024.06

Figure A.2: Bank of Spain balance sheet (1874-1914)



(a) Assets

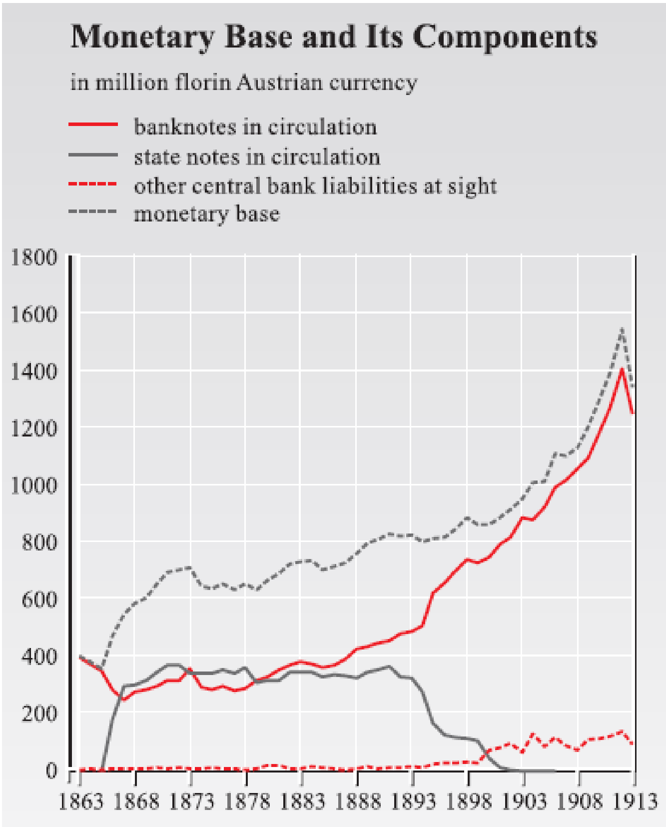


(b) Liabilities

Source: Fernández-Villaverde et al., 2020 p.5.
Note: The Private portfolio (assets) and the Current account (liabilities) show that there were claims and obligations vis-a-vis the private sector.

 Hungarian DOI: 10.14754/CEU.2024.06

Figure A.3: Monetary base in Austria-Hungary (1863-1913)



Source: Jobst and Scheiber, 2014 p.70.
Note: Other central bank liabilities at sight include giro accounts, not only of banks but also of the general public.

A.2 Proofs

Constraints for CBDC. 1. $IC_{B,g}$: $U_{B,g} \geq U_{B,b} \Leftrightarrow A_B - a + \beta p_H(R - R_L) \geq A_B - a + \mathcal{B} + \beta p_L(R - R_L) \Leftrightarrow R_L \leq R - \frac{\mathcal{B}}{\beta \Delta p} = \mathcal{P}$

2. IR_I: Table A.1 shows the Investor's utility both for the outside option and for the investment in the baseline setup.

Table A.1: Consumption and utility of Investor if others invest (unconditional taxes, γR_M)

C_I, U_I	Does not invest	Invests
$C_{I,0}$	$A_{I,0}$	$A_{I,0} - M$
$C_{I,1,s}$	$A_{I,1} - \tau_{I,1,s}$	$A_{I,1} + R_M - \tau_{I,1,s}$
Money	0	R_M
U_I	$A_{I,0} + \beta(A_{I,1} - \mathbb{E}(\tau_{I,1,s}))$	$A_{I,0} + \beta(A_{I,1} - \mathbb{E}(\tau_{I,1,s})) - M + (\beta+\gamma)R_M$

Note: $C_{I,t,s}$ and $\tau_{I,t,s}$ is Investor consumption and tax at time t in state s, respectively.

As $\tau_{I,1,b} > 0$, in the outside option $0 \leq C_{I,1,b} = A_{I,1} - \tau_{I,1,b} \Leftrightarrow 0 < \tau_{I,1,b} \leq A_{I,1}$, so there is a need for positive $t = 1$ endowment. Due to unconditional taxes, $U_I \geq U_{I,o}$(= outside option) $\Leftrightarrow M \leq (\beta + \gamma)R_M \Leftrightarrow R_M \geq \frac{M}{\beta+\gamma}$.

Table A.2 shows the Investor's utility both for the outside option and for the investment in an alternative setup with $U_I = C_{I,0} + \beta\mathbb{E}(C_{I,1}) + \gamma \min_s\{C_{I,1,s}\}$.

Table A.2: Consumption and utility of Investor if others invest (unconditional taxes, $\gamma \min_s\{C_{I,1,s}\}$)

C_I, U_I	Does not invest	Invests
$C_{I,0}$	$A_{I,0}$	$A_{I,0} - M$
$C_{I,1,s}$	$A_{I,1} - \tau_{I,1,s}$	$A_{I,1} + R_M - \tau_{I,1,s}$
$C_{I,1,b}$	$A_{I,1} - \tau_{I,1,b}$	$A_{I,1} + R_M - \tau_{I,1,b}$
U_I	$A_{I,0} + (\beta+\gamma)A_{I,1}$ $-(\beta\mathbb{E}(\tau_{I,1,s}) + \gamma\tau_{I,1,b})$	$A_{I,0} + (\beta+\gamma)A_{I,1}$ $-(\beta\mathbb{E}(\tau_{I,1,s}) + \gamma\tau_{I,1,b}) - M + (\beta+\gamma)R_M$

For similar reasons as in the baseline, $A_{I,1} > 0$ and $U_I \geq U_{I,o} \Leftrightarrow R_M \geq \frac{M}{\beta+\gamma}$.

Table A.3 shows the Investor's utility both for the outside option and for the investment if taxes were conditional on investment. In such a case, we can assume $A_{I,1} = 0$.

As $\tau_{I,1,s} \leq R_M$, there is no need for $t = 1$ endowment. That is $0 \leq C_{I,1,b} = R_M - \tau_{I,1,b}$ holds

Table A.3: Consumption and utility of Investor if others invest (conditional taxes, γR_M)

C_I, U_I	Does not invest	Invests
$C_{I,0}$	$A_{I,0}$	$A_{I,0} - M$
$C_{I,1,s}$	0	$R_M - \tau_{I,1,s}$
Money	0	R_M
U_I	$A_{I,0}$	$A_{I,0} - \beta\mathbb{E}(\tau_{I,1,s}) - M + (\beta+\gamma)R_M$

without endowment. In the bad state there is a circular claim between the Investor and the Government. In the Government's balance sheet, tax claim covers government debt, while in the Investor's balance sheet, money (claim on the government) backs tax obligation. The two are netted against each other. As ZP_G holds, again $U_I \geq U_{I,o} \Leftrightarrow R_M \geq \frac{M}{\beta+\gamma}$.

As there always exists an intersection of $IC_{B,g}$ and IR_I in the (L, R_L) plane (together with the Government's balance sheet and $ZP_{G,g}$), IR_I binds due to the Banker's maximisation.

3. $ZP_{G,g}$: $0 = \mathbb{E}(\pi_G)(= -\mathbb{E}(\tau)) = p_H(R_L - R_M) - (1-p_H)R_M = p_H R_L - R_M \Leftrightarrow R_M = p_H R_L$, as $\pi_{G,g} = -\tau_{I,1,g} = R_L - R_M > 0$ and $\pi_{G,b} = -\tau_{I,1,b} = -R_M < 0$.

4. $IR_{B,g}$: $U_{B,g} \geq U_{B,o}(=$ outside option$) \Leftrightarrow A_B - a + \beta p_H(R - R_L) \geq A_B$, together with the balance sheets and the definition of NPV_g: $\Leftrightarrow R_L \leq \frac{NPV_g + M}{\beta p_H}$.

   If IR_I binds (together with $ZP_{G,g}$), then $R_L = \frac{M}{(\beta+\gamma)p_H} < \frac{NPV_g+M}{\beta p_H}$, as $NPV_g > 0$ and $\gamma > 0$. Therefore, $IR_{B,g}$ holds.

■

Proof of Proposition 1.1. 1. As IR_I binds (together with $ZP_{G,g}$), $R_L = \frac{M}{(\beta+\gamma)p_H}$. So the problem is rewritten as

$\max_a U_{B,g} = A_B - a + \beta p_H[R - \frac{I-a}{(\beta+\gamma)p_H}]$.

The partial derivative of $U_{B,g}$ w.r.t. a is $\frac{\partial U_{B,g}}{\partial a} = -1 + \frac{\beta}{\beta+\gamma} < 0$.

As $\gamma > 0$, a is minimised (M maximised): $a^o = 0$ and $M^o = I$.

2. As IR_I binds and $ZP_{G,g}$ holds, $W^o = U^o_{B,g} - A_B = \beta p_H[R - \frac{I}{(\beta+\gamma)p_H}] = NPV_g + \frac{\gamma}{\beta+\gamma}I$.

■

Constraints for DI.

1. $IC_{B,g}$: $U_{B,g} \geq U_{B,b} \Leftrightarrow A_B - a - h_0M + \beta p_H[R - (R_M + h_1M)] \geq A_B - a - h_0M + \mathcal{B} + \beta p_L[R - (R_M + h_1M)] \Leftrightarrow R_M \leq R - \frac{\mathcal{B}}{\beta\Delta p} - h_1M = \mathcal{P} - h_1M$

2. $ZP_{G,g}$: $0 = \mathbb{E}(\pi_G)(= -\mathbb{E}(\tau)) = R_Gh_0M + p_Hh_1M - (1-p_H)R_M$, as $\pi_{G,g} = -\tau_{I,1,g} = R_Gh_0M + h_1M > 0$ and $\pi_{G,b} = -\tau_{I,1,b} = R_Gh_0M - R_M < 0$. That is the expected future value of the deposit insurance fee is equal to the expected future value of the compensation paid. Also, $R_Gh_0M = \alpha(1-p_H)R_M$ given the definition of α. $\Leftrightarrow h_0 = \alpha\frac{1-p_H}{R_G}\frac{R_M}{M}$ and $h_1 = (1-\alpha)\frac{1-p_H}{p_H}\frac{R_M}{M}$

3. IR_I: see the IR_I constraint for CBDC. As there always exists an intersection of $IC_{B,g}$ and IR_I in the (M, R_M) plane, IR_I binds due to the Banker's maximisation.

4. $IR_{B,g}$: $U_{B,g} \geq U_{B,o}$(= outside option) $\Leftrightarrow A_B - a - h_0M + \beta p_H[R - (R_M + h_1M)] \geq A_B$, together with the balance sheet and the definition of NPV_g: $\Leftrightarrow R_M \leq \frac{NPV_g + (1-h_0-\beta p_Hh_1)M}{\beta p_H}$.

   For $M = 0$, the right hand side of $IR_{B,g} = \frac{NPV_g}{\beta p_H} > 0 =$ the right hand side of IR_I for $M = 0$. Also, the slope of $IR_{B,g}$ w.r.t. M is $\frac{1-h_0-\beta p_Hh_1}{\beta p_H} = \frac{(\beta+\gamma)R_G - [\alpha+(1-\alpha)\beta R_G](1-p_H)}{\beta(\beta+\gamma)p_HR_G} > \frac{1}{\beta+\gamma} =$ slope of IR_I w.r.t. M where I use $ZP_{G,g,0}$, $ZP_{G,g,1}$ and assumption (1.5). So, if IR_I binds (together with $ZP_{G,g}$), then $IR_{B,g}$ holds.

■

Proof of Proposition 1.2.

1. As IR_I binds (together with $ZP_{G,g}$), $R_M = \frac{M}{\beta+\gamma}$, $h_0^o = \alpha\frac{1-p_H}{R_G}\frac{1}{\beta+\gamma}$ and $h_1^o = (1-\alpha)\frac{1-p_H}{p_H}\frac{1}{\beta+\gamma}$. So the problem is rewritten as

   $\max_a U_{B,g} = A_B - a - h_0^o(I-a) + \beta p_H[R - (\frac{1}{\beta+\gamma} + h_1^o)(I-a)]$.

   The partial derivative of $U_{B,g}$ w.r.t a is $\frac{\partial U_{B,g}}{\partial a} = -1 + h_0^o + \beta p_H(\frac{1}{\beta+\gamma} + h_1^o) = \frac{\alpha(1-p_H)(1-\beta R_G) - \gamma R_G}{(\beta+\gamma)R_G} < 0$, where I use $R_G \geq 1$, $\alpha \leq 1$ and assumption (1.5).

   Thus, a is minimised (M maximised): $a^o = 0$ and $M^o = I$.

2. As IR_I binds and $ZP_{G,g}$ holds, $W^o = \max_\alpha W = U_{B,g}^o - A_B = -h_0^oI + \beta p_H[R - (\frac{1}{\beta+\gamma} + h_1^o)I] = NPV_g + \frac{\gamma R_G - \alpha(1-p_H)(1-\beta R_G)}{(\beta+\gamma)R_G}I = NPV_g + \frac{\gamma}{\beta+\gamma}I$

3. $R_G \leq \frac{1}{\beta}$, so $\alpha^o = 0$, unless $R_G = \frac{1}{\beta}$, when α^o is arbitrary.

■

Proof of Proposition 1.3. 1. Similarly to the first best, a is minimised (M maximised), but s.t. $0 \leq a \leq A_B$ ($I - A_B \leq M \leq I$) and $IC_{B,g}$ hold. As by maximising M, R_L is also maximised, $R_L^* = \min\{\mathcal{P}, \frac{I}{(\beta+\gamma)p_H}\} = \mathcal{P}$ due to assumption (1.4). Then $M^* = (\beta+\gamma)p_H\mathcal{P}$. When $M^* < I - A_B$, then the good project is infeasible.

2. $W^* = U_{B,g}^* - A_B = -(I - M^*) + \beta p_H[R - \frac{M^*}{(\beta+\gamma)p_H}] = NPV_g + \frac{\gamma}{\beta+\gamma}M^* = NPV_g + \gamma p_H \mathcal{P}$.

■

Proof of Proposition 1.4. 1. Similarly to the first best, $h_0^* = \alpha\frac{1-p_H}{R_G}\frac{1}{\beta+\gamma}$ and $h_1^* = (1-\alpha)\frac{1-p_H}{p_H}\frac{1}{\beta+\gamma}$. a is again minimised (M maximised), but s.t. $0 \leq a \leq A_B - h_0^* M$ ($\frac{I-A_B}{1-h_0^*} \leq M \leq I$) and $IC_{B,g}$ hold. As by maximising M, R_M is also maximised, $R_M^* = \min\{\mathcal{P} - h_1^* M, \frac{I}{\beta+\gamma}\} = \mathcal{P} - h_1^* M$ due to assumption (1.4). $\Leftrightarrow M^* = \frac{\mathcal{P}}{\frac{1}{\beta+\gamma}+h_1^*} = (\beta+\gamma)\frac{p_H}{\alpha p_H + 1 - \alpha}\mathcal{P}$. When $M^* < \frac{I-A_B}{1-h_0^*} = \frac{(\beta+\gamma)R_G(I-A_B)}{(\beta+\gamma)R_G - \alpha(1-p_H)}$, then the good project is infeasible.

2. $W^* = U_{B,g}^* - A_B = -(I - M^*) - h_0^* M^* + \beta p_H[R - (\frac{1}{\beta+\gamma} + h_1^*)M^*] = NPV_g + \frac{\gamma R_G - \alpha(1-p_H)(1-\beta R_G)}{(\beta+\gamma)R_G}M^* = NPV_g + \frac{\gamma R_G - \alpha(1-p_H)(1-\beta R_G)}{R_G}\frac{p_H}{\alpha p_H + 1 - \alpha}\mathcal{P}$.

■

Proof of Proposition 1.6. 1. $0 < M_{CBDC}^* = (\beta+\gamma)p_H\mathcal{P}$ is a consequence of assumption (1.4).

$M_{CBDC}^* \leq M_{DI}^*$ is proved in Proposition 1.5.

$M_{DI}^* < M^o$ is again a consequence of assumption (1.4).

2. $0 < \min_{\alpha,R_G} W_{DI}^{n*} = [\gamma - (1-p_H)(1-\beta)]\mathcal{P}$ (with $\alpha = 1$ and $R_G = 1$) due to assumption (1.5).

$0 < \min_{\alpha,R_G} W_{DI}^{n*} < W_{CBDC}^{n*} \Leftrightarrow [\gamma - (1-p_H)(1-\beta)]\mathcal{P} < \gamma p_H \mathcal{P}$ due to $\beta + \gamma < 1$.

$W_{CBDC}^{n*} < \max_{\alpha,R_G} W_{DI}^{n*} \Leftrightarrow \gamma p_H \mathcal{P} < \gamma\mathcal{P}$ (with $\alpha = 1$ and $R_G = \frac{1}{\beta}$) due to $p_H < 1$.

$\max_{\alpha,R_G} W_{DI}^{n*} < W^{no} \Leftrightarrow \gamma\mathcal{P} < \frac{\gamma}{\beta+\gamma}I$ due to assumption (1.4).

■

A.3 Notations

$I > 0$: indivisible investment

$R > I$: outcome of project in good state

$0 < p_L < p_H < 1$: probability of high outcome for bad and good projects, respectively

$\Delta p = p_H - p_L$

$\mathcal{B} > 0$: private benefit of bad project to Banker

$0 < NPV_g = \beta p_H R – I$: expected net present value of good project

$0 > NPV_b = \beta p_L R – I + \mathcal{B}$: expected net present value of bad project

$0 > NPV_b^{'} = \beta(p_L R – \frac{I}{\beta+\gamma}) + \mathcal{B}$: adjusted NPV of bad project

$C_{i,t,s} \geq 0$: consumption of agent i at time t in state s

$U_I = C_{I,0} + \beta\mathbb{E}(C_{I,1}) + \gamma R_M$: Investor's lifetime utility

$U_{B,j} = C_{B,0} + \mathbb{1}_{j=b}\mathcal{B} + \beta\mathbb{E}(C_{B,1})$: Banker's lifetime utility for project j

$\gamma > 0$: convenience yield

$0 < \beta < 1 – \gamma$: subjective discount factor

$\mathcal{P} = R – \frac{\mathcal{B}}{\beta\Delta p}$: Banker's pledgeable income

$U_{i,o}$: outside option of agent i

$0 < A_B < I \leq A_{I,0}$: $t = 0$ endowment of Banker and Investor, respectively

$A_{I,1} \geq \frac{I}{\beta+\gamma}$: $t = 1$ endowment of Investor

$W = [U_I - (A_{I,0} + \beta A_{I,1})] + (U_B - A_B)$: utilitarian net welfare

$W^n = W - NPV_g$: net welfare above the NPV of the good project

$M \in (0, I]$: risk-free debt of Bank/Government ("money")

$a \in [0, A_B]$: Bank's equity capital/skin in the game

$a^g = a + h_0 M$: Bank's gross equity

$R_M \geq 0$: safe repayment on money by Bank/Government to Investor

$L \in (0, I]$: Government loan to the Bank

$R_L \geq 0$: offered repayment by Bank to Government

$h_t \geq 0$: deposit insurance premium paid by Bank to Government at period t on unit of deposit

$\alpha \in [0, 1]$: share of ex ante deposit insurance fee

$R_G \in [1, \frac{1}{\beta}]$: safe gross return on the DIF

 Hungarian DOI: 10.14754/CEU.2024.06

π_G: Government's profit

$\tau = -\pi_G$: net taxes paid by Investors

"*" stands for decentralised equilibrium, while "^{o}" for first best optimum

Hungarian DOI: 10.14754/CEU.2024.06

B Appendix for Chapter 2

B.1 Examples of exogeneity and endogeneity

Let us rewrite the reduced-form borrowers and depositors part of the model.

$$L_t = a_t - br_L \qquad \text{(loan demand at } t\text{)} \tag{B.1a}$$

$$D_t = c_t + dr_D \qquad \text{(deposit supply at } t\text{)} \tag{B.1b}$$

$$a_1 = a_0 + \lambda \qquad (t = 1 \text{ autonomous loan demand}) \tag{B.1c}$$

$$c_1 = c_0 + \delta \qquad (t = 1 \text{ autonomous deposit supply}) \tag{B.1d}$$

Due to fixed prices, $\Delta D_t = D_1 - D_0 = \delta$ and $\Delta L_t = L_1 - L_0 = \lambda$. That is, δ and λ shocks are not only shocks to the intercepts but also equilibrium changes in stocks.

B.1.1 Exogeneity

If δ and λ are considered as net flows, then money creation directly comes into the picture:

$$\delta = \theta\lambda + \varepsilon \tag{B.2a}$$

$$\begin{bmatrix} \varepsilon \\ \lambda \end{bmatrix} \sim \mathcal{N}(\mathbf{0}, \begin{bmatrix} \sigma_\varepsilon^2 & 0 \\ 0 & \sigma_\lambda^2 \end{bmatrix}) \tag{B.2b}$$

where θ is a parameter. Under exogeneity, ε and λ are uncorrelated. In this case it is easy to calculate (estimate) θ:

$$\theta = \frac{Cov(\delta, \lambda)}{Var(\lambda)} = Corr(\delta, \lambda)\frac{\sigma_\delta}{\sigma_\lambda} \tag{B.3}$$

B.1.2 Endogeneity: omitted confounder

One can assume both δ and λ are dependent on some variable z. z can be for example, the local output gap in the bank's region. (See for instance, Plosser, 2014.)

$$\delta = \beta z + \varepsilon \tag{B.4a}$$

$$\lambda = \gamma z + \nu \tag{B.4b}$$

$$\begin{bmatrix} z \\ \varepsilon \\ \nu \end{bmatrix} \sim \mathcal{N}(\mathbf{0}, \begin{bmatrix} \sigma_z^2 & 0 & 0 \\ 0 & \sigma_\varepsilon^2 & 0 \\ 0 & 0 & \sigma_\nu^2 \end{bmatrix}) \tag{B.4c}$$

where β and γ are parameters. Then, by solving B.4:

$$\delta = \theta\lambda + \varepsilon' \tag{B.5}$$

such that

$$\theta = \frac{\beta}{\gamma} \tag{B.6}$$

and

$$\varepsilon' = \varepsilon - \frac{\beta}{\gamma}\nu \tag{B.7}$$

So,

$$\rho = Corr(\lambda, \varepsilon') = -\frac{\frac{\beta}{\gamma}\sigma_\nu^2}{\sqrt{(\gamma^2\sigma_z^2 + \sigma_\nu^2)[\sigma_\varepsilon^2 + (\frac{\beta}{\gamma})^2\sigma_\nu^2]}} \neq 0 \tag{B.8}$$

That is, λ and ε' are correlated, there is endogeneity.

B.1.3 Endogeneity: simultaneity

We may assume (as, for example, Plosser, 2014 does) that lending also depends on deposit-taking, not just the other way round:

$$\delta = \theta\lambda + \varepsilon \tag{B.9a}$$

$$\lambda = \gamma\delta + \nu \tag{B.9b}$$

$$\begin{bmatrix} \varepsilon \\ \nu \end{bmatrix} \sim \mathcal{N}(\mathbf{0}, \begin{bmatrix} \sigma_\varepsilon^2 & 0 \\ 0 & \sigma_\nu^2 \end{bmatrix}) \tag{B.9c}$$

where θ and γ are parameters, and $\gamma\theta \neq 1$. By solving B.9, we get:

$$\delta = \frac{1}{1-\gamma\theta}\varepsilon + \frac{\theta}{1-\gamma\theta}\nu \tag{B.10}$$

$$\lambda = \frac{\gamma}{1-\gamma\theta}\varepsilon + \frac{1}{1-\gamma\theta}\nu \tag{B.11}$$

and

$$\rho = Corr(\lambda, \varepsilon) = sgn(1-\gamma\theta)\frac{\gamma\sigma_\varepsilon}{\sqrt{\gamma^2\sigma_\varepsilon^2 + \sigma_\nu^2}} \neq 0 \tag{B.12}$$

So, λ and ε are correlated again, there is endogeneity.

B.1.4 Endogeneity: measurement error

Suppose one can measure λ only with an error. That is, we see λ' instead of λ:

$$\delta = \theta\lambda + \varepsilon \tag{B.13a}$$

$$\lambda' = \lambda + \nu \tag{B.13b}$$

$$\begin{bmatrix} \lambda \\ \varepsilon \\ \nu \end{bmatrix} \sim \mathcal{N}(\mathbf{0}, \begin{bmatrix} \sigma_\lambda^2 & 0 & 0 \\ 0 & \sigma_\varepsilon^2 & 0 \\ 0 & 0 & \sigma_\nu^2 \end{bmatrix}) \tag{B.13c}$$

 Hungarian DOI: 10.14754/CEU.2024.06

where θ is a parameter. Then, by solving B.13, we get:

$$\delta = \theta\lambda' + \varepsilon' \tag{B.14}$$

such that

$$\varepsilon' = \varepsilon - \theta\nu \tag{B.15}$$

Then

$$\rho = Corr(\lambda', \varepsilon') = -\frac{\theta\sigma_\nu^2}{\sqrt{(\sigma_\lambda^2 + \sigma_\nu^2)(\sigma_\varepsilon^2 + \theta^2\sigma_\nu^2)}} \neq 0 \tag{B.16}$$

Thus, λ' and ε' are correlated, meaning endogeneity.

B.2 Modified model with shocked stocks

In the modified model, the initial stocks are multiplied by the shocks:

$$r_L = a - bL_0 \qquad (t = 0 \text{ inverse loan demand}) \tag{B.17a}$$

$$r_D = dD_0 - c \qquad (t = 0 \text{ inverse deposit supply}) \tag{B.17b}$$

$$L_1 = (1 + \lambda)L_0 \qquad (t = 1 \text{ loan demand}) \tag{B.17c}$$

$$D_1 = (1 + \varepsilon)D_0 + \theta\lambda L_0 \qquad (t = 1 \text{ deposit supply}) \tag{B.17d}$$

As a result, not only the intercepts but also the slopes are shocked. Moreover, the $t = 1$ deposit supply depends not only on r_D but also on r_L. In this case the net liquidity shock is $(1 - \theta)L_0\lambda - D_0\varepsilon$, thus the optimal reserve holding in the binding case depends on the bank's choice of stocks:

$$R^*_{0,bind} = -\sigma_{(1-\theta)L_0\lambda - D_0\varepsilon}\Phi^{-1}(p) \tag{B.18}$$

where

$$\sigma_{(1-\theta)L_0\lambda - D_0\varepsilon} = \sqrt{D_0^2\sigma_\varepsilon^2 - 2D_0L_0(1-\theta)\rho\sigma_\varepsilon\sigma_\lambda + L_0^2(1-\theta)^2\sigma_\lambda^2} \tag{B.19}$$

The Lagrangian (in terms of stocks) is:

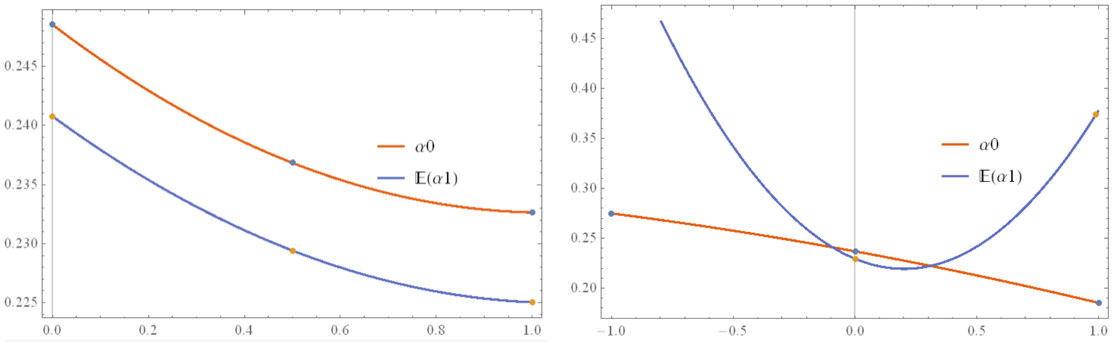
$$\mathcal{L}(D_0, L_0, \mu) = (1+\beta)[(a - bL_0)L_0 + r(D_0 - L_0) - (dD_0 - c)D_0] + \mu[(D_0 - L_0) - R^*_{0,bind}] \tag{B.20}$$

I could solve the system of F.O.C.'s only numerically. Figure B.1 shows the results for the reserve ratio. It decreases in the liquidity creation ability and also in the correlation. (However, the shocked reserve ratio is a non-monotonous function of ρ.)

Figure B.1: Reserve ratio as a function of...

(a) ...money creation ability (θ)

(b) ...correlation (ρ)



Note: α_0 is the $t = 0$ reserve ratio, $\mathbb{E}(\alpha_1)$ is the expected $t = 1$ reserve ratio, calculated at 3 elements of the domain, and interpolated. The inverse loan demand and deposit supply parameters: $a = 0.1$, $b = 1/110$, $c = 0.5/90$, $d = 1/90$. $p = 0.01$ (maximum probability of illiquidity), $r = 0.05$ (interest on reserves), $\beta = 0.995$ (subjective discount factor), $\sigma_\varepsilon = 0.1$ (residual deposit standard deviation), $\sigma_\lambda = 0.05$ (loan standard deviation), $\rho = 0$ (correlation), $\theta = 0.5$ (money creation ability).

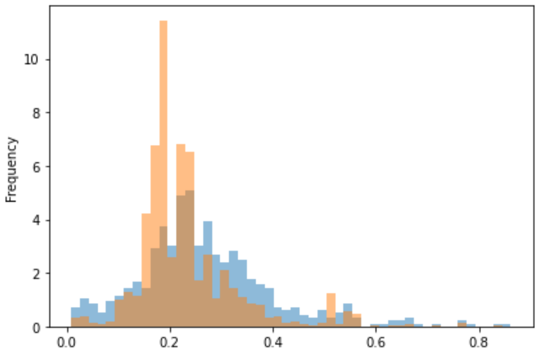
C Appendix for Chapter 3

C.1 Supplementary figures

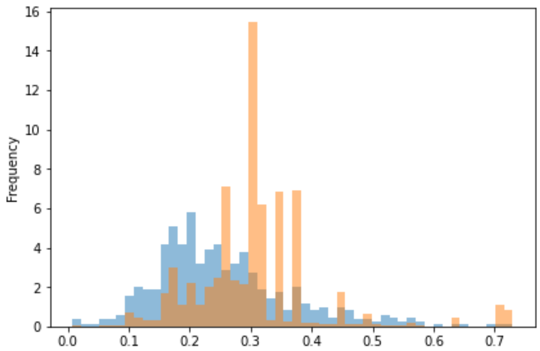
 Hungarian DOI: 10.14754/CEU.2024.06

Figure C.1: Histograms of liquidity (time series means)

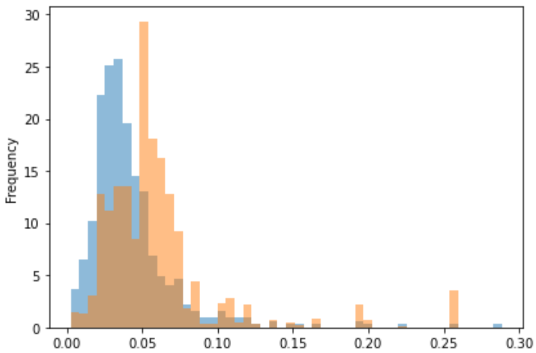
(a) Liquidity ratio pre-2008



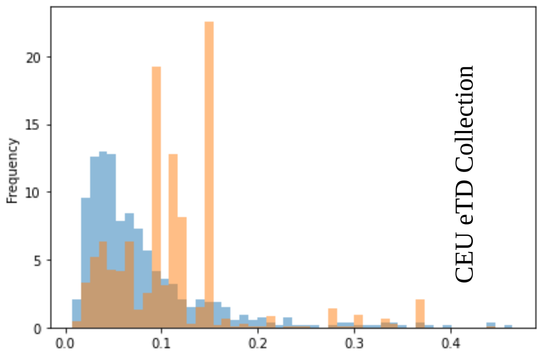
(b) Liquidity ratio post-2008



(c) Reserve ratio pre-2008



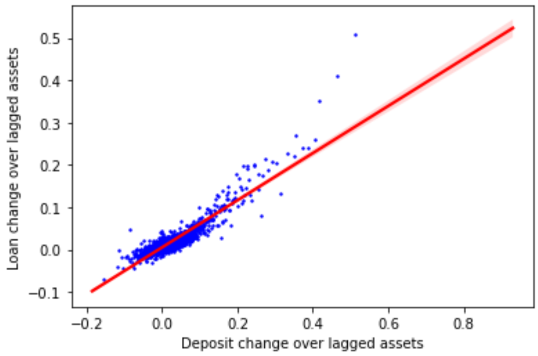
(d) Reserve ratio post-2008



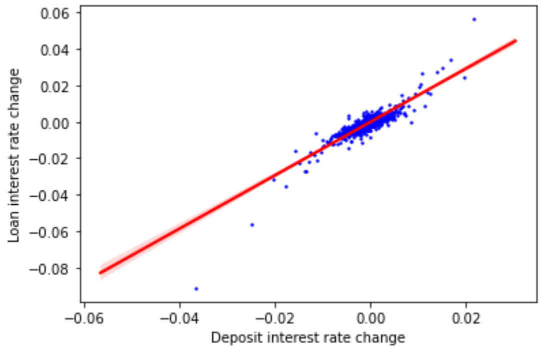
Note: One observation is a bank. The histograms are based on each bank's time series averages. Blue histograms are unweighted, orange ones are asset-weighted. Liquidity ratio is (reserves + securities)-to-assets, reserve ratio is reserves-to-assets.

Figure C.2: Bin scatter plots of deposits and loans

(a) Quantities



(b) Prices



Note: Quarterly changes, measured as scalars. 2500 bins of all bank-quarter pairs. The line is a pooled OLS regression line.

C.2 Supplementary tables

 Hungarian DOI: 10.14754/CEU.2024.06

Table C.1: Regression results: liquidity on correlation (baseline shocks, individual and time fixed effects)

	Reserve ratio			Liquidity ratio		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
Correlation	-0.01	-0.00	-0.00	-0.02***	-0.01	-0.02***
	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)
Deposit stdev	0.36***	0.08	0.37**	0.50***	0.49**	0.13
	(0.12)	(0.07)	(0.15)	(0.18)	(0.22)	(0.20)
Loan stdev	-0.40***	-0.02	-0.47***	-0.58***	-0.61**	-0.29
	(0.13)	(0.09)	(0.17)	(0.22)	(0.26)	(0.21)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Invididual FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	23455	10374	13081	23455	10374	13081
Entities	649	441	449	649	441	449
Time periods	103	52	51	103	52	51
R^2	0.02	0.01	0.02	0.06	0.03	0.05
Within R^2	0.00	0.01	0.02	0.05	0.05	0.05

Note: Standard errors clustered at entity level are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Reserve ratio is reserves-to-assets, liquidity ratio is reserves-and-securities-to-assets. Full sample: 1994Q1-2021Q2, Pre-GFC: 1994Q1-2008Q3, Post-GFC: 2008Q4-2021Q2. Stdev is backward-looking 5-year rolling standard deviation of shocks. Correlation is backward-looking 5-year rolling correlation of deposit and loan shocks. Shocks are represented by changes, divided by lagged assets. Controls are lagged log assets and lagged equity-to-assets ratio.

 Hungarian DOI: 10.14754/CEU.2024.06

Table C.2: Regression results: liquidity on correlation (baseline shocks, time fixed effect, control for LCR)

	Reserve ratio		Liquidity ratio	
	Full sample	Post-GFC	Full sample	Post-GFC
Correlation	-0.04***	-0.04***	-0.07***	-0.05***
	(0.01)	(0.01)	(0.01)	(0.01)
Deposit stdev	1.20***	1.48***	2.42***	2.54***
	(0.25)	(0.30)	(0.35)	(0.39)
Loan stdev	-0.93***	-1.01***	-2.92***	-3.08***
	(0.23)	(0.28)	(0.40)	(0.42)
Post x Large>$250bn	0.07**	0.09***	0.11**	0.06
	(0.04)	(0.03)	(0.05)	(0.05)
Post x Large$50-$250bn	0.04***	0.05***	0.04*	0.01
	(0.01)	(0.01)	(0.02)	(0.02)
Controls	Yes	Yes	Yes	Yes
Invididual FE	No	No	No	No
Time FE	Yes	Yes	Yes	Yes
Obs	17244	11260	17244	11260
Entities	273	273	273	273
Time periods	103	51	103	51
R^2	0.20	0.23	0.19	0.22
Within R^2	-0.02	-0.13	-0.04	-0.14

Note: Standard errors clustered at entity level are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Reserve ratio is reserves-to-assets, liquidity ratio is reserves-and-securities-to-assets. Full sample: 1994Q1-2021Q2, Post-GFC: 2008Q4-2021Q2. I only consider banks which are active in 2011Q4. Stdev is backward-looking 5-year rolling standard deviation of shocks. Correlation is backward-looking 5-year rolling correlation of deposit and loan shocks. Shocks are represented by changes, divided by lagged assets. Post is an indicator variable equal to 1 starting in 2013. Large>$250bn is an indicator variable if assets are above USD 250 billion at end-2011. Large$50-$250bn is an indicator variable if assets are between USD 50 billion and USD 250 billion at end-2011. Further controls are lagged log assets and lagged equity-to-assets ratio.

 Hungarian DOI: 10.14754/CEU.2024.06

Table C.3: Regression results: liquidity on correlation (alternative shocks, time fixed effect)

	Reserve ratio			Liquidity ratio		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
Correlation	-0.03***	-0.02***	-0.04***	-0.06***	-0.07***	-0.04***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Deposit stdev	1.36***	0.42***	2.18***	2.76***	2.36***	3.22***
	(0.28)	(0.12)	(0.41)	(0.37)	(0.45)	(0.49)
Loan stdev	-1.07***	-0.37***	-1.66***	-3.32***	-2.73***	-3.82***
	(0.25)	(0.10)	(0.39)	(0.41)	(0.51)	(0.52)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Invididual FE	No	No	No	No	No	No
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	22646	9876	12770	22646	9876	12770
Entities	578	399	414	578	399	414
Time periods	102	51	51	102	51	51
R^2	0.15	0.12	0.20	0.17	0.18	0.20
Within R^2	-0.01	-0.12	-0.11	-0.01	-0.01	-0.08

Note: Standard errors clustered at entity level are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Reserve ratio is reserves-to-assets, liquidity ratio is reserves-and-securities-to-assets. Full sample: 1994Q1-2021Q2, Pre-GFC: 1994Q1-2008Q3, Post-GFC: 2008Q4-2021Q2. Stdev is backward-looking 5-year rolling standard deviation of shocks. Correlation is backward-looking 5-year rolling correlation of deposit and loan shocks. Shocks are represented by deviations from trend, divided by lagged assets. Controls are lagged log assets and lagged equity-to-assets ratio.

Table C.4: Regression results: deposit quantity and price on loan demand and liquidity (with lagged liquidity, individual fixed effect)

	Deposit change			Deposit interest rate change		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
Loan demand	0.703***	0.615***	0.842***	0.011***	0.019***	0.001
	(0.064)	(0.091)	(0.054)	(0.003)	(0.004)	(0.001)
Lagged liq. x Loan demand	0.745***	1.067***	0.139	0.036***	0.047***	0.006*
	(0.228)	(0.329)	(0.211)	(0.011)	(0.017)	(0.004)
Lagged liquidity	-0.034***	-0.043***	-0.076***	-0.000	-0.000	-0.000**
	(0.006)	(0.011)	(0.009)	(0.000)	(0.000)	(0.000)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Invididual FE	Yes	Yes	Yes	Yes	Yes	Yes
State-time FE	No	No	No	No	No	No
Obs	28468	13588	14880	28468	13588	14880
Entities	817	534	557	817	534	557
Time periods	109	58	51	109	58	51
R^2	0.337	0.389	0.294	0.084	0.133	0.016
Within R^2	0.337	0.389	0.294	0.084	0.133	0.016

Note: Standard errors clustered at entity level are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Deposit and deposit interest rate changes are relative changes compared to the cross-sectional average. In the case of deposit change, there is a division by lagged assets. Full sample: 1994Q1-2021Q2, Pre-GFC: 1994Q1-2008Q3, Post-GFC: 2008Q4-2021Q2. Liquidity is reserves plus securities divided by assets. Loan demand is relative lending compared to the cross-sectional mean, divided by lagged assets, and multiplied by a loan demand shift indicator variable. Controls are lagged log assets, lagged equity-to-assets ratio, change in the Fed funds rate, and change in the interest paid on reserves.

Table C.5: Regression results: deposit quantity and price on loan demand and liquidity (with lagged liquidity, individual and state-time fixed effects)

	Deposit change			Deposit interest rate change		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
Loan demand	0.730***	0.649***	0.843***	0.011***	0.020***	0.002*
	(0.067)	(0.101)	(0.056)	(0.003)	(0.005)	(0.001)
Lagged liq. x Loan demand	0.662***	0.963***	0.141	0.033***	0.044**	0.003
	(0.242)	(0.365)	(0.224)	(0.012)	(0.019)	(0.004)
Lagged liquidity	-0.044***	-0.047***	-0.096***	-0.000	-0.000	-0.000**
	(0.007)	(0.015)	(0.013)	(0.000)	(0.000)	(0.000)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Invididual FE	Yes	Yes	Yes	Yes	Yes	Yes
State-time FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	28468	13588	14880	28468	13588	14880
Entities	817	534	557	817	534	557
Time periods	109	58	51	109	58	51
R^2	0.339	0.391	0.300	0.082	0.134	0.013
Within R^2	0.334	0.388	0.286	0.084	0.133	0.016

Note: Standard errors clustered at entity level are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Deposit and deposit interest rate changes are relative changes compared to the cross-sectional average. In the case of deposit change, there is a division by lagged assets. Full sample: 1994Q1-2021Q2, Pre-GFC: 1994Q1-2008Q3, Post-GFC: 2008Q4-2021Q2. Liquidity is reserves plus securities divided by assets. Loan demand is relative lending compared to the cross-sectional mean, divided by lagged assets, and multiplied by a loan demand shift indicator variable. Controls are lagged log assets and lagged equity-to-assets ratio.

Table C.6: Regression results: deposit quantity and price on loan demand and liquidity (with lagged reserves, no fixed effect)

	Deposit change			Deposit interest rate change		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
Loan demand	0.884***	0.789***	0.923***	0.020***	0.025***	0.001***
	(0.037)	(0.070)	(0.040)	(0.002)	(0.003)	(0.000)
Lagged res. x Loan demand	0.341	2.581**	-0.217	-0.029*	0.100*	0.017***
	(0.344)	(1.128)	(0.386)	(0.016)	(0.054)	(0.006)
Lagged reserves	-0.014*	-0.024	-0.014	0.001***	0.003***	0.000***
	(0.007)	(0.016)	(0.009)	(0.000)	(0.001)	(0.000)
Constant	0.004	0.012**	-0.002	-0.000*	0.000	-0.000***
	(0.003)	(0.005)	(0.005)	(0.000)	(0.000)	(0.000)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Invididual FE	No	No	No	No	No	No
State-time FE	No	No	No	No	No	No
Obs	28468	13588	14880	28468	13588	14880
Entities	817	534	557	817	534	557
Time periods	109	58	51	109	58	51
R^2	0.336	0.382	0.291	0.075	0.122	0.014
Within R^2	0.330	0.377	0.280	0.080	0.128	0.016

Note: Standard errors clustered at entity level are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Deposit and deposit interest rate changes are relative changes compared to the cross-sectional average. In the case of deposit change, there is a division by lagged assets. Full sample: 1994Q1-2021Q2, Pre-GFC: 1994Q1-2008Q3, Post-GFC: 2008Q4-2021Q2. Reserves is the reserve ratio. Loan demand is relative lending compared to the cross-sectional mean, divided by lagged assets, and multiplied by a loan demand shift indicator variable. Controls are lagged log assets, lagged equity-to-assets ratio, change in the Fed funds rate, and change in the interest paid on reserves.