Monetary Financing Without Inflation

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Abstract

By managing both the price and quantity of reserves, central banks can actively provide substantial government financing – seigniorage – while maintaining price stability. I develop a unifying framework that integrates heterogeneous households, incomplete markets, and an IO banking sector that demands reserves to hedge liquidity risk. Central banks control market interest rates by managing banks' liquidity demand. When the minimum reserve requirement (MRR) does not bind, seigniorage acts as a tax on bank profits and the welfare optimum features moderate excess reserves as supplying more reserves would reduce liquidity spreads but lower seigniorage. Conversely, when reserve holdings are enforced by a binding MRR, seigniorage effectively is a tax on liquid wealth and the welfare optimum is full-reserve banking (MRR of 100%). In this regime, government budgets are primarily financed by the nationalization of liquid wealth returns, and the effective interest rate on government debt is zero. All but the very poor would prefer the optimal excess reserve supply to the current system, and the less wealthy two-thirds of the population would, in turn, favor the full-reserve system.

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JEL: E42, E51, E58, E63

1 Introduction

Can central banks finance government expenditures without causing inflation? The predominant answer to this fundamental question is *no*: monetary financing can either be done directly, through the purchase of government debt, or indirectly, by deflating it. Both methods are inflationary – the direct purchase of government bonds due to its similarity to open market operations, and the indirect method by its very nature. However, a third option exists: the generation of seigniorage, that is, central bank profits subsequently transferred to the treasury.

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This paper focuses on this third option – to deliberately generate (to *scoop*) seigniorage while remaining committed to price stability. As I demonstrate, the operational framework of monetary policy can have far-reaching implications for government revenues, financial conditions, and the distribution of liquid wealth. While traditionally seen as neutral managers of interest rates, central banks possess instruments that shape not only the costs and benefits of borrowing and lending but also the broader allocation of liquid wealth across society.

It is not the objective of this paper to advocate for such *seigniorage scooping* or, equivalently, for using central bank tools explicitly for redistribution. In particular, it remains unclear whether an independent central bank has the mandate to pursue such actions deliberately. Instead, as demonstrated here, any central bank action – and framework decision –, even if non-intentional, inevitably affects seigniorage returns. Notably, operating with negative equity eliminates seigniorage remittances for years, potentially disrupting a significant source of government funding. Therefore, central banks may want to consider the findings outlined in this paper carefully.

Empirical evidence shows that seigniorage returns can constitute a significant contribution of government revenue. Between 2011 and 2021, the U.S. Federal Reserve remitted nearly $1 trillion to the Treasury, with annual profits of approximately 0.5% of U.S. GDP (Reuters, 2024). The Euro System generated an annual profit of about 0.3% of GDP until 2021 (ECB, 2021) while from 2000 to 2021, the Swiss National Bank's average annual profit equated to approximately 1.7% of GDP. These examples underline that the operational frameworks of monetary policy, depending on economic conditions, can shape fiscal outcomes.

In response to the 2008 and 2020 crises, most central banks have provided substantial liquidity injections, the majority of which have accumulated as massive excess reserves in banks' balance sheets. While this compressed liquidity spreads, they also had a major impact on seigniorage revenues since 2021: In October 2024, the Federal Reserve reported paper losses exceeding 0.8% of the U.S. GDP whereas the European Central Bank recorded a loss of €1.3 billion for the year 2023 (ECB, 2024) and the Swiss National Bank reported a record loss in 2022, equivalent to 18% of Switzerland's GDP.[1]

This paper shows that seigniorage functions as a hidden tax on profits, liquid wealth, and borrowing. By managing the quantity of reserves, the interest on reserves (IOR), and potential minimal reserve requirements (MRR), central banks determine whether the interest rate spread mainly supports government revenue or bank profitability. My analysis prescribes different effects depending on whether the MRR is set to be binding or not. Off the MMR banks hold excess reserves voluntarily and the central bank can control market rates – and, thereby, inflation – mainly by adjusting reserve returns, that is, the IOR rate. This allows the use the quantity of reserves to manipulate seigniorage returns. However, central banks face a trade-off: increasing the amount of excess reserves compresses liquidity spreads, which improves overall financial conditions but compresses the central banks profit margin.

If, on the other side, the MRR binds, reserves (quantity) policy becomes the primary tool for macroeconomic stabilization as IOR policy is largely ineffective. Such binding MRR signifies that banks are forced to hold reserves beyond any short-run consideration

[1] These losses were primarily due to losses on foreign currency positions (SNB, 2023).

of profitability. They thus tend to pass-on the associated costs of holding reserves to depositors and lenders, which implies that central bank can set the IOR rate to maximize profits. Seigniorage returns generated this way function as an implicit tax on household wealth by lowering household returns on liquid wealth and driving up rates for borrowers. This showcases that, regardless of whether the MRR binds or not, central banks posses an additional degree of freedom to pursue additional objectives such as providing government finances or enhancing financial stability.

To derive my findings, I develop an industrial organization (IO) model of the banking sector. Banks are not merely passive transmitters of monetary policy but, rather, face a liquidity risk problem akin to that in Poole (1968), where lending is funded by deposits that may be withdrawn or transferred, necessitating reserves for settlement management. In response, banks manage liquidity risk by balancing assets and reserves, and make trade-offs based on liquidity availability and credit demand. This IO approach reveals how changes in reserve quantities, reserve pricing, or requirements directly impact bank profits, interest rate spreads, and lending behavior, ultimately shaping the macroeconomic and distributional effects of monetary policy.

To examine the broader macroeconomic and distributional effects, and to allow for political economy considerations, this IO banking sector is embedded within a heterogeneous agent New Keynesian (HANK) framework. The presence of incomplete markets results in non-Ricardian behavior, making the source of government funding a determinant of macroeconomic dynamics and distributional outcomes. Specifically, households demand liquid bank deposits to partially insure against idiosyncratic risk. On the demand side, this establishes a connection between central bank liquidity policies, the banking sector, and the portfolio choices of both savers and borrowers. On the fiscal side, it links seigniorage returns, through the government's budget and taxation, to household behavior. Additionally, this framework allows to analyze the distributional impacts of changes in the monetary policy framework across the different income and wealth groups.

Based on this framework, I document that central banks' reserve policies extend well beyond liquidity adjustments; they act as foundational levers for shaping economic and distributional outcomes. While central banks can stabilize inflation independently of whether the MRR binds, this control has its limitations. The pass-through of reserves and IOR policy on lending rates is straightforward and enables central banks to maintain price stability. However, the effects of these policies on household deposit rates – the primary savings vehicle for liquid wealth – may be adverse, depending on the state of the financial sector. Household deposits at banks serve a dual role: they are the primary source of funding but also the source of liquidity risk. Consequently, the policy effects on household deposit rates may be either positive or negative, depending on the liquidity environment and reserve saturation in the banking sector, leading to state-dependent outcomes.

My analysis uncovers a welfare-optimal level of excess reserves, which is a compromise between liquidity provision and welfare maximization through seigniorage. Seigniorage represents the central bank's return for providing liquidity. For banks to pay a liquidity premium on holding reserves – sacrificing some profits in exchange for liquidity – some degree of liquidity risk must exist. Additional excess reserves narrow liquidity spreads, improving conditions for borrowers and savers, but they also reduce seigniorage, thereby shrinking fiscal revenue. Consequently, seigniorage compresses bank profits by redistributing liquidity costs without directly affecting households. This dual nature demonstrates the redistributive potential of reserve policies, offering insights into how central banks balance fiscal and financial stability objectives.

In contrast, in a full-reserve banking system, where the MRR reaches 100%, central banks effectively nationalize all banking returns because banks fully pass-on their associated costs of holding reserves to borrowers and lenders. This system generates substantial seigniorage returns that reduce the households' tax burden but completely neutralize their returns on deposits, functioning as a tax on liquid wealth. These findings suggest that reserve policies are state-dependent mechanisms, producing different outcomes based on the liquidity environment in the banking sector and banks' propensity to hold reserves

Related literature

Poole (1968) and Frost (1971) are foundational studies to, based on stochastic banking models, offer key insights into banks' decisions on excess reserves and responses to policy changes. Building on these early contributions, Stein (2012) explores how central bank policies shape banks' balance sheets and risk profiles, emphasizing the critical role of market structure. Similarly, Vives (2016) investigates the influence of market power and competition within banking sectors on monetary transmission and the effects of reserve requirements on lending and risk-taking. Bech and Monnet (2016) analyzes the impact of IOR rates on liquidity distribution and rate dispersion, highlighting potential limitations of central bank interventions in addressing liquidity asymmetries. Di Maggio et al. (2019) demonstrates how competition affects the extent to which banks pass liquidity benefits to borrowers, further illuminating the dynamics of monetary transmission in competitive banking environments.

Adjacent to this, a contemporary branch of the literature studies the interaction of the banking sector with the macroeconomy. Bianchi and Bigio (2022) demonstrate that reserve requirements and other central bank policies on liquidity constraints impact banks' lending and liquidity hoarding behaviors, amplifying responses to liquidity shocks and increasing credit supply volatility. Drechsler et al. (2017) introduce the "deposit channel," showing that central banks, by influencing deposit rates, shape banks' funding costs, which affects lending behavior and overall credit conditions. In concentrated markets, where banks may only partially pass on central bank rate changes, deposit rates become less responsive to policy shifts. Benigno and Nisticò (2020) incorporate a banking sector within a New Keynesian framework to examine the implications of open-market operations, while Diba and Loisel (2021) explore how pegging the interest rate on bank reserves can resolve certain New Keynesian puzzles. This paper extends these findings by modeling how reserve management directly influences fiscal revenues via seigniorage.

Subsequently, the DSGE literature has seen several efforts to enrich New-Keynesian models by a banking sector. Gertler and Karadi (2011) propose an early model demonstrating how quantitative easing (QE) lowers long-term interest rates and stimulates economic activity. A weakness of their model is the unclear alignment of its microfoundations with banks' behavior in reality, casting doubt on the transmission channels implied by the model. Sims and Wu (2021) build on this by examining the effects of QE and negative interest rate policies, focusing on their impact on economic outcomes, particularly at the zero lower bound. Cui and Sterk (2021) analyze the effects of on bank balance sheets, financial conditions, and credit markets in an incomplete market model with heterogeneous agents. Together, these studies highlight that reserve policies like

QE may be essential tools central banks use to shape credit conditions and economic stability.

Recent research has also studied the effects of unconventional monetary policy extensively. For example, Hörmann and Schabert (2015) analyze how central banks can expand economic output by adjusting their balance sheets' size and asset composition – such as through large-scale asset purchases – to provide liquidity when traditional interest rate policy is constrained by the zero lower bound. Chen et al. (2019) investigate the broader macroeconomic effects of asset purchase programs, reporting their success in lowering long-term interest rates and stimulating demand. However, they highlight side effects such as asset price inflation and increased risk-taking. In contrast, Boehl et al. (2024) find that asset purchases has merely supported firms but not households, thus boosting investment but dampening consumption and, eventually, inflation. Kiley and Mishkin (2024) explore how central banks have adjusted their monetary frameworks to address new economic realities, emphasizing the adaptability of these institutions.

Another branch of the literature investigates the implications of minimum reserve requirements (MRR). Brock (1989) examines how reserve requirements can generate government revenue through the inflation tax, exploring the relationship between reserve ratios, nominal interest rates, and seigniorage, while highlighting the efficiency and but also the welfare costs associated with inflationary finance. Similarly, Baltensperger (1992) investigates the role of reserve requirements in promoting economic stability by influencing bank liquidity and the stability of the financial system. Aizenman (1992) analyzes the optimal design of reserve requirements to balance revenue generation with economic efficiency. Other than these papers, I only study at equilibria which are strictly non-inflationary.

As a cornerstone in the research on fiscal-monetary policy interactions goes back, Sargent and Wallace (1981) show that large fiscal deficits can pressure central banks to monetize debt, limiting monetary policy's effectiveness and increasing inflation risks. Building on this, Aguiar et al. (2024) examine how fiscal policies can enhance welfare in low-interest-rate environments, particularly through improved risk-sharing and capital efficiency. Similarly, Amador et al. (2024) explore the role of government bond issuance within New Keynesian models, demonstrating how bond issuance supports fiscal goals and contributes to macroeconomic stability. This paper extends these insights to the role of deliberately generated seigniorage.

A related branch of the literature explores fiscal monetary interaction in DSGE models. Uhlig (2005) investigate how monetary policy affects output, while Mountford and Uhlig (2009) and Kliem et al. (2016) demonstrate the influence of the fiscal stance on inflation across contexts. This research also underscores the essential role of fiscal policy in economic stability, challenging the notion that monetary policy alone suffices (Leeper, 2013). Other than in this paper, these studies investigate scenarios which are inflationary by nature.

The Fiscal Theory of the Price Level (FTPL) highlights the role of fiscal policy in determining the price level by linking expectations about government debt sustainability to inflation. Sims (1994) introduced the core idea, challenging the traditional monetarist view by emphasizing fiscal policy's direct impact on price determination. Leeper (1991) laid the groundwork by classifying policy regimes as "active" or "passive," illustrating their influence on macroeconomic stability. Woodford (1995) formalized these insights within a dynamic equilibrium framework, demonstrating how fiscal dominance can override monetary policy in achieving price stability. Again, monetary financing via debt deflation as in FTPL is inflationary by nature.

Heterogeneous Agent New Keynesian (HANK) models, featuring incomplete markets and heterogeneity in asset holdings, are increasingly used to examine the effects of macroeconomic policy as they feature non-Ricardian behavior. Kaplan et al. (2018) show how household heterogeneity shape aggregate consumption responses to monetary policy Auclert (2019) emphasize the role of the redistribution channel in shaping consumption across households. Bayer et al. (2019) and Hagedorn et al. (2022) demonstrate how liquidity constraints and heterogeneity in marginal propensities to consume drive the distributional impacts of monetary policy. Gornemann et al. (2021), based on a HANK model, investigate how the systematic component of monetary policies affects the income distribution and income risks. For this paper, I rely on the solution methods of Boehl (2023) to simulate nonlinear HANK models, which is essential for capturing the complex dynamics implied by a HANK model with a nontrivial IO banking sector.

Outline

The rest of this paper is structured as follows. Section 2 presents the heterogeneous agent model including the IO model of the banking sector, and discusses its key implications. Simulations and results on the economy with excess reserves – i.e., with non-binding MRR – are presented in Section 3, whereas results for the economy with a binding MRR are presented in Section 4. Section 5 concludes.

2 The Model

This section contains the model of the banking sector, describes the heterogeneous agent New Keynesian (HANK) model in which it is embedded, and presents the model's calibration.

2.1 An IO model of the banking sector

Banks hold shares of firms, government bonds, and lend funds to households. These assets, summarized by A_t, are financed by deposits D_t, which are provided by households. Banks can exchange assets – mainly government bonds – against potentially interest-bearing central bank reserves J_t. The balance sheet of a bank i at time t then reads

$$A_{i,t} + J_{i,t} = D_{i,t}. \tag{1}$$

Households use deposits as a medium of exchange for their expenditures which means that from the perspective of bank i, deposits may be subject to intratemporal wire transfers to other banks. Assuming that assets $A_{i,t}$ are illiquid during period t, banks must use reserves to settle the associated cross-bank transfers. This implies that each bank is subject to liquidity risk: given a series of outgoing transfers, they may run out of reserves and temporarily be unable to execute further transactions. Banks hence face a portfolio problem of holding assets (for their return) versus reserves (for their liquidity value).

Denote bank i's net outflow of deposits in period t through households' transfers by $\Delta D_{i,t}$. For each transferred unit of $\Delta D_{i,t}$ that exceeds the current stock of reserves $J_{i,t}$

the banker has to pay a cost γ. γ thus summarizes various sources of liquidity costs, which can be associated with the interbank lending spread, the penalty rate for overshooting the discount window, or potential regulatory costs. Let χ be the unconditional probability for one unit of deposits to be transferred, and note that the probability for any unit of deposits that is transferred from any bank to end up at bank i is given by the fraction $\frac{D_{i,t}}{D_t}$ of deposits that bank i already holds. Proposition 1 states that $\Delta D_{i,t}$ is approximately normally distributed.

Proposition 1 (Liquidity risk)**.** *Given the probability χ that any unit of deposits get withdrawn, and the probability $\frac{D_{i,t}}{D_t}$ that any withdrawn unit (from any bank) is transferred to bank i, the probability for the event that $\Delta D_{i,t} = x$ for any $x \in \mathbb{R}$ is approximately normally distributed with*

$$\Delta D_{i,t} \sim \mathcal{N}\left(0, \frac{D_{i,t}D_{-i,t}}{D_t}(2\chi - \chi^2)\right). \tag{2}$$

Proof. See Appendix A.1. ■

Under the simplifying assumption that bankers are risk-neutral, this allows for an analytical expression for the expected costs of excess withdrawals, which is given in proposition 2. They are determined by the expected value of the excess withdrawals conditional on them being positive, $E[\Delta D_{i,t} - J_{i,t} | \Delta D_{i,t} > J_{i,t}]$.

Proposition 2 (Liquidity costs)**.** *If bankers are risk-neutral, the expected volume of withdrawals in excess of reserves holdings is*

$$g(J_{i,t}, D_{i,t}) = E[\Delta D_{i,t} - J_{i,t} | \Delta D_{i,t} > J_{i,t}], \tag{3}$$

$$= h(D_{i,t}) f\left(J_{i,t}|0, h(D_{i,t})\right) - J_{i,t}\left[1 - F\left(J_{i,t}|0, h(D_{i,t})\right)\right], \tag{4}$$

with $h(D_{i,t}) = \frac{D_{i,t}D_{-i,t}}{D_t}(2\chi - \chi^2)$ and where $f\left(J_{i,t}|0, h(D_{i,t})\right)$ is the PDF of the normal distribution at $J_{i,t}$ with mean zero and variance $h(D_{i,t})$.

Proof. See Appendix A.2. ■

Denote by $R_{i,t}$ bank i's deposit rate, that is, the (gross) nominal rate bank i pays on households' deposits. Households can choose to hold cash instead of deposits, but since deposits are perfectly safe and liquid for them, they only have incentive to do so if $R_{i,t} < 1$. This gives rise to a zero lower bound on deposit rates (deposit lower bound, DLB). The banks' deposit services are heterogeneous (e.g. through diversification of services) which gives banks some degree of market power similar to, e.g., Ulate (2021). The aggregator takes the form

$$D_t = N^{\frac{1}{\omega}} \left(\sum_i^N D_{i,t}^{\frac{\omega}{\omega-1}}\right)^{\frac{\omega-1}{\omega}}, \tag{5}$$

where N is the number of banks and $\omega > 1$ is the supply elasticity. Then, bank i faces an inverse supply function of the form

$$\frac{R_{i,t}}{R_t} = \left(N\frac{D_{i,t}}{D_t}\right)^{\frac{1}{\omega-1}}, \tag{6}$$

$$R_{i,t} \geq 1, \tag{7}$$

where the last equation is the DLB.

Assets A_t give a return of R_t^a and the asset market clears with $\sum_i A_{i,t} = A_t^b$ (assets held by commercial banks) and $A_t = A_t^b + A_t^{cb}$, that is, commercial banks and the central bank together hold all assets. The central bank pays an interest-on-reserves (IOR) rate R_t^j on reserves J_t. It may further enforce an (occasionally binding) minimal reserve requirement (MRR) of

$$\psi D_{i,t} \leq J_{i,t}, \tag{8}$$

and excess reserves are thus, if any, given by $J_{i,t} - \psi D_{i,t} \geq 0$. The necessary conditions for an equilibrium of the banking sector are stated in Proposition 3.

Proposition 3 (Equilibrium of the banking sector)**.** *Under the assumptions that*

1. *each bank i takes as given*
   (a) *the aggregate equilibrium variables $\{A_t, D_t, R_t^a, R_t\}$,*
   (b) *the nominal interest on reserves (IOR) rate R_t^j and the supply of reserves J_t,*
   (c) *the cumulative deposit choice of competitors $D_{-i,t}$,*
2. *the equilibrium is symmetric,*
3. *no entry and exit,*

a competitive equilibrium in the banking sector is given by

$$A_t = D_t, \tag{9}$$

$$\frac{\omega}{\omega-1}R_t = \max\left\{\frac{\omega}{\omega-1},\ (1-\psi)R_t^a + \psi R_t^j + \gamma\left(\psi\left[1-\hat{F}_t\right] - 0.5\hat{f}_t\right)\right\}, \tag{10}$$

$$R_t^j - R_t^a + \gamma\left[1-\hat{F}_t\right] = \min\left\{0,\ R_t^j - R_t^a + \gamma\left[1-\hat{F}_t^{\psi}\right]\right\}, \tag{11}$$

with PDF $\hat{f}_t = f\left(J_t/\nu|0, D_t/\nu\right)$ and CDFs $\hat{F}_t = F\left(J_t/\nu|0, D_t/\nu\right)$ and $\hat{F}_t^{\psi} = F\left(\psi D_t/\nu|\cdot\right)$, for which $\nu = (N-1)(2\chi - \chi^2)$.

Proof. See Appendix A.3. ■

It follows from the proposition that banks' aggregate liquidity cost sum up to

$$\kappa_t = \gamma\left(D_t\hat{f}_t - J_t(1-\hat{F}_t)\right). \tag{12}$$

Seigniorage – central bank profits which are remittances to the treasury – equate to

$$\Phi_t = \frac{R_{t-1}^a - R_{t-1}^j}{\pi_t}J_{t-1}, \tag{13}$$

and, using both relationships, the aggregation of banks' profits yields

$$\Pi_t^b = \frac{1}{\pi_t}\sum_i^N R_{t-1}^a A_{i,t-1} + R_{t-1}^j J_{i,t-1} - R_{t-1}D_{i,t-1} - \gamma g(J_{i,t-1}, D_{i,t-1}) \tag{14}$$

$$= \frac{R_{t-1}^a - R_{t-1}}{\pi_t} D_{t-1} - \Phi_t - \kappa_{t-1}. \tag{15}$$

Above, banks are price-takers and equilibrium rates are equal to marginal costs plus markups. The structure gives rise to spreads between borrowing, lending, and the IOR rate. The central bank, in turn, independently controls the supply of reserves J_t and the IOR rate R_t^j of the economy. Given these policy variables, an equilibrium consists of the three Equations (1), (9) and (10) for the three unknowns A, R and D. Equation (9) follows from inserting the central bank balance sheet into the aggregated bank balance sheet. (10) is the aggregated optimality condition for taking deposits, which equates the marginal profit of an additional unit of loans to the marginal costs of an additional unit of deposits, including the associated marginal liquidity risk. (11) is the aggregated optimality condition for holding reserves, linking the marginal profit of an additional unit of loans to the associated marginal increase in liquidity risk by reducing reserves holing.

The minimal reserve requirement and the deposit lower bound act as occasionally binding constraints in Equations (10) and (11). The expression at the LHS of (11) corresponds to the marginal profit of reserve holdings,

$$MPJ\left(J_t, R_t^j, R_t^a, D_t\right) = R_t^j - R_t^a + \gamma\left(1 - \hat{F}\right). \tag{16}$$

The MRR is binding whenever $MPJ\left(\psi D_t, \cdots\right) < 0$, i.e. when marginal profits of reserves *at the MRR* are negative. In this case equation (11) simply collapses to $J_t = \psi D_t$. If however $MPJ\left(\psi D_t, \cdots\right) \geq 0$ banks have an incentive to hold excess reserves and an interior solution with $J_t > \psi D_t$ exists, in which case Equation (11) reads $MPJ(\cdot) = 0$. Thus, if banks are willing to hold excess reserves, these are determined by a conventional optimality condition which equates marginal profits to zero. Respectively, the DLB translates directly to a constraint on the optimality condition for deposits, which becomes inactive once the DLB binds.

Figure 1 illustrates the equilibrium in the loan market for different levels $J_0 < J_1 < J_2$ of reserves. Loan demand (blue line) is exogenous and downwards sloping in the lending rate $r^a = R^a - 1$. The MRR gives the loan supply function a hockey-stick shape, composed of two segments: the horizontal orange line (dashed when $\psi D > J$) represents supply if the MRR is slack, i.e. where R^a equals the marginal costs of lending. This function is upwards sloping because, as loans require deposits, additional loans increase liquidity risk and thereby raise the associated marginal costs of lending. Since loans require deposits, the total loan volume is constrained by the reserves supplied by the central bank, J_0, leading to the vertical segment of the orange line where $J_0 = \psi D$. In the equilibrium for J_0 the MRR is binding. An increase in reserves from J_0 to J_1 shifts the vertical line outward, allowing more deposits at the MRR. Simultaneously, the horizontal line shifts downward, as additional reserves reduce liquidity risk. An additional expansion to J_2 again shifts both curves outwards and banks decide to hold some excess reserves, i.e. the MRR becomes slack.

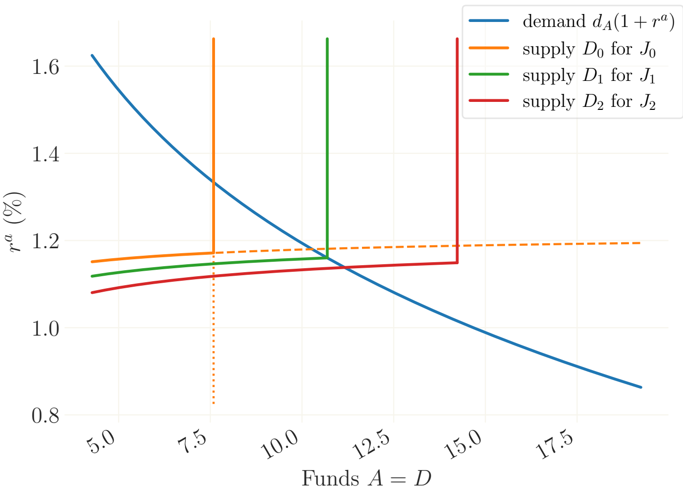

Figure 1: Banking equilibrium at the market for loans for a given demand function and fixed $R^j = 1$. Reserves increase exogenously from J_0 (orange curve) to $J_1 > J_0$ (green) to $J_2 = J_1$ (red). This shifts the loan supply curve (Eqns. (10) and (11)) outwards. In the equilibrium for J_0 the MRR (dotted line where $\psi D = J$) is binding. The dashed line depicts the hypothetical supply of loans without MRR. In the equilibrium for J_1 the MRR is just binding and for J_2 the MRR is slack and banks voluntarily hold excess reserves.

Following Proposition 3 the parameters N and χ can be summarized by the composite liquidity risk parameter ν, which scales J_t and D_t. Intuitively, a larger probability χ of deposits being withdrawn has a qualitatively similar effect to an increase in the number of banks N, as the probability of intra-bank wire transfers decreases with more banks. The relationship between ν and equilibrium rates is non-trivial: while, for a given IOR rate, an increase in liquidity risk always increases the lending rate R^a, the effect on R can go either way. Appendix B.1 provides additional insights.

2.2 Households, firms, and the government sector

Households, indexed by j, hold liquid deposits d_{jt} and face idiosyncratic labor income risk e_{jt}. They can indebt with the bank up to a borrowing constraint $\bar{d} \leq d_{jt} < 0$. For consumption smoothing and to insure against the associated idiosyncratic income risk, they strive to accumulate liquid wealth. Households further have Greenwood et al. (1988, GHH) preferences over the composite good x_{jt}, and their Bellman equation is given by

$$V_t(e_{jt}, d_{jt-1}) = \max_{c_{jt}, n_{jt}, d_{jt}} \left\{ \frac{x_{jt}^{1-\sigma_c}}{1-\sigma_c} + \beta \mathbb{E}_t \left[V_{t+1}(e_{j,t+1}, d_{jt}) | e \right] \right\}, \tag{17}$$

$$x_{jt} = c_{jt} - e_{jt} \frac{n_{jt}^{1+\sigma_l}}{1+\sigma_l}, \tag{18}$$

$$c_{jt} + d_{jt} = \frac{R(R_{t-1}, R_{t-1}^a, d_{j,t-1})}{\pi_t} d_{j,t-1} + (1-\tau_t) w_t e_{jt} n_{jt} + \left((1-\upsilon)\Pi_t^y + \Pi_t^b \right) \bar{\Pi}(e_{jt}) \tag{19}$$

$$d_{jt} \geq \bar{d}, \tag{20}$$

where n_{jt} denotes supplied labor and c_{jt} the consumption of household j. The borrowing and savings rates (thus, deposit rates) differ by

$$R(R_{t-1}, R_{t-1}^a, d_{j,t-1}) = \begin{cases} R_{t-1} & \text{if } d_{j,t-1} \geq 0, \\ R_{t-1}^a & \text{if } d_{j,t-1} < 0. \end{cases} \tag{21}$$

$\bar{\Pi}(e)$ are skill-specific incidence rules for dividends and bank profits and j's household-specific productivity follows an AR(1) process in logs,

$$\log e_{jt} = \rho_e \log e_{j,t-1} + \epsilon_{jt}^e. \tag{22}$$

Firms face price stickiness, modeled as in Calvo (1983), where in any given period, the firm has a probability $1-\theta$ of re-optimizing its price. Denoting the optimal reset price of firm k by P_{kt}^*, the re-optimizing firm solves the profit-maximization problem

$$\max E_t \sum_{s=0}^{\infty} (\beta\theta)^s \Lambda_{t+s} \left(\frac{P_{k,t}^*}{P_{t+s}} \overline{\Pi}^{k\omega} - mc_{t+s} \right) Y_{k,t+s}, \tag{23}$$

where mc_t are the firm's marginal costs (Symmetry across firms allows to drop index k) and $Y_{k,t}$ is firm ks output in t. The advantage of Calvo (1983) over Rotemberg (1982) is to avoid an ad-hoc deadweight loss which enters the economies resource constraint. The downside of using Calvo pricing in a nonlinear setup is that a host of additional nonlinear equations enter the equilibrium system. This, however, is not of relevance given that the solution method of Boehl (2023) is largely insensitive to the number of aggregate variables and equations.

For the baseline model, labor is the only production factor with the production function

$$y_t = z n_t \mathfrak{p}_t^{\eta}, \tag{24}$$

where $\mathfrak{p}_t$ is the distortionary price dispersion due to Calvo price setting and z is TFP, which we assume to be constant. Due to GHH preferences, labor supply simplifies to

$$n_t^{\sigma_l} = (1-\tau_t) w_t. \tag{25}$$

The fact that taxes appear in the labor supply equation implies that taxes are distortionary. Appendix B.3 provides robustness excercises for the results presented below under the assumption that taxes are non-distortionary. Markets clear with

$$\int_0^\infty c_{jt} dj = C_t, \tag{26}$$

$$\int_0^\infty d_{jt} dj = D_t, \tag{27}$$

$$\int_{\bar{d}}^0 d_{jt} dj = L_t, \tag{28}$$

where L_t denote loans to households. Firms' dividends are given by

$$\Pi_t^y = y_t - w_t n_t, \tag{29}$$

and no-arbitrage on financial markets requires that

$$s_t = \frac{E_t \left\{ \upsilon_\Pi \Pi_{t+1}^y + s_{t+1} \right\}}{R_t^a / E_t \pi_{t+1}}, \tag{30}$$

where s_t is the market price for firms equity and υ_Π is a parameter deciding how much dividends go to equity holdings. A share of $(1 - \upsilon_\Pi)$ of dividends are then distributed directly to the households. The government is running a balanced budget with

$$\tau_t w_t n + \Phi_t = \left(\frac{R_{t-1}^a}{\pi_t} - 1 \right) b + g_t, \tag{31}$$

which implies that the level of government bonds b remains constant. The central bank uses its tools to target the households' deposit rate rate R_t following a conventional monetary policy rule,

$$\ln R_t = \ln R_t^* + \phi_\pi \left[\ln \pi_t - \ln \bar{\pi} \right]. \tag{32}$$

The results presented in this paper are largely independent of the choice of the target rate, i.e. of using R_t or R_t^a.

From the banking sector, the pricing equations (10) and (11) as well as the banks' and central bank's profits (15) and (13) enter the macroeconomy. Assets A_t contain government bonds b, firms equity s_t and loans to households L_t, all for which the economy wide interest rate R_t^a applies. Only household deposits are compensated with R_t, which thus represents the risk-free savings rate. The aggregate balance sheet from Equation (9) becomes

$$A_t = b + s_t + L_t = D_t, \tag{33}$$

and the aggregate resource constraint is given by

$$C_t + g_t + \kappa_t = y_t. \tag{34}$$

2.3 Calibration

To calibrate the model, I target a benchmark steady state that approximately represents the average conditions of Western economies before the financial crisis –namely, without excess reserves and with a binding MRR. To facilitate the comparison of steady states and the analysis of transition dynamics between them, only the parameters are fixed after matching the various steady-state relationships, while the steady-state values remain flexible. These parameters are summarized in Table 1.

The calibration of the non-banking part of the model – aggregate and disaggregate – is quite conventional and anchored around at the values reported in Boehl (2022), where a similar model is estimated under inclusion of the households' preference parameters. The model of the banking sector features the parameters $\{\nu, \gamma, \omega, \upsilon\}$, which are taken as degrees of freedom to match the four steady state relationships $\{\Psi, \Phi/y, \kappa/y, MPJ\}$ from the table.

Parameter		Value/Target
b	bond supply	2.8
g	st.st. gov. spending	$0.2y$
ζ	Calvo probability	2/3
θ	net markup	0.1
π	inflation target	2% p.a.
ϕ_π	policy rule inflation sensitivity	1.5
z	TFP	normalize $y = 1$
ψ	minimal reserve requirement	3.6%
Ψ	st.st. banks' profits	0
Φ/y	st.st. CB profits over GDP	0.5%
κ/y	st.st. liquidity cost over GDP	0.7%
MPJ	st.st. marg. profit of reserves	-0.003
$R^j - 1$	net IOR rate	0%
σ_c	intertemporal elasticity of substitution	4
σ_l	disutility of labor	2
β	discount factor	0.98
$\bar{d}$	borrowing constraint	0
σ_e	standard error of earnings	0.6
ρ_e	autocorrelation of earnings	0.966
n_e	points for Markov chain of e	5
n_d	points for deposit grid	200
$\bar{d}$	borrowing constraint	20% indebted HH

Table 1: Model parameters.

The inflation target is set to 2% annually. The schedule for dividends and banks' profits, $\bar{\Pi}(e)$, distributes all returns to the most productive skill group. The value of $\Phi/y = 0.5\%$ is chosen as a compromise between the numbers presented in the introduction. Ψ is, for simplicity, set to 0 since the *level* of bank profits has no effect on the results. The steady state value of MPJ is chosen such that the MRR just holds. The results below are largely independent of this value. The choice of liquidity costs over GDP, κ/y, is most influential for ν and γ, which are central parameters of the banking model. I will throughout discuss robustness with respect to this choice. The MRR level, ψ, is set to match the pre-2010 average in the Euro Area.

3 The economy with excess reserves

This section studies how the choice of the policy tools – reserves J_t and reserve rate R_t^j – operate through the banking sector to steer equilibrium interest rates if the MRR is not binding. I first provide analytical insights on the pass-through on borrowing and saving rates $\{R_t^a, R_t\}$ and central bank profits. I then show how this affects the government budget in general equilibrium and translates into welfare implications of different wealth groups.

3.1 The pass-through of monetary policy tools

When neither the MRR nor the DLB binds and when ignoring monopoly markups, Equations (10) and (11) from Proposition 3 collapse to

$$R^a = R^j + \gamma\left(1 - \hat{F}\right), \tag{35}$$

$$R^a = R + 0.5\gamma \hat{f}, \tag{36}$$

where, as above, $\hat{f} = f\left(J_t/\nu|0, D_t/\nu\right)$ and $\hat{F} = F\left(J_t/\nu|0, D_t/\nu\right)$ are features of the normal distribution.

Reserves can either be supplied via asset purchases (or, until 2008, open market operations) or refinancing operations such as Long-term Refinancing Operations (LTROs). In both cases the central bank exchanges reserves for government bonds or private assets. The effects of asset purchases on equilibrium rates can be decomposed into the direct (expansionary) effect of mitigating liquidity risk by providing additional reserves $\frac{\partial R}{\partial J}$ (the *"liquidity effect"*), and an indirect contractionary effect $\frac{\partial R}{\partial D}\frac{\partial D}{\partial J}$ caused by attracting more deposits.[2] The latter effect arises because any decrease in R^a will cause an increase in the demand for loans, which, as loans create deposits through market clearing, leads to an expansion of deposit holdings. This in turn leads to a relative increase in liquidity risk.

To allow analytical results to include the indirect effects of changes in asset supply, assume that investment demand for assets is given by the demand function $A/\nu = d_A(R^a)$ with $\frac{\partial d_A}{\partial R^a} \leq 0$ and denote the demand elasticity (with respect to a one-percentage change in R^a) as $E_A = \frac{\partial d_A/A}{\partial R^a}$. The (partial) equilibrium in the loan and deposit market is then given by

$$d_A\left(R^a\right) = A/\nu = D/\nu, \tag{37}$$

which already accounts for those assets held by the central bank. Proposition 4 summarizes the implications of our model for an active reserves policy off the MRR, and captures the direct and indirect effects.

Proposition 4 (asset purchases under excess reserves)**.** *For $\psi D < J \leq D$ and $R_t \geq 1$ (MRR and DLB are slack), and given R^j, for any policy that purchases asset against reserves,*

[2]In terms of Figure B.10 in Appendix B.2, which shows the ceteris paribus effect of an increase in liquidity risk, both effects can be thought as moving along the horizontal axis to the left.

1. *the pass-trough on the lending rate is*

$$\frac{\partial R^a}{\partial J} = -2 \frac{R^a - R}{1 - J/\nu E_A(R^a - R)} < 0. \tag{38}$$

with a direct effect of $\frac{\partial R^a}{\partial J}|_D = -2\,(R^a - R) < 0$*,*

2. *the pass-trough on the interest margin is*

$$\frac{\partial (R^a - R)}{\partial J} = \left(E_A(R^a - R) - \frac{J}{D} \right) \frac{R^a - R}{1 - J/\nu E_A(R^a - R)} < 0. \tag{39}$$

with a direct effect of $\frac{\partial (R^a - R)}{\partial J}|_D = -\frac{J}{D}(R^a - R) < 0$*,*

3. *the pass-trough on the deposit rate is*

$$\frac{\partial R}{\partial J} = \left(\frac{J}{D} - 2 - E_A(R^a - R) \right) \frac{R^a - R}{1 - J/\nu E_A(R^a - R)}, \tag{40}$$

with a direct effect of $\frac{\partial R}{\partial J}|_D = \left(\frac{J}{D} - 2\right)(R^a - R) < 0$*.*

Proof. See Appendix A.4. ■

Part 1 of the proposition states that the lending rate R^a always decreases in J because additional reserves mitigate the liquidity risk associated with holding deposits, and thereby lowers liquidity costs. This is the direct effect, which follows from the result after setting E_A to zero. Clearly, direct and indirect effect run in opposite directions: a decrease in the lending rate raises investment demand and thereby requires additional deposits. Higher deposit holdings imply higher liquidity risk. However, the marginal effect of asset purchases on total assets (and thereby, deposits) cannot be negative since, given downwards sloping demand for loans, a fall in A would require an increase of R^a. This would be inconsistent because banks will only demand a higher rate R^a (c.f. Eq. (35)) if liquidity risk increases, and thus if either J declines or D expands.

These findings are also illustrated graphically by the solid lines in Figure 2, which shows equilibrium rates for various levels of supplied reserves. Indeed, as implied by the first part of the proposition, the solid blue lines are monotonously sloping downwards, independently of the demand elasticity. Part 2 states that the interest margin $(R^a - R)$ – which is the banks' profit margin –, also decreases in the amount of reserves supplied. In terms of Figure 2 this is represented by the difference between the blue and orange lines. Other than for the lending rate, the direct and indirect effect must not go in different directions: if the fraction of reserves over deposits, J/D, is large, then the pass-trough of reserves policy on the lending rate is larger for a higher demand elasticity. The reason is that then, banks are better insured against liquidity risk and thus are willing to accept a lower return through the interest margin in exchange for a higher volume.

Part 3 of Proposition 4 documents an important finding: an increase in the supply of reserves can potentially *raise* the deposit rate. Critically, as R is the households' savings rate, this could cause unwanted effects on the households' consumption-savings decisions in general equilibrium. To understand this effect, note that the response of the deposit rate is the net of the interest rate margin and the liquidity spread, $R = (R - R^a) - (R^a - R^j)$, which are both decreasing in J. For the direct effect the decrease

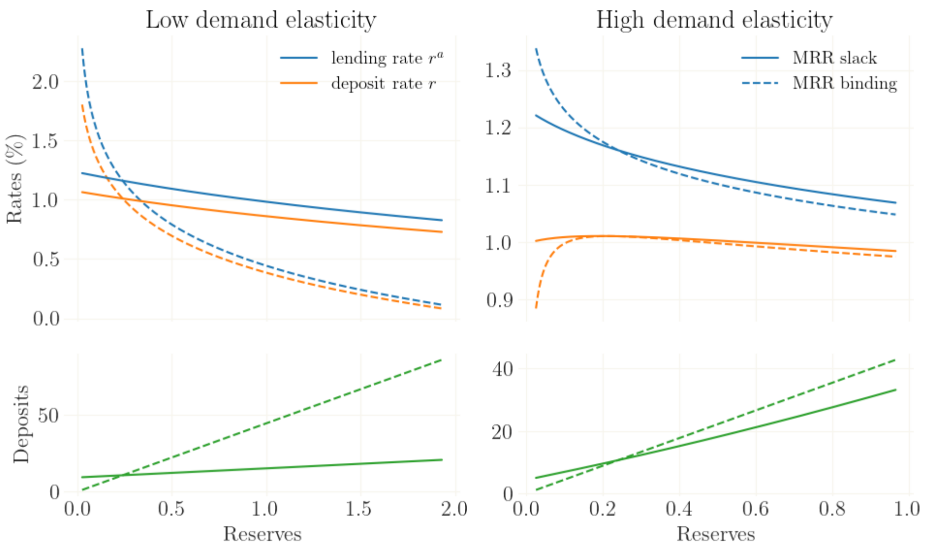

Figure 2: Responses of market rates in the banking equilibrium (Eqs. (9) to (11)) when varying the quantity of supplied reserves. The solid (dashed) lines depict the equilibrium outcome if the MRR is slack (binding). R^j is fixed to 1, $\psi = 2.26\%$ and the inverse loan demand function is given by $A/\nu = a_l(R^a)^{-1/0.005}$ (left) and $A/\nu = a_h(R^a)^{-1/0.008}$ (right).

in the lending rate dominates, and the deposit rate falls mechanically. The indirect effect is more nuanced and the demand elasticity plays a central role. If demand for funds is highly elastic, a slight decrease in the lending rate attracts many additional assets, thereby leaving the lending rate nearly unchanged. But, since liquidity risk still decreases, this reflects in a smaller interest rate margin and, thus, in higher deposit rates. This also means that, if the demand for funds is highly elastic, households gain from the fall in liquidity costs by benefiting from higher savings rates, whereas bank profits may only expand due to larger volumes. The right panel of Figure 2 features this effect for low values of supplied reserves.

The bottom panel in Figure 2 shows the pass-through of reserves to deposits and – by that, in terms of the model – the monetary base. While for a binding MRR, the pass-through is fixed by the level of the MRR, it is consistently less than that for the scenario with excess reserves. The following Proposition 5 summarizes the effects of an IOR rate policy for the economy when banks hold excess reserves.

Proposition 5 (IOR policy under excess reserves)**.** *Assume that $\psi D < J \leq D$ and $R_t \geq 1$ (MRR and DLB are slack), and take J as given.*

1. *Any IOR policy*
   a) *has a pass-through to the lending rate of*

$$\frac{\partial R^a}{\partial R^j} = \frac{1}{1-(J/\nu)E_A(R^a-R)} \in (0,1], \tag{41}$$

with a direct effect of unity, $\frac{\partial R^a}{\partial R^j}|_D = 1$,

b) *has an ambiguous pass-trough on the interest margin with*

$$\frac{\partial(R^a - R)}{\partial R^j} = \frac{\left((J/\nu)\frac{J}{D} - 1\right) 0.5 E_A(R^a - R)}{1 - (J/\nu)E_A(R^a - R)} \tag{42}$$

with a direct effect of zero, $\frac{\partial(R^a - R)}{\partial R^j}|_D = 0$,

c) *has an ambiguous pass-through on the deposit rate with*

$$\frac{\partial R}{\partial R^j} = \frac{1 + \left(1 - (J/\nu)\frac{J}{D}\right) 0.5 E_A(R^a - R)}{1 - (J/\nu)E_A(R^a - R)} \tag{43}$$

with a direct effect of unity, $\frac{\partial R}{\partial R^j}|_D = 1$.

2. *A stimulative (contractionary) IOR policy moves the economy towards (away from) the MRR.*

Proof. See Appendix A.5. ∎

Part 1a of the proposition states that the pass-through of R^j to R^a is significant, with a direct effect of unity. However, this direct effect is dampened by the indirect effect arising from the attraction of additional deposits. Figure 3 illustrates this relationship and highlights that the dampening indirect effect can be substantial (right panel). Part 1b asserts that the direct effect of an IOR rate policy on the interest margin is zero, while the total effect remains ambiguous. The total effect increases with R^j if the economy has a small amount of excess reserves and high demand elasticity but decreases otherwise.

The direct effect of an IOR policy on deposit rates is also unity, as stated in Part 1c of the proposition, but it can be significantly attenuated if the demand for funds responds strongly to changes in the lending rate. In such cases, the ambiguous response of the interest margin carries over to the deposit rate, which can even turn negative: when demand elasticity is very high and the IOR rate increases, banks offset the higher costs of holding reserves by reducing returns on deposits, i.e., lowering the deposit rate. This scenario is illustrated in the right panel of Figure 3. However, this effect diminishes at even higher IOR rates, as banks become unwilling to hold relevant volumes of assets. Taken together, Propositions 5 and 4 show that, off the MRR and under fairly normal circumstances, IOR policy is highly effective in controlling the deposit rate, while reserve policies exhibit only limited pass-through to equilibrium rates.

A second key result on the effects of IOR policy from Proposition 5 is that any stimulative IOR policy (i.e., decreasing R^j_t) will, through its positive effect on lending, eventually return the economy to the MRR. This outcome can be attributed to two effects. The first, direct effect is that a lower IOR rate increases the opportunity cost of holding reserves. The second, indirect effect dampens the direct effect as the lending rate decreases with the IOR rate, leading to a relative reduction in the marginal cost of holding reserves.

The above results can be combined to better understand how seigniorage depends on reserves and the IOR, as summarized in Lemma 1.

Lemma 1 (CB profits under excess reserves)**.** *If* $\psi D < J \leq D$ *and* $R_t > 1$ *(MRR and DLB are slack), and targeting either a fixed value of* $R = \bar{R}$ *or* $R^a = \bar{R}^a$*, a pair*

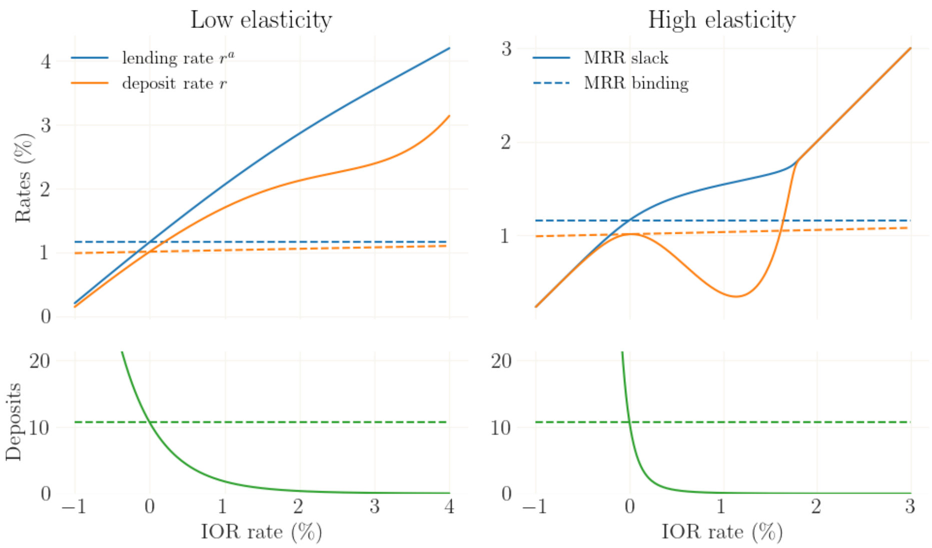

Figure 3: Responses of market rates in the banking equilibrium (Eqs. (9) to (11)) when varying the interest rate on reserves. The solid (dashed) lines depict the equilibrium outcome if the MRR is slack (binding). $J = \bar{J}$ is fixed, $\psi = 2.26\%$ and the inverse loan demand function is given by $A/\nu = a_l(R^a)^{-1/0.005}$ (left) and $A/\nu = a_h(R^a)^{-1/0.0008}$ (right).

$\{J^*, R^{j^*}\}$ *that maximizes central bank profits* Φ *must satisfy*

$$J^*/\nu = \frac{1}{2}\frac{R^a - R^{j^*}}{R^a - R}. \tag{44}$$

Proof. The result follows from Propositions 4 and 5. ∎

Importantly, the lemma states that for a given target lending or deposit rate, there is a relationship between reserves and the reserve rate that optimizes central bank profits. Intuitively, achieving a specific lending or deposit rate requires only one of the two policy tools, leaving an additional degree of freedom to maximize seigniorage. Since controlling either the lending or deposit rate is sufficient to adhere to a conventional Taylor rule, this implies that a central bank indeed possesses this additional degree of freedom. Therefore, it must decide on a specific strategy to effectively harness this flexibility.

3.2 General equilibrium effects

Having studied how, given a slack MRR, the central bank can use asset purchases and IOR policy to control equilibrium rates through the banking sector, let us turn now to the effects of these policies in general equilibrium. First, I compare the steady states of macroeconomic aggregates across different levels of reserves. Following this, I analyze the distributional impacts of these policies.

Figure 4 shows macroeconomic aggregates for different levels of supplied reserves. For each level, the central bank sets the interest rate on reserves such that in general

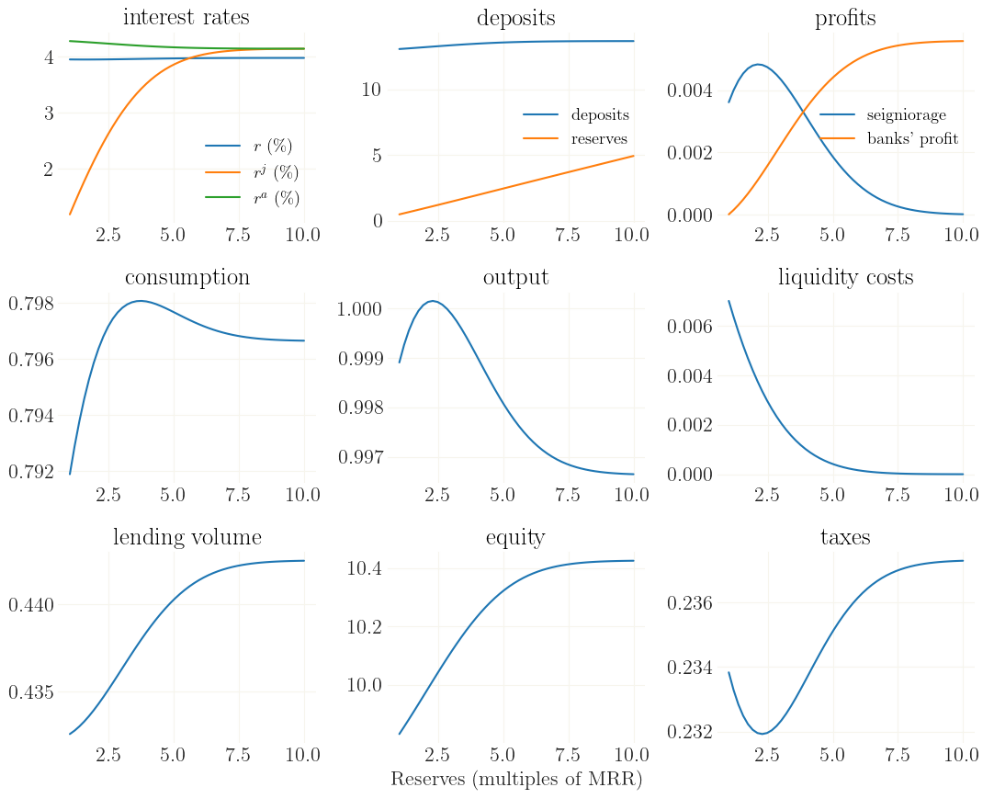

Figure 4: Steady state values of macroeconomic aggregates over a sequence of equilibria featuring different levels of excess reserves. The MRR is not binding. The levels of all variables are given relative to output in the benchmark scenario.

equilibrium, the inflation target is met perfectly and, thus, inflation remains constant. The figure shows that output reaches its maximum at approximately 2.5 times the MRR. Below this level, liquidity costs consume a significant share of output, which also distorts households' incentives to work. Conversely, exceeding this level reduces liquidity costs but increases distortionary labor taxation.

The increase in reserves lowers aggregate liquidity costs, causing consumption to rise at low values of J but to decline gradually at higher values. The central bank maintains full control over inflation by targeting the deposit rate through adjustments to the IOR rate. As larger reserves reduce liquidity spreads, the equilibrium IOR rate increases with the supply of reserves. In general equilibrium, this leads to a gradual decline in the lending rate, while the deposit rate remains nearly constant.

An increase in the supply of reserves boosts bank profits: while liquidity demand is generally saturated, the interest margin decreases only moderately. However, seigniorage declines because the central bank must raise the IOR rate to maintain target inflation, resulting in higher interest payments on reserves for banks. As Equation (15) demonstrates, if bank revenues remain largely unchanged while seigniorage declines, bank profits must

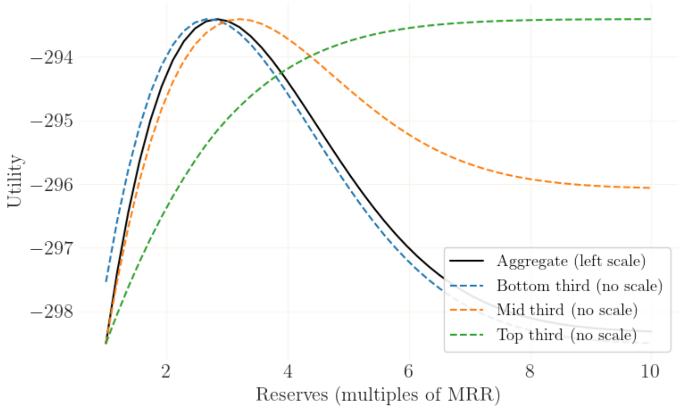

Figure 5: Utilitarian welfare in a sequence of equilibria featuring different levels of excess reserves (solid line, right axes). The MRR is not binding. The dashed lines represent utility of each third of the distribution of wealth. Dashed lines are given scale free to compare their respective maxima.

increase. Consequently, the rise in reserves can be interpreted as shifting the returns from the interest margin away from the central bank's and onto banks' balance sheets. Equivalently, seigniorage can be understood as a tax on bank profits, which diminishes after a certain point.

The decline in seigniorage for a reserve supply exceeding approximately 2.5 times the MRR is accompanied by an increase in the tax rate. While this increase is relatively modest, it carries two significant implications. First, higher taxation leads to a relative increase in earnings risk, which has notable welfare consequences. Second, as noted earlier, taxation distorts households' labor supply decisions, reducing output.

Figure 5 presents the utilitarian welfare measure across a given range of reserves. The figure indicates the existence of an internal maximum slightly below the point where the supply of reserves reaches three times the minimum reserve requirement. This maximum reflects a trade-off between a decreasing the borrowing-lending spread and reducing seigniorage. While lower spreads stimulate lending activity and decrease the government's debt burden, redistributing banks' profits to the treasury mitigates income risk by enabling lower tax rates. The figure also shows utility aggregated over different segments of the wealth distribution. Notably, only the top third of the wealth distribution – those who benefit from banks' profits – would slightly prefer a larger supply of excess reserves. It is worth noting that distortionary taxation is not a necessary condition for the existence of an interior maximum. Appendix Appendix B.3 demonstrates that these results also hold under non-distortionary taxation.

Finally, Figure 6 shows how households at different positions in the wealth distribution would fare with a transition from the current state of the financial system – excess reserves approximately 20 time the MRR – to the utilitarian optimum. The figure depicts consumption equivalent variations (CEVs), which measure how much additional consumption a household would require to be indifferent between experiencing the tax reform and remaining in the pre-reform economy. Negative CEVs indicate that households would be willing to forgo a specified amount of consumption to avoid the reform.

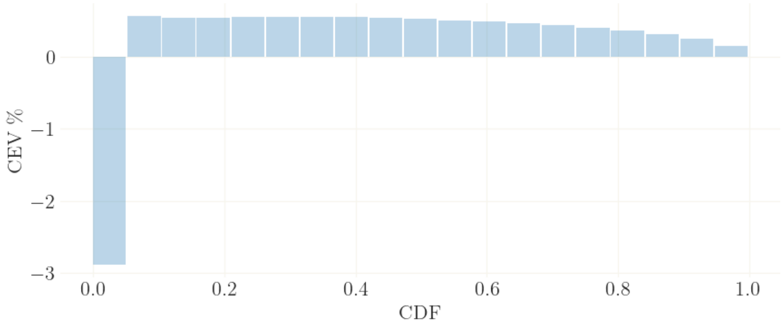

Figure 6: Consumption equivalent variation across the wealth distribution for a transition from 20 times the MRR to the welfare optimum from Figure 5 at $\frac{J}{\psi D} = 2.833$.

CEVs are determined by solving the equation

$$E_0 \sum_{t=0}^{\infty} \beta^t u([1 + \mathfrak{v}(e_{it}, d_{it})]c_{it}^*, n_{it}^*) = E_0 \sum_{t=0}^{\infty} \beta^t u(c_{it}, n_{it}), \tag{45}$$

where $\mathfrak{v}(e_{it}, d_{it})$ represents the CEV of a household with skill e_{it} and wealth d_{it}, and ${c_{it}}^*, {n_{it}}^*$ denotes the household's consumption and labor supply in the pre-reform steady state. Figure B.11 in Appendix Appendix B.2 presents the aggregate transition dynamics associated with this shift.

Clearly, the shift from the 2020s' high level of excess reserves to the significantly lower interior optimum benefits the majority of society. Middle-class households, in particular, would prefer the slightly reduced tax levels over lower interest rate margins. In contrast, only the very poor households would strictly oppose such a reform, as it entails higher lending rates and, consequently, a larger credit burden. At the margin, even the very wealthy would support this shift; although bank profits decline, labor income increases slightly during the transition to the new steady state.

4 "Socialist Central Banking"

Let us now consider the regime where the MRR is binding. As before, I first examine the pass-through of policy tools to equilibrium interest rates, followed by an analysis of the role of the MRR in general equilibrium.

4.1 The pass-through of monetary policy tools

If the MRR is binding, the banking equilibrium represented by Equations (10) and (11) reduces to

$$R = (1 - \psi)R^a + \psi R^j + \gamma \left(\psi \left[1 - \hat{F}\right] - 0.5\hat{f}\right), \tag{46}$$

$$J = \psi D, \tag{47}$$

with, again, $d_A(R^a) = D/\nu$. Note that now the deposit rate is a weighted average of R^a and R^j plus a liquidity spread where it always holds that $R < R^a$.[3] Via the MRR, deposits are directly linked to reserves and any exogenous increase in reserves will be reflected by an one-to-one increase in household deposits. Although seemingly trivial, this has important implications for the pass-through of reserves policy to rates in the banking equilibrium, as summarized in Proposition 6.

Proposition 6 (asset purchases under binding MRR)**.** *If $0 < J = \psi D$ and $R_t \geq 1$ (MRR is binding and DLB is slack) and given R^j, any policy that purchases assets against reserves,*

1. *always reduces the lending rate R^a with a pass-trough of*

$$\frac{\partial R^a}{\partial J} = E_A^{-1}/(J/\nu), \tag{49}$$

2. *has a pass-trough to the deposit rate R of*

$$\frac{\partial R}{\partial J} = \left[(1-\psi)E_A^{-1} + \gamma 0.25(1-\psi J\nu)f(\cdot)\right]/(J/\nu). \tag{50}$$

Proof. See Appendix A.6. ■

The lending rate is determined solely by the equilibrium in the funds market, which, via the MRR, is directly tied to the supply of reserves. Consequently, it depends only on the inverse elasticity of demand, as stated in Part 1 of the proposition. Similarly, since the deposit rate is a weighted average of the lending and reserves rates, the latter is also closely linked to demand elasticity. Accordingly, Part 2 of the proposition specifies that the degree of pass-through depends on the level of the MRR.

The equilibrium interest rates for different levels of reserves are illustrated in Figure 2. The dashed lines depict the equilibria under the assumption that the MRR is binding. As the level of reserves increases, both deposit and lending rates decrease sharply, with the lending rate being determined solely by the demand function for loans. In contrast, as discussed in the previous section, when the MRR is slack, the pass-through of reserves policy to interest rates is relatively flat, and the transmission from reserves to deposits is less than the MRR level. The right panel of the figure examines the same scenario with a more elastic investment demand function. In this case, the deposit rate rises at low levels of reserves, highlighting the role of the liquidity effect captured by the second term in Equation (50).

Proposition 7 (IOR policy with binding MRR)**.** *If $0 < J = \psi D$ and $R_t \geq 1$ (MRR is binding and DLB is slack), and given J, any IOR policy*

1. *is ineffective in altering the lending rate,*

$$\frac{\partial R^a}{\partial R^j} = 0, \tag{51}$$

[3] This can be seen by noting that (46) can be expressed as

$$R = R^b - 0.5\hat{f}_\psi + \psi MPJ_\psi, \tag{48}$$

where $MPJ_\psi < 0$ whenever the MRR binds.

2. *has a pass-through on the deposit rate of*

$$\frac{\partial R}{\partial R^j} = \psi. \tag{52}$$

Proof. See Appendix A.7. ■

Finally, Proposition 7 documents that an IOR policy has very limited transmission onto deposit and lending rates if the MRR is binding. In fact, because the lending rate is already determined by the supply of reserves, it is fully invariant to changes in the IOR rate. Since the deposit rate is a weighted average between the lending rate and the IOR rate, with weights $1-\psi$ and ψ, it is mainly determined by the lending rate, resulting in a insignificant pass-through of reserves policy as well. Since for most countries the MRR is small (typically between 0% and 5%), this suggests that the pass-through of IOR policy to equilibrium rates is almost negligible if the MRR binds. The dashed lines in Figure 3 represent the equilibria of the banking market for a given range of the IOR rate, assuming the MRR is binding. The figure confirms that the IOR rate has no relevant impact on equilibrium rates when the MRR is binding.

4.2 General equilibrium effects

The above analysis demonstrates that, if the MRR binds, lending and deposit rates can be effectively controlled by adjusting the supply of reserves. This ensures that the central bank retains control over inflation, regardless of whether the MRR is binding or its specific level. In Section 3, I show that there exists an optimal level of reserves that maximizes seigniorage, given the IOR rate and the inflation target being met. However, such a result does not exist when the MRR binds: to maximize central bank profits Φ_t (c.f. Equation 13), the optimal value of the MRR is $\psi = 1$.[4] Unlike the unconstrained case, the central bank cannot freely choose the reserve level, as it is directly tied to the lending rate via market-clearing conditions. Any deviation from the equilibrium reserve level would result in significant inflationary effects, thereby violating price stability.[5]

For these reasons, let us now turn to the general equilibrium effects of changing the level of the MRR. Figure 7 illustrates how macroeconomic aggregates respond to varying levels of the MRR. Inflation, which the central bank perfectly controls by adjusting the amount of reserves, again remains constant. The IOR rate is also assumed to remain constant at 0%, the lowest value possible to prevent a binding DLB in the full-reserve case. Output increases as distortions from taxation diminish. At low values of ψ, an increase in the MRR reduces liquidity costs, resulting in simultaneous growth in output and consumption. For banks, higher reserve holdings lead to fewer asset holdings

[4]This result follows from acknowledging that, by (37), R^a is an implicit function of D. Substituting (47) into central bank profits yields (ignoring inflation) $\Psi = \psi D(R^a(D) - R^j)$.

[5]As a sidenote, under full reserves Equations (46) and (47) become

$$R = R^j + \gamma\left(1 - \hat{F} - 0.5\hat{f}\right), \tag{53}$$

$$J = D = A, \tag{54}$$

meaning that the central bank can independently control deposit rate (by using the IOR rate) and lending rate (via investment demand by using reserves).

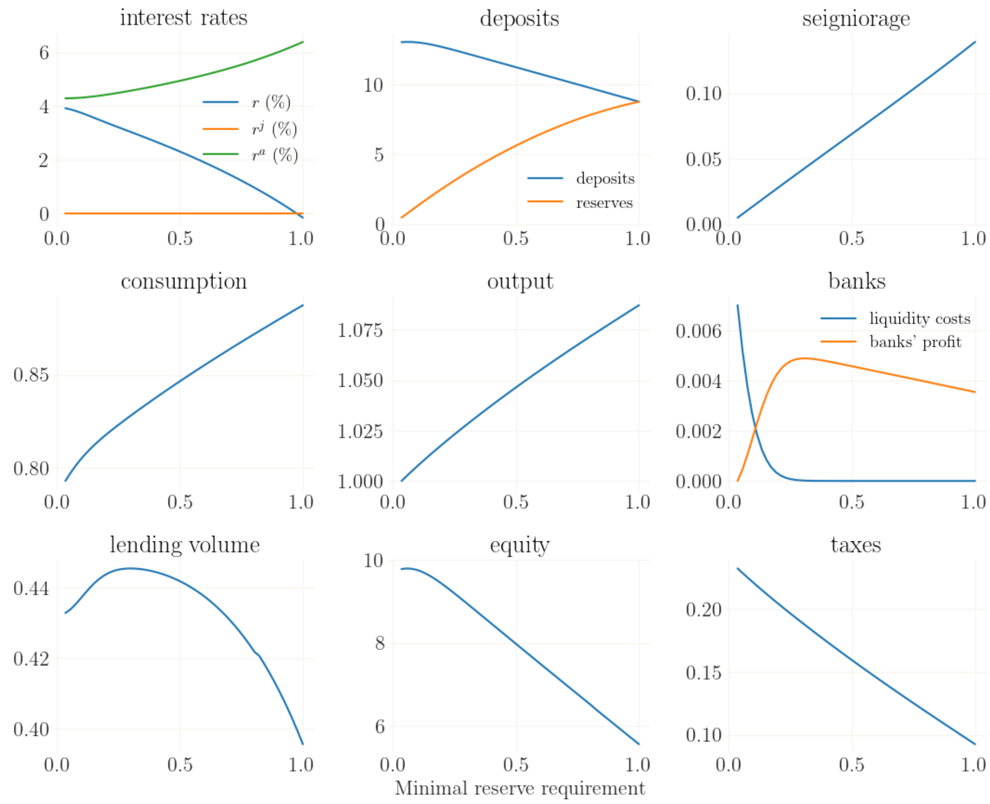

Figure 7: Steady state values of macroeconomic aggregates over a sequence of equilibria featuring different levels of excess reserves. The levels of all variables are given relative to output of the benchmark case.

and, consequently, lower returns. To compensate for these foregone returns and cover operating costs, banks raise their interest margins. In the extreme case of a full-reserve system ($\psi = 1$), deposit rates fall slightly below the IOR rate, while lending rates rise to exceptionally high levels. These elevated lending rates suppress demand for asset investment, reducing both lending volume and bank equity. Consequently, households' deposit holdings decline, reflecting the broader contractionary effects of such a regime shift.

However, the increase in the interest margin benefits banks' profits and, as the volume of reserves grows, particularly raises seigniorage. Notably, this latter effect is substantial: central bank profits exceed 13% of GDP in the full-reserve case. This significant level of remittances to the treasury results in a more than 50% reduction in the tax burden, with material implications for welfare. As net saving rates decline, seigniorage can also be interpreted as a wealth tax, further emphasizing its redistributive nature. Moreover, the fact that lending rates rise while the proceeds are collected by the central bank suggests that seigniorage functions as a tax on bank lending.

Figure 8 shows how Utilitarian welfare fares given increasing levels of the MRR. For

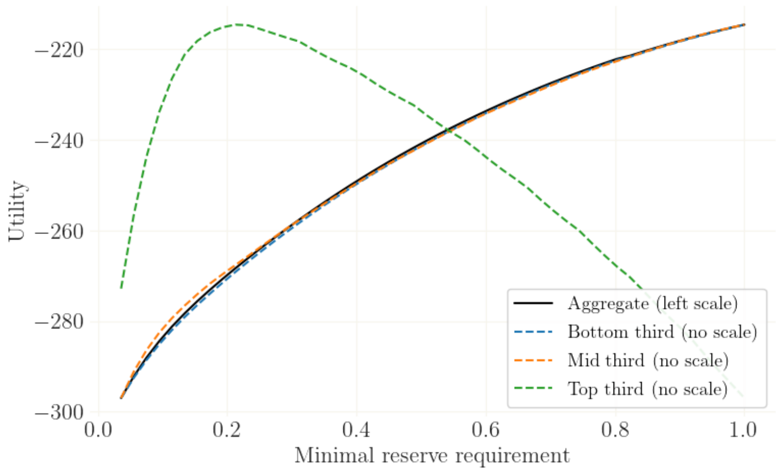

Figure 8: Utilitarian welfare in a sequence of equilibria featuring different levels of the MRR. The dashed lines represent utility of each third of the distribution of wealth. Dashed lines are drawn free of scale to compare their respective maxima.

all but the top third of the wealth distribution, the significantly lower tax burden under the full-reserves system implies a considerable welfare improvement. Again, this can be seen as helping households insure against idiosyncratic income risk by redistributing wealth from the top of the distribution to the bottom. For the same reason, the top third of the wealth distribution would prefer a notably lower level of the MRR of around 10%.

Lastly, Figure 9 compares four key states under consideration: the benchmark scenario with a binding MRR, the post-2022 scenario with ample excess reserves, the optimum under exceed reserves identified in the previous section, and the full-reserve case with $\psi = 1$. The right panel depicts the wealth distribution. Overall, the baseline scenario and the two excess-reserve scenarios exhibit relatively similar wealth distributions, with the baseline scenario featuring the slimmest tails. This suggests that redistributive differences across these policy scenarios are relatively minor. In contrast, the wealth distribution under a full-reserve system exhibits significantly more mass concentrated near the origin, reflecting a more egalitarian distribution. This outcome aligns with expectations, given that the seigniorage "tax" increases lending rates and the required return on equity, while simultaneously reducing returns on wealth. However, it is important to note that this economy is also poorer overall, as the rise in lending rates leads to an almost 50% reduction in equity.

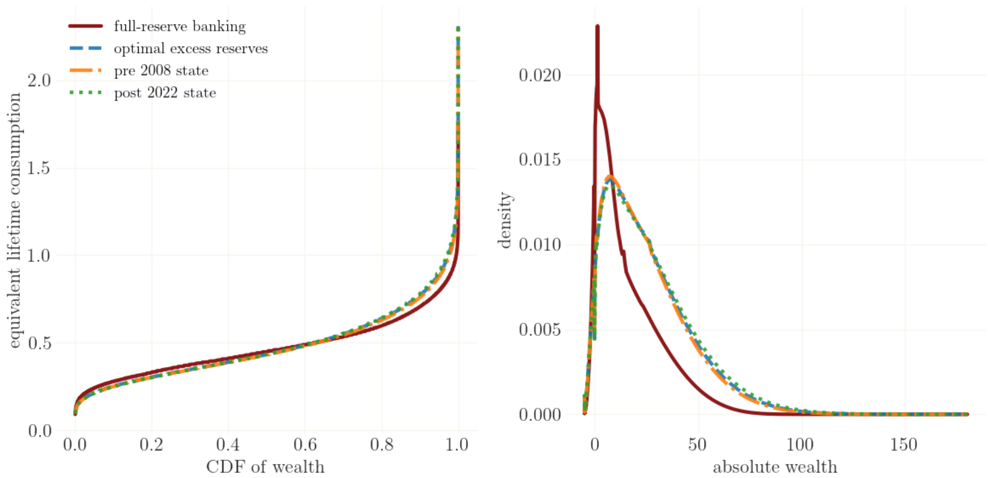

Figure 9: Comparison of different operating frameworks. Left: utility over the distribution of wealth in terms of equivalent lifetime consumption. Right: the distribution of wealth. The pre-2008 state is the benchmark calibration where the MRR binds. In the post-2022 the central bank provides exess reserves of about 20 times the MRR.

5 Conclusion

This paper demonstrates that central banks can maximize seigniorage revenues – while fully maintaining price stability – by appropriately balancing the supply of reserves and the interest rate on reserves. The qualitative and quantitative effects of such a strategy depend on whether the minimum reserves requirement (MRR) is binding or not. I present a model that incorporates an industrial organization approach to the banking sector within a heterogeneous agent New Keynesian (HANK) framework. By analyzing how central banks manage reserves to influence interest rates through the banking sector, this study highlights the dual function of reserves as a tool for monetary policy and as a source of government financing.

The model identifies an optimal level of excess reserves that compromises between a reduction in liquidity spreads with welfare improvements resulting from increased government revenues. In contrast, a full-reserve banking system with a 100% MRR entails the complete nationalization of banking profits and government debt interest payments, resulting in a significant reallocation of economic costs and benefits. Seigniorage acts as an implicit tax on household wealth and borrowing, whereas under excess reserves, it primarily taxes bank profits. Central bankers should thus consider taking into account that reserve policies are powerful tools for managing both economic stability and the distribution of wealth.

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Appendix A Proofs of the propositions

Appendix A.1 Proof of Proposition 1 (liquidity risk)

Proof. To simplify notation, denote bank js expected net inflow of deposits with $Z = \Delta D_{j,t}$, which consists of inflows Z^+ from other banks to j and outflows Z^- from j to other banks. Bank j's net outflow of deposits are hence given by the random variable

$$Z = Z^- - Z^+. \tag{A.1}$$

$Z > 0$ implies a net outflow of deposits with $Z^- > Z^+$. Denote by $D_{-i,t}$ the number of units of deposits *not* held by j. For each of these units the probability to end up at bank j is the probability χ to get transfered away from its current bank times the probability to be transfered to j, which is given by $\frac{D_{i,t}}{D_t}$. Thus, Z^+ and Z^- both follow a binomial distribution with

$$Pr\left(Z^+ = x\right) = f_B(x|D_{-i,t}, \chi\frac{D_{i,t}}{D_t}), \tag{A.2}$$

$$Pr\left(Z^- = x\right) = f_B(x|D_{i,t}, \chi\frac{D_{-i,t}}{D_t}). \tag{A.3}$$

We cannot directly sum over two Binomial distributions with different probabilities. However, for large sample sizes, a Binomial distribution with PDF $f_B(k|n,p)$ can be well-approximated by a normal distribution with PDF $f_N(k|np, np(1-p))$. Since both $D_{i,t}$ and $D_{-i,t}$ are large (in a stochastic context), we can rewrite

$$Z^+ \sim \mathcal{N}\left(\chi \frac{D_{-i,t} D_{i,t}}{D_t}, \chi \frac{D_{-i,t} D_{i,t}}{D_t}\left(1 - \chi \frac{D_{i,t}}{D_t}\right)\right), \tag{A.4}$$

$$Z^- \sim \mathcal{N}\left(\chi \frac{D_{-i,t} D_{i,t}}{D_t}, \chi \frac{D_{-i,t} D_{i,t}}{D_t}\left(1 - \chi \frac{D_{-i,t}}{D_t}\right)\right). \tag{A.5}$$

Since now Z is the difference of two normal distributed variables it follows that

$$Z \sim \mathcal{N}\left(0, \frac{D_{i,t} D_{-i,t}}{D_t}(2\chi - \chi^2)\right). \tag{A.6}$$

Note that this result assumes that the *number* of units and the real value of deposits are equal. It is easy to show that the result would hold up to a scaling factor of the variance if we instead assume that the number of units of deposits is proportional to the value of deposits, which can be incorporated into the parameter for the transfer probability χ. ■

Appendix A.2 Proof of Proposition 2 (liquidity costs)

Proof. Let f be the PDF of $Z = \Delta D_{i,t}$ from Proposition 1. From the definition of $h(D_{i,t})$ it follows that

$$g(J_{i,t}, D_{i,t}) = \int_J^\infty (z - J_{i,t}) f(z) dz \tag{A.7}$$

$$= \int_J^\infty z f(z) dz - J_{i,t} \int_J^\infty f(z) dz, \tag{A.8}$$

$$= -h(D_{i,t}) \int_J^\infty f'(z) dz - J_{i,t}(1 - F(J_{i,t})), \tag{A.9}$$

$$= h(D_{i,t}) f(J_{i,t}) - J_{i,t}(1 - F(J_{i,t})). \tag{A.10}$$

■

Appendix A.3 Proof of Proposition 3 (equilibrium of the banking sector)

Proof. Omitting expectations operators, bank i's profit maximization problem is

$$\max_{A_{it}, J_{it}, D_{it}, R_{it}} R_t^a A_{ti} + R_t^j J_{it} - R_{it} D_{it} - \gamma g(J_{it}, D_{it}) \tag{A.11}$$

s.t.

$$A_{it} + J_{i,t} = D_{i,t}, \tag{A.12}$$

$$g(J_{i,t}, D_{i,t}) = h(D_{i,t}) f(J_{i,t}, h(D_{i,t})) - J_{i,t}(1 - F(J_{i,t}, h(D_{i,t})) \tag{A.13}$$

$$h(D_{i,t}) = \frac{D_{i,t} D_{-i,t}}{D_{i,t} + D_{-i,t}} (2\chi - \chi^2) \tag{A.14}$$

$$\frac{R_{i,t}}{R_t} = \left(N \frac{D_{i,t}}{D_t} \right)^{\frac{1}{\omega - 1}}, \tag{A.15}$$

$$1 \leq R_{i,t}, \tag{A.16}$$

$$\psi D_{i,t} \leq J_{i,t}. \tag{A.17}$$

For the derivatives with respect to $g(\cdot)$ we can exploit that for the normal distribution it holds that $f'_Z(z) = -\frac{z}{h(D_{i,t})} f_Z(z)$, which simplifies the algebra considerably:

$$\frac{\partial g}{\partial J_{i,t}}(J_{i,t}, D_{i,t}) = -\gamma(1 - F_Z(J_{i,t})), \tag{A.18}$$

$$\frac{\partial^2 g}{\partial J_{i,t}^2}(J_{i,t}, D_{i,t}) = \gamma f_Z(J_{i,t}), \tag{A.19}$$

$$\frac{\partial g}{\partial D_{i,t}}(J_{i,t}, D_{i,t}) = 0.5\gamma h' f_Z(J_{i,t}), \tag{A.20}$$

$$\frac{\partial^2 g}{\partial D_{i,t}^2}(J_{i,t}, D_{i,t}) = 0.5\gamma \left(h'' + 0.5 \left(\frac{J^2}{h} - 1 \right) \frac{h'^2}{h} \right) f_Z(J_{i,t}), \tag{A.21}$$

$$= 0.5\gamma h'' f_Z(J_{i,t}) + 0.25 h'^2 f''_Z(J_{i,t}), \tag{A.22}$$

$$\frac{\partial^2 g}{\partial J_{i,t} D_{i,t}}(J_{i,t}, D_{i,t}) = -\gamma 0.5 J \frac{h'}{h} f_Z(J_{i,t}), \tag{A.23}$$

$$\tag{A.24}$$

where

$$h(D_{i,t}) = \frac{D_{i,t} D_{-i,t}}{D_{i,t} + D_{-i,t}} (2\chi - \chi^2), \tag{A.25}$$

$$h'(D_{i,t}) = \left(\frac{D_{-i,t}}{D_{i,t} + D_{-i,t}} \right)^2 (2\chi - \chi^2), \tag{A.26}$$

$$h''(D_{i,t}) = -2 \frac{D_{-i,t}^2}{(D_{i,t} + D_{-i,t})^3} (2\chi - \chi^2), \tag{A.27}$$

$$= -\frac{2}{D_{i,t} + D_{-i,t}} h'(D_{i,t}). \tag{A.28}$$

The FOCs are

$$J_{i,t}: -R_t^a + R_t^j + \gamma\left[1 - F(J_{i,t}, h(D_{i,t}))\right] + \hat{\mu}_{J,t} = 0, \tag{A.29}$$

$$D_{i,t}: -R_t^a + \frac{\omega}{\omega-1}R_t + \gamma\frac{1}{2}\left(\frac{D_{-i,t}}{D_t}\right)^2(2\chi - \chi^2)f(J_{i,t}, h(D_{i,t})) + \mu_{J,t} + \mu_{D,t} = 0, \tag{A.30}$$

together with (A.12) to (A.14), (A.16), (A.17) and the (modified) Kuhn-Tucker conditions

$$\mu_{J,t} \geq 0, \tag{A.31}$$
$$\mu_{D,t} \geq 0, \tag{A.32}$$
$$\mu_{J,t}(\psi D_{i,t} - J_{i,t}) = 0, \tag{A.33}$$
$$\mu_{D,t}(1 - R_{i,t}) = 0. \tag{A.34}$$

From the deposit market under monopsonistic competition (Equations (6) and (7)) it follows that a symmetric equilibrium is given by

$$D_t = ND_{i,t}, \tag{A.35}$$
$$R_t = R_{i,t}. \tag{A.36}$$

With $A_t^b = \sum A_{i,t}$ their best-responses can be aggregated to

$$A_t^b + J_t = D_t, \tag{A.37}$$
$$R_t^a = R_t^j + \gamma\left[1 - \Phi\left(\frac{J_t}{\sqrt{\nu D_t}}\right)\right] + \mu_{J,t}, \tag{A.38}$$
$$R_t^a = \frac{\omega}{\omega-1}R_t + 0.5\gamma\frac{N-1}{N}\sqrt{\frac{\nu}{D_t}}\varphi\left(\frac{J_t}{\sqrt{\nu D_t}}\right) + \psi\hat{\mu}_{J,t} + \mu_{D,t}, \tag{A.39}$$

with $\Phi(\cdot)$ as the standard normal CDF and $\varphi(\cdot)$ as the standard normal PDF and where $\nu = (N-1)(2\chi - \chi^2)$ is a measure of *liquidity risk* (or tail risk). The result from the proposition follows after assuming $\frac{N-1}{N} \approx 1$.

We must ensure that this is a (local or global) maximum of the profit function. This is unproblematic for the constrained case. For the unconstrained case the second partial derivative test requires that the hessian of the profit function is positive,

$$\det H_{\Pi}(D, J) > 0, \tag{A.40}$$

and that $\Pi_{JJ} < 0$. The latter is easy to see since $g_{JJ} < 0$ always. The condition on the determinant leads to

$$\frac{\omega}{(\omega-1)^2}R > 0.25\gamma h' f(J_{i,t}). \tag{A.41}$$

Plugging in the optimality condition for deposits results in

$$\frac{\omega(\omega+1)}{(\omega-1)^2} > \frac{R^a}{R}, \tag{A.42}$$

which is satisfied for the calibration presented in Section 2.3. ■

Appendix A.4 Proof of Proposition 4 (asset purchases under excess reserves)
Proof. It is useful to first calculate $R^{a\prime} = \frac{\partial R^a}{\partial J}$. Express (35) in terms of the standard normal distribution with CDF Φ and insert (37). The lending rate is then given by

$$R^a(J) = R^j + \gamma\left(1 - \Phi\left((J/\nu)/\sqrt{d_A(R^a(J))}\right)\right). \tag{A.43}$$

Let $d'_A = \frac{\partial d_A}{\partial R^a} < 0$ and define the second factor inside $\Phi(\cdot)$ as

$$h(J) = d_A(R^a(J))^{-1/2}, \tag{A.44}$$

with first derivative $h' = -0.5A^{-1.5}R^{a\prime}d'_A$. Inserting into (A.43) and taking the derivative w.r.t. J yields

$$\begin{aligned} R^{a\prime} =& -\gamma(h + J/\nu h')\phi(\cdot), && \text{(A.45)}\\ =& -\gamma A^{-0.5}\phi(\cdot) + \gamma J/\nu 0.5A^{-1.5}R^{a\prime}d'_A\phi(\cdot), && \text{(A.46)}\\ =&\gamma\hat{f}(0.5E_{DJ} - 1), && \text{(A.47)} \end{aligned}$$

where the last equation uses the fact that the elasticity of A w.r.t. J is

$$E_{DJ} = \frac{\partial d_A/A}{\partial J/J} = \frac{\partial d_A}{\partial R^a}\frac{\partial R^a}{\partial J}\frac{J}{A} = d'_A R^{a\prime}J/A. \tag{A.48}$$

Inserting the result from (A.47) into the definition of E_{DJ} yields

$$\begin{aligned} E_{DJ} &= d'_A R^{a\prime}J/A, && \text{(A.49)}\\ &= d'_A J/A\gamma\hat{f}(0.5E_{DJ} - 1), && \text{(A.50)} \end{aligned}$$

with $E_A = \frac{\partial d_A/A}{\partial R^a} = d'_A/A$, which provides the result on the pass-through of the lending rate.

For the result on the depost rate, note that in terms of the standard normal distribution with PDF φ and CDF $\Phi(\cdot)$, the latter is given by

$$R(J) = R^j + \gamma\left(1 - \Phi(Jh) - 0.5h\varphi(Jh)\right), \tag{A.51}$$

with derivative

$$\begin{aligned} R' &= \gamma\left(-(h + (J/\nu)h') - 0.5h' + 0.5\frac{J}{D}(h + Jh')\right)\varphi(\cdot), && \text{(A.52)}\\ &= \gamma\left(-1 + 0.5E_{DJ} + 0.25E_{DJ}/(J/\nu) + 0.5\frac{J}{D}(1 - 0.5E_{DJ})\right)\hat{f}. && \text{(A.53)} \end{aligned}$$

■

Appendix A.5 Proof of Proposition 5 (IOR policy under excess reserves)

1. (a) Again, the lending rate is then given by

$$R^a(J) = R^j + \gamma\left(1 - \Phi\left(Jh/\nu\right)\right), \tag{A.54}$$

with

$$h(R^j) = d_A(R^a(R^j))^{-1/2}, \tag{A.55}$$

and first derivative $h' = -0.5hR^{a\prime}d_A'/A$. Again define the elasticity as $E_{DR^j} = \frac{\partial d_A/A}{\partial R^a}\frac{\partial R^a}{\partial R^j} = R^{a\prime}d_A'/A$. The derivative of the lending rate is then given by

$$R^{a\prime} = 1 - \gamma(J/\nu)h'\varphi(Jh/\nu) \tag{A.56}$$

$$= \frac{1}{1 - 0.5\gamma(J/\nu)E_A\hat{f}}. \tag{A.57}$$

which is always positive.

(b) The interest margin is given by

$$s_m = 0.5h\varphi\left(Jh/\nu\right), \tag{A.58}$$

with first derivative

$$s_m{}' = 0.5\left(h' - \frac{J}{D}h\right)\varphi(Jh/\nu). \tag{A.59}$$

(c) The deposit rate is

$$R(J) = R^j + \gamma\left(1 - \Phi(Jh/\nu) - 0.5h\varphi(Jh/\nu)\right), \tag{A.60}$$

with derivative

$$R' = 1 + 0.5\gamma\left(0.5\frac{J^2}{\nu D} - 0.5 - J\right)E_{DR^j}\hat{f}. \tag{A.61}$$

2. The MRR is binding whenever $MPJ_\psi < 0$. Conversely, when the MRR is slack

$$R^j - R^a + \gamma\left[1 - \hat{F}_\psi\right] > 0. \tag{A.62}$$

The economy will hence move towards the MRR for stimulative IOR policy (when $\Delta R^j < 0$) if $\frac{\partial MPJ_\psi}{\partial R^j} > 0$. The term $\gamma\left[1 - \hat{F}_\psi\right]$ is independent of R^j (D is constrained by J at the MRR) and we know from above that

$$R^{a\prime} = \frac{1}{1 - 0.5\gamma J/\nu E_A\hat{f}}. \tag{A.63}$$

Hence,

$$\frac{\partial MPJ_\psi}{\partial R^j} = 1 - \frac{1}{1 - 0.5\gamma J/\nu E_A \hat{f}}, \tag{A.64}$$

$$= \frac{-\gamma J/\nu E_A \hat{f}}{1 - 0.5\gamma J/\nu E_A \hat{f}}, \tag{A.65}$$

$$> 0, \tag{A.66}$$

since $E_A < 0$.

Appendix A.6 Proof of Proposition 6 (asset purchases under binding MRR)

i) As above, it is that

$$E_{DJ}^\psi = \frac{\partial d_A/A}{\partial J/J} = \frac{\partial d_A}{\partial R^a} \frac{\partial R^a}{\partial J} \frac{J}{A} = d_A' R^{a\prime} J/A. \tag{A.67}$$

From $E_{DJ}^\psi = 1$ we can rearrange to

$$\frac{\partial R^a}{\partial J} J/\nu = \left(\frac{\partial d_A}{\partial R^a}\right)^{-1} A = E_A^{-1}. \tag{A.68}$$

ii) The proof follows from iii) via

$$s^{a\prime} = R^{a\prime} - R'. \tag{A.69}$$

iii) In terms of the standard normal distribution with PDF φ and CDF Φ, the deposit rate when the MRR is binding is given by

$$R = (1-\psi)R^a + \psi R^j + \gamma\left(\psi\left[1 - \Phi(Jh/\nu)\right] - 0.5h\varphi(Jh/\nu)\right). \tag{A.70}$$

Taking the derivative w.r.t. J:

$$R' = (1-\psi)R^{a\prime} + \gamma\left(0.5\frac{J}{D}(h + Jh'/\nu) - 0.5h' - \psi(h + Jh'/\nu)\right)\varphi(Jh/\nu), \tag{A.71}$$

$$= (1-\psi)R^{a\prime} - \gamma\left(0.5\psi(h + Jh'/\nu) + 0.5h'\right)\varphi(Jh/\nu). \tag{A.72}$$

Since we know that $Jh' = -.5E_{DJ}h = -.5h$:

$$R' = (1-\psi)R^{a\prime} - \gamma\left(0.25\psi - 0.25/(J/\nu)\right)\hat{f}. \tag{A.73}$$

Appendix A.7 Proof of Proposition 7 (IOR policy under binding MRR)

i. The proof follows from the MRR, $\psi D = J$, and the funds market equilibrium, $d_A(R^a) = D$. Since D is fixed because J is given

$$\frac{\partial d_A}{\partial R^j} = \frac{\partial d_A}{\partial R^a}\frac{\partial R^a}{\partial R^j} = 0. \tag{A.74}$$

If $\frac{\partial d_A}{\partial R^a} < 0$ it must be that $\frac{\partial R^a}{\partial R^j} = 0$. If however $\frac{\partial d_A}{\partial R^a} = 0$, $\frac{\partial R^a}{\partial R^j}$ is indetermined.

ii. The proof follows again from

$$s^{a\prime} = R^{a\prime} - R' \tag{A.75}$$

with R' given from below.

iii. As above, the deposit rate is

$$R = (1-\psi)R^a + \psi R^j + \gamma\left(\psi\left[1 - \Phi(Jh/\nu)\right] - 0.5h\varphi(Jh/\nu)\right). \tag{A.76}$$

We know from i. that the derivative of the first term is zero. Since $\frac{\partial d_A}{\partial R^j} = 0$ it follows that $h' = 0$ and the derivative of the last term is also zero.

Appendix B Additional results

Appendix B.1 The role of ν

Independent of the demand for loans, for a given IOR rate and a given reserves-deposits ratio J/D, the lending rate and the deposit rate are a function of ν.

Proposition 8 (Liquidity regimes)**.** *Ceteris paribus, if the DLB is slack, for a given IOR rate R^j and for a given ratio of reserves-deposits ratio J/D, the economy knows two liquidity regimes.*

1. *The deposit rate R is*
   (a) *increasing in liquidity risk ν if $\nu < J(2 - J/D)$,*
   (b) *decreasing in liquidity risk ν if $\nu > J(2 - J/D)$, and*
   (c) *goes from $\lim_{\nu\to 0} R(\nu) = R^j$ to $\lim_{\nu\to\infty} R(\nu) = -\infty$.*
2. *The lending rate R^a is continuously increasing in ν, bounded below by R^j for $\nu = 0$, and converges to 0.5γ when $\nu \to \infty$.*

Proof. Let $\theta = J/D$. For the first part, the deposit spread $s_d = \frac{R-R^j}{\gamma}$ in terms of ν is given by

$$s_d(\nu) = 1 - \Phi\left(\theta\sqrt{\frac{D}{\nu}}\right) - 0.5\sqrt{\frac{\nu}{D}}\varphi\left(\theta\sqrt{\frac{D}{\nu}}\right), \tag{B.1}$$

with first derivative

$$\frac{\partial s_d(\nu)}{\partial \nu} = \left(0.5\theta\sqrt{D}\nu^{-1.5} - 0.25/\sqrt{\nu D} - 0.25\theta^2\sqrt{D}\nu^{-1.5}\right)\varphi\left(\theta\sqrt{\hat{D}}\right), \tag{B.2}$$

which has a unique root at $\nu = (2\theta - \theta^2)D = 2J - J^2/D$.

The second part can be seen by defining $s_l = \frac{R^a - R^j}{\gamma}$ and acknowledging that $\partial s_l/\partial\nu > 0$ and then

$$\lim_{\nu\to\infty} s_l(\nu) = \lim_{\nu\to\infty} 1 - \Phi\left(\sqrt{\frac{J}{\nu D}}\right) \iff \lim_{x\to 0} 1 - \Phi(x) = 0.5. \tag{B.3}$$

■

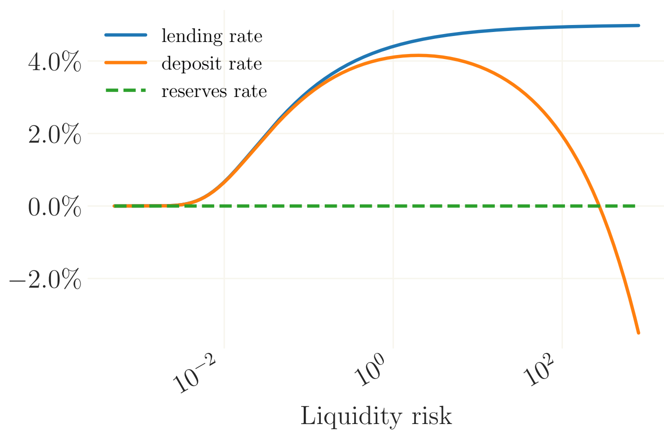

Figure B.10: Lending rate R^a and deposit rate R as a function of liquidity risk ν, given the IOR rate $R^j = 1$ and keeping the reserve-deposits ratio J/D fixed.

Figure B.10 illustrates this relationship between ν and $\{R^a, R\}$ graphically. Given a fixed ratio of J/D, the liquidity premium increases in ν. When liquidity risk is low, expected liquidity costs are negligible and banks pass the IOR rate directly to both market rates. An increase in liquidity risk at first raises the spread $R^a - R^j$ (the marginal benefit of holding reserves), indicating that banks wish a larger compensation for holding deposits. This grows faster than $R^a - R$ (the marginal benefit of holding assets), and banks are thus willing to pay a positive price for holding deposits. For $\nu > 2J - J^2/D$ the spread $R^a - R$ grows faster than $R^a - R^j$, implying that banks will be less willing to pay such price. This reflects that for high liquidity risk a marginal unit of reserves is less effective in mitigating risk than when liquidity risk is low. Ultimately, for very high liquidity risk banks charge a fee for holding deposits.

Appendix B.2 Transition dynamics to moderate excess reserves

Figure B.11 shows the transition dynamics associated with a shift from large amounts of excess reserves – here, a 20-fold of the MRR – to the interior optimum identified in Section 3. Overall, the transition is relatively slow-moving with very moderate overall effects. The shift is, in the short run, deflationary as the level of taxes decreases.

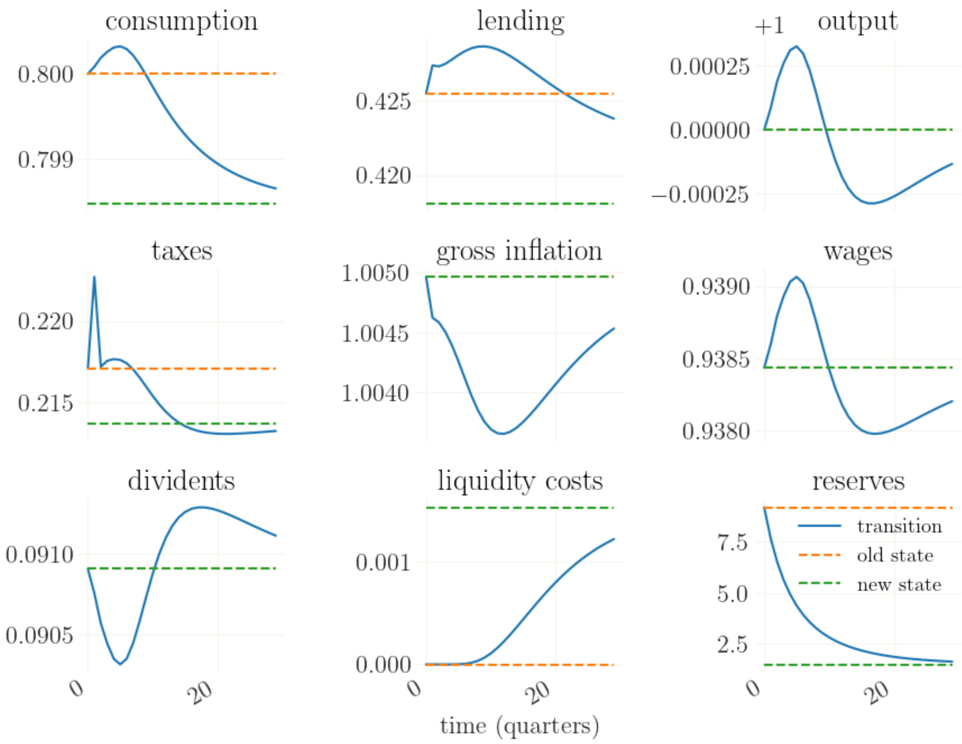

Figure B.11: Aggregate dynamics for the transition from 20 times the MRR to the welfare optimum from Figure 5 at $\frac{J}{\psi D} = 2.833$.

Appendix B.3 Results without distortionary taxation

This section confirms that the results presented in the main body also hold for the case in which taxes are not collected proportional to laber – and thus distortionary – but in a lum-sum fashion. The households' problem becomes

$$V_t(e_{jt}, d_{jt-1}) = \max_{c_{jt}, n_{jt}, d_{jt}} \left\{ \frac{x_{jt}^{1-\sigma_c}}{1-\sigma_c} + \beta \mathbb{E}_t \left[V_{t+1}(e_{j,t+1}, d_{jt}) | e \right] \right\}, \tag{B.4}$$

$$x_{jt} = c_{jt} - e_{jt} \frac{n_{jt}^{1+\sigma_l}}{1+\sigma_l}, \tag{B.5}$$

$$c_{jt} + d_{jt} = \frac{R(R_{t-1}, R_{t-1}^a, d_{j,t-1})}{\pi_t} d_{j,t-1} + w_t e_{jt} n_{jt} + \left((1-\upsilon)\Pi_t^y + \Pi_t^b \right) \bar{\Pi}(e_{jt}) - \tau_t \bar{\tau}(e_{jt}), \tag{B.6}$$

$$d_{jt} \geq \bar{d}, \tag{B.7}$$

where $\bar{\tau}(e)$ is a incidence rule which sets taxes proportional to the skill level, and labor supply is given by

$$n_t^{\sigma_l} = w_t. \tag{B.8}$$

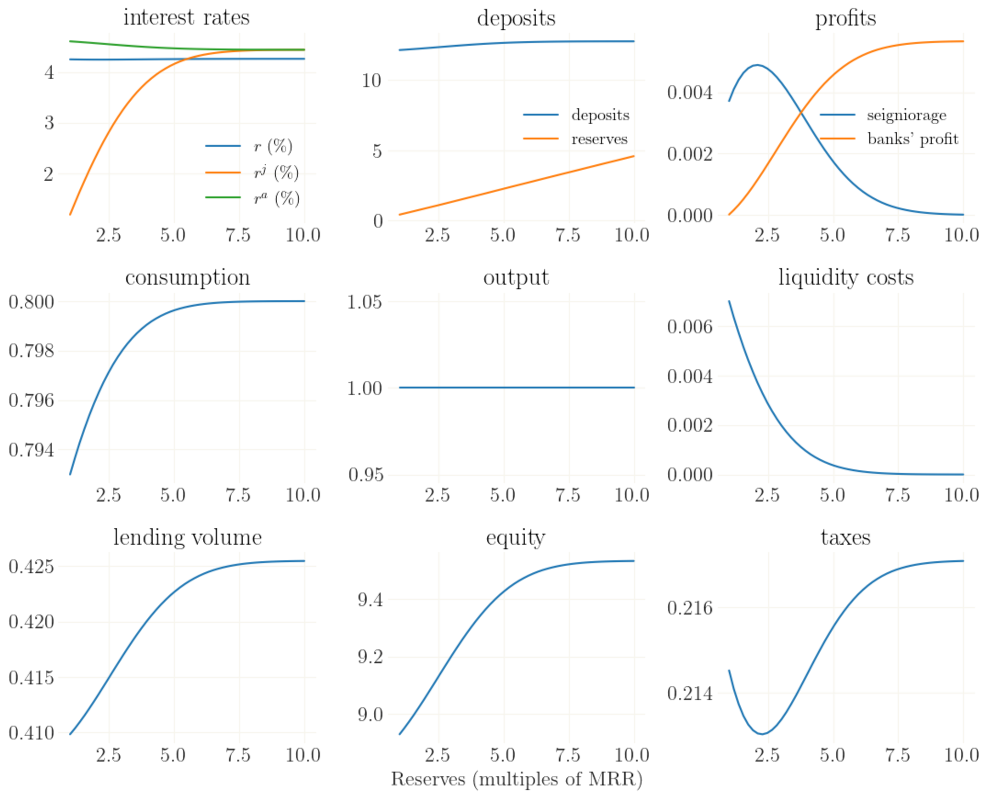

Figure B.12: Steady state values of macroeconomic aggregates over a sequence of equilibria featuring different levels of excess reserves. Taxes are non-distortionary. The MRR is not binding. The levels of all variables are given relative to output.

The government's balanced budget is given by

$$\tau_t + \Phi_t = \left(\frac{R^a_{t-1}}{\pi_t} - 1 \right) b + g_t. \tag{B.9}$$

Figure B.12 confirms that the overall comparison of steady states delivers similar results even if taxation is non-distortionary. The key difference is that output remains fully unaffected by the level of reserves because, via labor supply it is hard linked to the steady state markup and inaffected by taxes. Figure B.13 reiterates the welfare implications, showing that the redistributive effect of lower lump-sum taxes alone is sufficient to generate a significant welfare surplus if seigniorage is higher. Consumption equivalent variations presented in Figure B.14 confirm this and, additionally, indicate that the least well-off share of the population suffers less from a transition from high-to-low excess reserves than in the case with distortive taxation. Likewise, the Figures B.15 and B.16 substantiate the findings from the main body even absent the strong negative effect of a tax increase on output.

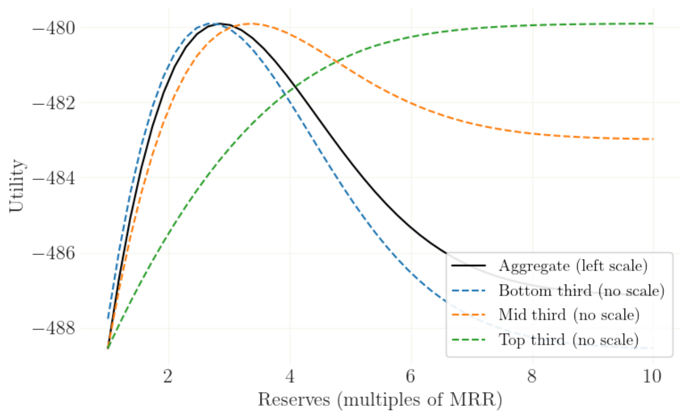

Figure B.13: Utilitarian welfare in a sequence of equilibria featuring different levels of excess reserves (solid line, right axes). The MRR is not binding. The dashed lines represent utility of each third of the distribution of wealth. Dashed lines are given scale free to compare their respective maxima.

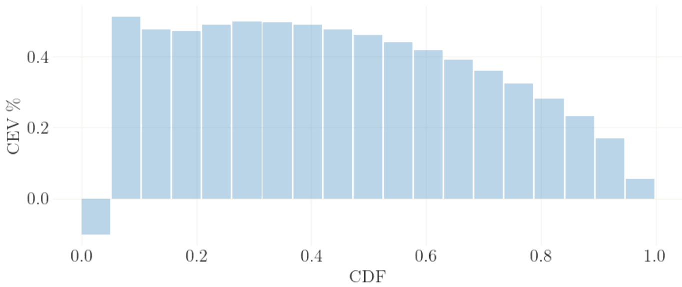

Figure B.14: Consumption equivalent variation across the wealth distribution for a transition from 20 times the MRR to the welfare optimum from Figure 5 at $\frac{J}{\psi D} = 2.833$.

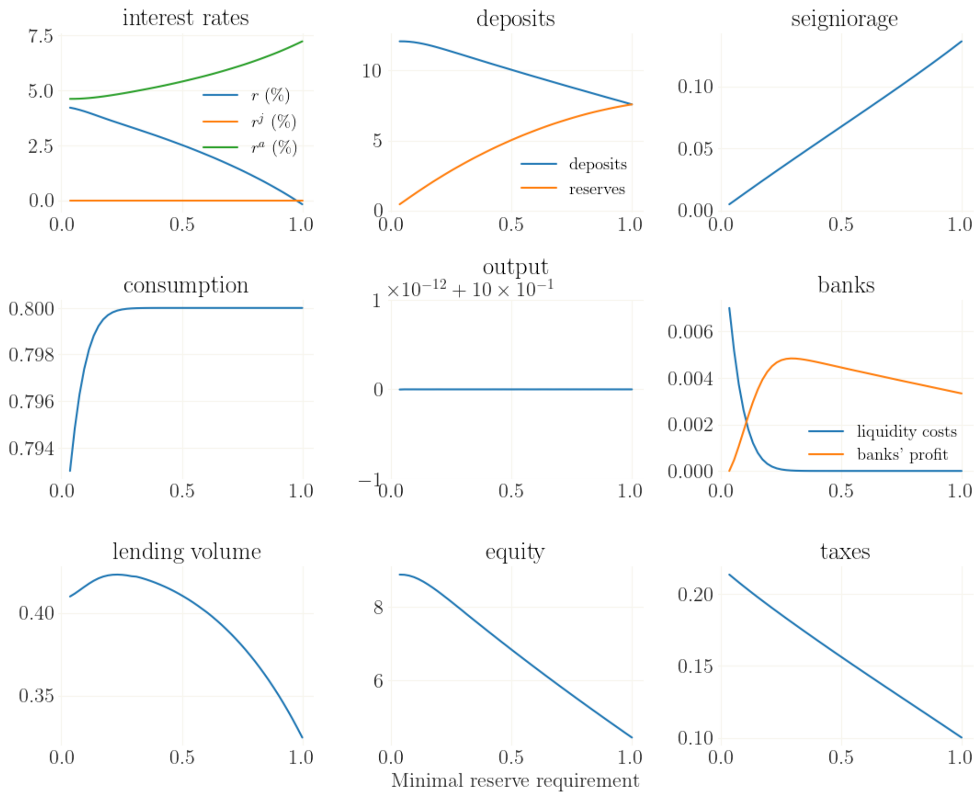

Figure B.15: Steady state values of macroeconomic aggregates over a sequence of equilibria featuring different levels of excess reserves. The levels of all variables are given relative to output.

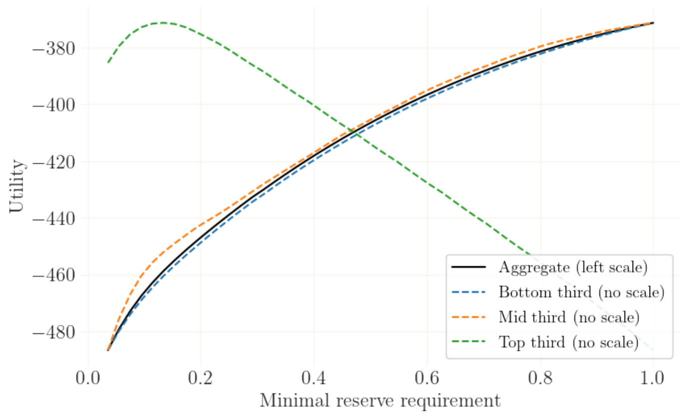

Figure B.16: Utilitarian welfare in a sequence of equilibria featuring different levels of the MRR. The dashed lines represent utility of each third of the distribution of wealth. Dashed lines are given scale free to compare their respective maxima.