Monetary Innovation and Financial Architecture*

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Abstract

Recent research emphasizes the importance of money-like assets in the financial system, as well as the changing nature of the financial architecture, in which banks are no longer dominant. We study innovations to the monetary side of the financial system – such as expansions in money supply, the emergence of privately or publicly issued digital currencies, or non-bank payment providers. We argue that the effects of monetary innovations on investment, financial stability, and welfare are substantially different in a modern financial architecture that includes non-banks. We analyze a general equilibrium model in which the convenience yields on money-like assets, banks' and non-banks' market shares, and the leverage of heterogeneous intermediaries are endogenously determined. Public monetary innovations reduce leverage and reallocate activity from banks to non-banks, increasing financial stability and welfare. Private sector innovations have ambiguous effects that depend on initial market shares, and can reduce stability.

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1 Introduction

In an important contribution, Friedman and Schwartz (1963) provided a monetary history of the United States from 1867-1960, highlighting a close connection between the banking system and the money supply. Among other things, they argued that the collapse of payment systems when banks failed contributed significantly to the costs of financial crises during this period. Although models of financial intermediation often abstract from the monetary role of banks (e.g., Diamond and Dybvig, 1983; Holmstrom and Tirole, 1997; Allen and Gale, 2004), there has been a recent revival of the Friedman-Schwartz perspective. On one hand, an influential empirical literature shows that the financial system produces a variety of liquid assets that earn *convenience yields* because they are close substitutes for money (Krishnamurthy and Vissing-Jorgensen, 2012; Nagel, 2016; Diamond and Van Tassel, 2021). On the other hand, economic models that take this point seriously have been shown to deliver novel implications for the propagation of economic policies and shocks (e.g., Bianchi and Bigio, 2022; Wang, 2024).

Another recent development is that the broader financial architecture is changing dramatically. According to recent data, traditional banks now supply less than half of aggregate credit in the United States (Buchak et al., 2024). Non-bank lenders are set up differently from banks: They are often enabled by new technology, less constrained by regulation, and less reliant on high levels of leverage (e.g., Hachem, 2018; Fuster et al., 2019; Jiang et al., 2020*a*). The growth of the non-bank financial system has wide-ranging consequences for the effects of monetary policy and financial regulation (e.g., Kashyap, Rajan and Stein, 2008; Corbae and D'Erasmo, 2021; Begenau and Landvoigt, 2021).

This paper analyzes the interaction between the modern financial *architecture* – where traditional banks are no longer dominant – with the *monetary* role of the financial system. The importance of this issue becomes apparent in the debate about recent monetary innovations. The advent of cryptocurrencies, particularly stable coins, and "FinTech" payment providers, are significant private innovations, which have largely emerged outside the traditional banking system. In turn, many central banks are considering publicly sponsored innovations, such as the introduction of central bank digital currencies. There is a widespread view that these innovations will compete with and "crowd out" bank deposits (e.g., Bordo and Levin, 2017; Bordo, 2021; Keister and Sanches, 2023; Whited, Wu and Xiao, 2023). At the same time, it is not clear how important these effects are in the modern system, where a large share of traditional banking activity has already shifted to non-bank institutions.

We propose a general equilibrium framework in which both the financial architecture and the money supply are endogenously determined. Our results emphasize that the positive and normative implications of monetary innovation are significantly more nuanced in this environment than in a traditional banking system. Moreover, new money-like assets originating in the private sector can have markedly different effects on lending, financial stability, and welfare relative to public innovations originating in central banks.

We model heterogeneous financial intermediaries, referred to as banks and non-banks,[1] who facilitate risky capital investments (e.g., loans to firms). These investments are financed with intermediaries' own equity and with debt securities issued to households (e.g., bank deposits or non-bank bonds). Intermediaries' debt is potentially risky: markets are incomplete and intermediaries may default if the returns on investment/lending are low. We allow banks to benefit from implicit or explicit government guarantees in the event of default.[2]

Households in our model derive utility from monetary services, as in the classical treatments by Sidrauski (1967) and Brock (1974).[3] We assume that monetary services are a function of households' aggregated holdings of money-like assets, such as bank deposits, non-bank bonds, or direct holdings of central bank/base money. Different types of assets can make different marginal contributions to monetary services, for example, because bank deposits are more convenient than non-bank liabilities in conducting transactions. A central bank controls the supply of base money in order to control the price level and nominal interest rates.

An important departure from the existing literature is that we characterize the endogenous determination of banks' and non-banks' investment and funding structures, which is a non-trivial task in environments with incomplete markets and default. In our model, households' willingness to pay for bank deposits and non-bank liabilities depends on their expected future payoffs – which account for the possibility of default by banks and non-banks – as well as their marginal contribution to monetary services. We show that, as in models without default, bank deposits and non-bank debt are priced to include a convenience yield,

[1]Our formal analysis extends readily to an arbitrary number of intermediary types but, for expositional reasons, we focus throughout the paper on two types, banks and non-banks.

[2]The empirical literature on near-money assets demonstrates that monetary services, and the associated convenience yields, are not exclusively provided by Treasuries, but also by certain classes of liquid risky assets (e.g., Krishnamurthy and Vissing-Jorgensen, 2012). In the case of bank deposits, there is residual risk because government guarantees do not cover all a failing bank's liabilities. A significant fraction of bank deposits in practice is uninsured, and uninsured debt is often the marginal source of finance for banks during an expansion (see, for example, Dávila and Goldstein, 2023; Jiang et al., 2024). Implicit government subsidies such as bailouts are also typically imperfect, covering only up to 10% of banks' asset values in most historical financial crises (e.g., Laeven and Valencia, 2013).

[3]Invoking the arguments in Feenstra (1986), this formulation yields similar conclusions to alternative modeling conventions that generate a demand for liquidity/monetary services, such as cash-in-advance constraints. In our treatment, the important aspect is that banks, non-banks and central banks all have a partial ability – modulated by technology – to satisfy this demand. For this reason, our approach is conceptually similar to a model with search costs (e.g., Lagos and Wright, 2005), in which banks and non-bank debt liabilities can both be used to facilitate transactions. Wang (2024), who follows a similar approach to ours, provides a more detailed discussion.

which acts as a market price that intermediaries take as given. When deciding whether to borrow for investment, banks and non-banks trade off the opportunity to earn convenience yields, as well as possible costs of equity finance, against the deadweight costs associated with potential default.[4]

We show that our model has a clean "separation" property which, despite the incompleteness of markets, makes our analysis tractable. All choices of default, borrowing and investment can be characterized as a function of convenience yields, regardless of any other outcomes on the monetary side of the economy. Therefore, we can define an upward-sloping private supply function of monetary services by banks and non-banks, which depends only on an aggregated price index for monetary services. Finding the general equilibrium then boils down to a simpler fixed-point problem, namely, finding a price index that clears the market for monetary services.

More concretely, convenience yields determine the optimal borrowing choices of banks and non-banks, consistent with the trade-off described above. Moreover, the value of a bank/non-bank evaluated at the optimal level of borrowing determines its willingness to pay for investment opportunities, which ultimately pins down banks' and non-banks' market share of investment/lending in equilibrium. If banks, for instance, start to earn lower convenience yields, then they borrow less in equilibrium, decrease their leverage and, ceteris paribus, account for a smaller share of the aggregate credit supply.

The remainder of the paper focuses on understanding the positive and normative effects of monetary innovations. Given the separation property noted above, one can characterize the response of the financial system to a monetary innovation in terms of convenience yields. A (bank or non-bank) intermediary takes more leverage in response to an innovation if and only if their convenience yield increases in general equilibrium. Moreover, banks increase their market share of lending/investment if and only if convenience yield on deposits, weighted by the overall market value of bank deposits, exceeds the equivalently weighted yield associated with bonds issued by non-bank intermediaries. We use this characterization to derive the consequence of two types of monetary innovations.

We first consider public innovations, such as a central bank policy that targets an expansion of households' direct holdings of base currency, or a technological improvement that increases the efficacy of such direct holdings. One example of this kind would be the introduction of a central bank digital currency. We show that, under mild conditions, this change leads to a reallocation of investments from banks to non-banks. It also leads to a decrease in leverage among all intermediaries. Another consequence of these responses is that financial instability – as measured by the likelihood of bank failure and the expected

[4] Our analysis extends the classical "trade-off" theory of capital structure (Kraus and Litzenberger, 1973; Myers, 1984), which is traditionally applied to real models that abstract from monetary services. Davila and Walther (2020; 2021) provide further examples of the real approach applied to banks and non-banks.

fiscal cost of government guarantees to the financial system – becomes less pronounced after the monetary innovation.

From a practical perspective, these results provide a new perspective on the argument that digital currencies will necessarily "crowd out" financial intermediation. First, while our model predicts that banks' lending/investment falls in response to a public monetary innovation, it also predicts that non-banks will concurrently expand. Second, we highlight another important margin of adjustment, namely, that leverage falls endogenously across the financial system when the central bank currency competes with bank deposits. This insight is complementary to recent work by Whited, Wu and Xiao (2023), who emphasize banks' increased reliance on non-deposit funding in response to central bank digital currencies. Indeed, while Whited, Wu and Xiao argue that banks may become less stable when a new currency competes with deposits, our analysis points out that they can also become more stable because their leverage and their systemic importance both decrease in general equilibrium.

Next, we turn to the consequences of private monetary innovation, which we view as a technological improvement that increases the efficacy of bonds issued by non-bank financial institutions in the provision of monetary services. Examples of this kind would include the introduction of a stable coin, backed by real assets, that can be used for payments, or "FinTech" payment providers such as Alipay, PayPal, or Stripe.[5]

Perhaps surprisingly, the equilibrium responses in our model are potentially quite different from the case of public innovation. One source of this difference is the contrast between the direct/partial equilibrium response to innovation, and the general equilibrium adjustments that follow it. The partial equilibrium effect of the innovation is that non-banks enjoy a larger convenience yield, all else equal, and therefore expand their supply of bonds – we refer to this mechanism as a debt valuation effect. By contrast, the general equilibrium adjustment arises from a change in the price of capital goods, which rises due to non-banks' increased willingness to pay for investments. This change triggers a reallocation effect, whereby investment/lending migrates from banks to non-banks. Since banks in our analysis are initially the main suppliers of monetary services, the reallocation effect leads to a contraction in the overall money supply. Depending on which effect dominates, the overall price of monetary services can therefore either fall or increase in response to a private monetary innovation. Likewise, the consequences for patterns of leverage, banks' market share, and financial stability are ambiguous.

Our final proposition considers the welfare effects of monetary innovations. We derive an interpretable formula that decomposes the marginal welfare effects of (private or public)

[5] Many of the firms driving these innovations in practice, like non-banks in our model, have expanded into consumer and business lending markets, and make risky investments.

monetary innovations into two components. The first component, by which monetary innovations typically increase welfare, captures effects related to the classical Friedman rule (e.g., Friedman and Bordo, 2017). The Friedman rule is based on the insight that increases in the supply of monetary services improve welfare at the margin as long as households' demand has not been saturated. In our context, an innovation that increases the efficacy of monetary service provision typically raises welfare via this channel. An additional, more subtle welfare effect is present in our model because the Friedman effect can be either amplified or attenuated by the endogenous response of deposit/bond prices in equilibrium. This feature arises due to a pecuniary externality in the provision of monetary services, which intermediaries in the model do not take into account when choosing optimal leverage and investment.

The second component of marginal welfare effects in our model arises due to the endogenous adjustment of the financial architecture, as measured by banks' and non-banks' leverage and investment choices. At the margin, these adjustments affect welfare if and only if they either increase or decrease the fiscal burden of the government guarantees enjoyed by banks. Under standard assumptions, this welfare effect is positive whenever banks reduce their leverage, or whenever banks give up some of their market share to non-banks. Thus, given our positive results described above, a public monetary innovation such as the expansion of central bank digital currency, has unambiguously positive welfare effects. By contrast, as discussed previously, a private monetary innovation can either expand or contract the money supply in general equilibrium, leading to ex ante ambiguous adjustments in leverage, investment, and welfare patterns. However, our formula gives a clear indication of how one could, in principle, form a quantitative assessment of the overall welfare effect.[6] It further complements the work of Stein (2012), who showed that monetary policy can have non-trivial welfare effects in economies with bank-based intermediation.

In terms of the applications of our model, it is worth pausing on this result because it stands in contrast to the practical discussion surrounding digital currencies. This debate frequently starts with the premise that the "crowding out" of banks' activities constitutes a social cost of these innovations. However, in a micro-founded general equilibrium model, this intuition is possibly incomplete. For instance, even if banks are much more efficient than non-banks at lending, owing perhaps to a complementarity between deposits and loans (e.g., Kashyap, Rajan and Stein, 2002), equilibrium prices and allocations will correctly balance this difference. Thus, to a first-order approximation, a marginal reallocation of lending has

[6] The class of economies we study operates at a second-best allocation in equilibrium, because the government is not able to perfectly correct the externalities associated with government guarantees for banks. Thus, our result is an instance of the more general principles discussed by Dávila and Walther (2021): The marginal welfare effects of innovations are driven by "leakage elasticities" that measure the general equilibrium responses of imperfectly regulated decisions.

no welfare effect when starting from this equilibrium, unless the adjustment is associated with uncorrected market failures/externalities. Of course, this "envelope" argument is standard in welfare economics but, given the emphasis on crowding out in the current debate, it bears repetition. In addition to our analysis, in which the envelope argument fails due to fiscal and pecuniary externalities, Keister and Sanches (2023) have pointed out that it can fail due to binding financing/collateral constraints.

The final part of the paper provides a numerical illustration of our model. The purpose of this section is not to provide a full structural model of the financial industry, but rather to illustrate the potential magnitude of the effects highlighted by our theoretical results. When we calibrate the model's parameters to standard values from the literature on corporate finance and banking, we find that it is able to match salient (untargeted) features of the US financial architecture. Starting from this baseline calibration, we then explore the implications of public and private monetary innovations. A public monetary innovation, depending on its magnitude, has the potential to increase the market share of non-banks by around 10 percentage points, and to significantly reduce the amount of leverage that banks choose to take. In this scenario, the innovation triggers a reduction in the expected fiscal cost of bank government guarantees. This effect is driven both by the reallocation of investments from banks to non-banks, and by the equilibrium adjustment of leverage patterns.

For private innovations, we consider two contrasting scenarios. In the first scenario, we assume that non-banks' market share is large initially, consistent with our baseline calibration to the US economy. Then, non-banks experience private monetary innovation and begin competing with banks for monetary services. In this scenario, the debt valuation effect of private innovation is dominant, the supply of monetary services expands, and the resulting patterns in financial architecture and stability are similar to those induced by public innovation. In the second scenario, we assume that non-banks' market share is initially small. One can heuristically interpret this scenario as one in which a new group of entrants, such as FinTech firms that currently do not account for a large share of the credit supply, begin to provide payment services.[7] In this case, the reallocation effect of private innovation is initially dominant, leading to a hump-shaped response in the price of monetary services. Accordingly, financial stability initially decreases, in the sense that banks take on more leverage and become more likely to fail. However, as non-banks become more established, the debt valuation effect again gains importance and financial stability improves.

Related literature. Our paper connects to a growing literature that follows Friedman and Schwartz (1963) in emphasizing the links between money markets and financial interme-

[7] Another interpretation is that this scenario represents more bank-reliant systems such as some European economies.

diation. Diamond and Rajan (2006) and Allen, Carletti and Gale (2014) introduce money into canonical models of financial intermediation, and highlight the novel effects of monetary policy adjustments when bank deposit contracts are written in nominal terms.[8] We abstract from monetary policy shocks, assuming that the central bank commits to constant inflation, and instead highlight the consequences of monetary innovations. Other recent contributions study the economic implications of convenience yields on liquid assets in the banking industry, for instance, in terms of the consequences of declining interest rates for bank lending (Wang, 2024), the effects of different modes for the implementation of monetary policy (Piazzesi, Rogers and Schneider, 2019), and the transmission of monetary policy in an imperfectly competitive banking industry (e.g., Drechsler, Savov and Schnabl, 2017; Wang et al., 2022; Abadi, Brunnermeier and Koby, 2023). Another strand of work including Kashyap, Rajan and Stein (2002), Bianchi and Bigio (2022) and Li and Li (2024) studies the complementarities/tensions between liquidity provision via deposits, payments, and lending.

A related literature studies the complexities of the financial system, money and repo markets, and monetary policy implementation. d'Avernas and Vandeweyer (2023) and Eisenschmidt, Ma and Zhang (2024), among others, study the details of monetary policy transmission in money markets in which both banks and non-banks are active. Ennis (2018), Afonso et al. (2022), and Acharya and Rajan (2024), among others, analyze the consequences of the post-2008 monetary regime, in which there was a large increase in the supply of reserves by central banks. Our model, by contrast, focuses on the endogenous leverage and investment choices of banks and non-banks.

We further build on the established body of work on the interactions between banks and non-banks – this is a large literature which is reviewed in detail, for example, in Adrian and Ashcraft (2016), Allen and Walther (2021) and Dávila and Walther (2021). Early contributions by Gennaioli, Shleifer and Vishny (2013), Plantin (2015), and Moreira and Savov (2017) develop theories that highlight the nature of regulatory arbitrage between banks and non-banks, and emphasize that this can exacerbate financial fragility. A more positive assessment is provided by Ordoñez (2018) who, in common with our normative analysis, emphasizes the potential welfare benefits of a shadow banking system, which in his model are driven by the ability to avoid problems associated with imperfect regulation. Begenau and Landvoigt (2021) provide a quantitative real model in which banks' and non-banks' deposits attract convenience yields. Hachem and Song (2021) highlight potential unintended consequences of regulation via reallocation effects between banks and shadow banks in the interbank market.

Finally, our results relate to recent work on monetary innovations, such as the introduc-

[8] Fernández-Villaverde, Schilling and Uhlig (2024), building on Allen, Carletti and Gale (2014), discuss the problem of bank runs, from which we abstract in our model, in the presence of central bank digital currencies.

tion of central bank/private digital currencies. The literature on digital currencies is already too large to review in detail. Ahnert et al. (2022) provide an overview of the large body of work on central bank digital currencies, including papers that share our focus on crowding out of bank deposits in competitive markets (e.g., Keister and Sanches, 2023; Whited, Wu and Xiao, 2023). Chiu et al. (2023) emphasize the connection between central bank digital currency and bank market power. Biais et al. (2023) review the literature on private digital currencies and cryptocurrencies. In principle, none of our analysis depends on monetary innovations being of a digital or cryptographic nature. A body of work delineates conditions under which different protocols, such as Bitcoin or stable coins, lead to efficiency of transaction/monetary services (e.g., Easley, O'Hara and Basu, 2019; Huberman, Leshno and Moallemi, 2021; Ma, Zeng and Zhang, 2023), which we take as given in our analysis. Recent contributions including Ma, Xiao and Zeng (2024) also analyze the possibility of deposit-like liquidity provision by non-bank institutions such as mutual funds. In this context, Brunnermeier and Niepelt (2019) provide an important irrelevance result as a benchmark: Monetary innovations can be neutralized by a government that has access to a full set of corrective tools, which it can use to counteract equilibrium reallocations.

The remainder of the paper is structured as follows: Section 2 sets up our baseline model, as well as discussing various possible extensions, and characterizes the equilibrium. Section 3 analyzes the positive and normative effects of financial innovations. Section 4 presents our numerical illustration, and Section 5 concludes.

2 Model

We propose a general but tractable model of financial architecture in a monetary economy. The analysis is geared towards understanding how monetary innovations impact the activities of banks and non-bank financial intermediaries, financial stability, and welfare. In this section, we begin by describing the model environment in Section 2.1, remark on possible extensions at the end of that section, and then provide characterizations of equilibrium quantities and prices in Section 2.2.

2.1 Environment

Agents, preferences and endowments. There are two dates $t \in \{0, 1\}$. The state of nature $s \in [\underline{s}, \bar{s}]$ becomes public information at $t = 1$, and is distributed according to the cumulative distribution $F(s)$, with density $f(s) > 0$. There is a single consumption good and fiat/base money that serves as numeraire. The price of consumption is p_0 at date 0, and $p_1(s)$ at date 1 in state s. There is a unit measure of households indexed by H, and unit measures of two types of financial intermediaries $j \in \{B, N\}$, where we write B for traditional banks/investors, and N for non-bank intermediaries/investors. Finally, there is also a government that issues sovereign bonds, engages in taxation and conducts monetary policy.

All agents are risk-neutral. The preferences of an intermediary of type $j \in \{B, N\}$ are given by

$$U^j = c_0^j + \beta^j \int_{\underline{s}}^{\bar{s}} c_1^j(s)\, dF(s) \tag{1}$$

where c_0^j is consumption at date 0 and $c_1^j(s)$ is consumption at date 1 in state s, and $\beta^j \in (0,1)$ is a discount factor. Intermediaries have endowments of n_0^j units of the consumption good at date 0, and $n_1^j(s)$ units of the consumption good at date 1 in state s.

The preferences of a household are given by

$$U^H = c_0^H + \beta^H \int c_1^H(s)\, dF(s) + v\left(\frac{\bar{m}}{p_0}\right) \tag{2}$$

where c_0^H and $c_1^H(s)$ denote consumption, $\bar{m}/p_0$ denotes real money balances, defined below, and $\beta^H \in (0,1)$ is households' discount factor. We assume throughout that $\beta^H > \beta^B = \beta^N$, so that banks and non-banks are less patient than households. Households have endowments of n_0^H units of the consumption good at date 0, and $n_1^H(s)$ units of the consumption good at date 1 in state s. Households also have an endowment of one unit of a capital good that can be used for investment at date 0, and is traded between households and intermediaries at an endogenous price p^K.

Monetary services. As in the canonical "money in utility" model (e.g., Sidrauski, 1967; Brock, 1974), households value monetary services according to a strictly concave function $v(.)$. We define money holdings $\bar{m}$ as an aggregate of heterogeneous securities:

$$\bar{m} = \theta^B d^B + \theta^N d^N + \theta^C d^C \tag{3}$$

where d^B and d^N are date 0 investment in banks' and non-banks' deposits/bonds, which we define in detail below, and d^C is direct investment into central bank money by households. As will become clear below, we do not restrict the nominal yield on base money to zero. Therefore, base money is not necessarily interpreted as physical cash in our model. Rather, d^C can also represent innovations such as households' direct holdings of central bank digital currency or reserves, perhaps facilitated by (unmodeled) intermediaries that collaborate with the central bank. Our main qualitative results go through, at the cost of more cumbersome exposition, when a non-linear aggregator (e.g., a CES aggregator as in Wang (2024)) is used to define $\bar{m}$.[9]

The parameters θ^B, θ^N and θ^M denote the relative usefulness/quality of bank and non-bank debt liabilities and base money in providing monetary services. As a baseline, we assume throughout that banks are initially more effective at supplying monetary services than non-banks, with $\theta^B > \theta^N$. We use this formulation to study several kinds of monetary innovation. On one hand, consider a public innovation such as the introduction of central bank (digital) currency. This change can be modeled as an expansion in households' direct holdings of central bank money d^C, because households were previously unable to have an account at the central bank and are enabled to do so by the innovation, or as an increase in the usefulness θ^C of such holdings, because new technology increases the convenience of central bank money for making payments. On the other hand, a private innovation such as the entry of non-bank "FinTech" payment providers can be modeled as an increase in the parameter θ^N associated with non-banks.

Investment technology. Intermediaries $j \in \{B, N\}$ invest in productive capital k^j at date 0. In reduced form, one can interpret these investments as loans that banks and non-banks grant to firms and households. Capital investments incur an additional adjustment cost of $\Phi^j\left(k^j\right)$ units of consumption at date 0, where $\Phi^j(.)$ is strictly convex. At date 1, the investments of intermediary type j yield state-contingent return of $s \cdot k^j$ units of the consumption good. Therefore, the state of the world s measures the return to capital investments.

Notice that banks and non-banks compete in the market for capital goods, which are in fixed (unit) supply via households' endowments. We make this stark assumption in order to focus our analysis on financial architecture, i.e., the allocation of capital investments between bank and non-bank intermediaries. In Section 3, we comment on the implications of allowing for an upward-sloping supply curve for capital goods.

Financial contracts and government guarantees. Intermediaries $j \in \{B, N\}$ issue deposits/bonds with nominal face value $b^j k^j$. Therefore, b^j is the promised repayment per unit of capital, and can be interpreted as the intermediary's debt-to-asset ratio. The amount of debt finance raised is denoted $Q^j\left(b^j\right)k^j$, where $Q^j\left(b^j\right)$ is the per-unit market value of debt at date 0, which will be determined endogenously in equilibrium.[10] At date 1, intermediaries have the option to either repay their debt or default. In case of default, households seize the capital investment and any government transfer. Households are able

[9] The key to tractability in our model is the fact that money market equilibrium is summarized by a single price index, denoted by λ in Proposition 2 below.

[10] In the terminology of Geanakoplos (2016), $Q^j\left(b^j\right)$ defines a *credit surface*, on which different debt prices are associated with different debt-to-asset ratios b^j.

to recover only a fraction ϕ of the returns to capital investments. The remaining fraction $1-\phi$ captures the deadweight losses associated with default.

In addition, banks receive a real government transfer $t^B\left(b^B,s\right)$ per unit of capital investments from the government, which we take as exogenous. This specification can capture, for instance, situations in which all agents implicitly expect the government to provide ex-post assistance to levered intermediaries (e.g., when the government does not have the ability to commit to refusing bailouts), or situations in which a pre-specified explicit guarantee is made. We assume that $0 \leq \frac{\partial t^B}{\partial b^B} \leq 1$. The first inequality reflects that, all else equal, more levered banks receive weakly larger government guarantees because they are more likely to be in financial distress. The second inequality ensures that government transfers increase less than one-for-one with the debt-to-asset ratio. Under this condition, an increase in bank leverage never reduces the likelihood of default. We note that the proofs of our main results also allow for government guarantees for non-banks, which our baseline model sets to zero for simplicity. The important aspect of the model is that banks, on average, enjoy larger guarantees than non-banks.

Budget constraints. Intermediaries' budget constraints are given by

$$p\left(c_0^j+\Phi\left(k^j\right)\right)+p^K k^j=p_0 n_0^j+Q^j\left(b^j\right)k^j, \tag{4}$$

$$p_1\left(s\right)c_1^j\left(s\right)=p_1\left(s\right)n_1^j\left(s\right)+\mathcal{E}^j\left(b^j,s\right)k^j,\ j\in\{B,N\} \tag{5}$$

The intermediary pays for her consumption, adjustment costs and capital purchases at date 0. This expenditure is financed by her own endowment n_0^j of consumption, as well as the amount raised through borrowing via the market value of debt $Q^j\left(b^j\right)$. Consumption at date 1 is financed by endowments and the nominal value of residual/equity claims on capital investments, which we define per unit of capital as

$$\mathcal{E}^j\left(b^j,s\right)=\max\left\{p_1\left(s\right)\left(\rho^j\left(s\right)+t^j\left(b^j,s\right)\right)-b^j,0\right\} \tag{6}$$

This definition takes into account that it is optimal to exercise the option to default whenever the promised nominal repayment b_0^j exceeds the nominal value $p_1\left(s\right)\left(s+t^j\left(b^j,s\right)\right)$ of the assets that can be seized by households. Notice that we are imposing market segmentation: Households are able to fund banks and non-banks only with debt investments, and any equity contribution must come from intermediaries' own endowments.

Households' budget constraints are given by

$$p_0 c_0^H + a + d^C + d^B + d^N = p_0 n_0^H - T_0 + p^K \tag{7}$$

$$p_1(s)\, c_1^H(s) = p_1(s)\, n_1^H(s) + \left(1 + i^C\right) m + (1+i)\, a + \sum_{j \in \{B,N\}} x^j \mathcal{R}^j\left(b^j; s\right) k^j \tag{8}$$

Households at date 0 spend on consumption, their holdings of base money m and government bonds a, as well as their nominal investments d^B and d^N in banks' and non-banks' debt liabilities. Concretely, these investments are made by purchasing fractions x^B and x^N of banks' and non-banks' issued debt at their market prices, so that $d^j = x^j Q\left(b^j\right) k^j$ for $j \in \{B, N\}$. This expenditure is covered by endowments net of taxes T_0, as well as the receipts p^K from selling capital goods. Anticipating our equilibrium definition below, market clearing will require that households optimally choose $x^B = x^N = 1$. At date 1, households' wealth available for consumption is determined by endowments, the return on holding of base money with nominal interest rate i^C, on government bonds with nominal interest rate i, and the nominal repayments on the fractions x^B and x^N of bank and non-bank, which we define per unit of capital as

$$\mathcal{R}^j\left(b^j, s\right) = \begin{cases} b^j, & s \in \mathcal{N}^j, \\ p_1(s)\left(\phi s + t^j\left(b^j, s\right)\right), & s \in \mathcal{D}^j. \end{cases} \tag{9}$$

where $\mathcal{D}^j$ stands for the set of states in which an intermediary of type j defaults, and $\mathcal{N}^j$ for the set of states in which she does not default.

Government policy. The government runs a balanced budget in each period. Hence, taxes at date 0 are given by $T_0 = -\left(a^s + d^s\right)$, where a^s and d^s denote the supply of government bonds and base money. Taxes at date 1 are given by

$$T_1(s) = (1+i)\, a^s + \left(1 + i^C\right) d^s + (1+\kappa)\, t^B\left(b^B, s\right) k^B$$

and cover the repayment of debt and monetary liabilities, as well as the cost of government guarantees for banks. We scale the last term by $(1+\kappa)$, where $\kappa \geq 0$ is a parameter capturing the deadweight costs associated with bailouts.

Monetary policy sets the interest rate i^C and the quantity d^s of base money. The central bank's policies must be consistent with market clearing. Therefore, the central bank has one effective free choice – either i^C or d^s – while the other is determined by household demand.

Equilibrium definition. In this economy, an equilibrium is a profile of intermediary choices $\left\{c_0^j, c_1^j(.), b^j, k^j\right\}$, a profile of household choices $\left\{c_0^H, c_1^H(.), x^B, x^N, a, d^C\right\}$, goods prices $\{p_0, p_1(s)\}$, a capital price p^K, debt pricing schedules $Q^j\left(b^j\right)$, and an interest rate i, given the monetary-fiscal policy regime $\left\{a^s, d^s, i^C\right\}$, satisfying the following:

1. Households maximize their expected utility subject to their budget constraints, taking prices and intermediaries' choices as given. Intermediaries maximize their expected utility subject to their budget constraints, taking prices and the pricing schedules $Q^j(.)$ as given.[11]

2. The markets clear for i) intermediary debt with $x^j = 1$, ii) base money with $d^C = d^s$, iii) government bonds with $a = a^s$, and iv) capital goods with $k^B + k^N = 1$.

In the remainder of the paper we focus on equilibria with a constant rate of inflation $1+\pi = p_1(s)/p_0$ for all s. We effectively assume that the central bank has commitment power to ensure a stable price level at date 1. We normalize the initial price level to $p_0 = 1$.[12] The assumption of a constant rate of inflation, which does not depend on s, is not without loss of generality. In particular, intermediaries and households trade debt securities in incomplete markets with the possibility of default. In this context, state-contingent inflation can affect the span of traded assets and therefore the equilibrium allocations, with possible additional implications for financial stability. This feature has been analyzed in detail, for example, by Allen, Carletti and Gale (2014) and Schilling, Fernández-Villaverde and Uhlig (2024). In order to shorten the exposition in this paper, we focus on a fixed rate of inflation and emphasize the implications of monetary innovations, which arise even in the absence of the interactions between inflation targeting and financial stability.

Remarks on the environment. We make three remarks on the model setup. First, we model two types of intermediaries – banks and non-banks – who have access to real capital investments and also provide monetary services to households. Banks and non-banks are different in the parameters θ^B and θ^N that define "money-likeness" associated with debt liabilities, in generosity of government guarantees, and potentially heterogeneous adjustment costs $\Phi^j\left(k^j\right)$. It is useful to note that our results extend without major modifications to economies with further sources of heterogeneity, such as many types of intermediary, different

[11]Notice that all intermediaries in equilibrium take the function $Q^j(b^j)$ as given, but realize that their individual choice of leverage b^j affects the pricing of their debt because it can change the probability of their default. This solution concept is standard in general equilibrium models with default (e.g., Dubey, Geanakoplos and Shubik, 2005; Dávila and Walther, 2023).

[12]For instance, in the spirit of the treatment of inflation targeting in infinite horizon macroeconomic models, one could introduce money in the utility or a cash-in-advance constraint at date 1, and allow the government to commit to a policy rule that adjusts the money supply at date 1 in order to guarantee a constant rate of inflation (e.g., Allen, Carletti and Gale, 2014).

returns to capital investment, preferences/discount factors, or the deadweight losses from default being different across intermediary types. We restrict ourselves to our baseline model in order to clarify the exposition. Moreover, our quantitative illustration in Section 4 demonstrates that this model is able to reflect some of the salient empirical differences between banks and non-banks.

Second, we have made the stark assumption that intermediaries can invest only in risky capital/loans. In other words, it is not possible to set up a "narrow bank" by issuing risk-free deposits/bonds that are fully backed by government bonds. A friction of this kind is necessary in order to avoid the counterfactual predictions that either i) deposit spreads (i.e., the difference between the yield on bank deposits and government bonds) are zero, or ii) banks wish to supply an infinite amount of deposits. In the related literature, several kinds of frictions have been explored, such as an exogenous/regulatory limit on the deposit rate (e.g., Nagel, 2016), imperfect competition (e.g., Drechsler, Savov and Schnabl, 2016), or liquidity or leverage constraints in banks (e.g., d'Avernas and Vandeweyer, 2023; Wang, 2024). Our qualitative results would be robust to introducing various frictions. Our assumption of risky capital investments is parsimonious and generates endogenous limits to the supply of deposits, which then facilitate both a finite supply of deposits and a positive deposit spread in equilibrium.

Finally, our baseline model allows intermediaries freely to chose their investments k^j and leverage b^j. It is straightforward to introduce regulatory constraints on b^j for banks, such as capital requirements, or equivalently Pigouvian taxes on bank borrowing. However, banks in practice hold significant capital buffers over regulatory minima (e.g., Begenau et al., 2020). We therefore assume as a baseline that such constraints are not binding – i.e., that the Pigouvian tax on borrowing is zero. When the Pigouvian tax is set at its optimal level rather than zero, one can show that our positive results on increases/decreases in bank borrowing (Propositions 3 and 4, for example) continue to go through. Moreover, the normative analysis in Proposition 5 can easily be adjusted for perfect/imperfect corrective regulations using the general approach in Dávila and Walther (2021).

2.2 Equilibrium Characterization

In this subsection, we derive properties of equilibrium prices and allocations that guide intuition and facilitate our main results in the next section. We begin our characterization by deriving the properties of equilibrium asset prices. In common with classical monetary models (e.g., Woodford, 2003, chapter 2), optimization by households in our model implies the following condition, which defines the convenience yield Δ^C on base money:

$$v'(\bar{m})\,\theta^C = \frac{i - i^C}{1+i} \equiv \Delta^C \tag{10}$$

The left-hand side is a household's marginal utility from holding an additional unit of base money. The right-hand side is the associated marginal opportunity cost, as measured by the discounted difference between the interest rate on government bonds and base money. In addition, the monetary aggregate $\bar{m}$ in our model contains near-money securities issued by banks and non-banks. The equilibrium prices of these securities must take into account their contribution to households' utility from holding money.

However, this relationship is more complex than in the classical model because households anticipate possible default by intermediaries and/or government guarantees. The following result characterizes equilibrium asset prices:

Lemma 1. *[Equilibrium Asset Prices] In any equilibrium, there exist nominal discount rates i^B for banks and i^N for non-banks, such that the market value of intermediary debt at date 0 is given by the following pricing schedule:*

$$Q^j\left(b^j\right) = \frac{1}{1+i^j}\int \mathcal{R}^j\left(b^j, s\right) dF\left(s\right),\ j \in \{B, N\}, \tag{11}$$

where $\mathcal{R}^j\left(b^j, s\right)$ is the realized debt repayment in state s, as defined in Equation (9). Moreover, discount rates satisfy the relationship

$$v'\left(\bar{m}\right)\theta^j = \frac{i - i^j}{1+i} \equiv \Delta^j,\ j \in \{B, N\}. \tag{12}$$

Each individual bank and non-bank takes Δ^j, and therefore i^j, as given in equilibrium.

The first part of Lemma 1 shows that, the date 0 nominal value $Q^j\left(b^j\right)$ of bank and non-bank debt is given by the expected repayment $\mathcal{R}^j\left(b^j, s\right)$, discounted by a fixed nominal rate i^j. Equation (12) characterizes the corresponding convenience yield for debt issued by banks (Δ^B) and non-banks (Δ^N). As in Equation (10), the left-hand side measures the marginal contribution of banks' or non-banks' securities to monetary services, which is set equal to the convenience yield on the right-hand side. For example, if non-bank securities are not considered money-like, with $\theta^N = 0$, then their cash flows will be discounted at the same rate i as standard bonds. More generally, Equation (12) shows that the convenience yield Δ^j earned by any intermediary depends only on the parameter θ^j and the marginal utility of aggregate money holdings $v'\left(\bar{m}\right)$. Therefore, each individual intermediary, whose choices do not affect $\bar{m}$, takes convenience yields as given.

This insight permits a characterization of intermediaries' optimal choices in equilibrium, which we state in the next result:

Proposition 1. *[Equilibrium Characterization: Financial Architecture] In any equilibrium, the optimal choices of investment/lending k^j and borrowing b^j by banks ($j = B$) and non-*

banks ($j = N$) solve the following problem:

$$\max_{b^j, k^j} \left[V^j \left(b^j, \Delta^j \right) - p^K \right] k^j - \Phi^j \left(k^j \right), \; j \in \{B, N\} \tag{13}$$

where Δ^j is the convenience yield for intermediaries of type $j \in \{B, N\}$, defined in Lemma 1. The function $V^j \left(b^j, \Delta^j \right)$ measures the value of the intermediary's firm per unit of capital, and is given by

$$V^j \left(b^j, \Delta^j \right) = \underbrace{\beta^j \int \frac{\mathcal{E}^j \left(b^j, s \right)}{1+\pi} dF(s)}_{equity} + \underbrace{\frac{\beta^H}{1-\Delta^j} \int \frac{\mathcal{R}^j \left(b^j, s \right)}{1+\pi} dF(s)}_{debt \, + \, monetary \, services}, \; j \in \{B, N\} \tag{14}$$

Moreover, the equilibrium price p^K of capital investments is the value that ensures $k^B + k^N = 1$ at the solution of the maximization problem in Equation (13).

Proposition 1 fully characterizes the financial architecture, i.e., the investment and borrowing choices of banks (k^B and b^B) as well as non-banks (k^N and b^N). The maximization problem of banks and non-banks reduces to the relatively simple problem of maximizing the value of the firm. For both banks ($j = B$) and non-banks ($j = B$), the function $V^j \left(b^j, \Delta^j \right)$ denotes the value of the firm per unit of capital as a function of its borrowing choice b^j and the associated convenience yield Δ^j. Equation (13) shows that intermediaries maximize this value, net of the costs of capital purchases and adjustment. Equation (14) shows that the relevant value function is given by the combined expected value of the equity and debt tranches. The value of the equity tranche is equal to the real expected value of the payoffs $\mathcal{E}^j \left(b^j, s \right)$ to the intermediary, discounted by the intermediary's internal discount rate β^j. The value of the debt tranche is equal to real expected value of the payoffs $\mathcal{R}^j \left(b^j, s \right)$ to households, discounted by the factor $\frac{\beta^H}{1-\Delta^j}$. This discount factor simultaneously values the cash-flow and monetary services that households derive from holding securities issued by banks ($j = B$) or non-banks ($j = N$).

Proposition 1 implies a stark separation property, which facilitates our analysis below. Indeed, the choices of investment k^j and borrowing b^j by intermediaries depend on the monetary side of the economy *only* via the convenience yields Δ^B and Δ^N, which are taken as given by individual intermediaries. Indeed, for given convenience yields, intermediaries' optimization problem in Equation (13) implies the following necessary conditions for equilibrium choices:

$$V^j \left(b^j, \Delta^j \right) = p^K + \Phi^{j\prime} \left(k^j \right), \tag{15}$$

$$\frac{\partial V^j \left(b^j, \Delta^j \right)}{\partial b^j} = 0 \tag{16}$$

The first condition shows that investment is determined by a generalization of Tobin's Q theory, which takes into account the possibility of default and monetary services. Each intermediary sets the value of the firm per unit of capital equal to the price of capital plus marginal adjustment costs. The second condition shows that banks and non-banks choose borrowing b^j in order to maximize this average value.

Under mild conditions, the problem of banks and non-banks has an interior solution for optimal borrowing/leverage b^j. This feature arises because of three violations of the Modigliani and Miller (1958) conditions in our model. First, there are segmented markets, and equity-holders are less patient than debt investors, which makes equity finance more costly than debt finance. Second, an additional incentive to use debt finance arises if the intermediary is able to earn a convenience yield $\Delta^j > 0$ on its debt securities. Finally, the possibility of default, with the associated deadweight costs, generates a marginal cost to increasing leverage, and ensures that the optimal amount of leverage is finite.

Figure 1 illustrates the optimal choices made by banks and non-banks. We draw the value function $V^j\left(b^j, \Delta^j\right)$ of intermediaries on the vertical axis as a function of their borrowing (or debt/asset ratio b^j) on the horizontal axis. The two uppermost curves (in blue and red) represent a bank's value function $V^B(.)$ for two different values of the convenience yield, a low yield Δ and a high yield $\Delta' > \Delta$. The higher convenience yield has two effects. First, the curve associated with the high yield has a maximum at a higher level of borrowing b^j, so that a bank who can earn the convenience yield Δ' takes more leverage. Second, the curve associated with the high yield is shifted upwards, so that it's maximized value is larger. Thus, a bank who can earn the high convenience yield Δ' will invest/lend more.[13]

The lowest curve in Figure 1 shows the value function $V^N(.)$ of a non-bank who earns the low convenience yield Δ. Relative to a bank that earns the same yield, this curve is again shifted downwards and reaches its maximum at a lower level of leverage. This feature arises in our model because non-banks do not benefit from government guarantees.[14]

Having characterized the determinants of financial architecture for a given set of convenience yields, we now state the conditions for equilibrium on the monetary side of the economy, which determine the market-clearing convenience yields Δ^B and Δ^N:

Proposition 2. *[Equilibrium Characterization: Monetary Choices] In any equilibrium, there is a constant λ, measuring the shadow price of monetary services, such that the convenience*

[13]For instance, with quadratic adjustment costs $\Phi^j\left(k^j\right) = \frac{\psi}{2}\left(k^j\right)^2$, the optimal investment of an intermediary is $k^j = \frac{1}{\psi}\left(\max_{b^j} V^B\left(b^j, \Delta^j\right) - c^j - p^K\right)$, and therefore proportional to the maximized value of $V^B(.)$.

[14]Lemmas 4 and 5 in the appendix provide a formal analysis of this and related properties of banks' and non-banks' value functions. Indeed, the proofs of these results rely only on the fact that non-banks enjoy strictly smaller government guarantees than banks – non-bank government guarantees do not need to be zero.

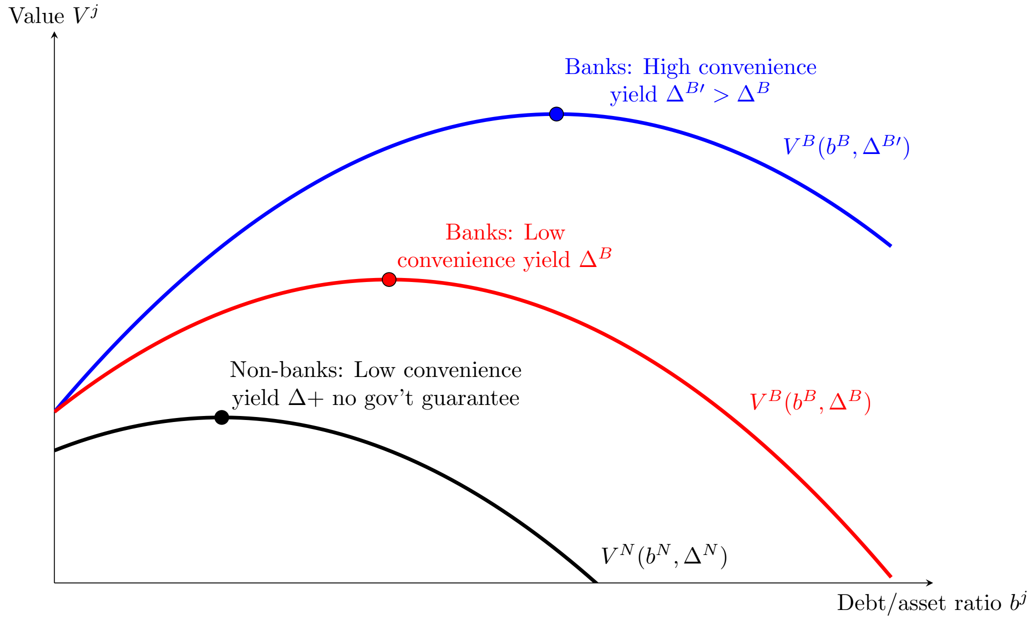

Figure 1: Banks' and Non-banks' Optimal Choices

yields Δ^B and Δ^N satisfy

$$\Delta^j = \theta^j \lambda,\ j \in \{B, N\} \tag{17}$$

Moreover, λ satisfies the market clearing condition $v'\left(\bar{m}^p(\lambda) + \theta^C d^C\right) = \lambda$. The private supply $\bar{m}^p(\lambda)$ of monetary services by banks and non-banks in this condition is defined as follows:

$$\bar{m}^p(\lambda) = \sum_{j \in \{B,N\}} \theta^j Q^j\left(b^j\right) k^j, \tag{18}$$

where b^j and k^j denote intermediaries' optimal choices, taking $\Delta^j = \theta^j \lambda$ as given, as characterized in Proposition 1.

Proposition 2 completes the characterization of equilibrium by providing two further sets of conditions.[15] First, the convenience yields earned by banks and non-banks are equal to their associated quality parameters θ^B and θ^N, scaled by a constant λ that measures the economy-wide (shadow) price of monetary services. Second, given household optimality, this shadow price must equal households' marginal utility $v'(\bar{m})$ at the market-clearing quantity

[15]Notice that Propositions 1 and 2 provide a system of eight equations and eight unknowns that fully determine equilibrium behavior. Proposition 1 implies four first-order conditions in Equations (17) and (18), as well as the market clearing requirement $k^B + k^N = 1$, which determine $\left\{b^j, k^j\right\}_{j\in\{B,N\}}$ and p^K as a function of Δ^B and Δ^N. Proposition 2 provides three equations that determine Δ^B , Δ^N and λ as a function of $\left\{b^j, k^j\right\}_{j\in\{B,N\}}$. Finally, the market-clearing interest rate on base money, for given supply d^C, follows from Equation (10).

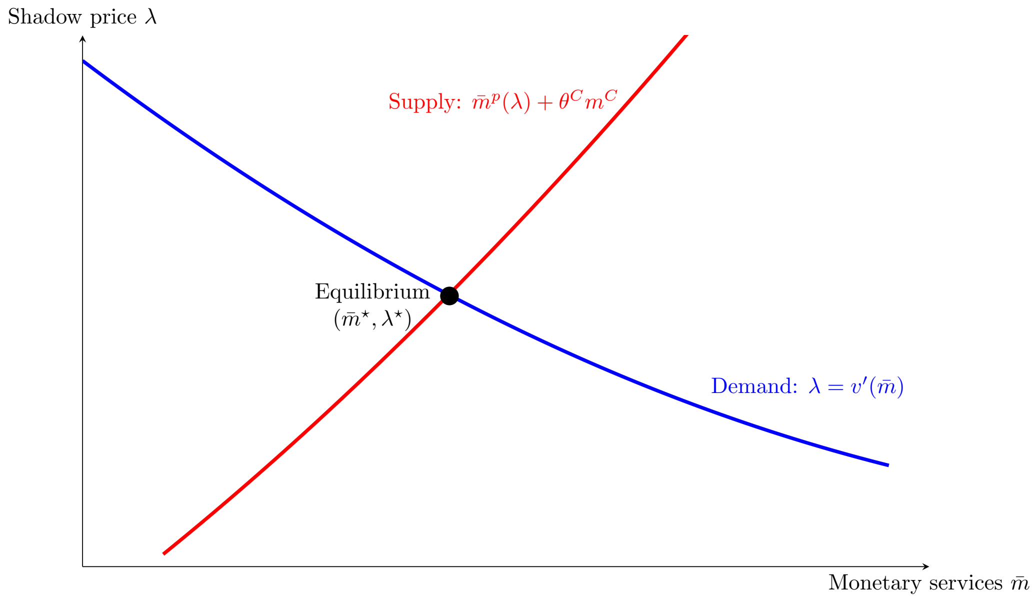

Figure 2: Equilibrium in the Market for Monetary Services

of $\bar{m}$. This quantity is the sum of the total amount of monetary services provided by private debt securities in the economy, given by $\bar{m}^p(\lambda)$ and defined in Equation (18), as well as the monetary services provided by households' direct holdings of base money d^C.[16]

Figure 2 provides a parsimonious summary of equilibrium in our model, which reduces to the problem of finding the market-clearing shadow price λ of monetary services, plotted on the vertical axis, and the quantity of money held $\bar{m}$, plotted on the horizontal axis. On one hand, households' behavior is fully determined by the condition $\lambda = v'(\bar{m})$, which induces a standard downward-sloping "LM curve" that traces the demand for monetary services. On the other hand, the shadow price λ directly determines convenience yields via Equation (17), which in turn pin down banks' and non-banks' optimal choices of borrowing b^j and investment k^j. These choices, along with the central banks' supply of base money, then determine the overall supply of money in the economy, which is $\bar{m}^p(\lambda) + \theta^C d^C$. By this reasoning, one can draw a supply curve for (private and public) money as a function of λ.

As we prove in the appendix,[17] the supply curve is upward-sloping, and there is a unique market-clearing level of λ. We briefly dwell on this result because it is non-trivial. As demonstrated by Equation (18), the response of private money supply to an increase in λ has to take into account i) the changes in optimal leverage b^j among banks and non-banks, ii) the endogenous re-pricing of deposits/bonds via the pricing schedule $Q^j(.)$, and

[16]Households' holdings d^C are determined by the central bank's supply decision $d^s = d^C$ in equilibrium. In the remainder of the paper, we characterize equilibrium directly in terms of d^C for simplicity.

[17]See the proof of Proposition 3.

iii) the reallocation of capital investments k^j among banks and non-banks. The reallocation effect can, in principle, lead to a locally downward-sloping supply curve. In the proof of Proposition 3, we show that this cannot happen if banks are more efficient at supplying monetary services with $\theta^B > \theta^N$, and if banks' debt is more valuable at equilibrium with $Q^B\left(b^B\right) > Q^N\left(b^N\right)$. We show, in turn, that both conditions are implied by our primitive assumptions.

Once the equilibrium level of λ is found, the financial architecture of the economy follows from Proposition 1. In the next section, we characterize changes in the equilibrium level of λ, and the concurrent changes in financial architecture, in response to the monetary innovations that motivate this paper.

3 The Effects of Monetary Innovation

This section studies the effects of monetary innovation in general equilibrium. We focus on two types of innovation. First, we model *public monetary innovations*, whereby households consume a greater quantity of monetary serves through their direct holdings of central bank/base money. Second, we model *private monetary innovations*, whereby non-banks become more competitive with banks in the provision of monetary services.

Section 3.1 begins our analysis by focusing on the positive economics. Section 3.2 supplements our analysis by focusing on the normative implications of either type of innovation. The normative perspective is useful because the responses of different equilibrium quantities/prices to monetary innovation can be complex. Marginal welfare effects provide a single metric by which one can evaluate the overall changes in the economy. In this context, Proposition 5 provides a simple equation that can be used to calculate the overall welfare effects as a function of those responses.

3.1 Positive Analysis

In this section, we focus on the effects of monetary innovations on investment/lending decisions k^j by banks and non-banks, borrowing decisions b^j, as well as convenience yields Δ^j in the market for monetary services. We further emphasize the effects of monetary innovation on financial stability, which we view from two perspectives. First, we analyze the effects of innovations on the probability of bank/non-bank failure, which is defined as the event that $b^j > s$. In this event, the intermediary either defaults or requires a government transfer to avoid default. Second, we analyze the effects on the overall fiscal burden of government guarantees for banks, which is given by $(1+\kappa)\int t^B\left(b^B, s\right) k^B dF\left(s\right)$. In order to shorten the exposition, we assume for the remainder of this section that the adjustment costs $\Phi^j\left(.\right)$ associated with investment/lending are quadratic with $\Phi^j\left(k^j\right) = \frac{\psi}{2}\left(k^j\right)^2$.

We first derive an auxiliary result that summarizes the comparative statics of banks' and non-banks' investment and borrowing decisions:

Lemma 2. *[Comparative Statics: Monetary Parameters] Let $\eta \in \left\{\theta^B, \theta^N, \theta^m, m^s\right\}$ be a parameter associated with the quality of monetary services or government money supply. The response of the equilibrium financial architecture to a marginal change in η satisfies the following conditions:*

$$\frac{db^j}{d\eta} = \frac{\frac{\partial^2 V^j}{\partial b^j \partial \Delta^j}}{-\frac{\partial^2 V^j}{\partial (b^j)^2}} \cdot \frac{d\Delta^j}{d\eta},\ j \in \{B, N\} \tag{19}$$

$$\frac{dk^B}{d\eta} = \frac{1}{2\psi}\left(\frac{\partial V^B}{\partial \Delta^B}\frac{d\Delta^B}{d\eta} - \frac{\partial V^N}{\partial \Delta^N}\frac{d\Delta^N}{d\eta}\right) = -\frac{dk^N}{d\eta}, \tag{20}$$

where all partial derivatives are evaluated at equilibrium quantities/prices, and where $\frac{d\Delta^j}{d\eta}$ denotes the marginal response of the equilibrium convenience yield. Moreover, $\frac{db^j}{d\eta}$ has the same sign as $\frac{d\Delta^j}{d\eta}$.

Lemma 2 characterizes the effects on financial architecture of monetary parameters of the model, i.e., parameters associated with the exogenous quality or quantity of money supply. We use η as shorthand to denote an arbitrary monetary parameter. The characterizations of equilibrium responses in Equations (19) and (20) inherit the separation property that we discussed in the context of Proposition 1. Indeed, the responses of intermediaries' leverage b^j and investment k^j depend only on properties of the value function $V^j\left(b^j, \Delta^j\right)$, and on the equilibrium response $\frac{d\Delta^j}{d\eta}$ of convenience yields. Other changes on the monetary side of the economy, e.g., changes in the quantity or composition of money supply, do not have any further effects on financial architecture.

Equation (19) characterizes the response of intermediaries' optimal leverage in equilibrium. This response driven by the cross-partial derivative $\frac{\partial^2 V^j}{\partial b^j \partial \Delta^j}$, which the appendix shows to be positive. Intuitively, the marginal incentive for a bank or non-bank to take leverage becomes stronger when its debt securities earn a greater convenience yield. Equation (20) characterizes the responses of equilibrium investments/market shares k^B and k^N. This formula already takes into account the fact that banks and non-banks compete for investments at an endogenous price p^K, and that this price increases when banks and non-banks earn greater convenience yields.[18] The key object in this context is $\frac{\partial V^B}{\partial \Delta^B}\frac{d\Delta^B}{d\eta}$, the product of the

[18]The proof of Lemma 2 in the appendix further characterizes the response of this price as follows:

$$\frac{dp^K}{d\eta} = \frac{1}{2}\sum_{j \in \{B,N\}} \frac{\partial V^j\left(b^j, \Delta^j\right)}{\partial \Delta^j}\frac{d\Delta^j}{d\eta}$$

sensitivity of banks' value to convenience yields, scaled by the equilibrium change in convenience yields. Banks increase their market share if and only if this quantity is greater than its analogue $\frac{\partial V^N}{\partial \Delta^N}\frac{d\Delta^N}{d\eta}$ for non-banks. Intuitively, if one type of intermediary experiences a stronger increase in its convenience yields than another, or if their market value increases by a larger amount in response to a given change in convenience yields, then this type will grow its market share.

This result also provides an intuition as to how our results would change in an economy in which the capital stock is not fixed. As described above and in footnote 18, the price of capital p^K in our economy changes in proportion to the average of $\frac{\partial V^B}{\partial \Delta^B}\frac{d\Delta^B}{d\eta}$ and $\frac{\partial V^N}{\partial \Delta^N}\frac{d\Delta^N}{d\eta}$. Thus, when convenience yields increase (decrease), intermediaries' willingness to pay for capital goods increases (decreases). In our baseline model, the supply of capital is inelastic and an increased willingness to pay manifests itself only in an increase in p^K. By contrast, if the supply of capital is elastic, increases (decreases) in convenience yields translate directly to an expansion (contraction) in aggregate investment/lending.

Lemma 2 is particularly useful because it boils down the problem of understanding the consequences of any monetary innovation to the simpler problem of characterizing the responses of convenience yields Δ^B and Δ^N. Moreover, using the characterization of equilibrium prices in Proposition 2, the responses of the Δ^j are ultimately determined by the technological parameters θ^j and by changes in the economy-wide price λ of monetary services. We emphasize below that the responses of λ are potentially very different depending on whether the monetary innovation relates to the supply of base money (i.e., a public monetary innovation) or to the supply of money-like debt securities by intermediaries (i.e., a private monetary innovation).

Our next result focuses on public innovations.

Proposition 3. *[The Effects of Public Monetary Innovation] In response to a marginal increase in the monetary quality θ^C (or, equivalently, in the quantity d^C) of base money, the shadow price λ of monetary services decreases. The financial architecture responds as follows:*

1. *The leverage of banks b^B and non-banks b^N decreases, and the market share k^B of banks decreases.*

2. *The likelihood of bank failure and the expected fiscal burden from government guarantees both decrease.*

Proposition 3 is illustrated in Figure 2. In order to study public monetary innovations, we consider an increase in either the quality θ^C or the quantity d^C of monetary services provided by direct household holdings of base/central bank currency. Recall that one can

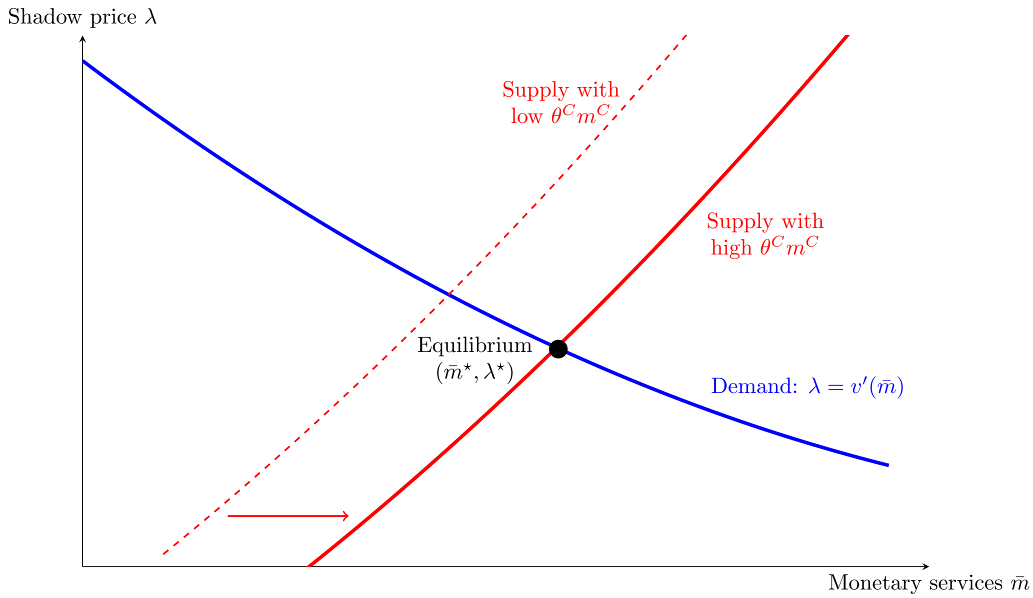

Figure 3: Example: Effects of Public Monetary Innovation

think of the central bank in our model as choosing d^C, and then allowing the yield on base currency to adjust in equilibrium. In our baseline model, the total supply of money is determined by the product $\theta^C d^C$, and the change in $\theta^C d^C$ (regardless of whether it is driven by quality or quantity) is also a sufficient statistic for the equilibrium response to a public monetary innovation.

Starting from an initial equilibrium in which $\theta^C d^C$ is low, represented by the dotted supply curve in the Figure 2, we consider an expansion in $\theta^C d^C$, represented by a shift to the solid supply curve. The opening statement in Proposition 3 states that the equilibrium value of λ falls as a result. As discussed in the previous section, the main difficulty in establishing this result is to prove that the supply curve is indeed upward sloping, given the complicated nature of private money supply.

The remaining statements now follow directly from the logic of Lemma 2. First, when λ decreases, the convenience yields of banks, $\Delta^B = \theta^B\lambda$, and of non-banks, $\Delta^N = \theta^N\lambda$, also necessarily decrease, because nothing has changed about the quality parameters θ^B and θ^N. Therefore, we observe a decline in the leverage of both banks and non-banks. Moreover, the convenience yield of banks decreases more steeply because banks are (by assumption) more effective at supplying monetary services with $\theta^B > \theta^N$. Banks' comparative advantage subsides, and investment/lending is reallocated from banks to non-banks. Second, if banks take less leverage and lose market share, their fragility and the expected fiscal cost of government guarantees both decline, suggesting greater financial stability.

At a deeper level, the fact that banks lose market share to non-banks in response to public monetary innovation is driven by our assumptions that i) banks initially provide more valuable monetary services ($\theta^B > \theta^N$), and ii) enjoy more generous government guarantees. The proof of Proposition 3, however, shows that these conditions are more than sufficient. More generally, the result holds as long as we start from an equilibrium in which banks earn greater convenience yields, with $\Delta^B > \Delta^N$, and banks' deposits are more valuable per unit of capital than non-bank bonds, with $Q^B\left(b^B\right) > Q^N\left(b^N\right)$.

We now turn to a private monetary innovation, which we model as an increase in the marginal value θ^N of non-bank debt in the production of monetary services. Perhaps surprisingly, the effects of private innovation are substantially more complex than those of public innovation. The following result introduces some of the economic effects that generate the complication:

Lemma 3. *[Private Monetary Innovation: Valuation and Reallocation Effects] Suppose that the shadow price λ of monetary services is fixed at an exogenous value λ_0. An increase in θ^N has the following marginal effect on the private money supply by banks and non-banks:*

$$\left.\frac{d\bar{m}^p(\lambda)}{d\theta^N}\right|_{\lambda=\lambda_0} = \underbrace{\left.\frac{d\left(\theta^N Q^N\left(b^N\right)\right)}{d\theta^N}\right|_{\lambda=\lambda_0} * k^N}_{\textit{non-bank debt valuation}} \underbrace{- \frac{\lambda_0}{2\phi}\left(\theta^B Q^B\left(b^B\right) - \theta^N Q^N\left(b^N\right)\right)\frac{\partial V^N\left(b^N;\Delta^N\right)}{\partial \Delta^N}}_{\textit{investment reallocation from banks to non-banks}} \tag{21}$$

The first term captures the response of the monetary value of non-bank debt per unit of capital. This is the sum of two components, which are spelled out in the appendix. On one hand, there is a mechanical positive effect on $\theta^N Q^N\left(b^N\right)$ as θ^N increases. On the other hand, the equilibrium valuation $Q^N\left(b^N\right)$ itself changes, both because debt attracts larger convenience yields for any given value b^N of non-bank leverage, and because non-banks endogenously choose higher leverage in equilibrium.

The second term captures the effects on money supply of the reallocation of capital investments from banks to non-banks. This reallocation happens in response to private monetary innovation because non-banks gain comparative advantage over banks and attract higher relative convenience yields, leading them to compete more aggressively for capital investments. This effect is negative in the baseline scenario where banks are initially the main suppliers of money-like debt, so that $\theta^B Q^B\left(b^B\right) > \theta^N Q^N\left(b^N\right)$. In this scenario, the reallocation drains capital investments from the bank sector which, for a given debt-to-asset ratio b^B, implies a reduction in the money supply by banks that is not compensated for in the non-bank sector.

The complex effects of private monetary innovation arise because it is, in general, unclear whether the valuation effect or the reallocation effect will dominate. The following proposition summarizes the two relevant scenarios:

Proposition 4. *[The Effects of Private Monetary Innovation] The response to a marginal increase in the monetary quality θ^N of non-bank debt is characterized by two mutually exclusive scenarios:*

1. *If the debt valuation effect in Lemma 3 dominates the reallocation effect,*[19] *then the shadow price λ of monetary services decreases. Moreover, the leverage of banks b^B decreases, and the market share k^B of banks decreases. The likelihood of bank failure and the expected fiscal burden from government guarantees both decrease.*

2. *If the reallocation effect in Lemma 3 dominates the valuation effect, then the shadow price λ of monetary services decreases. Moreover, the leverage of banks b^B can either increase or decrease. The responses of the likelihood of bank failure and the expected fiscal burden from government guarantees are also ambiguous.*

If the valuation effect dominates, then the basic response to an increase in θ^N is an expansion of money supply, just as in the case of public innovation, and the qualitative effects resemble those in Proposition 3, which we illustrated above in Figure 3. The money supply curve shifts outwards, the economy moves downwards along the money demand curve, and the shadow price λ of monetary services falls. Thus the qualitative implications are similar to a public innovation, as illustrated in Figure 3.[20]

If the reallocation effect dominates, by contrast, then the basic response is a contraction in money supply. This situation is illustrated in Figure 4. As a result, the economy moves upwards along the money demand curve, and the shadow price λ of monetary services rises. In this situation, most responses of the financial architecture and financial stability are ambiguous. Indeed, one can end up in a situation in which banks increase their leverage when non-banks become more efficient at supplying monetary services. This situation has adverse consequences for financial stability, as it would increase both the likelihood of bank failure and the expected fiscal burden from government guarantees.

The condition in Lemma 3 provides some intuition as to which of these two scenarios is more likely to arise. Indeed, the valuation effect scales with the level k^N of non-bank investments (equivalently, their initial market share). Thus, when non-banks' market share is initially low, the reallocation effect is more likely to be dominant. We illustrate the distinction between these two cases in our numerical illustration below.

[19]By this scenario, we mean the that the expression in Equation (21) satisfies $\left.\frac{d\bar{m}^p(\lambda)}{d\theta^N}\right|_{\lambda=\lambda_0} > 0$, where λ_0 is taken to be the initial equilibrium value of the shadow price λ.

[20]One sense in which the implications in this case still differ from public innovations is that shadow banks may take more leverage in response to a private innovation due to its direct, positive effect on their convenience yield. If this effect is strong enough, and if we considered an extension of our model in which non-banks benefit from some government guarantees, it is possible that the overall fiscal burden would not decrease.

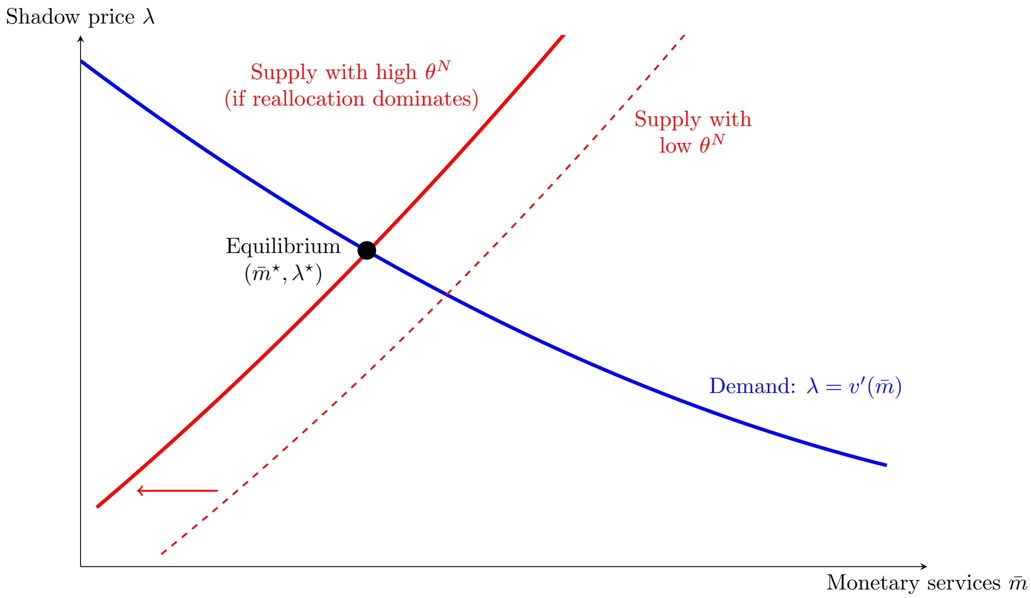

Figure 4: Example: Effects of Private Monetary Innovation

3.2 Normative analysis

We have shown that monetary innovations affect many dimensions of the equilibrium in our model, and that those effects can be ambiguous in terms of their implications for financial stability. In this context, it is useful to examine a general formula for the associated effects of social welfare. We consider a utilitarian social planner who evaluates welfare according to the sum W of the utility of agents (households, banks and non-banks) in the economy:

$$W = U^H + U^B + U^N$$

The following result characterizes the marginal effects of monetary innovations on this welfare criterion.

Proposition 5. *[Welfare Effects of Monetary Innovation] Let $\eta \in \left\{\theta^B, \theta^N, \theta^C\right\}$ be a parameter associated with the quality of monetary services. The marginal welfare effect of an* *increase in η is as follows:*

$$\frac{dW}{d\eta} = \underbrace{v'\left(\bar{m}\right)\left[\sum_{j\in\{B,N,C\}} d^j 1\left\{\eta=\theta^C\right\} + \sum_{j\in\{B,N\}} \frac{\theta^j d^j}{1-\Delta^j}\frac{d\Delta^j}{d\eta}\right]}_{\text{Friedman term}}$$
$$\underbrace{-\left(1+\kappa\right)\beta^H \mathbb{E}\left[\sum_{j\in\{B,N\}} \frac{\partial t^j\left(b^j,s\right)}{\partial b^j}\frac{db^j}{d\eta} + t^B\left(b^j,s\right)\frac{dk^B}{d\eta}\right]}_{\text{Bailout externality}} \tag{22}$$

Once again, this proposition uses the notation η as a stand-in for a parameter associated with the monetary side of the economy, and evaluates the welfare effects of a marginal increase in η. The first term in (22) states the utility benefits of increased money supply as a result of monetary innovation. This term scales with the marginal utility $v'\left(\bar{m}\right)$ of households' money holdings. We label it as the "Friedman" term because of its close link to the classical Friedman rule (Friedman and Bordo, 2017), which provides a rationale for increasing money supply until households are saturated. The marginal utility is multiplied by the direct effect of an increase in η on monetary services, which is simply equal to the representative household's holdings d^j of the security whose quality has improved. In addition, it is multiplied by terms that scale with $\frac{d\Delta^j}{d\eta}$, the equilibrium response of convenience yields to the innovation. These term arise because of a type of pecuniary externality, which strengthens or weakens the Friedman effect depending on whether the convenience yields on privately produced monetary services rise or fall in equilibrium. If an innovation increases Δ^j for an intermediary, for example, this change raises the equilibrium price of its debt, which in turn increases households effective money holdings. The pecuniary externality affects welfare because, unlike in classical models of general equilibrium, households' utility is a direct function of the price of "money-like" debt that they purchase at date 0.[21]

The second term in Equation (22) states the costs/benefit of monetary innovation in relation to the externality associated with government guarantees. An innovation has a positive marginal welfare effect if it leads to a reduction in leverage among intermediaries, with $\frac{db^j}{d\eta} < 0$. In addition, since we have assumed that bank guarantees are larger than non-bank guarantees ceteris paribus, welfare increases whenever an innovation reduces banks' market share of investments, with $\frac{dk^B}{d\eta} < 0$.

[21] There is a formal connection between this kind of pecuniary externality and the externalities that affect welfare in economies with incomplete markets (e.g., Lorenzoni, 2008; Dávila and Korinek, 2018). In those economies, pecuniary externalities can affect welfare if trading/collateral constraints depend on securities prices, so that a change in prices indirectly affects constrained agents' utility by relaxing/tightening a constraint. In our model, the effect is more immediate because an increase in the price of a "money-like" security, for a given set of trades, directly raises agents' utility.

A more general remark on Proposition 5 is that the marginal welfare effects of monetary innovation are, in general, driven only by i) the direct technological benefits of the innovation, and ii) the effects of the innovation that either exacerbate or alleviate uncorrected externalities in the economy. In principle, many other adjustments take place in the economy after a monetary innovation. However, all of these adjustments have only second-order effects on welfare and are therefore not present in Proposition 5. For instance, suppose that banks operate at lower marginal cost than non-banks. If an increase in θ^C reduces bank lending with $\frac{dk^B}{d\theta^C} < 0$, one might view this as a loss of efficiency, since activity has been reallocated from low- to high-cost intermediaries. By contrast, Proposition 5 makes clear that the welfare effects of this adjustment are independent of intermediaries' cost function, and depend only on the fiscal externality associated with government guarantees for banks. The reallocation itself has a zero marginal welfare effect because each type of intermediary, in equilibrium, operates at the point where the marginal benefits of another unit of investment are exactly equal to its marginal costs. This insight is standard in welfare economics and public finance, but worth stressing here, because the policy debate around central bank digital currency has considered many possible margins of adjustment after the introduction of such a currency. It is useful to consider which of these potential effects are associated with externalities and therefore have first-order implications for social welfare (see, also, Keister and Sanches, 2023).

4 Numerical Illustration

The purpose of this section is to illustrate the effects of monetary innovations in a modern financial architecture. We solve our model numerically by setting its parameters to values that are consistent with current patterns in the US banking system, in which non-bank lenders already supply a large share of aggregate credit. We outline our calibration in detail in Appendix D. We emphasize that we do not seek to provide a fully realistic structural model of the US banking sector. Rather, the purpose of this section is to illustrate the effects we have highlighted in our theoretical work, and to provide a sense of their respective magnitudes.

For a numerical solution, we assume the following functional forms: Returns on investment are normally distributed with $s \sim \mathcal{N}\left(\mu_s, \sigma_s^2\right)$.[22] Households' preferences for monetary services are $v\left(\bar{m}\right) = \gamma \log\left(\bar{m}\right)$. Adjustment costs are $\Phi^j\left(k^j\right) = c^j k^j + \psi\left(k^j\right)^2$. We assume that intermediaries in distress, which we define by a positive shortfall $b^j - s > 0$ between debt liabilities and assets, are bailed out by the government with probability α^j. As in our

[22] As we discuss in the appendix, the values of μ_s and σ_s that are consistent with the data imply a negligible probability of a negative return $s < 0$, so that our calibration is effectively consistent with free disposal.

baseline model, we set $\alpha^N = 0$ so that non-banks do not enjoy government guarantees.[23]

We set the parameters of the model to standard values from the literature on banking and corporate finance, and calibrate households' preferences so that the model generates realistic convenience yields on near-money assets. We set the marginal costs of banks c^B and non-banks c^N so that the model generates a share of non-banks in aggregate credit supply of 60%, consistent with estimates in Buchak et al. (2024). Moreover, even though we do not use bank and non-bank debt-to-asset ratios b^j as calibration targets, the baseline model is able to closely replicate the financing patterns reported by Jiang et al. (2020*a*), who highlight that banks tend to take substantially more leverage than non-banks.[24]

We now illustrate the consequences of monetary innovations that are implied by our theoretical results. In Section 4.1 we focus on public monetary innovations represented by an increase in households' direct holdings of central bank currency. In Section 4.2 we explore the consequences of innovation among non-banks or new "Fintech" entrants that compete with banks in the provision of monetary services to households.

4.1 Effects of Public Monetary Innovation

We analyze situations in which the government increases its target for households' direct holdings d^C of central bank currency, or in which the quality θ^C of monetary services by the central bank increases. Thus, we provide illustrations of the effects highlighted in Proposition 3. Throughout this example, we assume that non-bank bonds do not provide monetary services, setting $\theta^N = 0$. We normalize the quality of monetary services provided by bank deposits to $\theta^B = 1$.

To preface our numerical results, it is useful to recall the illustration of such innovations in Figure 3: The impact of this policy change is always determined by the associated change in the product $\theta^C d^C$. With an increase (decrease) in $\theta^C d^C$, the economy moves downwards (upwards) along the demand curve for monetary services in Figure 3, implying a lower (higher) shadow price for monetary services λ in equilibrium.

In Figure 5, we illustrate the equilibrium consequences of public monetary innovation as a function of the implied shadow price λ, which is drawn on the horizontal axis in each panel. Our baseline calibration, marked by the dotted vertical line in each panel, sets the shadow price $\lambda = 0.01$. We make this choice to generate convenience yields on bank deposits around one percent, consistent with the empirical literature on near-money assets (e.g., Krishnamurthy and Vissing-Jorgensen, 2012; Nagel, 2016). Lower (higher) values of λ

[23] In the event of a bailout, banks receive $t^B\left(b^B, s\right) = \min\left\{\max\left\{b^B - s, 0\right\}, t^{max}\right\}$. Intuitively, bailouts are sufficient to cover any shortfall between assets and liabilities, but are capped at a maximum value t^{max}, whose numerical calibration we describe in the appendix.

[24] Jiang et al. (2020*b*) report average debt-to-asset ratios around 90% for banks and 80% for non-banks. The model generates 89% for banks and 82% for non-banks.

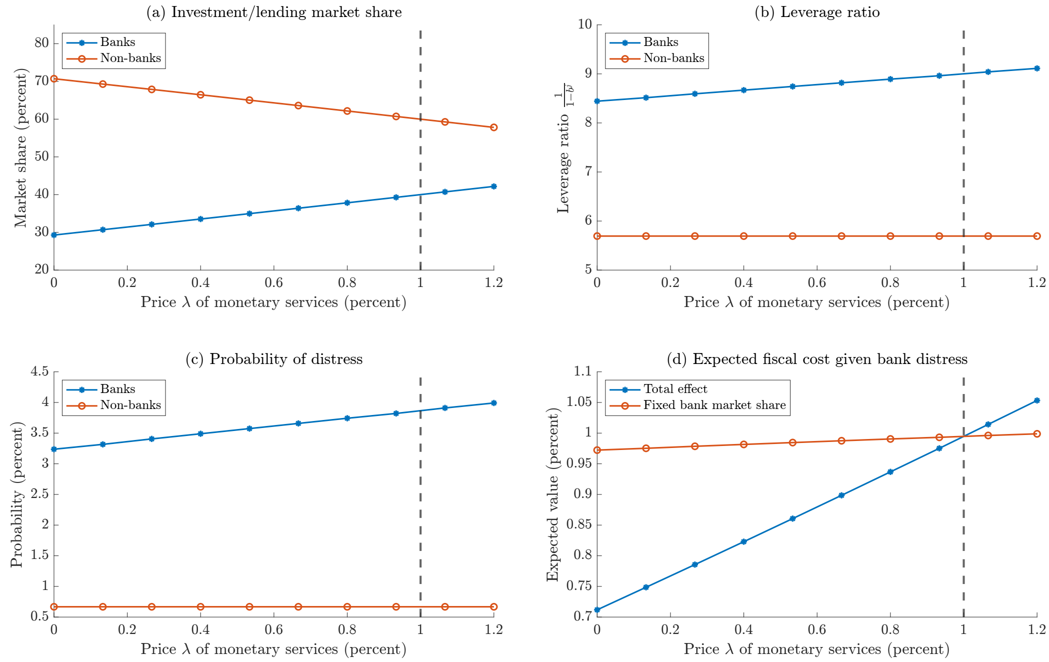

Figure 5: Numerical Illustration: Public Monetary Innovation

stand in for increases (decreases) in $\theta^C d^C$, associated with a move down (up) the demand curve in Figure 3. Therefore, values of λ below the baseline value in Figure 5 capture the equilibrium after a public monetary innovation.

Panel (a) shows the response of banks' and non-banks' market shares in aggregate investment/lending. In the baseline scenario, the model generates a 60% market share for non-banks. This share rises to around 70% in response to public monetary innovations that drive the shadow price of monetary services towards zero. Thus, even in the absence of any changes in the technological or regulatory advantages of non-banks, a change in public monetary policy can make a significant difference to the financial architecture, further decreasing its reliance on bank-based investment.

Panel (b) shows the response of banks' and non-banks' leverage choices, as measured by the ratio of assets to equity. In our baseline calibration, banks are around 9 times levered, which can drop to around 8.5 in response to public monetary innovation. Panel (c) shows that this reduction in bank leverage translates to a reduction in the probability of bank distress from 4% to 3.2%. Since our calibration is at the annual frequency, this implies a reduction in the incidence of bank distress from roughly once in 25 years to once in 31 years.

As shown in Proposition 3, the joint reduction in banks' market share and their fragility is reflected in the reduction in the expected fiscal costs conditional on bank distress, which is intimately related to the ultimate welfare effects according to Proposition 5. We illustrate

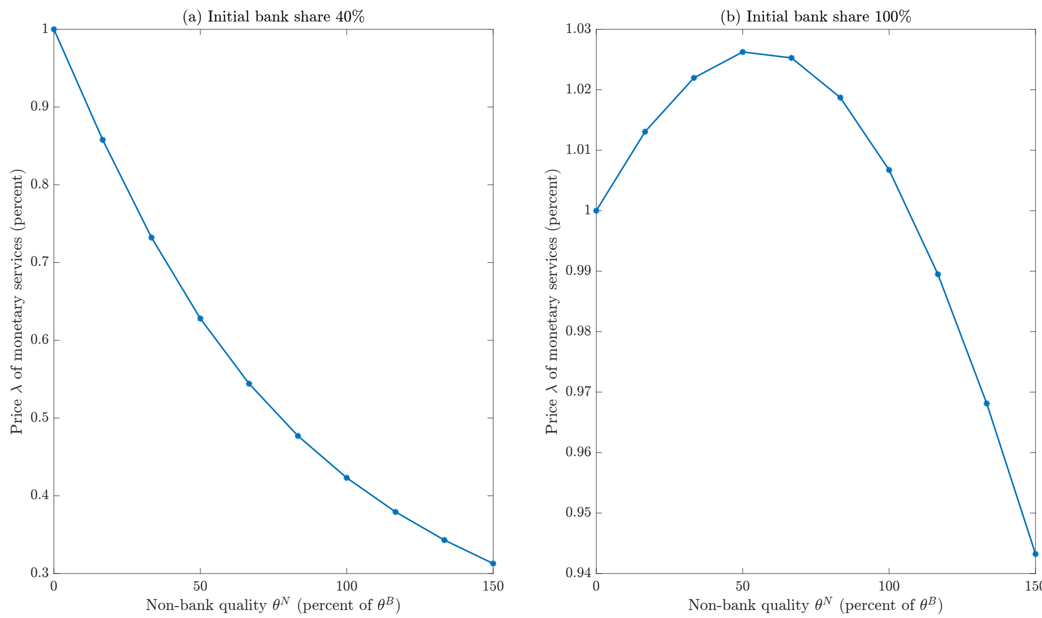

Figure 6: Numerical Illustration: Private Monetary Innovation

this effect in panel (d) of Figure 5. The total effect of a public monetary innovation that drives convenience yields towards zero is a reduction in the expected fiscal cost from one percent of the aggregate capital stock to around 0.7 percent. In order to understand the sources of this change, the figure also plots the expected fiscal cost in a counterfactual scenario in which the market share of banks is fixed at its baseline value. In this scenario, there is hardly any change in fiscal costs. Therefore, the majority of the change in fiscal costs (and the associated externality) comes from the change in banks' relative market share when they face fiercer competition from central bank currency.

4.2 Effects of Private Monetary Innovation

We now turn to situations in which non-banks experience improvements in their ability to provide monetary services to households by issuing bonds. This ability is parametrized by θ^N in our model, and our baseline calibration assumed that $\theta^N = 0$. In order to illustrate the theoretical results in Proposition 4, we consider two separate scenarios/calibration, which are represented in the two panels of Figure 6.

In the first scenario, which represents our baseline calibration above, banks have an initial market share of 40% in aggregate investment/lending. Non-banks have a market share of 60% and. In this case, consistent with the intuition provided by Lemma 3, the debt valuation effect of private monetary innovation is dominant, implying that the first bullet point in Proposition 4 is the relevant one. Panel (a) in Figure 6 shows the response of the price λ of monetary services to an increase in θ^N in this scenario. As non-banks' ability to provide monetary services improves and, on points above 100 on the horizontal axis, eventually overtakes that of banks, the equilibrium price of monetary services drops by around 60% in equilibrium, from its baseline value of one percent to between 30 and 40 basis points.

Figures OA-2 and OA-3 in the Online Appendix further illustrate the responses of equilibrium quantities and prices in this scenario. These responses are similar to the case of public monetary innovation discussed above: Banks' market share decreases in favor of non-banks, and banks take less leverage, leading to a lower probability of distress and lower fiscal costs. A possibly offsetting force is the fact that non-banks start taking more leverage in equilibrium as θ^N increases, because they reap larger convenience yields than in the baseline scenario. However, this effect is muted, and non-banks' leverage ratio never rises above 6. Intuitively, while increases in θ^N imply cheaper debt financing for non-banks, the substantial general equilibrium response of λ, which is declining, offsets their overall incentive to take more leverage.

Our second scenario represents an economy dominated by banks, whose initial market share is 100%.[25] While our baseline calibration corresponded to values similar to the US banking system, one could view this scenario (heuristically) in two ways. On one hand, it could represent the effects of private monetary innovation in the context of more bank-reliant systems, such as some European economies. On the other hand, one could view this scenario as a situation in which private monetary innovation occurs among a group of new entrants, such as FinTech payment providers, as opposed to among established non-bank lenders.

In this scenario, the reallocation effect of private monetary innovation is initially dominant, so that the equilibrium responses correspond to the second bullet point of Proposition 4. Panel (b) in Figure 6 shows the response of the shadow price λ of monetary services to an increase in θ^N, starting again from the baseline assumption that $\theta^N = 0$. As implied by the theory, when non-banks' market share is close to zero, the reallocation of investments/lending from banks to non-banks when θ^N increases implies a contraction in the money supply, leading to a move up the demand curve (see Figure 4, for example) and an associated increase in λ.

However, as θ^N continues to rise, the market share of non-banks also rises and the debt valuation effect eventually becomes dominant. Therefore, we observe a hump-shaped response of the price of monetary services to private innovations. While our model is not designed to be quantitatively realistic, we also note that the numerical response of λ is much

[25] Numerically, we generate a larger initial market share for banks by introducing a marginal cost disadvantage $c^N - c^B > 0$ for non-banks.

smaller in this scenario. Indeed, non-banks need to be able to provide monetary services at the same level of quality as banks (i.e., $\theta^N/\theta^B = 100$ percent on the horizontal axis in Figure 6) before λ begins to drop below its initial equilibrium level.

Figures OA-4 and OA-5 in the Online Appendix illustrate further responses of the economy in this scenario. Notably, bank leverage and the likelihood of bank distress inherit the hump-shaped – but quantitatively modest – response of λ to private monetary innovation. In terms of overall financial stability, the expected fiscal costs of bailouts still decline as θ^N increases due to the reallocation of investments from banks to non-banks, whose market share rises from zero to around 15 percent in our example.

5 Concluding Remarks

Friedman and Schwartz (1963) highlighted the social cost of financial crises and bank failures, which is particularly large because banks are the most important suppliers of money and payment systems. Over time, banks, particularly large ones became protected from failure through the introduction of subsidized deposit insurance and "too-big-to-fail" bailouts. After the 2007-2009 financial crisis, there has been an attempt to reduce the subsidies banks receive by policies designed to ensure that if they failed, they would be wound up and liquidated rather than bailed out. The failure of Credit Suisse in March 2023 and the Swiss government subsidized merger with UBS suggests bailouts continue to be difficult to avoid.

Another development in recent years has been considerable monetary innovation. The advent of Bitcoin and other cryptocurrencies, particularly stable coins, are a significant private innovation in payment systems, which has led many advanced economies to consider the adoption of publicly issued central bank digital currencies. While among large economies, only China has actually introduced one, it is expected that a number of other countries will soon follow suit. Non-bank payment providers are gaining in market share and have, in many cases, started extending credit to their customers.

In this paper, we have developed a theoretical model to assess the relationship between monetary innovation and the architecture of the financial system in terms of the shares of banks and non-banks given the extensive subsidies given to banks. Public monetary innovations such as CBDC's have the potential to reduce the role of banks and increase the role of non-banks. This can lead to a lower incidence of bank failure and the costs associated with that, and an improvement in welfare. We also show that while private monetary innovation can be beneficial, it can also lead to the opposite result.

Our framework can hopefully contribute to the important policy debates on the role of central banks in the provision of monetary payment services, bank and non-bank regulation, and the architecture of the financial system. Although we have provided some numerical simulations to illustrate the workings of our model, clearly careful empirical work is required to assess the various factors at play. We hope that our approach can form the foundation of such investigations.

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A Proofs: Section 2

Proof of Lemma 1

We derive the result using a variational argument. Suppose that a household marginally changes its holdings of debt issued by intermediary type j by $dx^j = \epsilon$, simultaneously adjusting its holdings of government bonds by da so as to keep its expected consumption $\mathbb{E}[c_1(s)]$ at date 1 fixed. Using the household's date 1 budget constraint in Equation (8) and our assumption of state-independent goods prices $p_1(s) = 1+\pi$, this variation needs to satisfy $da = -\frac{\bar{\mathcal{R}}^j(b^j)k^j}{1+i}\epsilon$, where $\bar{\mathcal{R}}^j\left(b^j\right) = \mathbb{E}\left[\mathcal{R}^j\left(b^j, s\right)\right]$. The date 0 budget constraint in Equation (7) now implies that consumption at date 0 changes by

$$dc_0 = -\frac{1}{p_0}\left[Q^j\left(b^j\right)k^j - \frac{\bar{\mathcal{R}}^j\left(b^j\right)k^j}{1+i}\right]\epsilon,$$

At the household's optimal choice, total utility, taking into account that the change in money holdings is $d\bar{m} = \theta^j Q^j\left(b^j\right)k^j\epsilon$, must be unaffected by this variation, which yields the condition

$$\begin{aligned} dU^H &= \frac{1}{p_0}\left[Q^j\left(b^j\right)\left(1 - v'\left(\bar{m}\right)\theta^j\right) - \frac{\bar{\mathcal{R}}^j\left(b^j\right)}{1+i}\right]k^j\epsilon = 0 \\ \Rightarrow 1 + i^j &\equiv \frac{\bar{\mathcal{R}}^j\left(b^j\right)}{Q^j\left(b^j\right)} = \left(1 - v'\left(\bar{m}\right)\theta^j\right)(1+i) \end{aligned} \tag{23}$$

which also establishes that i^j is independent of borrowing choice b^j, which is equivalent to our claim that each individual intermediary takes convenience yields as given. Rearranging yields Equations (11) and (12).

Proof of Proposition 1

Substituting an intermediary's budget constraints in Equations (4) and (5) into the objective function in Equation (1), we obtain

$$U^j = \text{constant} + \frac{1}{p_0}\left[Q^j\left(b^j\right) - p^K\right]k^j - \Phi^j\left(k^j\right) + \beta^j\mathbb{E}\left[\frac{\mathcal{E}^j\left(b^j, s\right)}{p_1(s)}\right]k^j$$

where the constant term depends only on exogenous endowments. From Equation (23) in the proof of Lemma 1 and Equation (12), we obtain $Q^j\left(b^j\right) = \frac{\bar{\mathcal{R}}^j(b^j)}{(1-\Delta^j)(1+i)}$. Finally, household optimality implies that the real rate of return on bonds must be equal to $\frac{1+i}{1+\pi} = \frac{1}{\beta^H}$, so that

$$Q^j \left(b^j\right) = \frac{\beta^H}{(1-\Delta^j)} \mathbb{E}\left[\frac{\mathcal{R}^j \left(b^j, s\right)}{1+\pi}\right]$$

Combining, and substituting $p_0 = 1$ and $p_1(s) = 1 + \pi$, we find that utility maximization (up to a constant) is equivalent to solving the problem in Equation (13).

Proof of Proposition 2

In any equilibrium, let $\lambda = v'(\bar{m})$ denote households' marginal value of money holdings $\bar{m}$. The requirement that $\Delta^j = \theta^j \mu$ in Equation (17) follows directly by substituting Equation (12). Moreover, substituting the definition of $\bar{m}$ from Equation (3), we obtain

$$\lambda = v'\left(\theta^B Q^B \left(b^B\right) k^B + \theta^N Q^N \left(b^N\right) k^N + \theta^C d^C\right)$$

which follows from the accounting identity $d^j = x^j Q^j \left(b^j\right) k^j$ for $j \in \{N, B\}$, and the market clearing conditions $x^j = 1$. Defining $\bar{m}^p(\lambda)$ as in Equation (18), we obtain the required result.

B Proofs: Section 3

Proof of Lemma 2

Totally differentiating intermediaries' first-order condition for borrowing in Equation (16) immediately yields Equation (19). Totally differentiating Equation (15) yields

$$\frac{\partial V^j\left(b^j, \Delta^j\right)}{\partial b^j}\frac{db^j}{d\eta} + \frac{\partial V^j\left(b^j, \Delta^j\right)}{\partial \Delta^j}\frac{d\Delta^j}{d\eta} = \frac{dp^K}{d\eta} + \phi\frac{dk^j}{d\eta}$$

where all partial derivatives are evaluated at their equilibrium values. Noting $\frac{\partial V^j\left(b^j, \Delta^j\right)}{\partial b^j} = 0$ in equilibrium, by Equation (16), and summing across $j \in \{B, N\}$ yields

$$\sum_{j\in\{B,N\}} \frac{\partial V^j\left(b^j, \Delta^j\right)}{\partial \Delta^j}\frac{d\Delta^j}{d\eta} = 2\frac{dp^K}{d\eta} + \phi\sum_{j\in\{B,N\}}\frac{dk^j}{d\eta}$$

and market clearing implies that $\sum_{j\in\{B,N\}} \frac{dk^j}{d\eta} = 0$, so that we obtain

$$\frac{dp^K}{d\eta} = \frac{1}{2}\sum_{j\in\{B,N\}} \frac{\partial V^j\left(b^j, \Delta^j\right)}{\partial \Delta^j}\frac{d\Delta^j}{d\eta}$$

Combining yields Equation (20). Our claim about the sign of $\frac{db^j}{d\eta}$ follows from the auxiliary Lemma 5 in the Online Appendix.

Proof of Proposition 3

We begin by characterizing the equilibrium response of the shadow price λ of monetary services to a change in a monetary parameter $\eta \in \left\{\theta^B, \theta^N, \theta^C, d^C\right\}$. For the case of public innovation, on which this proposition focuses, we later specialize to $\eta = \theta^C$, and revert to the case with $\eta = \theta^N$ in the proofs of Lemma 3 and Proposition 4 below. Totally differentiating the requirement that $v'(\bar{m}) = \lambda$, where $\bar{m}$ denotes households consumption of monetary services, we get

$$\frac{d\lambda}{d\eta} = v''(\bar{m}) \frac{d\bar{m}}{d\eta} \tag{24}$$

$$= v''(\bar{m}) \left[\sum_{j \in \{B,N\}} \frac{d}{d\eta} \left[\theta^j Q^j \left(b^j, \Delta^j\right) k^j\right] + \frac{d\left(\theta^C d^C\right)}{d\eta} \right] \tag{25}$$

Evaluating the total derivative in the first term, we have

$$\begin{aligned} \frac{d}{d\eta} \left[\theta^j Q^j \left(b^j, \Delta^j\right) k^j\right] &= Q^j \left(b^j, \Delta^j\right) k^j 1\left\{\theta^j = \eta\right\} + \theta^j Q^j \left(b^j, \Delta^j\right) \frac{dk^j}{d\eta} \\ &+ \theta^j \left[\frac{\partial Q^j \left(b^j, \Delta^j\right)}{\partial b^j} \frac{db^j}{d\eta} + \frac{\partial Q^j \left(b^j, \Delta^j\right)}{\partial \Delta^j} \frac{d\Delta^j}{d\eta} \right] k^j \end{aligned}$$

where all partial derivatives are evaluated at equilibrium prices/quantities. Substituting from Lemma 2, and summing over $j \in \{N, B\}$, we get

$$\begin{aligned} \frac{d}{d\eta} \left[\theta^j Q^j \left(b^j, \Delta^j\right) k^j\right] = &\sum_{j \in \{B,N\}} \left(Q^j \left(b^j, \Delta^j\right) 1\left\{\theta^j = \eta\right\} + \theta^j \left[\frac{\partial Q^j}{\partial b^j} \frac{\frac{\partial^2 V^j}{\partial b^j \partial \Delta^j}}{-\frac{\partial^2 V^j}{\partial (b^j)^2}} + \frac{\partial Q^j}{\partial \Delta^j} \right] \frac{d\Delta^j}{d\eta} \right) k^j \\ &+ \frac{1}{2\phi} \left(\theta^B Q^B \left(b^B, \Delta^B\right) - \theta^N Q^N \left(b^N, \Delta^N\right)\right) \left(\frac{\partial V^B}{\partial \Delta^B} \frac{d\Delta^B}{d\eta} - \frac{\partial V^N}{\partial \Delta^N} \frac{d\Delta^N}{d\eta} \right) \end{aligned} \tag{26}$$

In the case of public innovation with $\eta = \theta^C$, we have $\frac{d\Delta^j}{d\eta} = \theta^j \frac{d\lambda}{d\theta^C}$, and the expression in Equation (26) simplifies to

$$\frac{d}{d\theta^C} \sum_{j \in \{B,N\}} \left[\theta^j Q^j \left(b^j, \Delta^j\right) k^j\right] = \Xi \cdot \frac{d\lambda}{d\theta^C}$$

where

$$\Xi=\sum_{j\in\{B,N\}}\theta^{j}\left[\frac{\partial Q^{j}}{\partial b^{j}}\frac{\frac{\partial^{2}V^{j}}{\partial b^{j}\partial\Delta^{j}}}{-\frac{\partial^{2}V^{j}}{\partial(b^{j})^{2}}}+\frac{\partial Q^{j}}{\partial\Delta^{j}}\right]k^{j}\theta^{j}$$

$$+\frac{1}{2\phi}\left(\theta^{B}Q^{B}\left(b^{B},\Delta^{B}\right)-\theta^{N}Q^{N}\left(b^{N},\Delta^{N}\right)\right)\left(\theta^{B}\frac{\partial V^{B}}{\partial\Delta^{B}}-\theta^{N}\frac{\partial V^{N}}{\partial\Delta^{N}}\right)>0 \tag{27}$$

Lemmas 4 and 5 in the Online Appendix establish that, at any equilibrium, we have i) $\frac{\partial Q^j}{\partial b^j}>0$, ii) $\frac{\partial^2 V^j}{\partial b^j\partial\Delta^j}>0$, iii) $\frac{\partial Q^j}{\partial\Delta^j}>0$, iv) $Q^B\left(b^B,\Delta^B\right)>Q^N\left(b^N,\Delta^N\right)$, and v) $\frac{\partial V^B}{\partial\Delta^B}>\frac{\partial V^N}{\partial\Delta^N}$. In combination with our assumption that $\theta^B>\theta^N$, these inequalities suffice to ensure $\Xi>0$.[26] Combining the results above, we finally obtain

$$\begin{aligned}\frac{d\mu}{d\theta^{C}}&=v''\left(\bar{m}\right)\left[d^{C}+\Xi\cdot\frac{d\lambda}{d\theta^{C}}\right]\\&=\frac{v''\left(\bar{m}\right)d^{C}}{1-v''\left(\bar{m}\right)\Xi}<0\end{aligned}$$

where the inequality follows from $v''\left(\bar{m}\right)<0$ and $\Xi>0$. The statements about market shares and leverage in the proposition now follow directly by applying Lemma 2 with $\frac{d\Delta^j}{d\theta^C}=\theta^j\frac{d\lambda}{d\theta^C}$. Moreover, it is easy to see that the likelihood of bank failure decreases, because b^B decreases, and that the total fiscal burden decreases, because b^B and k^B both decrease.

Proof of Lemma 3 and Proposition 4

We specialize the general derivations in the proof of Proposition 3 to the case where $\eta=\theta^N$. In this case we have $\frac{d\Delta^j}{d\eta}=\theta^j\frac{d\lambda}{d\theta^N}+1\{j=N\}\lambda$. Substituting into Equation (26), we now obtain

$$\frac{d}{d\theta^{N}}\left[\theta^{j}Q^{j}\left(b^{j},\Delta^{j}\right)k^{j}\right]=\Xi\cdot\frac{d\lambda}{d\theta^{N}}+\Psi, \tag{28}$$

where Ξ is defined as in Equation (27), and where

$$\Psi=\left(Q^{N}\left(b^{N},\Delta^{N}\right)+\theta^{N}\left[\frac{\partial Q^{N}}{\partial b^{N}}\frac{\frac{\partial^{2}V^{N}}{\partial b^{N}\partial\Delta^{N}}}{-\frac{\partial^{2}V^{N}}{\partial(b^{N})^{2}}}+\frac{\partial Q^{N}}{\partial\Delta^{N}}\right]\lambda\right)k^{N}$$

$$-\frac{\lambda}{2\phi}\left(\theta^{B}Q^{B}\left(b^{B},\Delta^{B}\right)-\theta^{N}Q^{N}\left(b^{N},\Delta^{N}\right)\right)\frac{\partial V^{N}}{\partial\Delta^{N}} \tag{29}$$

[26] A corollary of this insight, which we refer to in the text, is that the private supply curve $\bar{m}^p(\lambda)$ is upward-sloping, since it is straightforward to show that, holding all parameters fixed, we have $\frac{d\bar{m}^p(\lambda)}{d\lambda}=\Xi>0$.

The claims in Lemma 3 follow as a corollary because Ψ is exactly equal to the response in private money supply when Θ^N increases but λ is held fixed at its initial equilibrium value λ_0, i.e., when we impose $\frac{d\lambda}{d\theta^N} \equiv 0$ in Equation (28). The first term in Equation (29) is written, more succinctly, as the valuation effect $\left.\frac{d\left(\theta^N Q^N\left(b^N\right)\right)}{d\theta^N}\right|_{\lambda=\lambda_0} * k^N$, to obtain the statement of Lemma 3. Furthermore, substituting Equations (24) and (25) with $\eta = \theta^N$, we get

$$\frac{d\lambda}{d\theta^N} = \frac{v''\left(\bar{m}\right)\Psi}{1 - v''\left(\bar{m}\right)\Xi}$$

This expression has the opposite sign to Ψ, which yields the claims about $\frac{d\lambda}{d\theta^N}$ in the proposition. The remaining statements in the proposition now follow directly by applying Lemma 2 with $\frac{d\Delta^j}{d\theta^C} = \theta^j \frac{d\lambda}{d\theta^N} + 1\left\{j = N\right\}\lambda$.

Proof of Proposition 5

Evaluating the utility of households and intermediaries in Equations (1) and (2), and substituting their budget constraints, we obtain the following representation of welfare:

$$\begin{aligned} W &= U^H + U^B + U^N \\ &= \sum_{j \in \{B,N\}} \left\{ \left(\beta^j \mathbb{E}\left[\frac{\mathcal{E}^j\left(b^j, s\right)}{1+\pi} \right] + \beta^H \mathbb{E}\left[\frac{\mathcal{R}^j\left(b^j, s\right)}{1+\pi} \right] - \beta^H \left(1+\kappa\right) \mathbb{E}\left[t^j\left(b^j, s\right) \right] \right) k^j - \Phi^j\left(k^j\right) \right\} \\ &\quad + v\left(\underbrace{\sum_{j \in \{B,N\}} \theta^j Q^j\left(b^j, \Delta^j\right) k^j + \theta^C d^C}_{=\bar{m}} \right) \end{aligned}$$

The only endogenous objects in the above expression are the financial architecture $\left\{b^j, k^j\right\}_{j \in \{B,N\}}$ and the convenience yields $\left\{\Delta^j\right\}_{j \in \{B,N\}}$. We can therefore write the marginal effect of an innovation to η as follows:

$$\frac{dW}{d\theta^i} = \frac{\partial W}{\partial \eta} + \sum_{j \in \{B,N\}} \left(\frac{\partial W}{\partial b^j} \frac{db^j}{d\eta} + \frac{\partial W}{\partial k^j} \frac{dk^j}{d\eta} + \frac{\partial W}{\partial \Delta^j} \frac{d\Delta^j}{d\eta} \right)$$

Evaluating each partial derivative in turn, we have $\frac{\partial W}{\partial \eta} = v'(\bar{m}) \sum_j d^j 1\left\{\eta = \theta^j\right\}$. Moreover,

$$\begin{aligned}
\frac{\partial W}{\partial b^j} &= \left(\beta^j \mathbb{E}\left[\frac{\frac{\partial \mathcal{E}^j\left(b^j,s\right)}{\partial b^j}}{1+\pi}\right] + \beta^H \mathbb{E}\left[\frac{\frac{\partial \mathcal{R}^j\left(b^j,s\right)}{\partial b^j}}{1+\pi}\right] + \underbrace{v'(\bar{m})\,\theta^j}_{=\Delta^j} \frac{\partial Q^j\left(b^j,\Delta^j\right)}{\partial b^j} - \beta^H (1+\kappa)\,\mathbb{E}\left[\frac{\partial t^j\left(b^j,s\right)}{\partial b^j}\right]\right) k^j \\
&= -\beta^H (1+\kappa)\,\mathbb{E}\left[\frac{\partial t^j\left(b^j,s\right)}{\partial b^j}\right] k^j
\end{aligned}$$

where the second line follows by substituting (11) and the first order condition in Equation (16). Moreover, we have

$$\begin{aligned}
\frac{\partial W}{\partial k^j} &= \beta^j \mathbb{E}\left[\frac{\mathcal{E}^j\left(b^j,s\right)}{1+\pi}\right] + \beta^H \mathbb{E}\left[\frac{\mathcal{R}^j\left(b^j,s\right)}{1+\pi}\right] - \beta^H (1+\kappa)\,\mathbb{E}\left[t^j\left(b^j,s\right)\right] - \Phi^{j\prime}\left(k^j\right) + v'(\bar{m})\,\theta^j Q^j\left(b^j\right) \\
&= p^K - \beta^H (1+\kappa)\,\mathbb{E}\left[t^j\left(b^j,s\right)\right]
\end{aligned}$$

and, finally, using Lemma 4, we have

$$\frac{\partial W}{\partial \Delta^j} = v'(\bar{m})\,\theta^j \frac{\partial Q^j\left(b^j,\Delta^j\right)}{\partial \Delta^j} k^j = v'(\bar{m})\,\theta^j \frac{Q^j\left(b^j,\Delta^j\right)}{1-\Delta^j} k^j$$

Combining the above results, and using the facts that $\sum_{j\in\{B,N\}} \frac{dk^j}{d\eta} \equiv 0$ and $Q^j\left(b^j,\Delta^j\right) k^j = d^j$, we obtain Equation (22).

Online Appendix

C Auxiliary Results

The proofs of our main propositions make use of two auxiliary lemmas stated in this appendix. The first lemma describes properties of the equilibrium prices $Q^j\left(b^j,\Delta^j\right)$ of intermediary debt, where we have made explicit that debt prices are determined by convenience yields.

Lemma 4. *[Auxiliary Result: Intermediary Debt Prices] The prices $Q^j\left(b^j,\Delta^j\right)$ of intermediary debt at any equilibrium have the following properties:*

1. *The marginal effect of an increase in leverage on debt prices is positive:*

$$\frac{\partial Q^j\left(b^j,\Delta^j\right)}{\partial b^j}>0,\ j\in\{B,N\} \tag{OA1}$$

2. *The marginal effect of an increase in convenience yields on debt prices is positive:*

$$\frac{\partial Q^j\left(b^j,\Delta^j\right)}{\partial \Delta^j}=\frac{Q^j\left(b^j,\Delta^j\right)}{1-\Delta^j}>0,\ j\in\{B,N\} \tag{OA2}$$

3. *The value of bank debt per unit of capital is greater than the value of non-bank debt, and banks take more leverage than non-banks:*

$$Q^B\left(b^B,\Delta^B\right)>Q^N\left(b^N,\Delta^N\right) \tag{OA3}$$

$$b^B>b^N \tag{OA4}$$

Proof. Using the argument in the proof of Proposition 1, debt prices are given by

$$Q^j\left(b^j,\Delta^j\right)=\frac{\beta^H}{\left(1-\Delta^j\right)}\mathbb{E}\left[\frac{\mathcal{R}^j\left(b^j,s\right)}{1+\pi}\right]$$

Equation (OA2) follows directly by differentiating with respect to Δ^j. Moreover, using the intermediary's first order condition for borrowing in Equation (16), along with the definition of $V^j\left(.\right)$ in Equation (14), we obtain

$$\begin{aligned}0&=\frac{\partial V^j\left(b^j,\Delta^j\right)}{\partial b^j}\\&=\frac{\partial Q^j\left(b^j,\Delta^j\right)}{\partial b^j}+\beta^j\int\frac{1}{1+\pi}\frac{\partial \mathcal{E}^j\left(b^j,s\right)}{\partial b^j}dF\left(s\right),\end{aligned}$$

Moreover, since Equation (6) implies that $\frac{\partial \mathcal{E}^j\left(b^j,s\right)}{\partial b^j}\leq 0$, with strict inequality for a set of states with positive measure, the second term in this expression is strictly negative, and we obtain Equation (OA1). Finally, to establish Equation (OA3), suppose that $Q^B\left(b^B,\Delta^B\right)\leq Q^N\left(b^N,\Delta^N\right)$. Notice that banks never choose smaller values of leverage than non-banks in equilibrium because i) they earn greater convenience yields, and ii) they obtain strictly more generous marginal government guarantees (in fact, zero in our baseline model). Indeed, for every b, we have $\frac{\partial V^B}{\partial b} > \frac{\partial V^N}{\partial b}$ and, therefore, $b^B > b^N$. Notice, moreover, that for equal leverage, bank debt is always valued more highly than non-bank debt, so that $Q^B\left(b, \Delta^B\right) > Q^N\left(b, \Delta^N\right)$ for all b. Now if a bank chose leverage b^N instead of b^B, the value of its equity weakly increases by Equation (6), and the value of its debt becomes

$$Q^B\left(b^N, \Delta^B\right) > Q^N\left(b^N, \Delta^N\right) \geq Q^B\left(b^B, \Delta^B\right)$$

We therefore have $V^B\left(b^N, \Delta^B\right) > V^B\left(b^B, \Delta^B\right)$, which contradicts optimality in Problem (13). □

The second auxiliary result establishes further properties of the value function $V^j\left(b^j, \Delta^j\right)$ that characterizes intermediaries' optimal choices:

Lemma 5. *[Auxiliary Result: Properties of Intermediary Value Functions] The value functions $V^j\left(b^j, \Delta^j\right)$ of intermediaries at any equilibrium have the following properties:*

1. *The marginal effect of a change in convenience yields on the value of the firm is larger for banks than non-banks:*

$$\frac{\partial V^B\left(b^B, \Delta^B\right)}{\partial \Delta^B} = \frac{Q^B\left(b^B, \Delta^B\right)}{1-\Delta^B} > \frac{Q^N\left(b^N, \Delta^N\right)}{1-\Delta^N} = \frac{\partial V^N\left(b^N, \Delta^N\right)}{\partial \Delta^N} \tag{OA5}$$

2. *The marginal effect of convenience yields for both types of intermediary is increasing in leverage:*

$$\frac{\partial V^j\left(b^j, \Delta^j\right)}{\partial \Delta^j \partial b^j} > 0,\ j \in \{B, N\} \tag{OA6}$$

Proof. Equation (OA6) follows by combining Equation (OA5) with Equation (OA1) from Lemma 4. Equation (OA5), follows from the fact that $Q^B\left(b^B, \Delta^B\right) > Q^N\left(b^N, \Delta^N\right)$ and $\Delta^B > \Delta^N$, which are guaranteed by Equations (OA3) and (17). □

D Calibration

Table OA-1 shows the parameter values in our baseline calibration. We explain each choice in term in this appendix.

Table OA-1: Model Calibration

	Description	Parameter(s)	Value(s)
Preferences	Households' discount factor	β^H	0.98
	Preference for monetary services	γ	0.0035
	Intermediaries' discount factor	β^B, β^N	0.93
Technology	Return mean	μ	1.05
	Return volatility	σ	0.0912
	Recovery rate in default	ϕ	0.7
	Marginal costs	c^B, c^N	0.0194, 0
	Adjustment cost curvature	ψ	0.0407
Bailouts	Probability of bailout	α^B,α^N	0.707, 0
	Cap on bailout/assets	t^{max}	0.1

Preferences. We set households' discount rate to $\beta^H = 0.98$, a standard value for macroeconomic models that implies a real interest rate of 2%. We set intermediaries' discount factors to $\beta^B = \beta^N = 0.93$, so that the effective cost of equity flotation is $\beta^H - \beta^B = 5\%$, consistent with estimates in Hennessy and Whited (2007). Households' preference γ for monetary services is chosen to ensure an equilibrium convenience yield on bank deposits of one percent, which is at the high end of the ranges reported in Krishnamurthy and Vissing-Jorgensen (2012) and Nagel (2016).

Technology. We set the average return on bank assets to match a market-to-book ratio of bank equity of 1.47, consistent with estimates for large banks in Minton, Stulz and Taboada (2017). Then, the volatility of bank returns σ is set to ensure that the likelihood of a financial crisis − defined as banks' asset values falling below their liabilities at their empirical debt-to-asset ratio − is 5%, implying a crisis every 20 years on average, which matches the historical estimates reported by Reinhart and Rogoff (2009) and Schularick and Taylor (2012). The recovery rate on intermediaries' assets after default is set to $\phi = 0.7$, in line with results in Granja, Matvos and Seru (2017).

We calibrate the marginal cost parameters c^B and c^N to generate a market share of banks in aggregate lending of 40%, which is consistent with Jiang et al. (2020a) and Buchak et al. (2024). Finally, the curvature ψ of adjustment costs is set so that Tobin's Q in banks, measured in our model by $V^B\left(b^B, \Delta^B\right)/p^K$, is 1.036 in equilibrium, as reported by Minton, Stulz and Taboada (2017). Intuitively, larger adjustment costs reduce the equilibrium price of capital p^K.

Government guarantees We choose the probability α^B of a bank receiving a bailout in order to achieve an average bailout of 3% of bank assets, conditional on being in distress, which is within the range of values reported by Laeven and Valencia (2013). Their database also suggests that a reasonable value of the cap on bank bailouts t^{max} is around 10% of aggregate bank assets.

E Additional Numerical Results

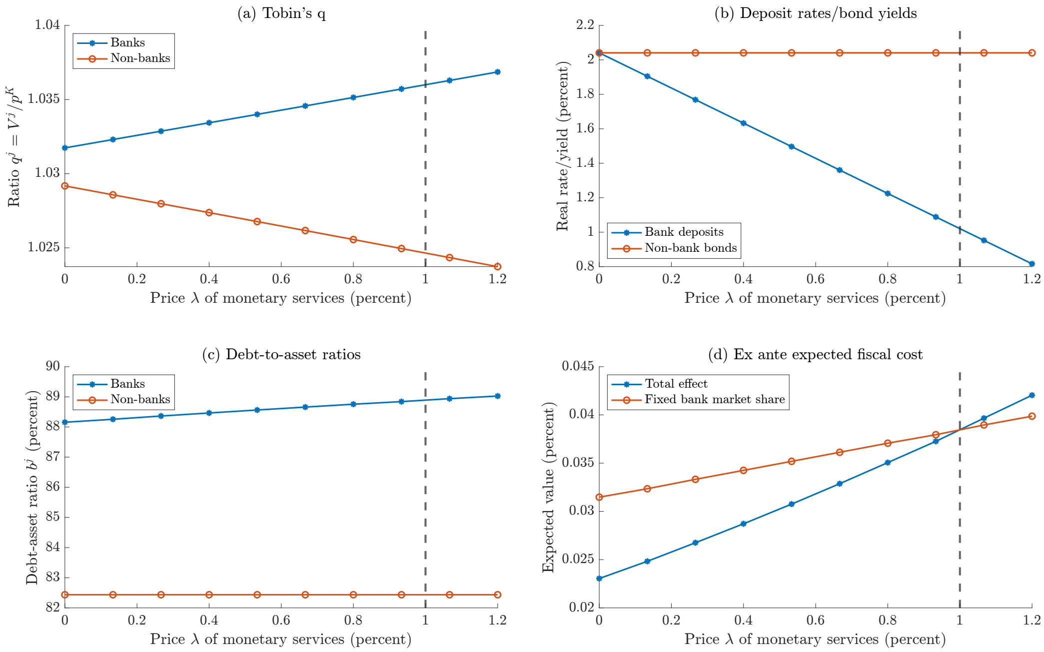

Figure OA-1: Additional Numerical Results: Public Monetary Innovation

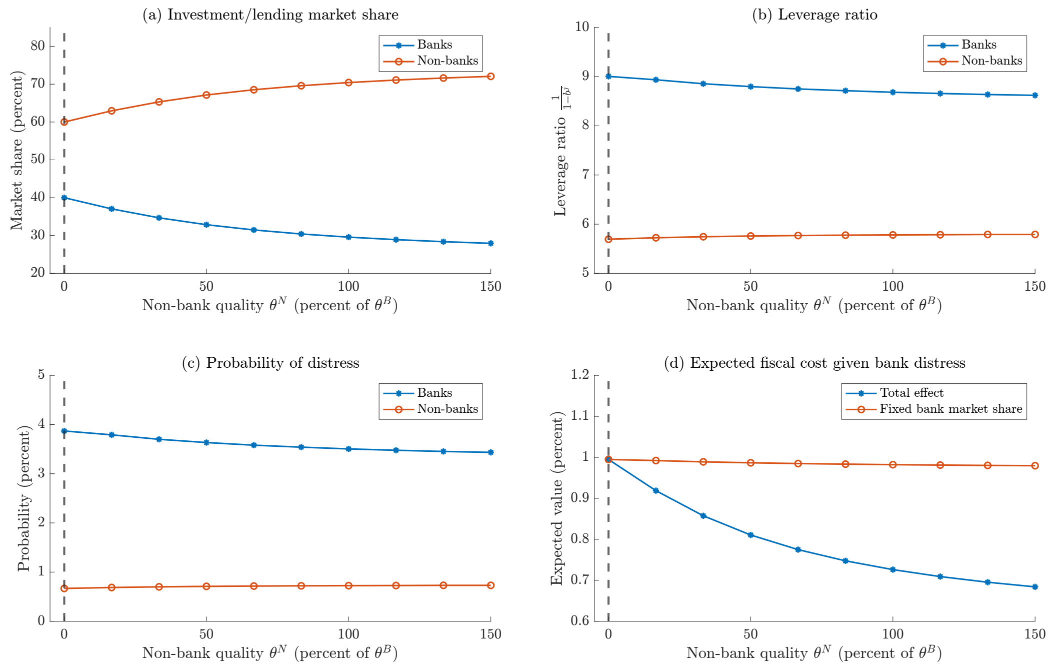

Figure OA-2: Numerical Illustration: Private Monetary Innovation, initial bank share 40%

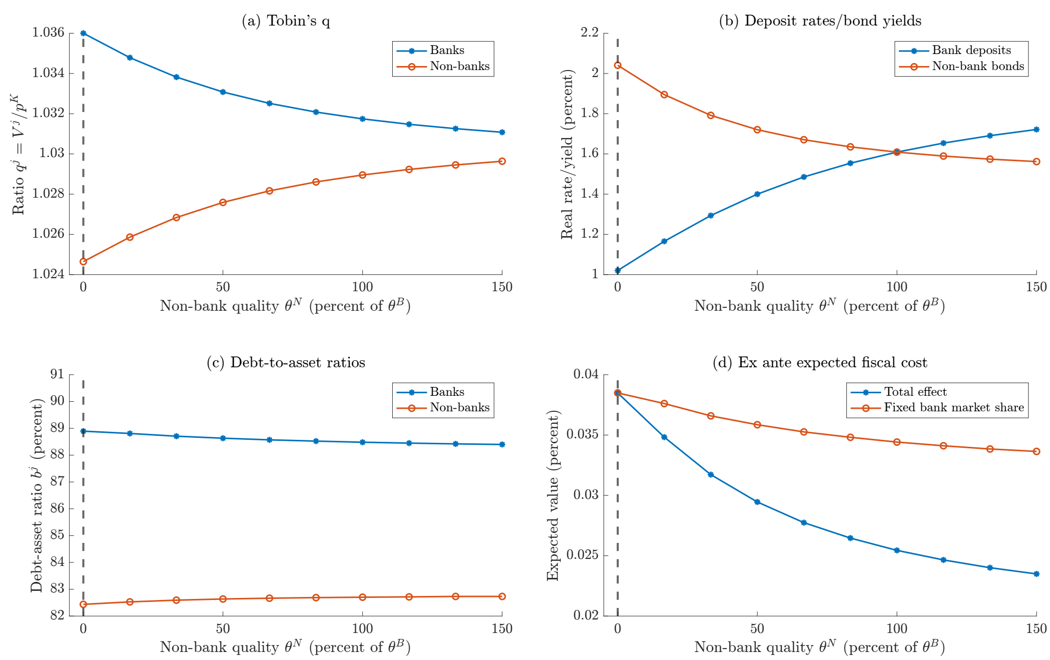

Figure OA-3: Additional Numerical Results: Private Monetary Innovation, initial bank share 40%

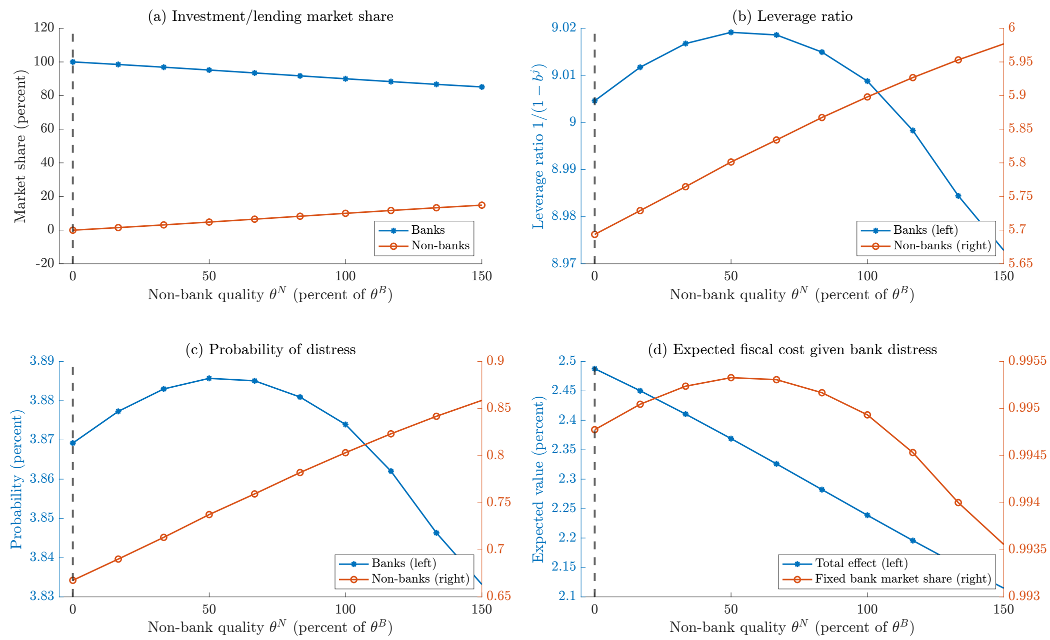

Figure OA-4: Numerical Illustration: Private Monetary Innovation, initial bank share 100%

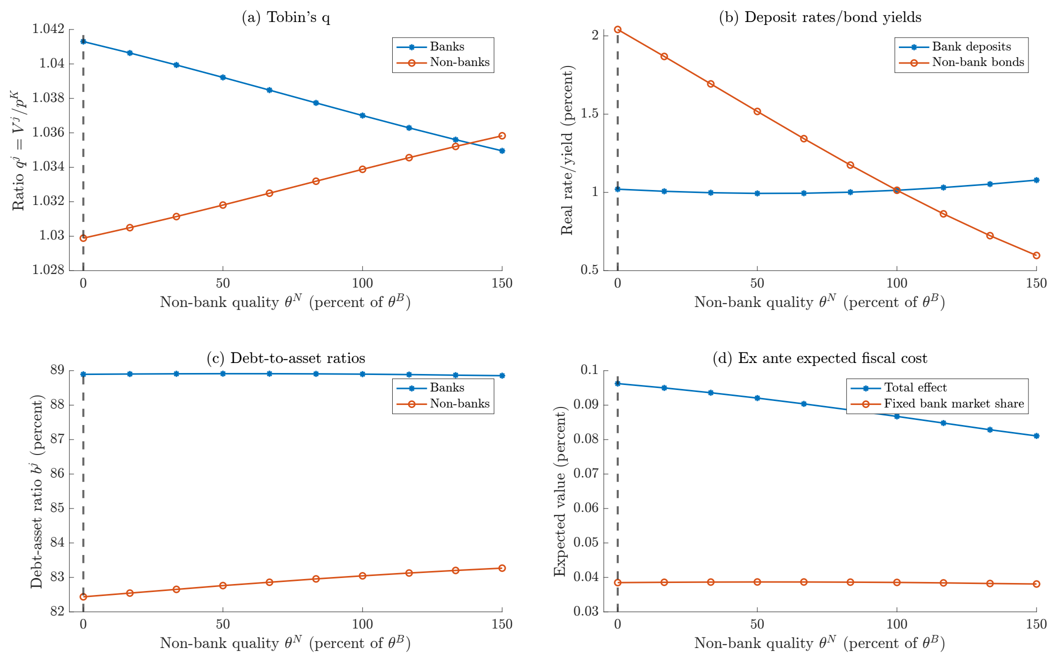

Figure OA-5: Additional Numerical Results: Private Monetary Innovation, initial bank share 100%