FEDERAL RESERVE BANK *of* ATLANTA WORKING PAPER SERIES

Diamond-Dybvig and Beyond: On the Instability of Banking

Chao Gu, Cyril Monnet, Ed Nosal, and Randall Wright

Working Paper 2023-2
February 2023

Abstract: Are financial intermediaries–in particular, banks–inherently unstable or fragile, and if so, why? We address this question theoretically by analyzing whether model economies with financial intermediation are more prone than those without it to multiple, cyclic, or stochastic equilibria. We consider several formalizations: insurance-based banking, models with reputational considerations, those with fixed costs and delegated investment, and those where bank liabilities serve as payment instruments. Importantly for the issue at hand, in each case banking arrangements arise endogenously. While the economics and mathematics differ across specifications, they all predict that financial intermediation engenders instability in a precise sense.

JEL classification: D02, E02, E44, G21

Key words: banking, financial intermediation, instability, volatility

https://doi.org/10.29338/wp2023-02

The authors thank George Selgin, Steve Williamson, David Andolfatto, Allen Head, Alberto Teguia, Yu Zhu, and William Diamond for their input. Wright acknowledges support from the Ray Zemon Chair in Liquid Assets and the Ken Burdett Chair in Search Theory and Applications at the Wisconsin School of Business. The views expressed here are those of the authors and not necessarily those of the Federal Reserve Bank of Atlanta or the Federal Reserve System. Any remaining errors are the authors' responsibility.

Chao Gu is with the University of Missouri. Cyril Monnet is with the University of Berne and Study Center Gersenzee. Randall Wright is with Zhejiang University and the University of Wisconsin-Madison. Please address questions regarding content to Ed Nosal, Federal Reserve Bank of Atlanta, ed.nosal@atl.frb.org.

> Banks, as several banking crises throughout history have demonstrated, are fragile institutions. This is to a large extent unavoidable and is the direct result of the core functions they perform in the economy. *Finance Market Watch Program @ Re-Define.*

1 Introduction

This essay reviews, consolidates and extends several branches of the literature on banking. It is, in part, a *survey*, but it also goes beyond past work in several ways. The unifying theme is this question: is instability, volatility or fragility endemic to financial intermediation, and, if so, why? The idea that financial institutions are inherently unstable goes way back, seemingly based on the notion that they are somehow special compared to, say, producers or retailers in goods markets. Rolnick and Weber (1986) give evidence of the widespread acceptance of this position when they say "Historically, even some of the staunchest proponents of laissez-faire have viewed banking as inherently unstable and so requiring government intervention." As a leading example, Friedman (1960) defended unfettered markets in virtually all contexts, yet advocated bank regulation in his Program for Monetary Stability.[1]

Rolnick and Weber (1986) study banks' instability using the historical record. In contrast, our approach is purely theoretical: we analyze various formal models of banking from the literature, combined and extended in novel ways, and in each case ask if the equilibrium set contains either a multiplicity of Pareto-ranked outcomes, or volatile dynamics – cyclic, chaotic or stochastic equilibria – with fluctuations arising as self-fulfilling prophecies. Saying that it engenders instability here means that environments with banking exhibit these types of outcomes for a larger set of parameters than otherwise-similar environments without such activity.

[1] The view that financial institutions are generally unstable is associated with names like Keynes (1936), Kindleberger (1978) and Minsky (1992). Others speaking to the issue include Diamond and Rajan (2001), Boyd et al. (2004), Allen and Gale (2007), Akerlof and Shiller (2009), Reinhart and Rogoff (2009), Shleifer and Vishny (2010), Admati and Hellwig (2014), Greenwood and Thesmar (2015) and Allen and Walther (2021). As to what people have in mind, Rolnick and Weber (1986) say "There is no agreement on a precise definition of inherent instability in banking. However, the conventional view is that it means that general bank panics can occur without economy-wide real shocks," consistent with Friedman and Schwartz (1963). We agree with this "conventional view" and hence focus squarely on volatility without aggregate real shocks.

This requires a discussion of several distinct models, because in reality banks have many different functions, and there is no general framework encompassing them all. These functions include: (i) acting as middlemen between savers and borrowers or asset sellers and asset buyers; (ii) finding, screening and monitoring investment opportunities on behalf of depositors; (iii) issuing liabilities (demand deposits) that facilitate third-party transactions; (iv) providing liquidity insurance or maturity transformation; (v) keeping cash and other valuables safe; and (vi) maintaining privacy or secrecy about their customers or their assets. Different approaches best capture these diverse activities, and we want to cover as many as we can.

Moreover, in each case we want intermediation to arise endogenously. As Gorton and Whinton (2002) said to start their survey a generation ago, crucial questions are: "Why do financial intermediaries exist? What are their roles? Are they inherently unstable?"[2] Describing in detail why these institutions exist is key for understanding if any instability that may arise is a "direct result of the core functions they perform" (from the epigraph). To say it differently, we want models *of* intermediation not just models *with* intermediation. It does not suffice to merely assert, e.g., that households can lend to banks and banks can lend to firms but households cannot lend to firms – that is a model *with* banking, not *of* banking, unless one spells out explicitly and in detail why households cannot lend to firms but banks can.[3]

Following Townsend (1987, 1988), our approach is to lay out an environment, including frictions like information or commitment problems, then interpreting endogenous outcomes in terms of institutions observed in reality. We want to know which frictions lead to banking. For this, one ought not *assume* missing markets, incomplete contracts etc., although something like that may *emerge*: "theory should explain why markets sometimes exist and sometimes do not, so that economic organisation falls out in the solution to the mechanism design problem" (Townsend

[2] Other surveys or textbooks pose similar questions (e.g., Freixas and Rochet 2008; Ennis and Keister 2010*a*; Calomiris and Haber 2014; Vives 2016).

[3] By analogy, Clower (1965) asserts that money buys goods and goods buy money, but goods do not buy goods, and while once a popular shortcut, it is hard to argue that his cash-in-advance constraint constitutes the last word in monetary economics – we would say it leads to models *with* money but not *of* money (see Wright 2017 for more on this).

1988). As Ennis and Keister (2010*a*) put it "The approach taken [in their preferred papers] has been to specify a complete physical environment and to study economic outcomes that agents in such an environment could achieve without imposing any artificial restrictions on their ability to enter mutually beneficial arrangements."

Relatedly, we adopt a generalization of Wallace's (1998) dictum, "money should not be a primitive in monetary theory – in the same way that a firm should not be a primitive in industrial organization theory or a bond a primitive in finance." We say a bank should not be a primitive in banking theory. In monetary economics, a pure view is that we should study models where money is *essential*, meaning the set of incentive-feasible allocations is better with money than without it, and we similarly want banks to be essential.[4] This is not to suggest that everything must always be endogenous – e.g., in Debreu (1959) households and firms are primitives, which is fine for some purposes, but presumably not for understanding family economics or industrial organization. Similarly, having banks arise endogenously is not crucial for all purposes, but it is for understanding their stability

In what follows, Section 2 presents Diamond and Dybvig's (1983) model of banking as liquidity insurance (or maturity transformation). This has inspired much research on bank runs, but as they make clear there are no runs in equilibrium unless one imposes ad hoc restrictions on contracts: "there is a simple variation on the demand deposit contract [defined below] which gives banks a defense against runs... suspension of convertibility [also defined below]." Whether runs occur in perturbations of their environment is the subject of much research, as discussed in Section 3. In any case, we want to broaden the conversation to include not only runs, but other types of fluctuations in bank activity due to self-fulfilling prophecies.

To this end, Section 4 embeds Diamond-Dybvig into an infinite-horizon environment to highlight the role of reputation, based on Gu et al. (2013*a*,*b*), and ultimately

[4] This notion of essentiality, which is usually attributed to Hahn (1973), is advocated by Wallace (2001, 2010) for several reasons discussed below (e.g., see fn. 8). In addition to work on the essentiality of money, Cavalcanti and Wallace (1999*a*,*b*), Araujo and Minetti (2011) and Gu et al. (2013*a*) discuss the essentiality of banks, Nosal et al. (2015, 2019) and Gong (2021) discuss the essentiality of other intermediaries, and Gu et al. (2016), Araujo and Ferraris (2020, 2021) and Buggenum and Rabinovich (2021) discuss the co-essentiality of money and credit.

on Kehoe and Levine (1993). There is no planner holding resources and doling them out – that task is performed by self-interested bankers that can be trusted only to some extent. They do not have exogenous commitment ability, but may be relatively trustworthy if they get a surplus from banking that they are not inclined to jeopardize by opportunistic behavior. Here we show there are multiple nonstationary equilibria where banks' reputation and activity fluctuate.

Section 5 features a different role for banks, based on Diamond (1984). This framework does not need anyone to have comparative advantage in banking. Instead it builds around the idea that delegated investment can be efficient when there are fixed costs of finding, evaluating, monitoring or implementing projects. In this situation, a group of agents may want to designate some to perform these tasks. Here bankers' reputations still play a role, and again there are equilibria where banking activity fluctuates over time, although, as will be explained later, both the economics and mathematics are different from Section 4.

Section 6 considers another approach, with bank liabilities (demand deposits) serving as payment instruments, like cash in Lagos and Wright (2005) or, more directly, the version with banks in Berentsen et al. (2007). Here demand deposits are useful for purchasing goods and services, and potentially less susceptible than cash to loss or theft (He et al. 2005, 2007; Sanches and Williamson 2010), or less sensitive to information (Andolfatto and Martin 2013; Dang et al. 2017). Again, volatile equilibria are more likely when banks are operative, but now the result is due to how they transform assets into better payments instruments. This result is especially relevant because the provision of efficient means of payment is missing from most work on banking, even if many people consider it an identifying characteristic.[5]

In summary, in every case economies with banking are more prone to multiplicity or volatility than those without it, say, because their activity has been taxed

[5] As Selgin (2018) says, "banks are distinguished from other kinds of financial intermediaries by the readily transferable or 'spendable' nature of their IOUs, which allows those IOUs to serve as a means of exchange, that is, money... Commercial bank money today consists mainly of deposit balances that can be transferred either by means of paper orders known as checks or electronically using plastic 'debit' cards." A classic reference on this is of course Gurley and Shaw (1960).

or regulated out of existence.[6] However, this does *not* mean banks lower welfare. To put this in context, Rajan (2005) argues modern economies are more susceptible to instability due to financial innovation expanding the roles of intermediaries. Summers (2005) counters that even if restricting their activities reduces volatility, that need not make it desirable, any more than restricting or eliminating airline innovation is necessarily desirable just because it reduces fatalities (grounding all flights eliminates plane crashes but that does not make it a good idea). Our work clearly bears on this discussion.

It is worth mentioning that, despite the differences, there is a commonality across the models: instability is directly related to the "core functions" of banks. A useful connection can be made to another literature. First, we obviously need frictions to get an essential role for banking – there is no such role in traditional GE (general equilibrium) theory. Now consider what Shell (1992) dubs the Philadelphia Pholk Theorem: in all models where the First Welfare Theorem fails there can be endogenous multiplicity/volatility. It is hard to prove this as stated, as it concerns *all* models, so corroboration comes from checking it in a series of specifications. Our approach is similar. What may not have been anticipated is that the same frictions leading to endogenous roles for banks lead to multiplicity/volatility.

It is also worth commenting on why people are so interested in the instability of banks, while other institutions are at least as volatile – after all, don't restaurants fail at least as often? As already mentioned, it is a venerable claim that financial activity is special. While it may also be interesting to study restaurants, and it is typical to regulate them to some extent, too, a focus on banking is timely given concerns arising from recent economic crises. Relatedly, there are policy issues related to banks – systemic risk, too big to fail, etc. – that make them different from restaurants or retailers. So in this essay we concentrate on banking.

[6] In the working paper (Gu et al. 2020), we also consider financial intermediaries other than banks. In that setup, similar to Nosal et al. (2019), middlemen hold inventories as in Rubinstein and Wolinsky (1987), but not in goods markets, rather in asset markets as in Duffie et al. (2005). We again show how these middlemen – who can be interpreted as asset dealers or brokers – contribute to instability, for different reasons. That model is omitted here since it is very different from the others. Still, we note the key results hold for non-bank financial intermediaries.

2 Banking as Insurance

Here is the environment in Diamond and Dybvig (1983) (see also Bryant 1980). There are three periods, $t = 0, 1, 2$, although $t = 0$ is mainly for planning, as all consumption takes place at $t = 1, 2$. There is one consumption good, which can be indexed by dates and states, as in GE theory. There is a set of agents each of which is endowed with 1 unit of the good at $t = 0$. There is an investment technology that turns 1 unit of the good at $t = 0$ into $R > 1$ units at $t = 2$, or 1 unit at $t = 1$ if the investment is interrupted. The good can also be stored to turn 1 unit at $t = 1$ into 1 unit at $t = 2$. This captures the idea that long-term projects yield less if interrupted – liquidated – before coming to fruition. Combined with the uncertainty described below, that generates a role for pooling investments.[7]

Uncertainty is incorporated as preference shocks: a constant fraction (for now there is no aggregate risk) α of agents value consumption at $t = 1$ but not $t = 2$, and are called early consumers. The rest value consumption at $t = 2$ but not $t = 1$, and are called late consumers. The period utility function at t is $u_t(c)$, with the usual properties (many applications use $u_1 = u_2$, but the generality is useful, as discussed below). The state of the economy at $t = 1$ is described by listing which members are early consumers and which are late, and this is for now publicly observable (private information is introduced later).

To begin, suppose there are two agents, denoted by a and b, and there are two equally probable states, $s = A, B$: in state A, agent a values consumption at $t = 1$ while agent b values it at $t = 2$; in State B, agent b values consumption at $t = 1$ while agent a values it at $t = 2$. Fig. 1 shows the event tree (all figures are at the end). There are 5 nodes, and the commodity space consists of vectors $\mathbf{c} = (c_0, c_{1,A}, c_{2,A}, c_{1,B}, c_{2,B})$.

*** Fig. 1 about here. ***

[7] At $t = 0$ you invest $x \in [0, 1]$ – say, put x potatoes in the ground – then at $t = 1$ dig up $x' \in [0, x]$, to consume, or to store to get x' at $t = 2$. The $x - x'$ potatoes stay in the ground to yield $(x - x')R$ at $t = 2$. We call them potatoes to emphasize this is a real model. Attempts to put Diamond-Dybvig into monetary models include Huangfu and Sun (2011) and Andolfatto et al. (2020). Other models with both money and banks are discussed below.

Consider the planner's problem of maximizing the equally-weighted sum of utility, or, equivalently, expected utility before agents know their type,

$$\max_{\mathbf{c}^a,\mathbf{c}^b} u_1\left(c_{1,A}^a\right)+u_2\left(c_{2,B}^a\right)+u_1\left(c_{1,B}^b\right)+u_2\left(c_{2,A}^b\right)$$
$$\text{st } \left(2-c_{1,A}^a\right)R=c_{2,A}^b \text{ and } \left(2-c_{1,B}^b\right)R=c_{2,B}^a,$$

where $\mathbf{c}^h$ is the consumption vector of agent h, and as elsewhere nonnegativity constraints are omitted to save space. As agents do not value the good at $t=0$, the solution puts all endowments in the investment technology and $c_0=0$. Similarly, $c_{1,B}^a=c_{2,A}^a=c_{2,B}^b=c_{1,A}^b=0$. Then $c_{1,A}^a=c_{1,B}^b\equiv c_1^*$, $c_{2,B}^a=c_{2,A}^b\equiv c_2^*$, where $c_2^*=(2-c_1^*)R$, and $u_1'(c_1^*)=u_2'(c_2^*)R$. This can be compared to autarky, where $c_{1,A}^a=c_{1,B}^b=1$ and $c_{2,B}^a=c_{2,A}^b=R$. If $u_1'(1)<u_2'(R)R$ then $c_1^*<1<R<c_2^*$, so early consumers get less than in autarky while the late consumers get more; if $u_1'(1)>u_2'(R)R$ then $1<c_1^*<c_2^*<R$, so late consumers gets less than in autarky while early consumers get more, which as explained below is the typical case considered in banking papers.

At the risk of being pedantic, we can show how the planner's efficient allocation can be supported by markets in competitive equilibrium, as in Debreu (1959), where agents trade date-and-state contingent commodities at $t=0$. Let c_0 be numeraire, $p_0=1$, and $p_{t,s}$ the relative price of the good at time t in state s. As the investment technology is accessible to all, anyone can operate as a firm to maximize profit by purchasing the $t=0$ good as an input and selling contingent output,

$$\max_{\mathbf{c}^f} -c_0^f+p_{1,A}c_{1,A}^f+p_{2,A}c_{2,A}^f+p_{1,B}c_{1,B}^f+p_{2,B}c_{2,B}^f$$
$$\text{st } \left(c_0-c_{1,s}^f\right)R=c_{2,s}^f,\ s=A,B$$

where c_0^f denotes the purchase and $c_{t,s}^f$ denotes sales. The FOCs are

$$1=p_{2,A}R+p_{2,B}R,\ p_{1,A}=p_{2,A}R \text{ and } p_{1,B}=p_{2,B}R.$$

Given the linear technology, equilibrium profits are 0.

Agent a maximizes utility by selling endowment and buying $c_{1,A}^a$ and $c_{2,B}^a$,

$$\max_{c_{1,A}^a,c_{2,B}^a} u_1\left(c_{1,A}^a\right)+u_2\left(c_{2,B}^a\right) \text{ st } p_{1,A}c_{1,A}^a+p_{2,B}c_{2,B}^a=1,$$

yielding the FOC

$$u_1'\left(c_{1,A}^a\right)=u_2'\left(\frac{1-p_{1,A}c_{1,A}^a}{p_{2,B}}\right)\frac{p_{1,A}}{p_{2,B}}.$$

The FOC for agent b is similar. Imposing market clearing and symmetry, we get $p_{1,A}=p_{1,B}=1/2$, $p_{2,A}=p_{2,B}=1/2R$, $c_{1,A}^a=c_{1,B}^b=c_1^*$, and $c_{2,B}^a=c_{2,A}^b=c_2^*$, so the allocation is efficient.

This can be extended to a large number of agents, perhaps making price-taking more reasonable, but we want to pursue a different course, since Debreu's model has no room for banking. Specifically, frictions to be incorporated include private information, lack of commitment and perhaps spatial or temporal separation. Hence, we shift focus to a mechanism design approach.[8] Consider the same environment, except with a continuum of agents, each of whom is an early consumer with probability α. They form a *coalition* that pools endowments and provides consumption depending on the preference shocks, which can be interpreted as banking.

In particular, the coalition designs a *contract* (c_1, c_2) to solve

$$\max_{c_1,c_2}\alpha u_1\left(c_1\right)+\left(1-\alpha\right)u_2\left(c_2\right) \tag{1}$$

$$\text{st}\ \left(1-\alpha\right)c_2=\left(1-\alpha c_1\right)R, \tag{2}$$

where c_1 and c_2 are consumption of early and late consumers, while (2) is a feasibility constraint. This problem is the same as the planner's problem when there is public information about individuals' consumption types. Thus, the outcome satisfies $c_1=c_1^*$, $c_2=c_2^*=\left(1-\alpha c_1^*\right)R/\left(1-\alpha\right)$, where $u_1'\left(c_1^*\right)=u_2'\left(c_2^*\right)R$, as is efficient.

Now suppose the preference shocks are private information. For agents to report their preference shock truthfully, we need $c_1^*\leq c_2^*$. If $u_1=u_2$, which is often the case in the literature, this truth-telling constraint does not bind. If $u_1\neq u_2$, there are two conditions under which still it does not bind: (i) $u_1'\left(1\right)<u_2'\left(R\right)R$,

[8] Wallace (2001, 2010) provides general motivation for using mechanism design in monetary economics. One virtue he emphasizes is that results do not depend on arbitrary ways of determining terms of trade. Walrasian price taking is a time-honored tradition, but we want to go beyond that, without being wed to a particular bargaining solution, since that can affect the results (see Appendix B). More generally, "mechanism design methods are attractive because they provide a clear distinction between the underlying environment and the rules of the game mapping actions into outcomes. Given a set of feasible mechanisms, it is possible to decide whether money [and we would add banking] is essential in an environment" (Jiang et al. 2022).

in which case $c_1^* < 1 < R < c_2^*$; and (ii) $u_1'(1) > u_2'(R)R$ and $u_1'(c) \leq u_2'(c)R$ at $c = R/(1-\alpha+\alpha R)$, in which case $1 < c_1^* < c_2^* < R$. In all these cases the contract resembles deposit banking: agents who want to consume early make a claim, typically described as a withdrawal, at $t = 1$, while the rest wait until $t = 2$. This achieves the efficient allocation. However, if neither (i) nor (ii) hold the truth-telling constraint binds, $c_1 = c_2$, and then the outcome is not first best.

One reason to focus on $1 < c_1^* < c_2^* < R$ is that it looks more like insurance, transferring resources from those who are happy to wait to those who need them sooner. Another is that in this case, in addition to the efficient outcome, there is another possibility: suppose you think all others will try to withdraw at $t = 1$; since the bank cannot pay $c_1^* > 1$ to all depositors at $t = 1$, they will go bust; so you want to try to withdraw early regardless of preferences. But this is due to imposing what is called a *simple demand deposit contract* paying c_1^* to everyone who wants to withdraw at $t = 1$ until resources are exhausted. That is not generally a good idea. At least with no aggregate uncertainty (see below), if the contract commits to pay c_1^* to at most a measure α of agents at $t = 1$, there are always resources to pay c_2^* to anyone waiting until $t = 2$. This *suspension of convertibility* eliminates late consumers' incentive to withdraw early, and is not unrealistic, as historically banks did close their doors in certain circumstances, sometimes called bank holidays.[9]

The conclusion is that there are no runs in equilibrium, at least if one defines equilibrium as including optimal contracts, as we do. To explain this, first, it is standard to say an outcome is not an equilibrium if an individual has a profitable deviation. For this application we want to extend that to say it is not an equilibrium if a feasible coalition of individuals has a profitable deviation, which they do under a simple deposit contract, to one with a suspension clause. It is fine to interpret this as saying we are not doing noncooperative game theory, but mechanism design, which

[9]This can be initiated by the banks or the government. Go to https://millercenter.org/the-presidency/presidential-speeches/march-12-1933-fireside-chat-1-banking-crisis to hear Roosevelt, after explaining the mechanics of bank runs, say: "By the afternoon of March 3 scarcely a bank in the country was open to do business. Proclamations temporarily closing them in whole or in part had been issued by the Governors in almost all the states. It was then that I issued the proclamation providing for the nation-wide bank holiday."

we think is the right approach for generating institutions like banking arrangements endogenously.

Many papers proceed differently. As one of many examples, consider Goodhart and Huang (2000), who say "Banks exist, as in Diamond and Dybvig (1983), because of their role in creating liquidity according to a standard demand deposit contract;" and then "We will stick to the standard deposit contract for the sake of simplicity, although we are aware of some criticisms about the use of such a standard deposit contract." It is admirable that they are more upfront about this than many papers that do not acknowledge the issue. However, one still has to ask, is it really just "for the sake of simplicity" when a restriction drives the main result? Of course, a virtue of some contracts is that they are realistic, but should that not be an output of our theories, not an input?

Still, in general, endogenizing banking arrangements need not automatically yield first-best outcomes. One possibility is that depositors lack commitment, so that they might agree to something ex ante then renege. Another possibility is that bankers' lack commitment as discussed, in various contexts, below. Also discussed below are cases where only subsets of agents can contact, and hence contract with, each other due to temporal (Section 4) or spatial (Section 5) separation. Another point worth emphasis is this: even if the model does not generate runs without ad hoc restrictions, that does not diminish the contribution of Diamond-Dybvig, which we take to be the development of a rigorous framework for thinking about banks.[10]

3 Extending Diamond-Dybvig

With aggregate uncertainty – i.e., with α random – suspension of convertibility is more delicate when one imposes a *sequential service constraint*, meaning the bank must serve depositors as they show up. One rationale is that agents are spatially/temporally isolated, as in search theory, which Andolfatto and Nosal (2020) take relatively seriously. More generally it can mean that agents contact the bank

[10]Before closing this section, we mention Jacklin (1987), who shows banking is not the only way to get efficiency here, even with private information (see Gu et al. 2020 for a discussion).

at most once at $t = 1$, or that early agents realize shocks sequentially and must consume immediately. While Diamond and Dybvig (1983) are aware that this matters, its importance was clarified by Wallace (1988). One way it matters is that the aggregate state α is revealed gradually to the bank as agents show up, but payments must be made to individuals before they all show up.[11]

Wallace (1990) shows how sequential service and aggregate risk can make partial suspension efficient. Suppose agents contact the bank sequentially and report their types. First, a batch with measure χ show up one at a time, where each is independently early with probability α or late with probability $1-\alpha$. Then the rest show up, where with probability ς they are all late and with probability $1-\varsigma$ all early. When the bank deals with agents in the first batch, it does not know the state of the second batch, but everything is revealed from the first agent in the second batch.

The contracting problem is therefore

$$\max_{c_1,c_2,c_1',c_2'} \chi\alpha u\left(c_1\right)+\varsigma\left(1-\chi\alpha\right)u\left(c_2\right)+\left(1-\varsigma\right)\left[\left(1-\chi\right)u\left(c_1'\right)+\chi\left(1-\alpha\right)u\left(c_2'\right)\right]$$

$$\text{st } c_2\left(1-\chi\alpha\right)=\left(1-\chi\alpha c_1\right)R$$

$$c_2'\chi\left(1-\alpha\right)=\left[1-\chi\alpha c_1-\left(1-\chi\right)c_1'\right]R$$

where c_1 is consumption of early agents in the first batch, c_2 is consumption of all late consumers when the second batch are all late, c_1' is consumption of early consumers in the second batch if all are early and c_2' is consumption of late consumers in the first batch when the second batch are all early. FOCs are

$$\begin{aligned} u'\left(c_1\right) &= \varsigma u'\left(c_2\right)R+\left(1-\varsigma\right)u'\left(c_2'\right)R \\ u'\left(c_1'\right) &= u'\left(c_2'\right)R \end{aligned}$$

Given $u'(1) > u'(R)\,R$, one can show $c_1 > c_1'$. This is partial suspension: early consumers in the second batch get less than those in the first batch.

[11] Sequential service has implications for public deposit insurance, which is supposed to rule out runs when they may occur, for any reason, including inefficient contracts. A typical policy proposal taxes individual withdrawals at $t = 1$ at rates depending on total withdrawals at $t = 1$, with the proceeds plowed, like potatoes, back into long-term investment. Wallace (1988) argues this violates sequential service (it also violates the idea that all long-run investments happen at $t = 0$, but Keister 2016 has a fix for that).

Green and Lin (2000, 2003) raise important issues. They have a finite number of agents N that are early or late consumers with probability α or $1-\alpha$, independently, so there is aggregate risk. After depositing and learning their types, all agents visit the bank sequentially – say, they form a line – where for now everyone knows the positions in line, and each reports "early" or "late." This is a direct mechanism, with agents reporting types, subject to truth-telling constraints. Consumption is provided contingent on an agent's position in line, his report, and the reports of previous agents. Green and Lin show the unique equilibrium is efficient.

The intuition is straightforward. First, note that when the last consumer reports the bank maximizes the equally-weighted utility of him and previous agents who declared "late" given the available resources. Let n_{N-1} be the number of agents who report "late" before the last agent shows up, and let y_N denote the resources available when he shows up. If he reports "late" then the bank keeps y_N in the long-term investment and doles it out equally to all late agents, so $c_2 = y_N R/(n_{N-1}+1)$. If he reports "early" then, assuming $u_1 = u_2 = u$, the bank solves

$$\max_{c_{1,N}, c_2'} u(c_{1,N}) + n_{N-1} u(c_2') \tag{3}$$

$$\text{st } (y_N - c_{1,N}) R = n_{N-1} c_2' \tag{4}$$

where $c_{1,N}$ is consumption of the last agent and c_2' is consumption to others that previously reported "late."

The solution entails $u'(c_{1,N}) = u'(c_2') R$, which means $c_{1,N} < c_2'$ since u is concave. By (4), $c_1 < y_N R/(n_{N-1}+R) < c_2$. Thus, regardless of previous reports, the last agent gets less when he reports "early" than when he reports "late," so there is no incentive to misreport. Knowing that he reports truthfully, it is not hard to see that the agent before him reports truthfully, too. By induction, all agents report truthfully, and a run cannot happen: banks are stable.

Much of the literature following up on this is fairly technical. Andolfatto et al. (2007) and Ennis and Keister (2009*a*), e.g., discuss how the independence of individual shocks matters. Here we focus on Peck and Shell (2003), who make three changes in the model: First, $u_1 \neq u_2$, which means truth-telling constraints may bind. Second, agents do not know their positions in line. Third, they use indirect mechanisms that do not require all agents report their type, which is not crucial but means, in contrast to Green and Lin (2003), now only those that want to withdraw at $t = 1$ visit the bank, which is effectively a report.

Consider two agents, where each is early with probability α. If it were true that everyone reports truthfully, the contract would solve

$$\max_c \bar{W}(c) = \alpha^2 [u_1(c) + u_1(2-c)] + 2\alpha(1-\alpha)\{u_1(c) + u_2[(2-c)R]\} + (1-\alpha)^2 u_2(R)$$

$$\text{st } \alpha[u_2(c) + u_2(2-c)]/2 + (1-\alpha)u_2(c) \leq \alpha u_2[(2-c)R] + (1-\alpha)u_2(R).$$

Note that if neither agent visits the bank at $t = 1$ both get R at $t = 2$; otherwise c is consumption for the first agent to visit the bank at $t = 1$ and $2 - c$ is left over for the other agent. The objective function includes four events: both agents are early; one is early and the other is late; etc. The constraint says that when agent i is late he does not want to withdraw at $t = 1$, given that the other agent j acts truthfully, i.e., given j withdraws at $t = 1$ iff he is early.

This implies there is an equilibrium where both act truthfully, and we let c^* solve the above problem, with $\bar{W}(c^*)$ the optimized objective function providing an upper bound on welfare. However, now suppose patient agent i believes j withdraws at $t = 1$ independent of j's type. Then it is a best response for i to also withdraw at $t = 1$ independent of i's type if

$$u_2(c^*) + u_2(2-c^*) \geq 2u_2[(2-c^*)R],$$

which can hold in examples. This does not yet yield an equilibrium with runs, however, since c^* was chosen predicated on agents acting truthfully.

To proceed, welfare if both agents withdraw at $t = 1$ (regardless of type) is

$$\underline{W}(c) = \alpha^2[u_1(c) + u_1(2-c)] + \alpha(1-\alpha)[u_1(c) + u_2(2-c)] + (1-\alpha)^2[u_2(c) + u_2(2-c)]$$

for any c that satisfies $u_2(c) + u_2(2-c) \geq 2u_2[(2-c)R]$. But now notice depositing and running is not an equilibrium: if agents expect a run, they do not use the bank, as autarky provides a higher payoff. Given this, Peck and Shell (2003) consider sunspot equilibria, as we now discuss.

First, define a run-proof contract as the solution to the above maximization problem given the additional constraint

$$u_2(c) + u_2(2-c) \leq 2u_2[(2-c)R], \tag{5}$$

which says agent i prefers to wait if he is late no matter what j does. Let welfare under the best run-proof contract be W_0. Now consider a run-admitting contract, where agents coordinate by running when an intrinsically-irrelevant sunspot variable takes a certain value at $t=1$, which occurs with probability ζ. Welfare under the best run-admitting contract is $W_1 = \max_c \left[\zeta \underline{W}(c) + (1-\zeta)\bar{W}(c)\right]$. If ζ is small, $W_1 > W_0$ and this run-admitting contract beats the run-proof contract. So agents deposit with a run-admitting contract, then run with probability ζ.[12]

The mechanism in Peck and Shell (2003) *restricts* the space of feasible reports. In contrast, indirect mechanisms in Andolfatto et al. (2017) and Cavalcanti and Monteiro (2016) *expand* it. Suppose agents can announce their type at date $t=1$, early or late, plus whether they plan to run. The mechanism can reward those telling the truth, with payoffs designed so that running is not an equilibrium (effectively, agents agree to ignore the sunspots in Peck-Shell). The unique equilibrium has truth telling, so banking is stable. To be clear, the revelation principle says direct mechanisms are unrestrictive if we want to support a good outcome as an equilibrium; it does not say they let us support it as the unique equilibrium. These papers use indirect mechanisms to get efficiency as the unique equilibrium.

Readers by now may have noticed a tendency for the literature to oscillate: there is a sequence of models where runs can occur, cannot occur, can occur... And we are not done. The next insight is to notice that in above models only depositors make reports, but the bank gathers information over time, and there may be role for passing it on to depositors. In particular, if depositors do not know their place

[12] Cooper and Ross (1998) also use sunspots to trigger runs. Relatedly, Goldstein and Pauzner (2005) use techniques from global games to endogenize the run probability, while Postlewaite and Vives (1987) use real aggregate risk.

in line, as in Peck and Shell (2003), Andolfatto et al. (2007) show that giving them the information eliminates runs, although perhaps surprisingly that may or may not be desirable. Nosal and Wallace (2009) show that giving agents more information can increase or decrease the set of incentive-feasible allocations and welfare.

Ennis and Keister (2009*b*) take yet another angle: banking is hindered by commitment problems: Knowing a run is ongoing, suspending payments hurts those who are truly in need of early consumption, and so a benevolent bank may want to re-optimize the payment scheme ex post, but then that might trigger a run. To pursue this, Ennis and Keister modify the investment technology by saying that if it is interrupted at $t = 1$ output is $1 - \varepsilon$, with ε interpreted as a liquidation cost (the efficient allocation is not affected by this but it allows banking to dominate autarky for more parameters). With deterministic α, the bank keeps αc_1^* in storage and puts the rest in the investment technology. The bank pays early agents c_1^* and late agents c_2^*. Suspension of convertibility after a fraction α of the agents withdraw uniquely implements the efficient allocation.

When a run happens, a banker knows it when more agents show up after paying a fraction α of them. If the bank suspends convertibility some early agents go without, so a benevolent banker may pay more than a fraction α at $t = 1$. Letting α_s be the fraction actually paid, and normalizing $u(0) = 0$, the banker solves

$$\max_{\alpha_s} \alpha_s u(c_1^*) + (1 - \alpha_s)(1 - \alpha) u(c_2(\alpha_s))$$

$$\text{st } c_2(\alpha_s)(1 - \alpha_s)(1 - \alpha) = \left[1 - \alpha c_1^* - \frac{(\alpha_s - \alpha) c_1^*}{1 - \varepsilon}\right] R \quad (6)$$

$$\alpha \leq \alpha_s \leq \bar{\alpha} \equiv \frac{(1 - \alpha c_1^*)(1 - \varepsilon)}{c_1^*} + \alpha. \quad (7)$$

Here (6) is the resource constraint, where the LHS is total payments at $t = 2$, and the term in the square bracket on the RHS is the resources at the end of $t = 1$. The $\hat{\alpha}_s$ solving $c_2(\hat{\alpha}_s) = c_1^*$ is the threshold above which an agent withdraws at $t = 1$ if all others do the same. Also, (7) says suspension must occur after α agents receive payments but before exhausting resources at $t = 1$.

Solving this yields the stopping point α_s^*, which can be above $\hat{\alpha}_s$. Now banking is fragile in the sense that if an agent expects the bank to suspend convertibility at α_s^* instead of α, he withdraws early when he expects others to. Notice that in this run equilibrium $\alpha(1-\alpha_s)$ impatient agents do not consume anything. Ennis and Keister ($2009b, 2010b$) pursue various applications, such as showing that banks are more fragile when α is larger, and that there can be multiple waves of runs over time. In any case, the lack of commitment in these models is interpreted as a time-inconsistency problem for bankers acting on behalf of depositors; below we discuss commitment problems for bankers who only care about their own payoffs.

While sequential service may be necessary for runs in some environments, Andolfatto and Nosal (2020) argue that during the last financial crisis there was a run on shadow banks, like money market mutual funds, that do not seem subject to anything like sequential service. Hence, they do not impose it, but add a fixed cost κ to the setup in Peck and Shell (2003). Intuitively, by running with others, late agents avoid fixed costs at $t=2$. As long as κ is not too small, a late agent gets a higher payoff by running than waiting. And as long as the probability of a run is not too big, a run-admitting contract dominates the best run-proof contract.

To avoid such details, again, many papers simply assume inefficient deposit contracts to study applied issues. There are too many to go into them all, but examples on the macro impact of banking crisis include Ennis and Keister (2003), Gertler and Kiyotaki (2015) and Gertler et al. (2020). Another branch of the literature is summarized by Allen and Gale (2007) based on much previous work (see their references). They argue that other models may account for runs on a single institution, but not system-wide crises characterized by large swings in asset prices. Their framework incorporates asset markets and aggregate shocks to get large price swings, usually assuming incomplete markets to preclude insurance against these shocks.[13]

A notable feature of some models is that a small shock to one financial institution can propagate through the system and turn into a crisis. Chari and Jagannathan

[13] One might worry this is like imposing exogenously inefficient contracts. If agents want to hedge against shocks, subject to imperfect information or commitment, can we justifiably preclude that just by saying "assume missing markets"? Again, one can appeal to realism, but for the issues at hand market structure should be an output of, not an input to, the theory.

(1988), e.g., model withdrawals by informed depositors leading to withdrawals by others, and Gu (2011) formalizes this as rational herding, but those papers use simple demand deposit contracts. In what follows, the approach is to allow contracts that are efficient, subject to explicit frictions, and see if dynamic equilibrium can exhibit fluctuations as self-fulfilling prophecies, focusing not on bank runs per se but on recurrent periods of boom and distress.

4 Reputational Dynamics

We now extend the model to an infinite-horizon setting. This combines the standard environment in Diamond and Dybvig (1983) with the model of banker's reputational concerns in Gu et al. (2013*b*), which is closely related to the literature on credit markets following Kehoe and Levine (1993). Moreover, we use methods from the dynamic analysis of credit (without banks) in Gu et al. (2013*a*) and Bethune et al. (2018*a*,*b*), since the current theme is instability.[14]

To begin, note that in Diamond-Dybvig agents share resources at $t = 1$. In the usual case, with $c_1^* > 1$, e.g., one can think of every agent investing on his own at $t = 0$, then at $t = 1$ late agents interrupt some of their project and transfer goods to early agents. What if they cannot commit? Clearly, they will renege. Perhaps someone can be delegated to control the investments and make the required payouts (transfers). But what if they cannot commit? A key feature here is that agents are more or less trustworthy. To capture this in a stark way, suppose that some of them live forever, while at each t there are others around for only 1 period. This can be generalized so the latter are around for any finite number periods, but 1 is easiest.[15]

Emulating the previous models, each period has three subperiods, corresponding to the planning, early withdrawal and late withdrawal stages in the benchmark Diamond-Dybivg model. Also, the finite-lived agents have the same endowment

[14] Related models of banks include Donaldson et al. (2018), Auer et al. (2021) and others discussed below. Another paper on bank dynamics, in a different model, is Benhabib et al. (2016).

[15] Alternatively, we can say all agents live forever, but some are more trustworthy because they are relatively patient, easier to monitor, more attached to the market, better at investing, or different in some other way that makes it easier to provide them with the right incentives (Gu et al. 2013*b*); to illustrate ideas it suffices to differentiate them only by their horizons.

and preferences as above, while the infinitely-lived agents have 0 endowment and get utility c from c units of consumption in either subperiod 1 or 2. The technology is the same as above, too, and anyone can operate it. What is key is that the short-lived agents cannot commit, and hence cannot insure each other. That leads to a potential role for long-lived agents, as bankers, who accept deposits, invest them, and make payouts on demand.

Importantly, the long-lived agents do *not* have exogenous commitment ability – it is based on reputation, which means they may honor obligations lest they get identified as renegers, whence they are punished to autarky (a credible threat because there are many substitutes for any given banker). Just how trustworthy they will be is endogenous, given there is a temptation to misbehave, modeled as in the "cash diversion" framework of Biais et al. (2007) or DeMarzo and Fishman (2007). Namely, if a banker misappropriates d deposits, he gets payoff λd, where $\lambda > 0$ is not too big, so this is socially inefficient. One can think of them as diverting resources in any number of ways, e.g., they simply just abscond with d.[16]

As in some related papers, misbehaving bankers get detected, or monitored, with probability $\mu \leq 1$, and if they get caught they are punished with autarky. One interpretation of μ is the probability one generation of depositors can communicate misbehavior to the next, but there are others. Moreover, $\mu = 1$ works, but that does not simplify things much, and $\mu < 1$ is known to be interesting from other applications (e.g., Gu et al. 2016). Also, μ can be endogenized as in Huang (2017), where it is interpreted as a monitoring probability, and a nice if not surprising result is that $\mu < 1$ is optimal when bank examiners are costly.

Depositors may choose $d < 1$, and invest $1-d$ on their own, as that affects banks' incentive to misbehave, different from Sections 2-3 where $d = 1$, but similar to Peck and Setayesh (2019). In addition to d, contracts specify returns per unit deposited contingent on withdrawal time, r_j, where $j = 1, 2$ denotes the subperiod, plus a payment to the banker $b \in [0, d]$, made in the first subperiod and invested by him to

[16] On that interpretation we can say $1 - \lambda$ of the deposits are lost in transit. See also Ennis and Keister (2009*b*, 2010*b*) and Andolfatto and Nosal (2008).

yield utility Rb. While there are many long-lived agents that could be bankers, only one will be the banker (the optimal number of banks is analyzed in Section 5; for now it is too costly to monitor more than one). Still, ex ante competition between long-lived agents implies the contract maximizes depositors' expected utility, although a banker still must get some reward so they have an incentive to behave appropriately.

This is summarized by the constraint

$$b_t R + \beta V_{t+1} \geq \lambda d_t + \beta (1-\mu) V_{t+1}, \tag{8}$$

where β is his discount factor, V_t is his equilibrium payoff and the RHS is the deviation payoff, including λd for sure and V_{t+1} iff he is not caught misbehaving.[17] Importantly, V_{t+1} is his value next period, facing a new generation of depositors, and hence is taken as given at t. The contracting problem is

$$\max_{d_t, r_{1t}, r_{2t}, b_t} \alpha u_1 (d_t r_{1t} + 1 - d_t) + (1-\alpha) u_2 [d_t r_{2t} + (1-d_t) R] \tag{9}$$

$$\text{st} \;\; (1-\alpha) d_t r_{2t} = (d_t - b_t - \alpha d_t r_{1t}) R \tag{10}$$

$$r_{2t} \geq r_{1t} \tag{11}$$

$$\lambda d_t - b_t R \leq \phi_t, \tag{12}$$

where (12) rewrites (8) using $\phi_t \equiv \beta \mu V_{t+1}$.

We call ϕ_t a banker's *franchise value*, capturing his reputation for trustworthiness, and that is something put in jeopardy by opportunistic behavior (see also Monnet and Sanches 2015). Without (12) clearly $b_t = 0$ and $d_t = 1$, so this reduces to the basic Diamond-Dybvig model; with (12) the solution depends on ϕ_t, a natural generalization of Diamond-Dybvig. Substituting (10) into (9) to eliminate r_2 and taking FOCs wrt (r_1, d, b) we get

$$\begin{aligned}
0 &= d \{\alpha [u_1'(c_1) - R u_2'(c_2)] - \eta_1 (1 - \alpha + R\alpha)\} r_1 \\
0 &= \{(r_1 - 1) \alpha [u_1'(c_1) - R u_2'(c_2)] + \eta_1 [R - (1 - \alpha + R\alpha) r_1] - \eta_2 \lambda\} d \\
0 &= [-u_2'(c_2) - \eta_1 + \eta_2] b,
\end{aligned}$$

[17] A detail is that a deviant banker gets λd but forfeits his honest income b, which is not a big deal, but does affect a few results. Also, note that the actions of the bank are observable and R is deterministic, excluding some considerations in related work by Ordonez (2013, 2018).

where $c_1 = dr_1 + 1 - d$ and $c_2 = dr_2 + (1-d) R$, while η_1 and η_2 are multipliers.

The FOCs yield two critical values, $\phi^* > 0$ and $\hat{\phi} < \phi^*$, delineating three regimes. (i) If $\phi \geq \phi^*$ then (12) is slack, so $b = 0$, and the franchise value keeps a banker honest without $b > 0$. In this case there is a continuum of contracts achieving the full-insurance outcome, since depositors can have the bank invest a lot or a little, and invest the rest on their own. (ii) If $\phi \in [\hat{\phi}, \phi^*)$ either $d < d^* \equiv \phi^*/\lambda$ or $b > 0$ is needed to satisfy (12). While $d < d^*$ means incomplete insurance, this is second-order, by the envelope theorem, so we get $d = \phi/\lambda$ and $b = 0$. (iii) If $\phi < \hat{\phi}$, lowering d further entails too much risk, so we get $b > 0$.

In regime (i), one of many payoff-equivalent contracts has $r_1 = r_2$; in (ii) or (iii) the unique optimal contract has $r_1 = r_2$; so from now on we set $r_1 = r_2 = r$. Given this, from the FOCs one can show the contract looks as shown in Fig. 2, drawn for an example where depositor utility in subperiod j is

$$u_j(c_j) = A_j \frac{(c_j + \upsilon_j)^{1-\sigma_j} - \upsilon_j^{1-\sigma_j}}{1 - \sigma_j} \tag{13}$$

and parameters are $\upsilon_j = 0.01$, $\sigma_j = 2$, $A_1 = 1$, $A_2 = 0.1$, $R = 2.1$, $\mu = 0.7$, $\alpha = 0.25$, $\lambda = 0.7$, and $\beta = 0.99$. Notice $\hat{\phi} > 0$ in Fig. 2, which is relevant because $\hat{\phi} > 0$ is needed to get banking in steady state (see below).

*** Fig. 2 about here. ***

So far the contract takes ϕ as given. To endogenize it, use $\phi_t = \beta\mu V_{t+1}$ to write $V_t = b_t R + \beta V_{t+1}$ as the following dynamical system,

$$\phi_{t-1} = f(\phi_t) \equiv \beta\mu b(\phi_t) R + \beta\phi_t, \tag{14}$$

where $b(\phi_t)$ comes from the FOCs, and one can check $b'(\phi) < 0$ for $\phi < \hat{\phi}$. Equilibrium is defined as a nonnegative, bounded path for ϕ_t solving (14), from which other variables in the contract follow. A steady state solves $\bar{\phi} = f(\bar{\phi})$.

Proposition 1 *There is a unique steady state $\bar{\phi}$. If $\hat{\phi} \leq 0$ it has $\bar{\phi} = d = 0$. If $\hat{\phi} > 0$ it has $\bar{\phi} \in (0, \hat{\phi})$ and $d > 0$.*

Proof: If $\hat{\phi} \leq 0$ then (14) reduces to $\phi_{t-1} = \beta\phi_t$ and the only equilibrium is the steady state with $\bar{\phi} = 0$. If $\hat{\phi} > 0$ then $f(0) > 0$ and $f(\hat{\phi}) = \beta\hat{\phi} < \hat{\phi}$ implies $\bar{\phi} \in (0, \hat{\phi})$ exists. To see it is unique, first solve (14) for $\phi = \beta\mu b(\phi) R/(1-\beta)$. The LHS is decreasing in ϕ and the RHS is decreasing as $b' < 0$. The solution is therefore unique. ■

Going beyond steady state, note from (14) that $f(\phi_t)$ has a linearly increasing term and a nonlinear decreasing term due to $b'(\phi) < 0$. If on net $f'(\phi_t) < 0$ over some range, the system exhibits nonmonotone dynamics. Fig. 3a shows f and f^{-1} for the above example, which intersect uniquely on the 45^o line at $\bar{\phi} = 0.1491$. This system is monotone so there is a unique equilibrium, the steady state, which is the only bounded solution to (14). Fig. 3b changes the example to $\sigma_1 = 10$ and $\mu = 1$, so $f'(\bar{\phi}) < -1$. Hence f and f^{-1} intersect not only on the 45^o line at $\bar{\phi} = 0.0283$, but off it at (ϕ_L, ϕ_H) and (ϕ_H, ϕ_L) with $\phi_H = 0.0285$ and $\phi_L = 0.0282$.

*** Fig. 3 about here. ***

As is standard (e.g., Azariadis 1993), this means there is a 2-cycle equilibrium where ϕ_t oscillates between ϕ_L and ϕ_H. It also means there are sunspot equilibria where ϕ_t fluctuates randomly between values close to ϕ_L and ϕ_H (see Appendix A). Hence deterministic or stochastic volatility is possible with banking, while without it the only equilibrium, autarky, is stable if not desirable – i.e., banking is essential, dominating autarky by providing insurance to agents that cannot insure each other due to commitment issues.

The intuition is actually simple: if V_{t+1} is high then ϕ_t is high and we can discipline bankers at t with low b_t; but then V_t and hence ϕ_{t-1} are low, inducing a tendency to oscillations, although for a cycle this must dominate the linear term in $f(\phi_t)$. Fig. 4 shows the time path of (ϕ, d, b, r) over the 2-cycle. Notice r moves with ϕ, b moves against it, and while deposits d can go either way in this example it moves against ϕ. The point is not to take this quantitatively seriously, but to show theory makes predictions – it does not say "anything goes."

*** Fig. 4 about here. ***

A 2-cycle is a fixed point of $f^2 = f \circ f$. It is not hard to construct examples (e.g., $\sigma_1 = 14$, $\sigma_2 = 1.5$, $\upsilon_j = 0.01$, $A_1 = 1$, $A_2 = 0.075$, $R = 2.2$, $\mu = 1$, $\alpha = 0.28$, $\lambda = 0.75$ and $\beta = 0.76$) with 3-cycles, fixed points of f^3. Standard results (Azariadis 1993) say the existence of 3-cycles implies there exist cycles of all periodicity plus chaos. So the model can display quite a variety of complicated dynamics. Now we do not claim that actual data are best explained by these deterministic or stochastic cycles, but we suggest that if simple banking models like this can deliver equilibria where endogenous variables vary over time, as self-fulfilling prophecies, it lends credence to the view that banks can in reality engender instability.

5 Delegated Investment

The next formulation has intermediation originating from economies of scale – fixed costs of finding, screening and monitoring investment opportunities.[18] Reputation again plays a role, since as in Section 4 we embed the standard version of this framework in a dynamic setting, but now all agents are homogeneous so no one has a comparative advantage in trustworthiness. Also, what makes banking essential here is not insurance – rather, given fixed costs, it can be efficient to delegate a subset of agents to be bankers that invest on behalf of depositors.

Let κ be the fixed cost of a project and R the return per unit invested. A large number of agents at each date are together in one of a large number of locations, and they get randomly relocated at the end of each period. Random relocation appears in many banking papers (e.g., Champ et al. 1996, Bencivenga and Smith 1991, Smith 2002 or Bhattacharya et al. 2005, and we note that such papers usually use monetary models). Its role here is to avoid long-term bank contracting, which is interesting but complicated (e.g., Gu et al. 2013*b*). In Section 4 we avoided that issue by having short-lived depositors, but here we want all long-lived agents, so that they can all potentially act as bankers.

Period utility is $u(x) - c(d)$, where x is consumption and d investment (the

[18]This is the approached taken by Diamond (1984). Related papers, in addition to those we mention elsewhere, include Williamson (1986,1987), Haubrich (1989) and Diamond (1996).

same as deposits in equilibrium), with the usual assumptions, plus $u'(0)R > c'(0)$, so that agents would invest if κ were small. The payoff to investing on one's own is

$$W_1 = \max_{x,d} \{u(x) - c(d)\} \text{ st } x = Rd - \kappa. \tag{15}$$

Suppose for the sake of discussion κ is big enough that $W_1 < 0$, where $W_0 = 0$ is the autarky payoff. Then there is an incentive to form a coalition where some, called depositors, delegate their investments to others, called bankers. As is standard in environments with nonconvexities, the coalition uses a lottery: a measure ω_t of agents are chosen as bankers at random. For consistency, we model opportunistic bank behavior as above, with λ and μ, leading now to the incentive condition

$$\beta V_{t+1} \geq \lambda x_t (1 - \omega_t) / \omega_t + (1 - \mu) \beta V_{t+1}, \tag{16}$$

where the RHS is the deviation payoff, given each depositor is promised x_t and each banker controls $(1 - \omega_t) x_t / \omega_t$ of the resources.

As emphasized by Huang (2017), a key trade-off is that having fewer banks saves fixed costs but raises their temptation to misbehave because they must be larger for a given amount of deposits. The relevant problem is

$$\max_{\omega,X,D,x,d} \omega [u(X) - c(D)] + (1 - \omega) [u(x) - c(d)] \tag{17}$$

$$\text{st } \omega X + (1 - \omega) x = R [\omega D + (1 - \omega) d] - \kappa \omega \tag{18}$$

$$u(x) - c(d) \geq 0 \tag{19}$$

$$x (1 - \omega) / \omega \leq \phi, \tag{20}$$

where again $\phi_t \equiv \mu \beta V_{t+1} / \lambda$, while (X, D) is consumption/investment for bankers while (x, d) is the same for depositors. Substituting (18) into (17) to eliminate X, and letting η_1 and η_2 be multipliers, we get FOCs wrt (D, d, x, ω):

$$\begin{aligned}
0 &= u'(X) R - c'(D) \\
0 &= (1 - \omega) [u'(X) R - c'(d)] - \eta_1 c'(d) \\
0 &= (1 - \omega) [u'(x) - u'(X)] + \eta_1 u'(x) - \eta_2 \frac{1 - \omega}{\omega} \\
0 &= \omega \left\{ u(X) - c(D) - [u(x) - c(d)] + u'(X) \frac{x - Rd}{\omega} + \eta_2 \frac{x}{\omega^2} \right\}
\end{aligned}$$

Let $W(\phi)$ be the value of this problem. Note $W'(\phi) \geq 0$, and $W(0) = 0$, so we get no banking when $\phi = 0$. Also, $\omega \to 0$ as $\phi \to \infty$, so we get very few large banks when ϕ is big, and in the limit we get $W(\infty) = W^* \equiv \max_d [u(Rd) - c(d)]$, the payoff if $\kappa = 0$. Fig. 5 shows the contract given ϕ for an example where $u(q)$ is as in (13), although now there is no early or late subperiod, and $c(d) = Bd$, with $A = \upsilon = 0.001$, $\sigma = 2$, $B = 0.1$, $\kappa = 230$, $R = 1.2$, $\beta = 0.76$, $\mu = 0.95$ and $\lambda = 9$. This contract is different from Fig. 2, since the role of banks is different but there are commonalities, e.g., there is a cutoff $\tilde{\phi}$ here such that banking is viable iff $\phi \geq \tilde{\phi}$.

*** Fig. 5 about here. ***

As in Section 4 $V_t = W(\phi_t) + \beta V_{t+1}$, and emulating the earlier approach equilibrium is as a bounded, nonnegative solution to

$$\phi_t = f(\phi_{t+1}) \equiv \frac{\beta\mu}{\lambda} W(\phi_{t+1}) + \beta\phi_{t+1}. \tag{21}$$

From the observation that $f(\phi) = \beta\phi$ for $\phi \leq \tilde{\phi}$ and $f(\phi) < \phi$ for big ϕ, we get:

Proposition 2 *There is a steady state $\bar{\phi} = 0$ (no banks). There can be steady states with $\bar{\phi} > 0$, generically an even number, alternating between stable and unstable.*

Fig. 6 plots phase plane for the example. It has three steady states, one at 0, plus two with banking, $\phi_2 > \phi_1 > 0$. In contrast, in Section 4 there is a unique steady state. Moreover, the Section 4 model has cycles if $f'(\bar{\phi}) < -1$, but that cannot happen here since $f'(\phi) > 0$. So deterministic cycles are impossible, but with multiple steady states a different approach is used to construct sunspot equilibria in Appendix A. Hence, we can switch stochastically between big d_t and small d_t, or even $d_t = 0$. In contrast, in Section 4 d_t can fluctuate but we must have $d_t > 0$. So while the role of reputation is similar in the two models, the economics and the mathematics are different.

*** Fig. 6 about here. ***

Appendix B integrates these two models. At each t there are two agents at each location, who negotiate contracts using the generalized Nash bargaining. Delegated investment is efficient due to $\kappa > 0$, but one agent is infinitely lived and thus can be a banker, while the other is around for just that period, and replaced by a similar agent at $t+1$. Letting θ denote bankers' bargaining power, we get a system $\phi_t = f(\phi_{t+1})$ that can be nonmonotone for $\theta < 1$. This can have multiple steady states, with $f'(\phi) > 0$ around the stable ones and hence sunspots, plus $f'(\phi) < -1$ around the unstable ones and hence cycles and sunspots. The reason for $f'(\phi) < 0$ when $\theta < 1$ is that generalized Nash implies an agent can get a smaller surplus when the bargaining set expands (Kalai 1977). Hence, bankers' surplus can fall with ϕ, similar to $b'(\phi) < 0$ in Section 4, but for different reasons. Given that bargaining is natural in banking theory (see Rocheteau et al. 2018 and Bethune et al. 2022), it provides another source of instability.

6 Safety and Secrecy

Bank liabilities facilitate third-party transactions, and indeed some say that is their defining characteristic (recall fn. 5). We pursue this in a model with an explicit need for payment instruments, building on the literature surveyed by Lagos et al. (2017) and Rocheteau and Nosal (2017), with banks added in two related but distinct ways. First, their liabilities – demand deposits – may be *safe* relative to other assets, i.e., less susceptible to theft or loss. Second, payment instruments originating with banks can be *informationally insensitive* when these institutions act as secret keepers. What is common to the two specifications is that banking can transform payment instruments without desirable properties into ones with them.[19]

A version of Lagos and Wright (2005) is ideal for capturing these ideas, and we first summarize that framework when there are no banks. In each period of discrete

[19] While the safe-keeping function of banks is well known (see fn. 20), informational insensitivity is relatively novel (see Gorton and Pennachi 1990, Andolfatto and Martin 2013, Andolfatto et al. 2014, Dang et al. 2017, Monnet and Quintin 2017 or Imhof et al. 2021). The reason secrecy is related to safety, and so both are naturally analyzed in the same setting, is that having information revealed that your assets are low quality is similar to having some of them lost or stolen.

time two markets convene sequentially: a decentralized market, or DM, with frictions detailed below; and a frictionless centralized market, or CM. There are two types of infinitely-lived agents, a measure 1 of buyers and a measure n of sellers. Their roles differ in the DM, but are similar in the CM, where everyone trades a numeraire consumption good x and labor ℓ for utility $U(x) - \ell$. They also trade assets in the CM, like the trees in the standard Lucas (1978) model, giving off a dividend $\rho > 0$ in CM numeraire. All agents discount by $\beta \in (0, 1)$ between the CM and the next DM. This setup captures an asynchronicity of expenditures and receipts central to any analysis of money or credit: some agents' income accrues in the CM, but they may want to buy something in the DM, so to pay for it they must bring assets from a previous CM or promise payment in a future CM.

In the DM, where agents meet bilaterally, sellers can provide something q that buyers want – it can be a good (different from x) if the agents are consumers, but applications also consider cases where q is an input or an asset and agents are producers or financial institutions, and the math is basically the same (see the above-mentioned surveys). Let γ be the probability a buyer meets a seller, and γ/n the probability a seller meets a buyer. If a seller produces for a buyer the former incurs cost $c(q)$ and the latter gets payoff $u(q)$, satisfying the usual assumptions, where the efficient q^* solves $u'(q^*) = c'(q^*)$. Assume q and x are nonstorable, so they cannot serve as commodity money, and due to limited commitment, plus information frictions detailed in the literature, credit is not viable. Hence, sellers only produce if they get assets in exchange, and buyers face a liquidity constraint: they cannot hand over more assets than they bring to a meeting.

The terms of trade are given by a generic pricing mechanism, as discussed in Gu and Wright (2016), in the spirit of not having the results depend on a particular bargaining protocol or other solution concept. It means this: for a buyer to get q, he must give the seller a payment worth $v(q)$ in CM numeraire, for some function with $v(0) = 0$ and $v'(q) > 0$. A simple example is Kalai's (1977) proportional bargaining solution, $v(q) = \theta c(q) + (1 - \theta) u(q)$. Generalized Nash is similar but the formula for $v(q)$ is more complicated (although they are the same when there are no liquidity constraints). Walrasian pricing is also encompassed by this formalization. In any case, for any such $v(q)$, if a buyer has enough assets to make his liquidity constraint slack he gets the efficient $q = q^*$ and pays $p^* = v(q^*)$, while if his assets are worth $p < p^*$ he pays all he can $q = v^{-1}(p) < q^*$.

The first version of the model emphasizes safety.[20] To capture this in a simple way, suppose assets can be held in forms that differ in safety and liquidity, where the former is captured by the probability of being stolen or lost, and the latter by the probability it can be used as medium of exchange in the DM. To maintain stationarity, any assets that are stolen or lost return to the system next period, say because thieves or finders bring them to the CM. Let $\mathbf{a} = (a_1, a_2)$ be a buyer's portfolio: a_1 denotes assets held in a safe but illiquid form (say stashed away in one's house, maybe under the mattress); and a_2 denotes assets held in a liquid form (in one's pocket) with a probability $\delta > 0$ of being stolen or lost.

The CM price of the asset in terms of the numeraire good is ψ, independent of whether it is held as a_1 or a_2, as those are perfect substitutes in a frictionless market. A buyer's CM value function is $W(A)$ where $A = (\psi + \rho)\Sigma_j a_j$ is wealth. His DM value function $V(\mathbf{a})$ depends on the mix, not just the value, of his portfolio. His CM problem is

$$W_t(A_t) = \max_{x_t, \ell_t, \hat{\mathbf{a}}_t} \{U(x_t) - \ell_t + \beta V_t(\hat{\mathbf{a}}_t)\} \text{ st } x_t = A_t + \ell_t - \psi_t \Sigma_j \hat{a}_{j,t}$$

where $\hat{\mathbf{a}} = (\hat{a}_1, \hat{a}_2)$ is the updated portfolio, and the CM real wage is 1 assuming for simplicity x is produced one-for-one with ℓ (this is easy to relax). A seller's CM problem, not shown, is similar. Given an interior solution to the FOCs, standard results are immediate: (i) $x_t = x^*$ solves $U'(x^*) = 1$; (ii) $\hat{\mathbf{a}}_t$ solves $\beta \partial V_{t+1} / \partial \hat{a}_{j,t} \leq \psi_t$,

[20] It is obviously worse to have your cash lost or stolen than your checkbook or bank card; also, if a purchase turns out to be fraudulent or defective (a form of theft) it may be easier to stop payment made by check or bank card rather than cash. Historically, safety was a salient feature of banking: "At first [British goldsmiths] accepted deposits merely for *safe keeping*; but early in the 17th century their deposit receipts were circulating in place of money" (from Encyclopedia Britannica, quoted in He et al. 2005, with emphasis added). Also, "In the 17th century, notes, orders, and bills (collectively called demandable debt) acted as media of exchange that spared the costs of *moving, protecting and assaying* specie" (Quinn 1997; emphasis added). Safety was also crucial for earlier bankers, including the Templars (Sanello 2003). So modeling bank liabilities as relatively safe means of payment seems reasonable, even if much of the literature ignores the idea.

$= 0$ if $\hat{a}_{j,t} > 0$, which is independent of $\mathbf{a}_t$, so all buyers exit the CM with the same portfolio; and (iii) $W_t'(A_t) = 1$, so $W_t(A_t)$ is linear in wealth.

A buyer's DM value function is

$$V_{t+1}(\hat{\mathbf{a}}_t) = (1-\delta)\left\{\gamma\left[u(q_{t+1}) - v(q_{t+1})\right] + W_{t+1}(\hat{A}_{t+1})\right\} + \delta W_{t+1}[(\psi_{t+1}+\rho)\,\hat{a}_{1,t}],$$

where $\hat{A}_{t+1}$ is the wealth implied by $\hat{\mathbf{a}}_t$, and q_{t+1} solves: $v(q_{t+1}) = (\psi_{t+1}+\rho)\,\hat{a}_2$ if $(\psi_{t+1}+\rho)\,\hat{a}_2 < v(q^*)$; $v(q_{t+1}) = v(q^*)$ otherwise. Buyer's surplus in DM transaction is $u(q) - v(q)$ since $W(\cdot)$ is linear. Equilibrium is described by the Euler equations, which come from inserting derivatives of V into the FOCs from the CM,

$$0 = \hat{a}_{1,t}\left[\beta(\psi_{t+1}+\rho) - \psi_t\right] \tag{22}$$

$$0 = \hat{a}_{2,t}\left\{\beta(\psi_{t+1}+\rho)(1-\delta)\left[1+\gamma\lambda(q_{t+1})\right] - \psi_t\right\}, \tag{23}$$

where $\lambda(q) = u'(q)/v'(q) - 1 > 0$ is called the *liquidity premium*.

Normalizing the aggregate asset supply to 1, we can describe the dynamical system implied by the model as follows. At any t, there are three possible regimes: (i) $\hat{a}_{2,t} = 0$; (ii) $0 < \hat{a}_{2,t} < 1$; and (iii) $\hat{a}_{2,t} = 1$. We solve the dynamics in each regime and characterize the parameters where it applies, in Appendix C. The main result is this: there exists $\hat{\delta}$ above which the economy is in regime (i), where $\psi_t = \psi^F \equiv \beta\rho/(1-\beta)$ and $q_t = 0\ \forall t$; and below $\hat{\delta}$ we have

$$f_0(\psi) \equiv \begin{cases} \beta(\psi+\rho)(1-\delta)\left[1+\gamma\lambda\circ v^{-1}(\psi+\rho)\right] & \text{if } \psi < \tilde{\psi} \\ \beta(\psi+\rho) & \text{if } \psi \geq \tilde{\psi}, \end{cases} \tag{24}$$

where $\tilde{\psi} \equiv v\circ\lambda^{-1}\left[\delta/\gamma(1-\delta)\right] - \rho$. The subscript 0 on $f_0(\psi)$ indicates that there are no banks for now.

Intuitively, buyers bring no assets to the DM if the theft probability is too high, so the DM shuts down and the asset is priced fundamentally at ψ^F.[21] If the theft probability is low, assets will be held as a_2. The current asset price consists of two parts: its value as a savings vehicle $\psi_{t+1}+\rho$, plus its liquidity value captured by the premium λ. If ψ_{t+1} is low, liquidity at $t+1$ is scarce so $\lambda > 0$, which means it is

[21] One might argue $(1-\delta)\beta(\psi+\rho)$, and not $\beta(\psi+\rho)$, is the fundamental price, since an asset holder only gets the return when it is not stolen. A rebuttal is that someone gets the payoff, even if it is a thief.

more desirable to acquire assets at t. Higher demand drives ψ_t above ϕ^F. If ψ_{t+1} is high, liquidity is abundant at $t+1$, so $\lambda = 0$ and the asset is priced fundamentally.

As usual, equilibrium is a nonnegative and bounded path for $\psi_t = f\left(\psi_{t+1}\right)$, with steady state solving $\psi = f(\psi)$. A steady state can either be on the linear or the nonlinear branch of $f(\cdot)$ (see Appendix C details). In the former case, $\bar{\psi} = \psi^F > \tilde{\psi}$ and steady state is the only equilibrium. In the latter case, $\psi^F < \bar{\psi} < \tilde{\psi}$, and there are cyclic, chaotic or stochastic equilibria where ψ_t fluctuates around $\bar{\psi}$ if $f'\left(\bar{\psi}\right) < -1$. So in this economy asset prices can be above their fundamental value and can exhibit excess volatility, even without banks, as in most monetary models.

Let us now introduce intermediation by having banks accept assets as deposits and issue receipts as claims on them. Bankers are agents that can keep assets safe from theft or loss. This can involve a coalition of depositors organizing a safe-keeping facility, similar to Section 2, or delegating that task to a few agents with comparative advantage, as in Section 4, or delegating it to a few not because of comparative advantage but to economize on fixed costs, as in Section 5. To focus on other issues we do not dwell on these details in this presentation, or in the presentation of the secrecy model below, but in general they may well matter.

Let a_3 denote assets on deposit and assume they are safer than a_2 but still liquid in the DM.[22] However, deposits may have a lower yield than the original assets if banks have operating costs, which means one must sacrifice return for safety. If ι is the interest rate on deposits, bank profit is

$$\Pi(a_3) = a_3(\rho - \iota) - k(a_3), \tag{25}$$

where $k(a_3)$ is the cost of managing deposits, with $k', k'' \geq 0 = k(0)$. Maximization equates the spread $\rho - \iota$ to marginal cost $k'(a_3)$.

Now $\hat{a}_j > 0\ \forall j$ is possible because there are three asset characteristics, liquidity, safety and rate of return. However, to begin, suppose deposits are perfectly liquid and safe, and set $k(a_3) = 0$ so that $\iota = \rho$ (but see below). Then a_3 strictly dominates

[22] One can make deposits endogenously less than perfectly liquid – some sellers do not accept them or accept them only up to a limit – using private information about assay quality as in Lester et al. (2012) or Li et al. (2012). That is interesting but would be a distraction for our main points.

a_2 and the dynamics are just like an economy with $\delta = 0$ and no banks. This is shown in Fig. 7a, where f_1 and f_0 are the dynamical systems with and without banks. Adding banks shifts up the nonlinear branch of $f(\cdot)$, which increases $\tilde{\psi}$ and $\bar{\psi}$, since agents can now park assets in a safe place and still use them for DM transactions. Hence, banking increases DM output and welfare by increasing the size and number of trades because it reduces the number of thefts.

*** Fig. 7 about here. ***

What does it do for volatility? Starting without banks, suppose steady state is on the linear branch of $f_0(\cdot)$, so there is a unique equilibrium, $\psi_t = \psi^F \; \forall t$. Then adding banks shifts $f_0(\cdot)$ up to $f_1(\cdot)$, which may be enough that the new steady state is on the nonlinear branch. Thus, banking makes possible cyclic, chaotic and stochastic equilibria that were impossible without it. For some parameters such outcomes are also possible without banking, but if the economy has a unique equilibrium with banking the same is true without banking. With the usual function forms, and bargaining with $\theta = 1$, Fig. 7a uses $k(a_3) = 0$, $A = 0.15$, $\sigma = 3.1$, $\upsilon = 0.16$, $\rho = 0.033$, $\beta = 0.8333$, $\delta = 0.85$ and $\gamma = 1$. Without banks there is a unique equilibrium, the steady state $\bar{\psi} = \psi^F = 0.1650$. With banks there is a steady state $\bar{\psi} = 0.3183 > \psi^F$ plus a two-cycle where $\psi_L = 0.3193$ and $\psi_H = 0.3502$.

While this example makes the point, it is worth mentioning that the model can generate concurrent circulation of assets and bank liabilities. So that $\hat{a}_3$ does not strictly dominate $\hat{a}_2$, consider a more general cost function $k(a_3)$. Then bank's FOC defines a supply curve that is increasing in ι, which is endogenous in equilibrium but taken as given by individuals. Equilibrium is characterized by (22)-(23) with

$$\upsilon(q_{t+1}) = \left(\psi_{t+1} + \rho\right)\hat{a}_2 + \left[\psi_{t+1} + \iota(\hat{a}_3)\right]\hat{a}_3,$$

since DM purchases now use a_2 and a_3. The demand for a_3 satisfies

$$0 = \hat{a}_{3,t}\left\{\beta\left(\psi_{t+1} + \iota_t\right)\left[1 + \delta\gamma\lambda\left(q'_{t+1}\right) + (1-\delta)\gamma\lambda\left(q_{t+1}\right)\right] - \psi_t\right\} \tag{26}$$

where $\upsilon\left(q'_{t+1}\right) = \left[\psi_{t+1} + \iota(\hat{a}_3)\right]\hat{a}_3$ and q'_{t+1} is the DM purchase when a_2 is stolen.

Consider an example with $k(a_3) = 0.03a_3$, $A = 2.5$, $\sigma = 2.5$, $\upsilon = 0.001$ $\rho = 0.04$, $\beta = 0.8$, $\delta = 0.01$ and $\alpha = 1$. It has a unique steady state where $\bar{\psi} = 1.3125$, $\hat{\mathbf{a}} = (0,0,1)$ and $\iota = 0.01$, plus a two-cycle with $\psi_L = 1.2128$, $\hat{\mathbf{a}}_L = (0,0,1)$, $\psi_H = 1.4760$ and $\hat{\mathbf{a}}_H = (0.0384, 0.2293, 0.7323)$. In the L state, ψ is low and all assets are deposited, so only bank liabilities are used in the DM; in the H state, ψ is high and assets are held in all three forms, so both a_2 and a_3 used in the DM.

Now consider the version based on secrecy rather than safety. First, following Hu and Rocheteau (2015) or Lagos and Zhang (2020), assume assets die (disappear) with probability δ at the beginning of each CM, which for an individual is like having them lost or stolen. To maintain stationarity, dead trees are replaced by new ones distributed as lump sum transfers from nature. Suppose this is an aggregate shock – all or no assets survive each period – and information about a shock in the next CM is revealed in the current DM, before agents trade, thus hindering assets role as media of exchange (it is extreme to have assets' value drop to 0 after a shock, but all we really need is that it goes down).

The CM problem is now

$$W_t(a_t) = \max_{x_t, \ell_t, \hat{a}_t} \{U(x_t) - \ell_t + \beta V_{t+1}(\hat{a}_t)\} \text{ st } x_t = (\psi_t + \rho)a_t + \ell_t - \psi_t \hat{a}_t + T$$

where T denotes transfers. Notice that for our secrecy discussion $W(a)$ is a function of the amount of the single asset held, unlike our safety discussion where $W(A)$ is a function of the value of the assets in the portfolio. Here we assume the asset is the only DM means of payment, and of course it only works when it is revealed that it will survive to the next CM. Hence,

$$V_{t+1}(\hat{a}_t) = (1-\delta)\{\gamma[u(q_{t+1}) - v(q_{t+1})] + W_{t+1}(\hat{a}_t)\} + \delta W_{t+1}(0)$$

where, as previously, $v(q_{t+1}) = (\psi_{t+1} + \rho)\hat{a}_t$ if $(\psi_{t+1} + \rho)\hat{a}_t < v(q^*)$ and $v(q_{t+1}) = v(q^*)$ otherwise. Again, we get $\psi_t = f_0(\psi_{t+1})$, where the subscript 0 indicates there are no banks, with

$$f_0(\psi) = \beta(1-\delta)(\psi + \rho)\left[1 + \gamma\lambda \circ v^{-1}(\psi + \rho)\right]. \tag{27}$$

Now introduce banks that take deposits and issue receipts. These deposits are not insured – they are simply claims to assets, which are worthless if the assets die. The role of banks here is not to provide insurance, but to maintain secrecy. To this end assume agents holding assets can see if they will die by the next CM, but once deposited it in a bank they cannot, and although the banker can see this he may or may not inform people. This is the spirit of the ideas in Andolfatto and Martin (2013), Dang et al. (2017) and others mentioned above: some assets are more informationally insensitive than others, and banks can have a role as secret keepers. The key point is that it can be better to use bank liabilities as payment instruments, rather than the original assets, when $u(q)$ is concave, because the former trade at their expected value rather than their realized value. Thus bank money provides a steadier stream of liquidity.

With banks, the DM value function is

$$V_{t+1}(\hat{a}_t) = \gamma \left[u\left(q_{t+1}\right) - \upsilon\left(q_{t+1}\right) \right] + (1-\delta) W_{t+1}\left(\hat{a}_t\right) + \delta W_{t+1}\left(0\right),$$

and $\psi_t = f_1\left(\psi_{t+1}\right)$, where

$$f_1\left(\psi\right) = \beta\left(1-\delta\right)\left(\psi+\rho\right)\left\{1 + \gamma\lambda \circ \upsilon^{-1}\left[\left(1-\delta\right)\left(\psi+\rho\right)\right]\right\}. \tag{28}$$

As $\lambda(\cdot)$ is decreasing, f_1 lies above f_0 on the nonlinear branch, and hence f_1 reaches a higher steady state. Again, banking is essential: the liquidity provided by deposits is lower than that provided directly by assets when they do not die, and higher when they do, and on net, banking improves welfare.

But again banking can lead to instability. This is shown in Fig.7b for $k(a_3) = 0$, $A = 0.5$, $\sigma = 3.5$, $\upsilon = 0.15$, $\rho = 0.5$, $\beta = 0.9$, $\delta = 0.5$ and $\gamma = 1$. Without banking, the unique equilibrium is steady state $\psi = 0.4091$, and $q = q^* = 0.6703$ if assets survive while $q = 0$ otherwise. With banking, there is a steady state where $\psi = 0.7187$ and $q = 0.6093$, and welfare is higher, but there is also a two-cycle where $\psi_L = 0.6081$ and $\psi_H = 0.8514$. The time series (not shown) in this case is simple since all variables move with ψ. Thus, banking eliminates fundamental cycles induced by information about asset values, but introduces volatility as a self-fulfilling prophecy.

The first part of Proposition 3 below says banks can generate volatility as a self-fulfilling prophecy; the second part says they cannot eliminate it, since if there is a unique equilibrium $\psi_t = \psi^F$ $\forall t$ with banking there is also a unique equilibrium with $\psi_t = \psi^F$ $\forall t$ without it.

Proposition 3 *When the steady state $\bar{\psi} = \psi^F$ is the unique equilibrium without banking, adding banks can introduce nonstationary equilibria. When the steady state $\bar{\psi} = \psi^F$ is the unique equilibrium with banking, the steady state is also the unique equilibrium without banking.*

The models of safety and secrecy have similar results and intuition. In both, $\psi_t = f\left(\psi_{t+1}\right)$ has two terms: one reflects a store-of-value component making price today increasing in price tomorrow; the other reflects a medium-of-exchange component making price today a possibly nonmonotone function in price tomorrow. If $f'\left(\bar{\psi}\right) < -1$, as usual, endogenous dynamics emerges. In the safety model, without banks we have $f_0\left(\psi\right)$ and with banks we have $f_1\left(\psi\right) = f_0\left(\psi\right)/(1-\delta)$ on the nonlinear branch. This is why we can get $f_0'\left(\psi\right) > -1$ without banks and $f_1'\left(\psi\right) < -1$. In addition, steady state moves from $\bar{\psi}_0$ without banking to $\bar{\psi}_1$ with banking, which can also make $f_1'\left(\bar{\psi}\right) < -1$ more likely.

In the model of safety, banks make the asset better as a store of value and as a medium of exchange by reducing the risk of theft. In the model of secrecy, banks do not make the asset a better store of value, because there is no way to avoid the aggregate shock, but they make it a better medium of exchange by keeping information to themselves. Hence, in the model of secrecy agents unambiguously put more weight on the nonmonotone medium-of-exchange component, making $f_1'\left(\psi\right) < -1$ more likely. Details aside, again this shows how banking can engender instability. We also mention that in both the safety and secrecy models, agents are better off with banking at least if the dynamics stay close to steady state, but not necessarily in general – it is possible that a cycle with banking is worse than the outcome with no banking if the cycle starts in the low ψ state. Then again, sometimes cycles are better than steady states if the cycle starts in the high ψ state.

To close this part of the conversation, we emphasize that it is not only natural to build integrated models of banking and money, it also leads to extra insights. Consider Berentsen et al. (2007), which was one of the first papers to incorporate banking in the monetary setting of Lagos and Wright (2005).[23] After the CM closes, but before the DM opens, information revealed to agents about their need for money in the latter market – e.g., information about whether they will be a buyer or a seller or neither, interpretable as finding out who they will meet, or as a specification of preference shocks not unlike classic Diamond-Dybvig. Banks act as intermediaries between those who want more money and those who have more than they need, and intermediation is required because, as in the models discussed above, these agents cannot trust each other due to commitment and enforcement problems.

Heuristically, one might think the essential role for banking is allocating more money to those in need. That would be wrong – just giving everyone, e.g., twice as much money does not change anything, as a rudimentary example of classical neutrality. Actually, what makes banking desirable is not allocating more money to those who want it, but providing a repository for those who need less. By depositing excess liquidity in the bank, they can earn interest, which is better than sitting on idle cash. The interest paid to depositors is funded by the interest paid by borrowers, although in general there may be a spread if the bank is able to turn a profit or has to pay operating costs. The important point is that the ability to earn interest on otherwise-idle cash increases the demand for money in the CM, which increases output and welfare via DM trade. All of this suggests it is worth further pursuing integrated models of money and banking in future research.

Another insight of these models has to do with holdup problems when traders bargain upon meeting in the DM, after investing in liquidity in the CM. Since sellers capture part of the DM surplus, in general buyers do not get the full return on their liquidity and hence underinvest in the CM. However, if banks are open during the negotiations, a buyer has a superior outside option: rather than sitting on idle cash,

[23] In addition to papers mentioned elsewhere, see Chiu and Meh (2011) and Chiu et al. (2017) for applications of the Berentsen et al. (2007) framework.

he can deposit it at interest. Again, the interest is paid by those borrowing from the bank, which would not work if everyone deposited and no one took a loan, but in equilibrium an individual buyer has a better threat point when he can deposit unused cash. That ameliorates holdup and underinvestment problems, leading to higher output and welfare.

7 Conclusion

The goal of the project was to ask if banks engender instability in a precise sense: multiple steady states or complicated dynamics are more likely with them than without them. The method was to consider a variety of models, which led to an extensive if somewhat selective survey of the literature. We found that several different models imply banks can indeed engender instability in this sense, although that need not mean they lower welfare.

While all the models can be generalized, we used simple versions to make our points more easily, but future work might extend and apply them to other issues. Future research can also explore the empirical relevance of the theoretical results, but one point is worth emphasizing: we do not claim the data are best explained by simple cycles or sunspots, only that when rudimentary models have equilibria where prices, quantities, liquidity and welfare vary as self-fulfilling prophecies, it seems more likely that actual economies can, too.

Finally, we reiterate how the different formalizations are related. We take it as given that theories of banking should build on environments where explicit frictions give rise to endogenous roles for these institutions. At the same time, frictions can lead to multiple Pareto-ranked equilibria or belief-based dynamics. We considered different environments capturing different reasons for essential banking. While we there may well be models not covered here, the results lead us to conclude this: endogenizing banking in various ways suggests that they can indeed be unstable, although that does not mean undesirable.

Appendix A: Sunspot Equilibria

A dynamical system that allows for a two-state sunspot equilibrium solves

$$\phi_{s,t-1} = \zeta_s f\left(\phi_{s,t}\right) + (1-\zeta_s) f\left(\phi_{-s,t}\right) \tag{29}$$

where $s = A, B$ are the sunspot states, $\zeta_s \in (0,1)$ is the probability of staying state s, and f is the dynamical system in the deterministic case. We seek a pair of probabilities $(\zeta_A, \zeta_B) \in (0,1)^2$ satisfying (29) in stationary equilibrium.

To proceed, rewrite (29) as

$$\zeta_A = \frac{f(\phi_B) - \phi_A}{f(\phi_B) - f(\phi_A)} \text{ and } \zeta_B = \frac{\phi_B - f(\phi_A)}{f(\phi_B) - f(\phi_A)}$$

Consider $\phi_B > \phi_A$ without loss of generality. If f is decreasing on (ϕ_A, ϕ_B), the denominator is negative. Then $\zeta_A, \zeta_B \in (0,1)$ iff $f(\phi_A) > \phi_B > \phi_A > f(\phi_B)$, which implies that f crosses the 45^o line from above and $[f(\phi_A) - f(\phi_B)] / (\phi_A - \phi_B) < -1$. Therefore, in Section 4 where f is decreasing at steady state, there exist sunspot equilibria if $f\left(\bar{\phi}\right) < -1$. Similarly, if f is increasing on (ϕ_A, ϕ_B), the denominator is positive. Then $\zeta_A, \zeta_B \in (0,1)$ iff $f(\phi_B) > \phi_B > \phi_A > f(\phi_A)$, which implies f crosses the 45^o line from below on $[\phi_A, \phi_B]$. So in Section 5 there exist sunspot equilibria around a stable steady state ϕ_1 for any $\phi_A \in (0, \phi_1)$ and $\phi_B \in (\phi_1, \phi_2)$.

Appendix B: Delegated Investment with Bargaining

There are two agents on each island, one who lives for one period and one who lives forever, so the former should be the depositor and the latter the banker. Assume the cost κ is too high for them to invest individually. If the banker's bargaining power is θ, the generalized Nash problem is

$$W(\phi) = \max_{X,x,D,d} [U(X) - C(D)]^{\theta} [u(x) - c(d)]^{1-\theta} \tag{30}$$

$$\text{st } X + x = R(D+d) - \kappa \tag{31}$$

$$u(x) - c(d) \geq 0 \tag{32}$$

$$x_t \leq \phi_t. \tag{33}$$

The last constraint is from the banker's incentive condition $\beta V_{t+1} \geq \lambda x_t + (1 - \mu)\beta V_{t+1}$ rewritten using $\phi_t \equiv \beta\mu V_{t+1}/\lambda$. Notice $W'(\phi) > 0$ if (33) binds, and there is a cutoff $\tilde{\phi}$ above which banking is viable and below which it is not.

Denote the solution ignoring (32) and (33) by (X^*, x^*, D^*, d^*). Further, consider the case $u(x^*) > c(d^*)$ and let $\phi^* = x^*$. Substituting (31) into the objective function and taking FOCs wrt (D, d, x, ω), we get

$$\begin{aligned} 0 &= U'(X)R - C'(D) \\ 0 &= \theta U'(X)R[u(x) - c(d)] - (1-\theta)c'(d)[U(X) - C(D)] - \eta_1 c'(d) \\ 0 &= -\theta U'(X)[u(x) - c(d)] + (1-\theta)u'(x)[U(X) - C(D)] + \eta_1 u'(x) - \eta_2 \end{aligned}$$

where η_1 and η_2 are multipliers. From this one can see the banker's surplus may decrease with ϕ at least close to ϕ^*:

$$\left.\frac{\partial[U(X)-C(D)]}{\partial\phi}\right|_{\phi\to\phi^*} = \frac{(1-\theta)U'c''(U-C)\left(R^2U''-C''\right)}{(C''-R^2U'')[C'c'+(1-\theta)c''(U-C)]-\theta R^2U''C''(u-c)} < 0.$$

The banker's value function is $V_t = U(X_t) - C(D_t) + \beta V_{t+1}$, and using $\phi_t = \beta\mu V_{t+1}/\lambda$ we have

$$\phi_{t-1} = \frac{\beta\mu}{\lambda}[U(X_t) - C(D_t)] + \beta\phi_t. \tag{34}$$

Now (34) can be written as

$$\phi_{t-1} = \begin{cases} \beta\phi_t & \text{if } \phi_t < \tilde{\phi} \\ \frac{\beta\mu}{\lambda}[U \circ X(\phi_t) - C \circ D(\phi_t)] + \beta\phi_t & \text{if } \tilde{\phi} \leq \phi_t < \phi^* \\ \frac{\beta\mu}{\lambda}[U(X^*) - C(D^*)] + \beta\phi_t. & \text{if } \phi_t \geq \phi^* \end{cases}$$

Fig. A1 shows the dynamical system for the following parameterization: $U(x) = u(x) = x$ and $C(d) = c(d) = 0.1d^5$, where $R = 2$, $k = 1.5$, $\theta = 0.01$, $\lambda = 0.01$, $\mu = 1$ and $\beta = 0.35$. There are three steady states, $\phi = 0$ and $\phi_2 > \phi_1 > 0$, with f crossing the 45^o line from below at ϕ_1 and from above at ϕ_2. Hence there are sunspot equilibria around ϕ_1 fluctuating between any $\phi_A \in (0, \phi_1)$ and $\phi_B \in (\phi_1, \phi_2)$, similar to the baseline version of the model in Section 5, and since $f'(\phi_2) < -1$ there is a two-cycle with periodic points ϕ_L and ϕ_H, plus sunspot equilibria for any $\phi_A \in (\phi_L, \phi_2)$ and $\phi_B \in (\phi_2, \phi_H)$, similar to Section 4.

Appendix C: Steady State in Safety Model

The solution to $(\hat{a}_{1,t}, \hat{a}_{2,t})$ has three possibilities. In regime (i), inserting $\hat{a}_{1,t} = 1$ and $\hat{a}_{2,t} = 0$ into (22)-(23), we get $\psi_t = \beta(\psi_{t+1} + \rho)$ and $(1-\delta)[1+\gamma\lambda(0)] < 1$, with the latter equivalent to $\delta \geq \hat{\delta} \equiv \gamma\lambda(0)/[1+\gamma\lambda(0)]$. Now assume $\delta < \hat{\delta}$ and consider regime (ii). Inserting $\hat{a}_{1,t}$,$\hat{a}_{2,t} > 0$ into (22)-(23), we get $\psi_t = \beta\left(\psi_{t+1} + \rho\right)$ and $q_{t+1} = \tilde{q}$, where $\gamma\lambda(\tilde{q}) = \delta/(1-\delta)$. One can show regime (ii) obtains iff $\psi_{t+1} + \rho > v(\tilde{q})$ and $\delta < \hat{\delta}$. Finally, consider regime (iii). By (22) and (23), we get $\psi_t \geq \beta\left(\psi_{t+1} + \rho\right)$ and

$$\psi_t = \beta\left(\psi_{t+1} + \rho\right)(1-\delta)\left[1+\gamma\lambda\left(q_{t+1}\right)\right], \tag{35}$$

where $q_{t+1} = v^{-1}(\psi_{t+1} + \rho) < \tilde{q}$. This last condition is equivalent to $\psi_{t+1} \leq \tilde{\psi} \equiv v(\tilde{q}) - \rho$. Hence if $\delta < \hat{\delta}$ the dynamic system is $\psi_t = f\left(\psi_{t+1}\right)$ where:

$$f(\psi) \equiv \begin{cases} \beta(\psi+\rho)(1-\delta)\left[1+\alpha\lambda \circ v^{-1}(\psi+\rho)\right] & \text{if } \psi < \tilde{\psi} \\ \beta(\psi+\rho) & \text{if } \psi \geq \tilde{\psi} \end{cases}$$

Routine algebra yields the following result:

Proposition 4 *Steady state exists uniquely and is described as follows. Define* $\tilde{\delta} \in [0, \hat{\delta})$ *by*

$$\tilde{\delta} = \frac{\alpha\lambda \circ v^{-1}(\psi^F + \rho)}{1 + \alpha\lambda \circ v^{-1}(\psi^F + \rho)}. \tag{36}$$

Then (i) $\delta \geq \hat{\delta}$ *implies* $\hat{a}_1 = 1$, $\hat{a}_2 = 0$ *and* $\bar{\psi} = \psi^F$*; (ii)* $\delta \in (\tilde{\delta}, \hat{\delta})$ *implies* $\hat{a}_1 > 0$, $\hat{a}_2 > 0$ *and* $\bar{\psi} = \psi^F$*; and (iii)* $\delta \leq \tilde{\delta}$ *implies* $\hat{a}_1 = 0$, $\hat{a}_2 = 1$ *and* $\bar{\psi} > \psi^F$*.*

Fig. A2 shows how steady state depends on δ. In regime (i) the DM is inactive and $\bar{\psi} = \psi^F$. In regime (ii) the DM is active at $q = \tilde{q} > 0$, but since $\hat{a}_1 > 0$, $\bar{\psi} = \psi^F$ with $\partial q/\partial\delta < 0$. Thus DM output goes down with δ because it reduces output per trade $\tilde{q}$ as well as the number of trades $(1-\delta)\gamma$. In regime (iii), with $\hat{a}_2 = 1$, $\bar{\psi} > \psi^F$ and $\partial q/\partial\delta < 0$, not because $\hat{a}_2$ falls but because ψ falls.

References

Admati A., Hellwig M., 2014. The Banker's New Clothes: What's Wrong with Banking and What to Do about It. Princeton.

Allen F., Gale D., 2007. Understanding Financial Crises. Oxford.

Allen F., Walther A., 2021. Financial Architecture and Financial Stability. Annual Rev. Fin. Econ. 13, 129-51.

Akerlof G, Shiller R., 2009. Animal Spirits. Princeton.

Andolfatto D., Berentsen A., Waller C., 2014. Optimal Disclosure Policy and Undue Diligence. J. Econ. Theory 149, 128-52.

Andolfatto D., Berentsen A., Martin F., 2020. Money, Banking, and Financial Markets. Rev. Econ. Stud. 87, 2049-86.

Andolfatto D., Martin F., 2013. Information Disclosure and Exchange Media. Rev. Econ. Dyn. 16, 527-39.

Andolfatto D., Nosal E., 2020. Shadow Bank Runs. Mimeo.

Andolfatto D., Nosal E., Sultanum B., 2017. Preventing Bank Runs. Theor. Econ. 12, 1003-28.

Andolfatto D., Nosal E., Wallace N., 2007. The Role of Independence in the Green-Lin Diamond-Dybvig Model. J. Econ. Theory 137, 709-15.

Araujo L., Minetti R., 2011. On the Essentiality of Banks. Int. Econ. Rev. 52, 679-91.

Araujo L., Ferraris L., 2020. Money, Bonds and the Liquidity Trap. J. Money Credit Bank 52, 1853-1867.

Araujo L., Ferraris L., 2021 Money and Credit Remix. Macroecon. Dyn. in press.

Auer R., Monnet C., Shin H., 2021. Distributed Ledger and the Governance of Money. Mimeo.

Azariadis C., 1993. Intertemporal Macroeconomics. Blackwell.

Bencivenga V., Smith B.,1991. Financial Intermediation and Endogenous Growth. Rev. Econ. Stud. 58, 195-209.

Benhabib J., Miao J., Wang P., 2016. Chaotic Banking Crises and Regulations. Econ. Theory 61, 393-422.

Berentsen A., Camera G., Waller C., 2007. Money, Credit, and Banking. J. Econ. Theory 135, 171-95.

Bethune Z., Hu T., Rocheteau G., 2018*a*. Indeterminacy in Credit Economies. J. Econ. Theory 175, 556-84.

_________ 2018*b*. Optimal Credit Cycles. Rev. Econ. Dyn. 27, 231-45.

Bethune Z., Rocheteau G., Wong T., Zhang C., 2022. Lending Relationships and Optimal Monetary Policy. Rev. Econ. Stud. 89,1833-72.

Bhattacharya J., Haslag J., Martin A., 2005. Heterogeneity, Redistribution and the Friedman Rule. Int. Econ. Rev. 46, 437-54.

Biais B., Mariotti T., Plantin G., Rochet J., 2007. Dynamic Security Design: Convergence to Continuous Time and Asset Pricing Implications. Rev. Econ. Stud. 74, 345-90.

Boyd J., De Nicoló G., Smith B., 2004. Crises in Competitive versus Monopolistic Banking Systems. J. Money Credit Bank. 36, 487-506.

Bryant J., 1980. A Model of Reserves, Bank Runs, and Deposit Insurance. J. Bank. Finance 4. 335-44.

Buggenum H. van, Rabinovich S., 2021. Co-Essentiality of Money and Credit: A Mechanism Design View. Mimeo.

Calomiris C., Haber S., 2014. Fragile by Design: The Political Origins of Banking Crises and Scarce Credit. Princeton.

Cavalcanti R., Monteiro P., 2016. Enriching Information to Prevent Bank Runs. Econ. Theory 62, 477-94.

Cavalcanti R., Wallace N., 1999*a*. Inside and Outside Money as Alternative Media of Exchange. J. Money Credit Bank. 31, 443-57.

_________ 1999*b*. A Model of Private Bank-Note Issue. Rev. Econ. Dyn. 2, 104-36.

Champ B., Smith B., Williamson S., 1996. Currency Elasticity and Banking Panics: Theory and Evidence. Can. J. Econ. 29, 828-64.

Chari V., Jagannathan R., 1988. Banking Panics, Information, and Rational Expectations Equilibrium. J. Finance 43, 749-61.

Chiu J., Meh C., 2011. Financial Intermediation, Liquidity, and Inflation. Macroecon. Dyn. 15, 83-118.

Chiu J., Meh C., Wright R., 2017. Innovation and Growth with Financial, and Other, Frictions. Int. Econ. Rev. 58, 95-125.

Clower R., 1965. A Reconsideration of the Microfoundations of Monetary Economics. Western Econ. Journal 6, 1-8.

Cooper R., Ross T., 1998. Bank Runs: Liquidity Costs and Investment Distortions. J. Monet. Econ. 41, 27-38.

Dang T., Gorton G., Holmström B., Ordoñez G., 2017. Banks as Secret Keepers. Am. Econ. Rev. 107, 1005-29.

Debreu G., 1959. Theory of Value. Wiley.

Diamond D., 1984. Financial Intermediation and Delegated Monitoring. Rev. Econ. Stud. 51, 393-414.

_________ 1996. Financial Intermediation as Delegated Monitoring: A Simple Example. FRB Richmond Econ. Quarterly 82, 51-66.

Diamond D., Rajan R., 2001. Banks and Liquidity. Am. Econ. Rev. 91, 422-5.

Donaldson J., Piacentino G., Thakor A., 2018. Warehouse Banking. J. Fin. Econ. 129, 250-67.

DeMarzo P., Fishman M., 2007. Agency and Optimal Investment Dynamics. Rev. Financ. Stud. 20, 151-88.

Duffie D., Gârleanu N., Pederson L., 2005. Over-the-Counter Markets. Econometrica 73, 1815-47.

Huberto E., Keister T., 2003. Economic Growth, Liquidity, and Bank Runs. J. Econ. Theory 109, 220-45.

_________ 2009*a*. Run Equilibria in the Green-Lin Model of Financial Intermediation. J. Econ. Theory 144, 1996-2020.

_________ 2009*b*. Bank Runs and Institutions: The Perils of Intervention. Am. Econ. Rev. 99, 1588-607.

_________ 2010*a*. On the Fundamental Reasons for Bank Fragility. FRB Richmond Econ Quarterly 96, 33-58.

_________ 2010*b*. Banking Panics and Policy Responses. J. Monet. Econ. 57, 404-19.

Freixas X., Rochet J., 2008. Microeconomics of Banking, MIT.

Friedman M., 1960. A Program for Monetary Stability. Fordham.

Friedman M., Schwartz A., 1963. A Monetary History of the United States, 1867-1960. Princeton.

Gertler M., Kiyotaki N., 2015. Banking, Liquidity, and Bank Runs in an Infinite Horizon Economy. Am. Econ. Rev. 105, 2011-43.

Gertler M, Kiyotaki N., Prestipino A., 2020. A Macroeconomic Model with Financial Panics. Rev. Econ. Stud. 87, 240-88.

Goldstein I., Pauzner A., 2005. Demand Deposit Contracts and the Probability of Bank Runs. J. Finance 60, 1293-327.

Gong G., 2021. Middlemen in Search Models with Intensive and Extensive Margins. Mimeo.

Goodhart C., Huang H., 2000. A Simple Model of an International Lender of Last Resort. Econ Notes 29, 1-11.

Gorton G., Pennacchi G., 1990. Financial Intermediaries and Liquidity Creation. J. Finance 45, 49-71.

Gorton G., Winton A., 2003. Financial Intermediation. G. Constantinides et al., eds. Handbook of the Economics of Finance 1. Elsevier.

Green E., Lin P., 2000. Diamond and Dybvig's Classic Theory of Financial Intermediation: What's Missing? FRB Minneapolis Quarterly Rev. 24, 3-13.

________ 2003. Implementing Efficient Allocations in a Model of Financial Intermediation. J. Econ. Theory 109, 1-23.

Greenwood R., Landier A., Thesmar D., 2015. Vulnerable Banks. J. Financ Econ. 115, 471-85.

Gu C., 2011. Herding and Bank Runs. J. Econ. Theory 146, 163-88.

Gu C., Mattesini F., Monnet C., Wright R., 2013*a*. Banking: A New Monetarist Approach. Rev. Econ. Stud. 80, 636-62.

________ 2013*b*. Endogenous Credit Cycles. J. Polit. Econ. 121, 940-65.

Gu C., Mattesini F., Wright R., 2016. Money and Credit Redux. Econometrica 84, 1-32.

Gu C., Monnet C., Nosal E., Wright R., 2020. On the Instability of Banking and Other Financial Intermediation. BIS Working Papers No 862.

Gu C., Wright R., 2016. Monetary Mechanisms. J. Econ. Theory 163, 644-57.

Gurley J., E Shaw E., 1960. Money in a Theory of Finance. Brookings.

Hahn F., 1973. On the Foundations of Monetary Theory. Modern Economics, ed. M. Parkin and A. Nobay. Barnes & Noble.

Haubrich J., 1989. Financial Intermediation: Delegated Monitoring and Long-term Relationships. J. Bank. Financ. 13, 9-20.

He P., Huang L., Wright, R., 2005. Money and Banking in Search Equilibrium. Int. Econ. Rev. 46, 637-70.

________ 2008. Money, Banking, and Monetary Policy. J. Monet. Econ. 55, 1013-24.

Hu T., Rocheteau G., 2015. Monetary Policy and Asset Prices: A Mechanism Design Approach. J. Money Credit Bank. 47, 39-76.

Huang A., 2017. On the Number and Size of Banks. Mimeo.

Huangfu S., Sun H., 2011. Private money and bank runs. Can. J. Econ. 44, 859-879.

Imhof S., Monnet C., Zhang S., 2021. The Risk-Taking Channel of Banks' Debt and Monetary Policy. Mimeo.

Jacklin C., 1987. Demand Deposits, Trading Restrictions, and Risk Sharing. Prescott E. and Wallace N., eds, Contractual Arrangements for Intertemporal Trade, Minnesota, 26-47.

Jiang J., Norman P., Puzzello D., Sultanum B., Wright R., 2022. Is Money Essential: An Experimental Approach. Mimeo.

Kalai E., 1977. Proportional Solutions to Bargaining Situations: Interpersonal Utility Comparisons. Econometrica 45, 1623-30.

Kehoe T., Levine D., 1993. Debt-Constrained Asset Markets. Rev. Econ. Stud. 60, 865-88.

Keister T., 2016. Bailouts and Financial Fragility. Rev. Econ. Stud. 83, 704-36.

Keynes J., 1936. The General Theory of Employment, Interest and Money. Macmillan.

Kindleberger C., 1978. Manias, Panics and Crashes: A History of Financial Crises. Palgrave Macmillan.

Kocherlakota N., 1998. Money is Memory. J. Econ. Theory 81, 232-51.

Lagos R., Rocheteau G., Wright R., 2017. Liquidity: A New Monetarist Perspective. J. Econ. Lit. 55, 371-440.

Lagos R., Wright R., 2005. A Unified Framework for Monetary Theory and Policy Analysis. J. Polit. Econ. 113, 463-84.

Lagos R., Zhang S., 2020. Turnover Liquidity and the Transmission of Monetary Policy. Am. Econ. Rev. 110, 1635-1672..

Lester B., Postlewaite A., Wright R., 2012. Liquidity, Information, Asset Prices and Monetary Policy. Rev. Econ. Stud. 79, 1209-38.

Li Y., Rocheteau G., Weill P., 2012. Liquidity and the Threat of Fraudulent Assets. J. Polit. Econ. 120, 815-46.

Minsky H., 1992. The Financial Instability Hypothesis. Levy Econ. Institute WP 74.

Monnet C., Quintin E., 2017. Rational Opacity. Rev. Financ. Stud. 30, 4317-48.

Monnet C., Sanches D., 2015. Private Money and Banking Regulation. J. Money

Credit Bank. 47, 1032-62.

Nosal E., Wallace N., 2009. Information Revelation in the Diamond-Dybvig Banking Model. FRB Chicago Policy DP 7.

Nosal E., Wong Y., Wright R., 2015. More on Middlemen: Equilibrium Entry and Efficiency in Intermediated Markets. J. Money Credit Bank. 47, 7-37.

_________ 2019. Intermediation in Markets for Goods and Markets for Assets. J. Econ. Theory 183, 876-906.

Ordoñez G., 2013. Fragility of Reputation and Clustering of Risk-Taking. Theor. Econ. 8, 653-700.

Ordoñez G., 2018. Confidence Banking and Strategic Default. J. Monet. Econ. 100, 101-113.

Peck J., Shell K., 2003. Equilibrium Bank Runs. J. Polit. Econ. 111, 103-23.

Peck J., Setayesh A., 2019. A Diamond-Dybvig Model in which the Level of Deposits is Endogenous. Mimeo.

Postlewaite A., Vivies X., 1987. Bank Runs as an Equilibrium Phenomenon. J. Polit. Econ. 95, 485-91.

Quinn S., 1997. Goldsmith-Banking: Mutual Acceptance and Interbanker Clearing in Restoration London. Explorations Econ. History 34, 411-42.

Rajan R., 2005. Has Financial Development Made the World Riskier? Proceedings of the Jackson Hole Conference.

Reinhart C., Rogoff K., 2009. The Aftermath of Financial Crises. Am. Econ. Rev. 99: 466-72.

Rocheteau G., Nosal E., 2017. Money, Payments and Liquidity, 2nd ed. MIT.

Rocheteau G., Wright R., Zhang C., 2018. Corporate Finance and Monetary Policy. Am. Econ. Rev. 108: 1147-1186.

Rolnick A., Weber W., 1986. Inherent Instability in Banking: The Free Banking Experience. Cato J. 5, 877-90.

Rubinstein A., Wolinsky A., 1987. Middlemen. Q. J. Econ. 102, 581-94.

Sanches D., Williamson S., 2010. Money and Credit with Limited Commitment and Theft. J. Econ. Theory 145, 1525-49.

Sanello F., 2003. The Knights Templars: God's Warriors, the Devil's Bankers. Taylor Trade.

Selgin G., 2018. Banks. Mimeo, written for Encyclopedia Britannica.

Shell K., 1992. Sunspot Equilibria. New Palgrave Dictionary of Money and Finance.

Palgrave MacMillan.

Shleifer A., Vishny R., 2010. Unstable Banking. J. Financ. Econ. 97, 306-18.

Smith B., 2002. Monetary Policy, Banking Crises, and the Friedman Rule. Am. Econ. Rev. 92, 128-34.

Summers L., 2005. Comments on 'Has Financial Development Made the World Riskier?' by Rajan R., Proceedings of the Jackson Hole Conference.

Townsend R., 1987. Arrow-Debreu Programs as Microfoundations of Macroeconomics. Bewley T. ed. Advances in Economic Theory. Cambridge.

Townsend R., 1988. Models as Economies. Econ. J. 98, 1-24.

Vives X., 2016. Competition and Stability in Banking: The Role of Regulation and Competition Policy. Princeton.

Wallace N., 1988. Another Attempt to Explain an Illiquid Banking System: The Diamond and Dybvig Model With Sequential Service Taken Seriously. FRB Minneapolis Quarterly Rev. 12, 3-16.

Wallace N., 1990. A Banking Model in Which Partial Suspension is Best. FRB Minneapolis Quarterly Rev. 14, 11-23.

_________ 1998. A Dictum for Monetary Theory. FRB Minneapolis Quarterly Rev. 22, 20-6.

_________ 2001. Whither Monetary Economics? Int. Econ. Rev. 42, 847-69.

_________ 2010. The Mechanism-Design Approach to Monetary Theory. Handbook of Monetary Economics 3, B. Friedman and M Woodford, eds. Elsevier.

Williamson S., 1986. Costly Monitoring, Financial Intermediation and Equilibrium Credit Rationing. J. Monet. Econ. 18, 159-79.

Williamson S., 1987. Financial Intermediation, Business Failures, and Real Business Cycles. J. Polit. Econ. 95, 1196-216.

Wright R., 2018. On the Future of Macro: A New Monetarist Perspective. Oxford Rev. Econ Policy 34, 107-31.

Figures

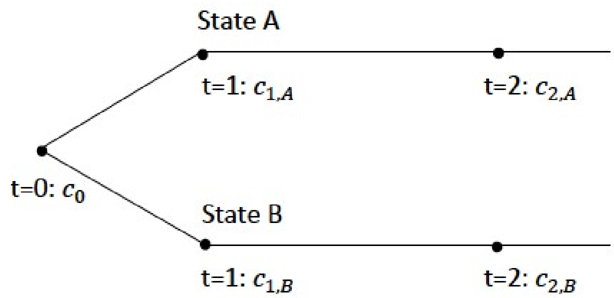


Fig. 1: Insurance model event tree.

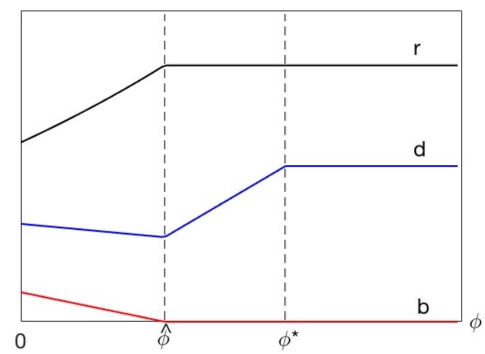
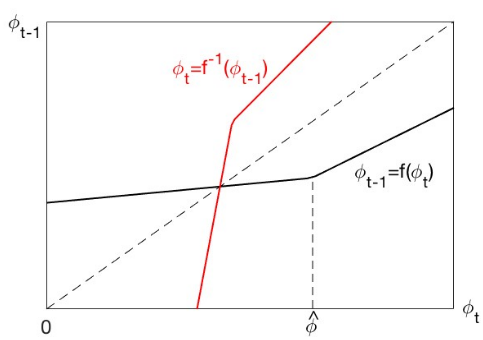


Fig. 2: Insurance model bank contract as a function of ϕ.



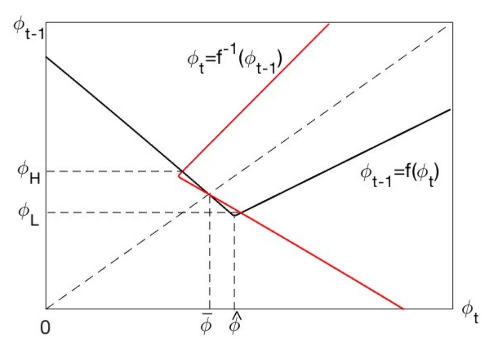


Fig. 3a: Insurance model monotone f. Fig. 3b: Insurance model nonmonotone f.

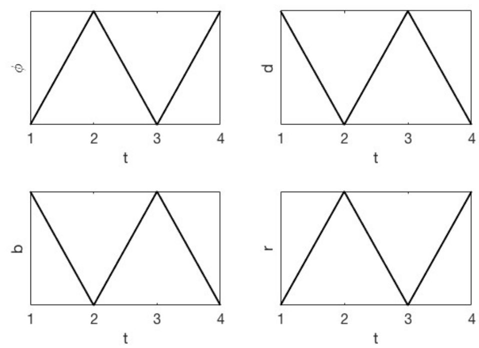


Fig. 4: Insurance model 2-cycle.

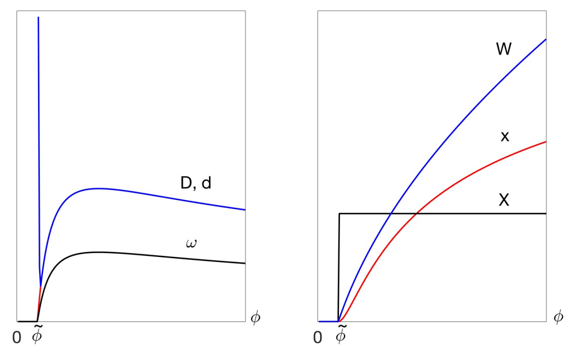


Fig. 5: Delegated investment model banking contract.

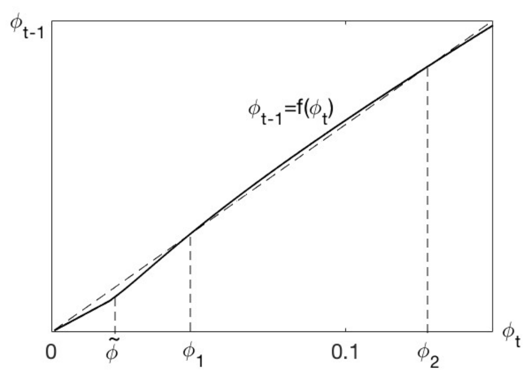
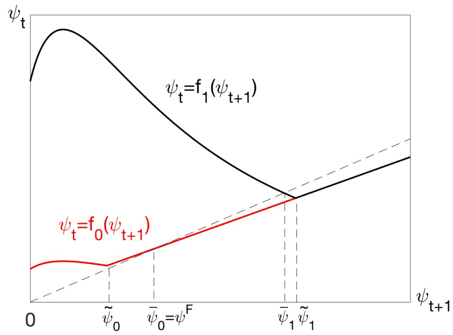


Fig. 6: Delegated investment model phase plane.



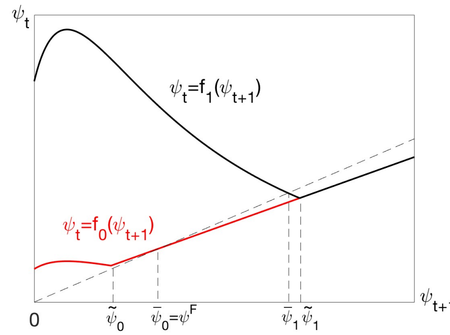


Fig. 7a: Safety model phase plane. Fig. 7b: Secrecy model phase plane.

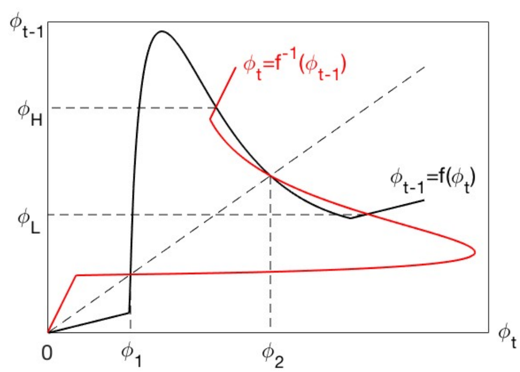


Fig. A1: Reputation model with bargaining phase plane.

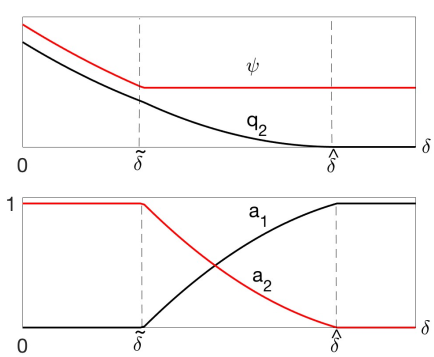


Fig. A2: Safety model steady state.