On the Instability of Banking and Financial Intermediation*

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Abstract

Are financial intermediaries inherently unstable? If so, why? What does this suggest about government intervention? To address these issues we analyze whether model economies with financial intermediation are particularly prone to multiple, cyclic, or stochastic equilibria. Four formalizations are considered: a dynamic version of Diamond-Dybvig incorporating reputational considerations; a model with delegated monitoring as in Diamond; one with bank liabilities serving as payment instruments similar to currency in Lagos-Wright; and one with Rubinstein-Wolinsky intermediaries in a decentralized asset market as in Duffie et al. In each case we find, for different reasons, that financial intermediation engenders instability in a precise sense.

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> Banks, as several banking crisis 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, Banks: How they Work and Why they are Fragile.*

Introduction

It is often said that banks, or more generally financial intermediaries, are inherently unstable and prone to volatility. This seems to be based on the notion that financial institutions are "special" compared to, say, producers or middlemen in retail. Keynes (1936), Kindleberger (1978) and Minsky (1992) are names associated with such a position, with Williams (2015) providing a recent perspective (see also Akerlof and Shiller 2009 or Reinhart and Rogoff 2009). Rolnick and Weber (1986) provide evidence of the widespread acceptance of this view 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 case, Friedman 1960, who defended unfettered markets in virtually all other contexts, advocated bank regulation in his program for monetary stability). As additional evidence, consider the voluminous literature dedicated to the study of bank runs.[1]

We share an interest in the questions with which Gorton and Whinton (2002) start their well-known survey: "Why do financial intermediaries exist? What are their roles? Are they inherently unstable? Must the government regulate them?" While there are different ways to proceed, our approach is to build formal models of the institutions and see if they are particularly prone to multiple equilibria or volatile dynamics, including cyclic, chaotic or stochastic outcomes that entail fluctuations even if fundamentals are constant. Central to this approach, by models *of*

[1] For now we discuss bank runs, panics, financial crises, etc. without defining these formally. As Rolnick and Weber (1986) put it, "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." They add "The usual explanation... involves a local real economic shock that becomes exaggerated by the actions of incompletely informed depositors," and suggest this is consistent with Friedman and Schwartz's (1963) view. In terms of models, Chari and Jagannathan (1988) have withdrawals by informed depositors lead to withdrawals by others, while Gu (2011) formalizes this as rational herding. Our approach is different, and avoids fixating only on runs, but we focus squarely on volatility "without economy-wide real shocks."

intermediation we mean more than models *with* intermediation. It does not suffice to assert, say, that households lend to banks and banks lend to firms but households do not lend to firms – that may be a model *with* banking but not *of* banking.[2]

While there is much work on financial intermediation, there is no generally-accepted, all-purpose model. This is because the institutions perform a myriad of functions that are difficult to capture in a single setup: they serve as middlemen between savers and borrowers or asset sellers and buyers; they screen and monitor investment opportunities on behalf of depositors; they issue liabilities like demand deposits that facilitate third-party transactions; they provide liquidity insurance or maturity transformation; they are safe keepers of cash and other valuables; and they maintain privacy about their assets or their customers. Different approaches are typically used to model these diverse activities, and, in this tradition, we consider several distinct specifications. All of these are constructed using building blocks taken from off-the-shelf models, although the ways in which we combine and apply them are novel, as dictated by the applications at hand.

The first formulation extends Diamond and Dybvig's (1983) model of liquidity insurance to an infinite horizon, to highlight bankers' reputation as in Gu et al. (2013*a*), which is itself based on the model of unsecured credit in Kehoe and Levine (1993). The second features fixed costs of exploiting investment opportunities, similar to Diamond (1984) and Huang (2017). The third, an adaptation of Nosal et al. (2017), puts intermediaries like those in Rubinstein and Wolinsky (1987) into an OTC asset market similar to Duffie et al. (2005). The fourth has bank liabilities serving as payment instruments, similar to currency in Lagos and Wright (2005) and Berentsen et al. (2007), in an environment where bank liabilities are less sus-

[2]The declaration that households lend to banks and banks lend to firms but households do not lend to firms is reminiscent of monetary economics following Clower (1965), who said money buys goods and goods buy money but goods do not buy goods. While once a popular shortcut, it is hard to argue that Clower (cash-in-advance) constraints constitute the last word in monetary theory, and we feel similarly about banking (see Wright 2017 for more on this). Of course it is not necessary for every study to make everything endogenous – e.g., Debreu (1959) made progress using a theory *with* firms and households but not a theory *of* firms and households – but it is crucial, we think, to have financial institutions emerge endogenously when asking if they are unstable as "the direct result of the core functions they perform" (from the epigraph).

ceptible to loss or theft, as in He et al. (2007) and Sanches and Williamson (2010), or less sensitive to information, as modeled by Andolfatto and Martin (2013), Dang et al. (2017) and others mentioned below.

We find in each case that financial intermediation can indeed engender instability: an economy with these institutions has multiple equilibria or volatile dynamics for more parameters than the same economy without them. In some cases there is a unique equilibrium without intermediation and multiple or volatile equilibria with it; in other cases both can have multiple or volatile equilibria but intermediation expands the set of parameters for which this is the case. Further, while the economic logic differs across models, in each case the results are directly related to the *raison d'etre* for intermediation.

As the literature on financial intermediation is vast, we refer to standard references (e.g., Freixas and Rochet 2008; Calomiris and Haber 2014; Vives 2016). We do mention Shleifer and Vishny (2010), which has a similar title and provides additional motivation, even if our methods are quite different, coming mainly from monetary theory as surveyed by Lagos et al. (2017) or Rocheteau and Nosal (2017). In particular, we study infinite-horizon economies because our interest is in economic dynamics, and moreover, finite-horizon models are ill suited for capturing salient aspects of financial activity, including unsecured credit, reputational considerations, and money.[3] We also use general equilibrium, in the sense of logically closed systems, without (as much as possible) exogenous assumptions on prices, contracts or behavior. This is because we want to know if instability arises from intermediation *per se* and not extraneous features like noise traders, irrational expectations, etc. To be clear, we impose frictions such as limited commitment, imperfect information or communication, and spatial separation, but those are imposed on the environment, not on prices, contracts or behavior. Thus, we think, what follows are models *of* financial intermediation, not merely those *with* financial intermediation.

[3] If there is a terminal date T, then at T no one honors obligations to preserve their reputations, nor do they accept currency; so no one does at $T-1$, and so on – at least without *ad hoc* devices, e.g., imposing exogenous default penalties or putting money in utility functions.

Model 1: Insurance

As mentioned, while our various specifications are mutually distinct, they all make use of standard building blocks from the literature, to make it clear that we are not introducing features that have not been previously deemed relevant. The first setup extends Diamond and Dybvig's (1983) model of liquidity insurance, or maturity transformation, to an infinite horizon world. As in Gu et al. (2013*a*), this lets us incorporate reputational considerations à la Kehoe and Levine (1993).

There are some agents that live forever, plus at each date in discrete time there is a $[0, 1]$ continuum of agents that are around only for that period, which is a simple way to have agents care differently about reputations. Each period has two subperiods. The short-lived agents are homogeneous *ex ante* but face idiosyncratic shocks: any individual is impatient with probability π and patient with probability $1 - \pi$, where the impatient (patient) ones derive utility only from consumption in the first (second) subperiod. Given the shock, which is private information, short-lived agents have utility $u_j(c_j)$, $j = 1, 2$, where c_j is the single consumption good in subperiod j, with $u_j' > 0$ and $u_j'' < 0$.[4] Infinite-lived agents have period utility $v(c)$ for c in the first or second subperiod, with $v' > 0$, $v'' \leq 0$ and $v(0) = 0$.

Short-lived agents have an endowment of 1; infinitely-lived agents have 0. The (completely standard) technology is this: a unit of the good invested at the start of the first subperiod yields $R > 1$ units in the second subperiod, or the investment can be terminated at the end of the first subperiod to get back the input. The good can also be stored one-for-one across subperiods. As in any Diamond-Dybvig model, to insure against the shocks, the short-lived agents can form a coalition that resembles, and is interpreted as, a bank. Thus they design a contract (c_1, c_2) to solve

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

$$\text{st } (1-\pi) c_2 = (1 - \pi c_1) R \tag{2}$$

$$c_2 \geq c_1, \tag{3}$$

[4] Many applications of Diamond-Dybvig assume $u_1(\cdot) = u_2(\cdot)$, but not all (e.g., Peck and Shell 2003). The flexibility of the general version is useful for constructing illustrative examples.

where (2) is feasibility and (3) is a truth-telling constraint (if $c_2 < c_1$ patient agents would claim to be impatient, get c_1 and store it to the next subperiod). There are also nonnegativity constraints omitted to save space.

This problem is well understood. One result is: assuming $u_1'(1) > u_2'(R) R$ and $u_1'(c) \leq u_2'(c) R$ at $c = R/(1 - \pi + \pi R)$, we get $1 < c_1^* < c_2^* < R$, so (3) is not binding, and full insurance/efficiency obtains. However, this requires commitment; otherwise, when they learn they are patient and are supposed to make transfers to the impatient, agents will renege. Given our short-lived agents cannot commit, naturally, there emerges a role for long-lived agents as bankers who accept deposits, invest them, and pay off depositors on demand at terms to be determined. Importantly, bankers do not have exogenous commitment ability – it is endogenous and based on reputation. Thus, bankers honor obligations lest they get identified as renegers, whence they are punished to autarky, which is a credible threat because there are many perfect substitutes for any given banker.

In particular, a banker may be tempted to misbehave as in the "cash diversion" models in Biais et al. (2007) or DeMarzo and Fishman (2007): if he misappropriates d deposits, he gets payoff λd, where λ is not too big, so this is socially inefficient, but he might do it opportunistically. As in Gu et al. (2013a,b), the cost is that he gets caught, and punished, with probability $\mu \leq 1$, where one interpretation is that μ is the probability one generation of depositors can communicate banker misbehavior to the next generation.[5] In any case, depositors may set $d < 1$, and invest $1 - d$ on their own, to reduce bank incentives to misbehave, different from most papers that simply assume $d = 1$, but similar to Peck and Setayesh (2019). In addition to d, the contract now specifies payouts per deposit contingent on withdrawal time r_j, $j = 1, 2$, and the banker's income $b \in [0, d]$, which he invests for utility $v(bR)$.

Since there is more than one long-lived agent, the short-lived agents can choose any of them to act as banker, and in the spirit of Diamond-Dybvig they make this choice as a coalition. However, we assume they can choose only one, to avoid

[5] While $\mu = 1$ is fine, it does not simplify things much, and it is known from other applications that $\mu < 1$ can be interesting (e.g., the extension of Kocherlakota 1998 in Gu et al. 2016).

determining the optimal number of bankers, because while that is interesting (see Model 2) it would be a distraction here; it can be rationalized by assuming that it is too costly to monitor more than one. Still, since they can choose any one, for reasons often summarized as Bertrand competition, the contract maximizes the expected utility of the depositors. Still, a banker may get positive surplus – rent on his option to act opportunistically – because the contract must give him incentives to not to abscond with the deposits.

The banker's incentive constraint is

$$v\left(b_t R\right) + \beta V_{t+1} \geq \lambda d_t + \beta\left(1-\mu\right) V_{t+1}, \tag{4}$$

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. Note that V_{t+1} is his valuation next period, facing a new generation of depositors, and hence is taken as given when designing a contract at t. Also note that bankers do not run off with d on the equilibrium path, but if one were to, he would get λd and not $v\left(Rb\right)$ – i.e., his income b is treated the same as any other funds under his control.

This leads to a new contracting problem

$$\max_{d_t, r_{1t}, r_{2t}, b_t} \left\{\pi u_1\left(d_t r_{1t} + 1 - d_t\right) + \left(1-\pi\right) u_2\left[d_t r_{2t} + \left(1-d_t\right) R\right]\right\} \tag{5}$$

$$\text{st} \;\; \left(1-\pi\right) d_t r_{2t} = \left(d_t - b_t - \pi d_t r_{1t}\right) R \tag{6}$$

$$r_{2t} \geq r_{1t} \tag{7}$$

$$\lambda d_t - v\left(b_t R\right) \leq \phi_t, \tag{8}$$

where (8) rewrites (4) using $\phi_t \equiv \beta\mu V_{t+1}$. Note that ϕ_t is a bank's *franchise value*, capturing the banker's reputation for trustworthiness. Substituting (6) into (5) to eliminate r_2, ignoring t subscripts for now, and taking FOC's wrt $\left(r_1, d, b\right)$ we get

$$\begin{aligned}
r_1 &: \; d\left\{\pi\left[u_1'\left(c_1\right) - Ru_2'\left(c_2\right)\right] - \eta_1\left(1-\pi+R\pi\right)\right\} r_1 = 0 \\
d &: \; \left\{\left(r_1 - 1\right)\pi\left[u_1'\left(c_1\right) - Ru_2'\left(c_2\right)\right] + \eta_1\left[R - \left(1-\pi+R\pi\right) r_1\right] - \eta_2\lambda\right\} d = 0 \\
b &: \; \left[-u_2'\left(c_2\right) - \eta_1 + \eta_2 v'\left(bR\right)\right] b = 0,
\end{aligned}$$

where $c_1 = dr_1 + 1 - d$ and $c_2 = dr_2 + (1-d) R$, while η_1 and η_2 are multipliers for constraints (7) and (8).

These FOC's yield two critical values, $\phi^* > 0$ and $\hat{\phi} < \phi^*$, delineating three regimes. (i) If $\phi \geq \phi^*$ then (8) is slack, and $b = 0$, since the franchise value keeps the 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 in the latter case invest the rest on their own (exactly as in Peck and Setayesh 2019). (ii) If $\phi \in [\hat{\phi}, \phi^*)$ we must either lower $d < d^*$ or raise $b > 0$ to satisfy (8). While lowering d from d^* means less-than-full insurance, this is second-order by the envelope theorem, so we set $d = \phi/\lambda$ and keep $b = 0$. (iii) If $\phi < \hat{\phi}$, lowering d further entails too much risk, so we set $b > 0$. In case (i), one of the payoff-equivalent contracts has $r_1 = r_2$, and (ii)-(iii) the unique contract has $r_1 = r_2$; hence wlog we set $r_1 = r_2 = r$ from now on.

In regime (iii), e.g., (d, r, b) satisfies

$$\begin{aligned} b &= d/R\,[R - (1 - \pi + R\pi)\, r] && (9) \\ \phi &= \lambda d - v(bR) && (10) \\ \frac{u_2'(c_2)}{u_1'(c_1) - Ru_2'(c_2)} &= \frac{\pi}{1 - \pi + R\pi}\left[\frac{(R-1)(1-\pi)}{\lambda} v'(bR) - 1\right] && (11) \end{aligned}$$

with $c_1 = 1 - d + (d - b) R/(1 - \pi + R\pi)$, $c_2 = (1-d) R + (d-b) R/(1 - \pi + R\pi)$. These and the analogs from regimes (i)-(ii) characterize the contract given ϕ, and in particular, one can easily check $b'(\phi) < 0 \; \forall \phi < \phi^*$, which is important below. This is shown Fig. 1 for the following parameterization:[6]

Example 1: *Let* $v(b) = Bb$,

$$u_1(c_1) = A_1 \frac{(c_1 + \varepsilon)^{1-\sigma_1} - \varepsilon^{1-\sigma_1}}{1 - \sigma_1} \text{ and } u_2(c_2) = A_2 \frac{(c_2 + \varepsilon)^{1-\sigma_2} - \varepsilon^{1-\sigma_2}}{1 - \sigma_2},$$

where $B = 0.95$, $\sigma_1 = \sigma_2 = 2$, $\varepsilon = 0.01$, $A_1 = 1$, $A_2 = 0.1$, $R = 2.1$, $\mu = 0.7$, $\pi = 0.25$, $\lambda = 0.6$ *and* $\beta = 0.99$.

[6] Notice $\hat{\phi} > 0$ here (in fact, for the example $\hat{\phi} = 0.3257$ and $\phi^* = 0.600$); the case $\hat{\phi} < 0$ is less interesting because it never has banking in steady state. In terms of primitives, one can show that $\hat{\phi} > 0$ iff $\pi [u_1'(1) - Ru_2'(R)] [(R-1)(1-\pi) v'(0) - \lambda] > u_2'(R)(1 - \pi + R\pi) \lambda$.

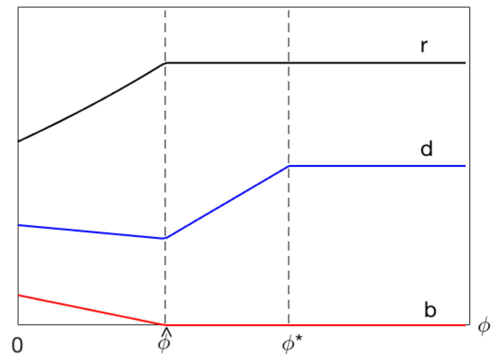

Figure 1: Model 1, bank contract vs ϕ

As mentioned, the contract takes ϕ as given. To embed this in general equilibrium, use $\phi_t \equiv \beta\mu V_{t+1}$ to write $V_t = v(b_t R) + \beta V_{t+1}$ as a dynamical system,

$$\phi_{t-1} = f(\phi_t) \equiv \beta\mu v[b(\phi_t) R] + \beta\phi_t, \tag{12}$$

where the function $b(\phi_t)$ comes from the contracting problem. Equilibrium is defined as a nonnegative, bounded path for ϕ_t solving (12), from which the other endogenous variables follow using the FOC's. A stationary equilibrium, which is the same as a steady state here, solves $\bar{\phi} = f(\bar{\phi})$. The nature of steady state depends on whether $\hat{\phi} \leq 0$ or $\hat{\phi} > 0$ (conditions for which are given in fn. 6). Appendix A proves:

Proposition 1 *If $\hat{\phi} \leq 0$ the unique steady state has no banking, $d = 0$. If $\hat{\phi} > 0$ the unique steady state has $\bar{\phi} \in (0, \hat{\phi})$ and banking, $d > 0$.*

For dynamic equilibria, first note from (12) that $f(\phi_t)$ has an increasing linear term and a decreasing nonlinear term since (as remarked above) $b'(\phi) < 0$. If the net effect implies $f'(\phi_t) < 0$ over some range the system can exhibit nonmonotone dynamics. For Example 1, Fig. 2a shows f and f^{-1}, which cross on the 45^o line at $\bar{\phi} = 0.3215$. In this case the system is monotone and there is a unique equilibrium, which is the steady state, because that is the only bounded path solving (12). To see this is not true in general, consider:

Example 2: *Same as above except $\sigma_1 = 10$ and $\mu = 1$.*

As Fig. 2b shows, Example 2 implies $f'(\bar{\phi}) < -1$, and so f and f^{-1} intersect off the 45^o line, at (ϕ_L, ϕ_H) and (ϕ_H, ϕ_L) with $\phi_H = 0.0696$ and $\phi_L = 0.0689$. As is standard (see Azariadis 1993), this means there is a two-cycle equilibrium where ϕ_t oscillates deterministically 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 B). Thus we can get deterministic or stochastic volatility with banking and not without it. That does not mean banking is a bad idea, as it provides insurance to agents who cannot get it otherwise, due to commitment issues. It does mean banking can engender instability.

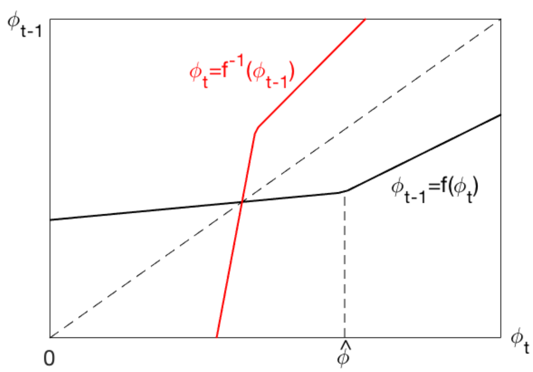

Figure 2a: Model 1, monotone f

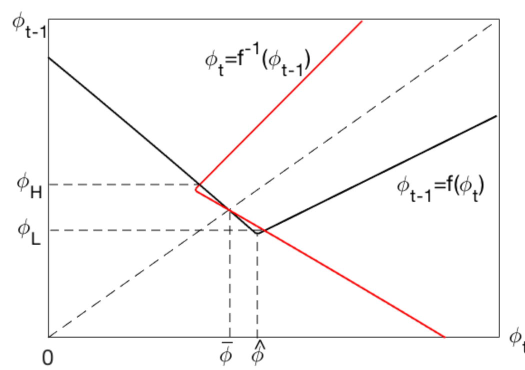

Figure 2b: Model 1, nonmonotone f

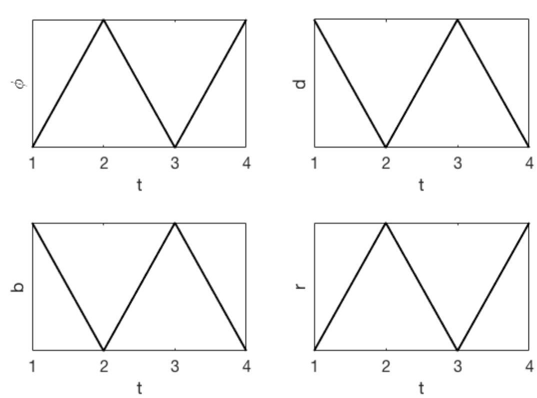

Figure 3: Model 1, time series for a two-cycle

The intuition is straightforward: if next period V_{t+1} is high then this period ϕ_t is high and we can discipline bankers with low b_t; but that makes the current V_t and hence ϕ_{t-1} low. This simple logic induces a tendency towards oscillations, but for a cycle the effect has to dominate the linear term in $f(\phi_t)$, which is why parameters matter. Fig. 3 plots time series of (ϕ, d, b, r) over the cycle in Example 2. Notice r moves with ϕ and b against ϕ. Whether d moves with or against ϕ depends on parameters, but here it is the latter. While the point is not to take this example seriously in a quantitative sense, obviously, it is worth noting that the theory does make qualitative predictions, and does not say that "anything goes."

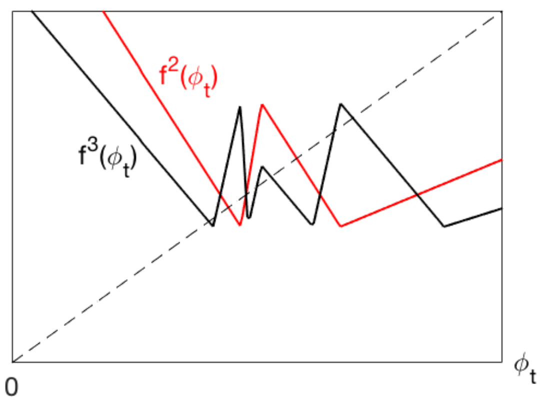

Figure 4: Model 1, two- and three-cycles

Fig. 4 displays the existence of two-cycles in a different way, as fixed points of the second iterate $f^2 = f \circ f$, for another parameterization:

Example 3: *$B = 1$, $\sigma_1 = 14$, $\sigma_2 = 1.5$, $\varepsilon = 0.01$, $A_1 = 1$, $A_2 = 0.075$, $R = 2.2$, $\mu = 1$, $\pi = 0.28$, $\lambda = 0.75$ and $\beta = 0.76$.*

Notice f^2 has three fixed points, $\bar{\phi}$, plus ϕ_L and ϕ_H from the two-cycle. Also shown is f^3, which has seven fixed points, $\bar{\phi}$ plus a pair of three-cycles. Standard results (again see Azariadis 1993) say the existence of three-cycles implies the existence of

$n-$cycles for any n, plus chaos, which is basically a cycle with $n = \infty$.

To summarize, banking can introduce many equilibria, including deterministic, stochastic and chaotic dynamics, directly attributable to the idea that banks depend on trustworthiness, and at least to some extent that is a self-fulfilling prophecy. We have more to say about this after presenting some other models.

Model 2: Delegated Investment with Fixed Costs

The next formulation has intermediation originating from economies of scale, based on Diamond (1984) and Huang (2017) (see also Leland and Pyle 1976 or Boyd and Prescott 1986 on the bigger picture). Time is discrete and continues forever as in Model 1, but here all agents are infinitely lived. Also, they are now spatially separated – say, across a large number of islands – and randomly relocated at the end of each period, following a literature on banking including Champ et al. (1996), Bencivenga and Smith (1991), Smith (2002) and Bhattacharya et al. (2005).[7] Economies of scale are captured as follows: agents must pay a fixed cost κ, in terms of goods, to locate/evaluate/monitor investment projects, after which any project returns R per unit invested.

Period utility is $u(x) - c(d)$, where x is consumption and d investment – say, output produced one-for-one with labor – where $u', c' > 0$ and $c'' \geq 0 > u''$. Also, $u'(0) R > c'(0)$, so that agents invest if $\kappa = 0$. If $\kappa > 0$ the payoff is

$$W_1 = \max_{x,d} \{u(x) - c(d)\} \text{ st } x = Rd - \kappa, \tag{13}$$

from investing on one's own (omitting nonnegativity constraints as usual). Suppose κ is too high to support this, so $W_1 < 0$, and denote the autarky payoff by $W_0 = 0$. Now consider agents forming a coalition where some, that we call depositors, delegate their investment to others, that we call bankers, to share the fixed cost.

[7] The main function of random relocation here is to let us avoid long-term contracting considerations, which are interesting but complicated (e.g., in Gu et al. 2013a, bankers' rewards can be backloaded over multi-period contracts). Elsewhere in the paper we avoid those issues using short-lived agents, but here we want all agents to be long-lived, so that *ex ante* anyone can potentially be a banker. In any case, it is important to emphasize that these are not restrictions on contracting *per se*, but assumptions on the environment that impinge on the contract. Does it matter? Yes, because without making them explicit one cannot know, in general, how these assumptions impinge on all endogenous variables.

As in many models with nonconvexities, a coalition uses a lottery to chose a subset of members to act as bankers.[8] Thus, ω_t is the probability of being a banker, and the measure of bankers if the island population is normalized to 1. As in Model 1, bankers have the option to misbehave, with λ and μ playing similar roles. The relevant incentive condition is therefore

$$\beta V_{t+1} \geq \frac{\lambda \left(1-\omega_t\right) x_t}{\omega_t} + (1-\mu)\beta V_{t+1}, \tag{14}$$

where the RHS is the deviation payoff, given each depositor is promised x_t and each banker controls $\left(1-\omega_t\right) x_t/\omega_t$ of the resources.[9] The trade-off, as in Huang (2017), is that having fewer banks saves on fixed costs but raises their temptation to misbehave, because they must be large, unless we lower total deposits.

The contract maximizes the payoff to the representative agent on the island

$$W\left(\phi\right) = \max_{\omega, X, D, x, d} \left\{\omega\left[u\left(X\right) - c\left(D\right)\right] + \left(1-\omega\right)\left[u\left(x\right) - c\left(d\right)\right]\right\} \tag{15}$$

$$\text{st } \omega X + \left(1-\omega\right) x = R\left[\omega D + \left(1-\omega\right) d\right] - \kappa\omega \tag{16}$$

$$u\left(x\right) - c\left(d\right) \geq 0 \tag{17}$$

$$\frac{1-\omega}{\omega} x \leq \phi, \tag{18}$$

where $\phi_t \equiv \mu\beta V_{t+1}/\lambda$, while (X, D) and (x, d) are the consumption/investment allocations of bankers and depositors. Here (16) is the resource constraint, (17) is the incentive constraint for depositors, and (18), which is the same as (14), is the incentive constraint for bankers.

Substituting (16) into (15) to eliminate X, and letting η and γ be multipliers, we get the FOC's:

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

[8]This is similar to, e.g., Rogerson's (1988) indivisible-labor model, except unlike his, our agents cannot commit, so our contracts must be incentive compatible before and after the lottery.

[9]Here we assume that a deviating banker receives $u(X) - c(D)$ in addition to $\lambda[(1-\omega_t)x_t/\omega_t]$.

One can check $W'(\phi) \geq 0$. Moreover, $W(0) = 0$, so we get no banking at $\phi = 0$. In the limit as $\phi \to \infty$ we get $\omega \to 0$, which means very few banks but they are huge. Also as $\phi \to \infty$ we get $W(\phi) \to W^* \equiv \max_{x,d}[u(x) - c(d)]$ st $x = Rd$, which totally dissipates the fixed cost (i.e., delivers the same payoff as $\kappa = 0$).

Fig. 5 shows the contract given ϕ for the following parameterization:

Example 4: *Let*

$$u(x) = A\frac{(x+\varepsilon)^{1-\sigma} - \varepsilon^{1-\sigma}}{1-\sigma} \text{ and } c(d) = Bd,$$

with $A = \varepsilon = 0.001$, $\sigma = 2$, $B = 0.1$, $\kappa = 230$, $R = 1.2$, $\beta = 0.76$, $\mu = 0.95$ *and* $\lambda = 9$.

Notice that there is a cutoff $\tilde{\phi}$, which happens to be $\tilde{\phi} = 0.0182$ in this example, and banking is viable iff $\phi \geq \tilde{\phi}$.

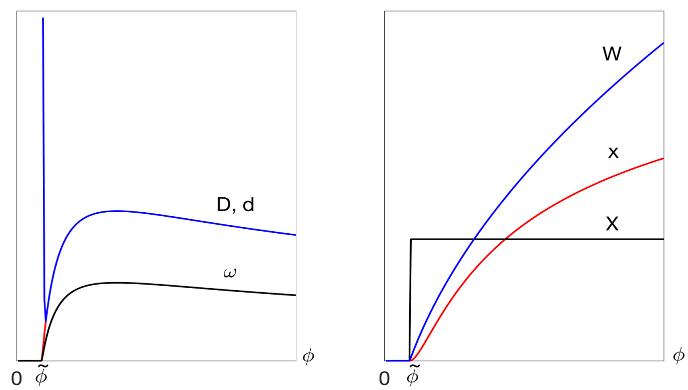

Figure 5: Model 2, bank contract vs ϕ

To embed this in equilibrium we use $V_t = W(\phi_t) + \beta V_{t+1}$ and emulate the methods from Model 1 to get

$$\phi_t = f(\phi_{t+1}) \equiv \frac{\beta\mu}{\lambda} W(\phi_{t+1}) + \beta\phi_{t+1}. \tag{19}$$

Equilibrium is a bounded, nonnegative solution to (19). Notice $f(\phi) = \beta\phi$ for $\phi \leq \tilde{\phi}$, and $f(\phi) < \phi$ for big ϕ due to the fact that $W \leq W^*$ – if $\phi = \mu W^*/\lambda$, e.g., then (19) necessarily implies $\phi < f(\phi)$. Then we have:

Proposition 2 *There is always a steady state with $\bar{\phi} = 0$, without banking. There can be steady states with banking, generically an even number that alternate between stable and unstable.*

Fig. 6 shows Example 4 has three steady states, the ubiquitous $\phi = 0$, plus two with banking $\phi_2 > \phi_1 > 0$. This is different from Model 1, which has a unique steady state $\bar{\phi}$, and has nonstationary equilibria iff $f'\left(\bar{\phi}\right) < -1$. Now $f'(\phi) > 0$, so deterministic cycles are impossible, but if there are multiple steady states we can use a different approach to construct sunspot equilibria around the stable ones.[10] Appendix B shows there are equilibria where ϕ fluctuates between ϕ_A and ϕ_B for any $\phi_A \in (\phi_0, \phi_1)$ and $\phi_B \in (\phi_1, \phi_2)$. In particular, $\phi_A < \tilde{\phi}$ means we switch stochastically between $d_t > 0$ and $d_t = 0$ – i.e., random episodes of crises, where deposits dry up and banking shuts down due to fundamentally irrelevant events (sunspots). This is different from Model 1, where d_t can fluctuate, but only with $d_t > 0\ \forall t$.

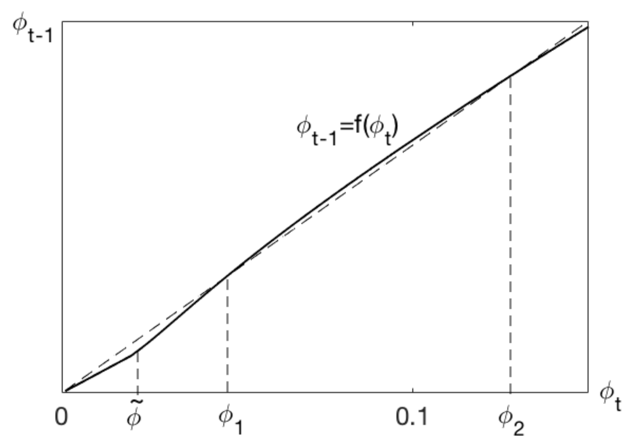

Figure 6: Model 2, monotone f with multiple steady states

[10]To give credit where credit is due, in Model 2 we use the method in Azaridais (1981), while in Model 1 we use the method in Azaridais and Guesnerie (1986).

While Models 1 and 2 are different, in terms of economics and mathematics, Appendix C presents an environment that integrates elements of both. It has two agents on each island, one that is infinitely lived and one that is only around for one period, who bargain over the terms of the contract (having just two is natural for bargaining, but we also considered many depositors and one banker, with multilateral bargaining, and got similar results). There are gains to delegating investment due to $\kappa > 0$, as in Model 2, but now only long-lived agents can act as bankers, as in Model 1. Letting θ denote bankers' bargaining power, we get a dynamical system $\phi_t = f\left(\phi_{t+1}\right)$ that can be nonmonotone for $\theta < 1$. For this system Appendix C shows we can have multiple steady states, with $f'(\phi) > 0$ around the stable ones and hence sunspot equilibria as in the benchmark Model 2, as well as $f'(\phi) < -1$ around the unstable steady states and hence cycles and sunspots as in Model 1.

The reason $f(\phi)$ is decreasing in Appendix C is the following well-known (see Kalai 1977) feature of Nash bargaining: agents with bargaining power $\theta < 1$ can get a smaller surplus when the bargaining set expands. Here this is manifest in bankers' surplus falling with ϕ, similar to $b'(\phi) < 0$ in Model 1. That does not happen in the baseline Model 2, where agents in the coalition are *ex ante* identical and hence treated symmetrically, which means they all get a bigger surplus when ϕ increases. Details aside, we conclude there are distinct ways to formalize how banking might engender instability though reputation/trust, but they can be integrated.[11]

Model 3: Asset Market Intermediation

Banks are not the only interesting financial intermediaries. Work following Duffie et al. (2005) studies financial markets using search theory, where agents may trade assets with each other, or with middlemen/dealers that buy from those with low valuation and sell to those with high valuation. We pursue this with a few changes

[11] Model 1 can actually be interpreted as bargaining where banks have $\theta = 0$, since that is basically the same as Bertrand competition. Hence, one may conjecture that similar dynamics emerge in Model 1 if we allow $\theta \in (0, 1)$, but then it becomes intractable, while the setup in Appendix C does not. Another model that gets nonmonotone dynamics from $\theta \in (0, 1)$ can be found in Gu et al. (2013b, Appendix B), but that has simple borrowing and lending without banks. Still, we put our model with $\theta \in (0, 1)$ in the Appendix because it is not the first formulation where nonmonotone dynamics emerge from generalized Nash bargaining.

in their environment. In particualr, most papers following Duffie et al. (2005) give middlemen continuous access to a frictionless interdealer market (with some exceptions, e.g. Weill 2007, but they do not study the issues analyzed below). Hence, their intermediaries do hold assets in inventory. Our middlemen are more like those in Rubinstein and Wolinsky (1987), who buy from producers and hold inventories until they randomly sell to consumers. However, here they trade assets and not goods, which matter a lot as argued by Nosal et al. (2017), on which this section is based, even if we amend their setup in many ways. These include: adding heterogenous projects; modifying the market composition conditions (see fn. 12); and switching from continuous to discrete time, which generates a few new results.

There are large numbers of three risk-neutral types, B, S and M, for asset buyers, sellers and middlemen. Type M agents stay in the market forever, while type S and B stay for one period, although we also studied alternatives, like letting everyone stay forever, with similar results. Upon exit S and B are replaced by 'clones' to maintain stationarity (a device borrowed from Burdett and Coles 1997). Type B agents, sometimes called end users, want to acquire an asset – let's call it capital – to implement a project for profit $\pi > 0$, where π is observable when agents meet, but random across end users with CDF $F(\pi)$. The originators of capital, type S, if they enter the market each bring 1 indivisible unit; those that stay out put their capital to alternative uses, defining their opportunity cost of participation, denoted $\kappa_s > 0$, which for simplicity is the same for all S.

Type M agents, who are always in the market, can acquire capital from S, but as usual in these models their inventories are restricted to $k \in \{0, 1\}$ (with exceptions, e.g. Lagos and Rocheteau 2009, but they do not study the issues analyzed below). Let n_t be the measure of type M at t with $k = 1$. Capital held by M depreciates by disappearing each period with probability $\delta \geq 0$, but while he holds it M gets a return $\rho > 0$. His crucial choice is then, if he has $k = 1$ and meets B, should he trade or keep k for himself? This depends on fundamentals, of course, including the end user's π, but it can also depend on equilibrium considerations.

Market composition is determined as follows: the measures n_m and n_b of types M and B are fixed, but entry by S makes n_s endogenous.[12] Given this, the meeting technology is standard: each period everyone in the market contacts someone with probability α, and each contact is a random draw from the participants. In particular, if N_t is the total measure of participants then types M and S both meet type B with probability $\alpha n_b/N_t$, so M has no advantage over S that regard – different from the original Rubinstein-Wolinsky setup, it is but fine for our purposes. When B and S meet they trade for sure since this is S's only chance and cost κ_s is sunk. Similarly, when S meets M with $k = 0$ they trade for sure. When M with $k = 1$ meets B, as mentioned, they may or may not trade.

As regards prices, if type j gives i capital the latter pays p_{ij} (in terms of transferable utility), determined by bargaining. Thus, if Σ_{ij} is the total surplus available when i and j meet, as long as $\Sigma_{ij} > 0$ they trade, and type i's surplus is $\theta_{ij}\Sigma_{ij}$, where $\theta_{ij} \in [0,1]$ is his bargaining power. To flesh this out, let $V_{s,t}$ and $V_{b,t}$ be value functions for types S and B; let $V_{k,t}$ be the value function for M when he has $k \in \{0,1\}$; and let $\Delta_t = V_{1,t} - V_{0,t}$ be M's gain from having inventory. Then

$$\Sigma_{bs,t} = \pi,\ \Sigma_{ms,t} = (1-\delta)\,\beta\Delta_{t+1},\ \Sigma_{bm,t} = \pi - (1-\delta)\,\beta\Delta_{t+1},$$

where $\beta \in (0,1)$ is M's discount factor. Note there are no continuation values or threat points for S and B, as they are in the market for just one period, but while that simplifies some algebra it is not otherwise important. Bargaining now yields

$$p_{bs,t} = \theta_{sb}\pi,\ p_{ms,t} = \theta_{sm}\,(1-\delta)\,\beta\Delta_{t+1},\ p_{bm,t} = \theta_{mb}\pi + \theta_{mb}\,(1-\delta)\,\beta\Delta_{t+1}. \tag{20}$$

When M with $k = 1$ and B with project π meet, they trade with probability $\tau_t = \tau(\pi, R_t)$, where

$$\tau(\pi, R) = \begin{cases} 0 & \text{if } \pi < R \\ [0,1] & \text{if } \pi = R \\ 1 & \text{if } \pi > R \end{cases} \tag{21}$$

[12] Entry by S is nice because it lets us compare economies with the same entry conditions with and without middlemen. Still, results for entry by M are given in Appendix D; entry by B is less interesting and hence omitted. Arguably these alternatives are all better than Nosal et al. (2017), where agents choose to be either type M or S. That is awkward because, e.g., in cyclic equilibria they switch back and forth over time between being M and S. Here no one switches, but participation by a type can vary as in conventional search theory (e.g., Pissarides 2000).

and $R_t \equiv (1-\delta)\,\beta\Delta_{t+1}$ is the *reservation value* of a project making $\Sigma_{mb} = 0$. Hence, the market payoff for B with project π is

$$V_{b,t}(\pi) = \frac{\alpha n_{s,t}}{N_t}\theta_{bs}\pi + \frac{\alpha n_t}{N_t}\tau(\pi, R_t)\,\theta_{bm}\left[\pi - (1-\delta)\,\beta\Delta_{t+1}\right]. \tag{22}$$

The first term on the RHS is the probability B meets S, times his share of the surplus; the second is the probability he meets M with $k = 1$, times the probability they trade, times his share of the surplus; and note prices do not appear since they were eliminated using (20). Similarly, the market payoff for S is

$$V_{s,t} = \frac{\alpha n_b}{N_t}\theta_{sb}\int_0^\infty \pi dF(\pi) + \frac{\alpha(n_m - n_t)}{N_t}\theta_{sm}(1-\delta)\,\beta\Delta_{t+1}. \tag{23}$$

The payoff for M depends on inventory. Using $R_t = (1-\delta)\,\beta\Delta_{t+1}$, we have

$$V_{0,t} = \frac{\alpha n_{s,t}}{N_t}\theta_{ms}R_t + \beta V_{0,t+1} \tag{24}$$

$$V_{1,t} = \rho + \frac{\alpha n_b}{N_t}\theta_{mb}\int_{R_t}^\infty (\pi - R_t)\,dF(\pi) + (1-\delta)\beta V_{1,t+1} + \delta\beta V_{0,t+1}. \tag{25}$$

Subtracting and simplifying with integration by parts, we get

$$R_{t-1} = (1-\delta)\,\beta\left\{\rho + R_t + \frac{\alpha n_b\theta_{mb}}{N_t}\int_{R_t}^\infty \left[1 - F(\pi)\right]d\pi - \frac{\alpha n_{s,t}\theta_{ms}}{N_t}R_t\right\}. \tag{26}$$

giving the evolution of R over time. The evolution of inventories held by M is

$$n_{t+1} = n_t(1-\delta)\left[1 - \frac{\alpha n_b}{N_t}\mathbb{E}\tau(\pi, R)\right] + \frac{(n_m - n_t)\alpha n_{s,t}(1-\delta)}{N_t}. \tag{27}$$

where $\mathbb{E}\tau(\pi, R) = prob(\pi > R)$ is the unconditional probability that M and B trade. The first term on the RHS is current n times the probably a unit of k does not depreciate or get traded; the second is current $n_m - n$ times the probability M acquires k and it does not depreciate.

We can eliminate N_t in (26)-(27) using S's entry condition, $V_{s,t} = \kappa_s$, which reduces to

$$n_{s,t} = \frac{\alpha n_b\theta_{sb}\mathbb{E}\pi + \alpha(n_m - n_t)\,\theta_{sm}R_t}{\kappa_s} - n_b - n_m. \tag{28}$$

What's left is a two-dimensional dynamical system that is compactly written as

$$\begin{bmatrix} n_{t+1} \\ R_{t-1} \end{bmatrix} = \begin{bmatrix} f(n_t, R_t) \\ g(n_t, R_t) \end{bmatrix}. \tag{29}$$

Given an initial n_0, an equilibrium is a nonnegative, bounded path for (n_t, R_t) solving (29).[13]

With no intermediaries, $n_m = 0$, as both S and B are one-period lived, the equilibrium is static and it is easy to check that it is unique. With $n_m > 0$, first note that the locus of points satisfying $n = f(n, R)$, called the n-curve, and the locus satisfying $R = g(n, R)$, called the R-curve, both slope up in (n, R) space. Then, to develop some intuition, consider the special case where $\pi = \bar{\pi}$ is constant. As shown in Fig. 7, for this case there are three possible regimes: (i) $R < \bar{\pi}$, so M with $k = 1$ and B trade with probability $\tau = 1$; (ii) $R > \bar{\pi}$, so they trade with probability $\tau = 0$; and (iii) $R = \bar{\pi}$, so they trade with probability $\tau \in (0, 1)$. Appendix A proves:

Proposition 3 *With $\pi = \bar{\pi}$ there exist $\tilde{\rho} > 0$ and $\hat{\rho} > \tilde{\rho}$ such that: (i) if $\rho \in [0, \tilde{\rho})$ there is a unique steady state and it has $R < \bar{\pi}$; (ii) if $\rho \in (\hat{\rho}, \infty)$ there is a unique steady state and it has $R > \bar{\pi}$; (iii) if $\rho \in (\tilde{\rho}, \hat{\rho})$ there are three steady states, $R < \bar{\pi}$, $R > \bar{\pi}$, and $R = \bar{\pi}$.*

[13] A distinction between this model and others in the paper is that this system is two dimensional: R is a jump variable, like ϕ in the previous sections, while n is a (predetermined) state variable, so transitions are nontrivial. Interestingly, the version of Model 3 in Appendix D, with entry by M instead of S, is different: there one can solve a univariate system $R_{t-1} = G(R_t)$ to get the path for R_t, after which n_t, N_t etc. follow from simple conditions. Intuitively, with entry by M (entry by S) the model is (is not) block recursive, as discussed in Shi (2009).

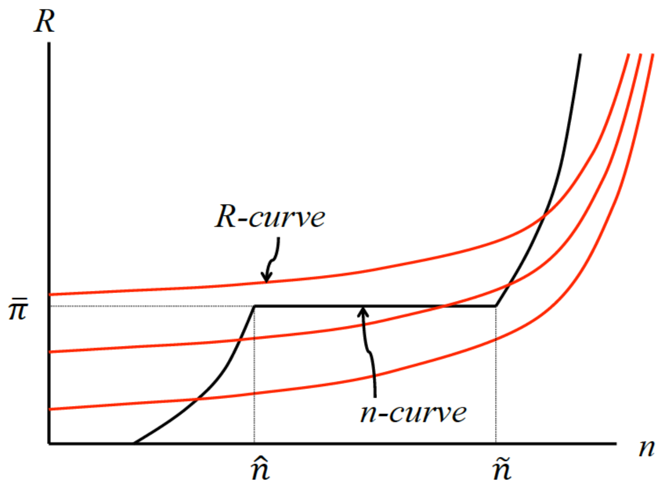

Figure 7: Phase plane in Model 3 for different ρ when π is degenerate

For several reasons we prefer a nondegenerate $F(\pi)$.[14] So, consider a smooth mean-preserving spread of the degenerate case:

Example 6: *Let*

$$F(\pi) = \begin{cases} \pi_1 \pi / \pi_0 & \text{if } 0 \le \pi \le \pi_0 \\ \pi_1 + (\pi_3 - \pi_1)(\pi - \pi_0)/(\pi_2 - \pi_0) & \text{if } \pi_0 < \pi \le \pi_2 \\ \pi_2 + (1 - \pi_3)(\pi - \pi_2)/(\pi_4 - \pi_2) & \text{if } \pi_2 < \pi \le \pi_4 \end{cases} \tag{30}$$

with $\pi_0 = 0.99$*,* $\pi_1 = 0.05$*,* $\pi_2 = 1.01$*,* $\pi_3 = 0.95$ *and* $\pi_4 = 2$*. Also, let* $\alpha = 1$*,* $\kappa_s = 0.1$*,* $n_b = 0.05$*,* $n_m = 0.5$*,* $\theta_{sm} = 0.5$*,* $\theta_{sb} = 1$*,* $\theta_{mb} = 0.7$*,* $\beta = 1/1.04$*,* $\delta = 0.008$ *and* $\rho = 0.2$*.*

[14] For the nondegenerate $F(\pi)$ studied below, the flat portion of the n-curve in Fig. 7 is eliminated. Related to this, in any steady state M and B are indifferent to trade only in the rare event $\pi = R$, in contrast to the mixed-strategy equilibrium in the degenerate case, where they are always indifferent. Moreover, with the nondegenerate $F(\pi)$, if R varies across pure-strategy steady states intermediation activity does too, but not necessarily to the extreme extent of the degenerate case, where it is either $\tau = 1$ or $\tau = 0$. Similarly, for real-time dynamics, cycles with nondegenerate $F(\pi)$ have fluctuations in intermediation activity but not necessarily between $\tau = 0$ and $\tau = 1$. Now it may be intereresting to have τ fluctuate between 0 and or 1, which can happen with a nondegenerate $F(\pi)$, but so can less extreme cycles.

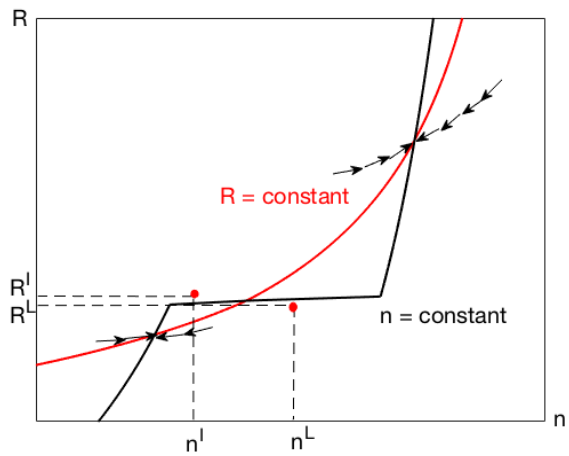

Figure 8: Phase plane in Model 3 including a two-cycle

This is shown in Fig. 8, which is similar to Fig. 7, but the slope of the n-curve is always positive. Hence the results are similar to Proposition 3, including multiplicity $\forall \rho \in (\tilde{\rho}, \hat{\rho})$.

Here is the intuition. First suppose R is low, so M trades k to B with a high probability. Then the probability M has $k = 0$ is high, which is good for sellers, so n_s is high. That makes it easy for M to get k and rationalizes his low R. Now suppose R is high, so M trades k to B with a low probability. Then the probability M has $k = 0$ is low, which is bad for sellers, so n_s is low. That makes it hard for M to get k and rationalizes his high R. Heuristically, this requires multiple intermediaries acting independently – if they could somehow collude (or if there were a monopoly intermediary comprised of many agents, who match like the individual M's in the baseline model, to preserve the nature of the frictions), they could internalize the impact of their τ decision on entry by S. This is different from other models in the paper, where the main results are independent of the number of banks, except to the degree that this may affect the size of their surplus.

Moreover, market liquidity – i.e., the ease with which agents can buy and sell k – is high (low) if R is low (high). Multiplicity means liquidity is not pinned down by fundamentals, a recurring theme in monetary theory (e.g., Kiyotaki and Wright 1989), but the intuition here is different. In monetary economies, whether an agent accepts something as medium of exchange depends on what others accept. Here, whether type M agents trade away k depends on n_s, and n_s depends on whether type M trade away k, which is not the same idea. In particular, our result requires endogenous market composition, which is not true in monetary models.

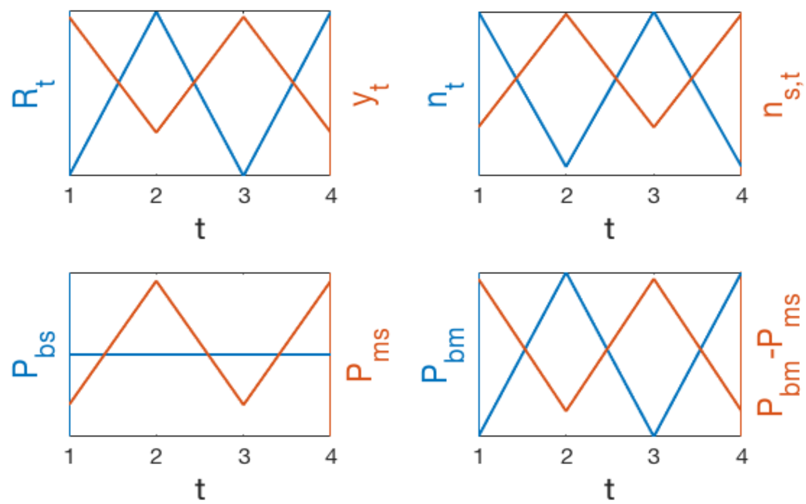

Figure 9: Time series for a two-period cycle in Model 3 with entry by S

Now consider a two-cycle oscillating between a liquid regime with low R and an illiquid regime with high R. That is, we seek $\left(R^L, n^L\right)$ and (n^I, R^I) solving

$$\begin{bmatrix} n^I \\ R^I \end{bmatrix} = \begin{bmatrix} f(n^L, R^L) \\ g(n^L, R^L) \end{bmatrix} \text{ and } \begin{bmatrix} n^L \\ R^L \end{bmatrix} = \begin{bmatrix} f(n^I, R^I) \\ g(n^I, R^I) \end{bmatrix}. \tag{31}$$

One can verify a solution is $\left(R^L, n^L\right) = (0.9862, 0.4504)$ and $\left(R^H, n^H\right) = (1.0103, 0.4312)$. Hence, we have real-time dynamics with excess volatility in liquidity, trade volume, prices and quantities. Fig. 9 shows the times series. In the liquid regime: R is low, making M more inclined to trade with B; n is high, because M and B traded less last period; and n_s is low, because low R and high n discourage entry by S. The illiquid regime has the opposite properties. Whether output y is higher or lower in the liquid regime depends on parameters.

We do not claim that actual data are best explained by a two-cycle; we do suggest this that if such a simple model can deliver equilibria where liquidity, prices, quantities and other endogenous variables vary over time, as self-fulfilling prophecies, it lends credence to the notion that intermediated asset markets in the real world might be prone to similar instability.[15]

Model 4: Safety and Secrecy

An important role of banks is the issuance of liabilities that facilitate third-party transactions. Indeed, as conventional wisdom has it, that is virtually their defining characteristic: "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" (Selgin 2018). We pursue this idea in a model with an explicit need for payment instruments, building on the New Monetarist framework recently surveyed by Lagos et al. (2017) and Rocheteau and Nosal (2017), where we introduce banks in two related ways.

The first says that bank liabilities are safe relative to other assets in the sense that they are less susceptible to theft or loss (this is similar to He et al. 2007; see also Sanches and Williamson 2010). Traveler's checks are a case in point but not the only one – e.g., it is obviously worse when one has their cash lost or stolen than one's checkbook or debit card. Similarly, if merchandise turns out to be fraudulent or defective, which is another type of theft, it is typically easier to stop payment when one pays by check or credit card rather than with cash.[16] The second version

[15] Prices are also shown in Fig. 9 (averaged over π when B trades). The price B pays S is constant over time, as it depends only on fundamentals, but the price M pays S or B pays M moves with R. The spread can go either way, but here it moves against R. This is all broadly consistent with the data discussed in Comerton-Forde et al. (2010), and other stylized facts (e.g., inventories are volatile than output). While this is obviously not a calibration, the finding that it is qualitatively consistent with several observations may lend further credence to the story.

[16] Safety was a critical feature of banks historically. Consider the British goldsmiths: "At first

builds on the idea that payment instruments originating with banks can be, as Dang et al. (2017) put it, informationally insensitive when these institutions act as secret keepers (an earlier exposition of this is Gorton and Pennachi 1990; Andolfatto and Martin 2013, Andolfatto et al. 2014, Loberto 2017, and Monnet and Quintin 2017 are versions that go deeper into the microfoundations of exchange, as we do here).[17]

While there are different approaches to modeling media of exchange, one based on Lagos and Wright (2005) is convenient for this application. In that setup, in each period of discrete 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 they are similar in the CM, where they all trade a numeraire consumption good x and labor ℓ for utility $U(x) - \ell$, with $U'(x) > 0 > U''(x)$. They also trade assets in the CM, like the 'trees' in the standard Lucas (1978) model, giving off a dividend $\rho > 0$ in the CM in numeraire. All agents discount by $\beta \in (0,1)$ between one CM and the next DM, but wlog they do not discount between the DM and CM.

In the DM agents meet bilaterally, and sellers can provide a good q (different from x) that buyers want. Let α be the probability a buyer meets a seller, so that α/n is the probability a seller meets a buyer. In any meeting, if a seller produces for a buyer the former incurs cost $c(q)$ and the latter gets utility $u(q)$, where $c(0) = u(0) = 0$, $c'(q), u'(q) > 0$ and $c''(q) \geq 0 > u''(q)$. Also, let q^* be the efficient quantity, $u'(q^*) = c'(q^*)$. Goods q and x are nonstorable, so they cannot serve as commodity money. Credit is not viable because there is limited commitment and DM trading is anonymous. Hence, as is standard in these models, sellers only produce if they

[they] accepted deposits merely for *safe keeping*; but early in the 17th century their deposit receipts were circulating in place of money" (Encyclopedia Britannica, quoted in He et al. 2005; 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), who specialized in moving purchasing power over dangerous territory.

[17] Other models of bank liabilities circulating as media of exchange that are similar in spirit but very different in detail include Cavalcanti and Wallace (1999*a,b*) and Cavalcanti et al. (1999).

get assets in exchange.

Let the terms of trade be given by a generic mechanism, as in Gu and Wright (2016), meaning this: for a buyer to get q, he must give the seller assets 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, $v(q) = \theta c(q) + (1-\theta) u(q)$. For a fairly general class of mechanisms, Gu and Wright (2016) show this: if a buyer has enough assets to make his liquidity constraint slack, he gets the efficient $q = q^*$ and pays $p^* = v(q^*)$; but if he has assets worth $p < p^*$, he gives them all to the seller and gets $q = v^{-1}(p) < q^*$.

Assets can be held in forms that differ in safety and liquidity, where safety is measured by the probability of being stolen (or lost), and liquidity is measured by whether it is accepted as means of payment 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 hidden in one's basement, meaning that it cannot be stolen (or lost) but cannot be used in the DM; and a_2 denotes assets held in a liquid form, which means they are brought to the DM, where can be used as payment instruments, but there is a probability $\delta > 0$ of being stolen (or lost).

The ex dividend price of the asset in terms of numeraire is ϕ independent of whether it is held as a_1 or a_2. A buyer's CM value function is $W(A)$ where $A = (\phi + \rho)\Sigma_{j=1}^{2} a_j$ is wealth. His DM value function is $V(\mathbf{a})$, which depends on his portfolio and not just its value. A buyer's CM problem is then

$$W_t(A_t) = \max_{x_t, \ell_t, \hat{\mathbf{a}}_t} \{U(x_t) - \ell_t + \beta V_t(\hat{\mathbf{a}}_t)\} \text{ st } x_t = A_t + \ell_t - \phi_t \Sigma_{j=1} \hat{a}_{j,t}$$

where $\hat{\mathbf{a}} = (\hat{a}_1, \hat{a}_2)$ is his updated portfolio, and the CM real wage is 1 assuming that x is produced one-for-one with ℓ. Assuming an interior solution, several standard results immediate: (i) $x_t = x^*$ solves the FOC $U'(x^*) = 1$; (ii) $\hat{\mathbf{a}}_t$ solves the FOC's $\beta \partial V_{t+1} / \partial \hat{a}_{j,t} \leq \phi_t, = 0$ if $\hat{a}_{j,t} > 0$, which means is 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.[18]

A buyer's value function is

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

where $\hat{A}_{t+1}$ is the wealth implied by $\hat{\mathbf{a}}_t$, and q_{t+1} is the quantity transacted when paying with $\hat{a}_{2,t}$, where $v\left(q_{t+1}\right) = \left(\phi_{t+1}+\rho\right)\hat{a}_2$ if $\left(\phi_{t+1}+\rho\right)\hat{a}_2 < v\left(q^*\right)$ and $v\left(q_{t+1}\right) = v\left(q^*\right)$ otherwise. The buyer's surplus in the DM transaction is simply $u\left(q\right) - v\left(q\right)$, because of the result that $W\left(\cdot\right)$ is linear. Equilibrium is described by the Euler equations, which we get from inserting the derivatives of V into the FOC's from the CM:

$$0 = \hat{a}_{1,t}\left[\beta\left(\phi_{t+1}+\rho\right) - \phi_t\right] \tag{32}$$

$$0 = \hat{a}_{2,t}\left\{\beta\left(\phi_{t+1}+\rho\right)(1-\delta)\left[1+\alpha\lambda\left(q_{t+1}\right)\right] - \phi_t\right\} \tag{33}$$

where $\lambda\left(q\right) = u'\left(q\right)/v'\left(q\right) - 1 > 0$ is the *liquidity premium* on assets in the DM.[19]

If we normalize the aggregate asset supply to 1, the dynamical system implied by the model is described as follows. At any date t, there are three possible regimes: (i) $\hat{a}_{2,t} = 0$; (ii) $0 < \hat{a}_{2,t} < 1$; and (iii) $\hat{a}_{2,t} = 1$. In regime (i), inserting $\hat{a}_{1,t} = 1$ and $\hat{a}_{2,t} = 0$ into (32) and (33), we get $\phi_t = \beta(\phi_{t+1}+\rho)$ and $(1-\delta)\left[1+\alpha\lambda\left(0\right)\right] \le 1$, with the latter equivalent to

$$\delta \ge \hat{\delta} \equiv \frac{\alpha\lambda\left(0\right)}{1+\alpha\lambda\left(0\right)}. \tag{34}$$

Thus, agents bring no assets to the DM if the probability of theft is high. With Kalai bargaining and the Inada condition $u'\left(0\right)/c'\left(0\right) = \infty$, e.g., this reduces to $\hat{\delta} = \alpha\theta/(1-\theta+\alpha\theta)$, so $\hat{\delta} = 1$ if $\theta = 1$ and $\hat{\delta} < 1$ otherwise. If (34) holds, the DM shuts down, in which case the only possible equilibrium outcome has $\phi_t = \phi^F\ \forall t$,

[18] A seller's CM problem (not shown) is similar except, unlike buyers, they have no need for liquidity, so they only hold assets that are priced fundamentally, as discussed more below. In particular, their CM payoff is also linear in wealth.

[19] It is also the Lagrange multiplier on the constraint that a buyer cannot give a seller more assets than he has, which here means $\hat{a}_2$. Note that $\lambda\left(q\right) > 0$, given $\delta > 0$, because buyers worry about getting robbed.

where $\phi^F \equiv \beta\rho/(1-\beta)$ is sometimes called the fundamental price of the asset.[20]

Now assume $\delta < \hat{\delta}$, and consider regime (ii), where agents hold some but not all their assets in liquid form. Inserting $\hat{a}_{1,t}$,$\hat{a}_{2,t} > 0$ into (32) and (33), we get $\phi_t = \beta\left(\phi_{t+1} + \rho\right)$ and $(1-\delta)\left[1 + \alpha\lambda\left(q_{t+1}\right)\right] = 1$, which means $q_{t+1} = \tilde{q}$ where

$$\alpha\lambda\left(\tilde{q}\right) = \frac{\delta}{1-\delta}. \tag{35}$$

Now λ is decreasing (Gu and Wright 2016), so $\tilde{q}$ is the highest possible q one can get given δ. Thus, $\hat{a}_{2,t} < 1$ obtains iff $\phi_{t+1} + \rho > \hat{a}_{2,t}\left(\phi_{t+1} + \rho\right) = v\left(\tilde{q}\right)$ and $\delta < \hat{\delta}$.

Finally, consider regime (iii). Inserting $\hat{a}_{1,t} = 0$ and $\hat{a}_{2,t} = 1$ into (32) and (33), we get $\phi_t \geq \beta\left(\phi_{t+1} + \rho\right)$ and

$$\phi_t = \beta\left(\phi_{t+1} + \rho\right)(1-\delta)\left[1 + \alpha\lambda\left(q_{t+1}\right)\right], \tag{36}$$

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

$$\Phi\left(\phi\right) \equiv \begin{cases} \beta\left(\phi + \rho\right)(1-\delta)\left[1 + \alpha\lambda \circ v^{-1}\left(\phi + \rho\right)\right] & \text{if } \phi < \tilde{\phi} \\ \beta\left(\phi + \rho\right) & \text{if } \phi \geq \tilde{\phi} \end{cases} \tag{37}$$

This says if the asset price is low, all assets will be brought to the DM. As usual, equilibrium is a nonnegative and bounded path for $\phi_t = \Phi\left(\phi_{t+1}\right)$.

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

$$\tilde{\delta} = \frac{\alpha\lambda \circ v^{-1}(\phi^F + \rho)}{1 + \alpha\lambda \circ v^{-1}(\phi^F + \rho)}. \tag{38}$$

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

Fig. 10 shows how steady state depends on δ. In regime (i) the DM is inactive and $\bar{\phi} = \phi^F$, because assets are not safe enough to use as payment instruments.[21]

[20] One might argue for $\phi^F = \beta(1-\delta)(\phi + \rho)$, not $\phi^F = \beta(\phi + \rho)$, since the asset holder only gets the return when it is not stolen. A rebutal is that someone gets the payoff, even if it is only a thief. To avoid this semantic issue, one can simply interpret ϕ^F as notation for $\beta\rho/(1-\beta)$.

[21] The DM can be active in regime (i) if we allow some barter or some credit, as is easy to do, but still assets would not be used in payments, so it is still the case that $\phi_t = \phi^F\ \forall t$.

In regime (ii) the DM is active at $q = \tilde{q} > 0$, but since some wealth is parked in the illiquid $\hat{a}_1$, we again have $\bar{\phi} = \phi^F$, and we have $\partial q/\partial\delta < 0$. Thus DM output goes down with δ because it reduces output per trade $\tilde{q}$, as well as the number of trades $(1-\delta)\,\alpha$. Regime (iii) is the most interesting, since it maximizes 'cash in the market' with $\hat{a}_2 = 1$, and implies $\bar{\phi} > \phi^F$. Here $\partial q/\partial\delta < 0$ not because $\hat{a}_2$ falls, but because ϕ falls, with δ. Also notice that $\tilde{\delta}$ is decreasing in ρ, so for a given δ the economy is more likely to be in this regime when ρ is smaller, meaning liquidity is more scarce.

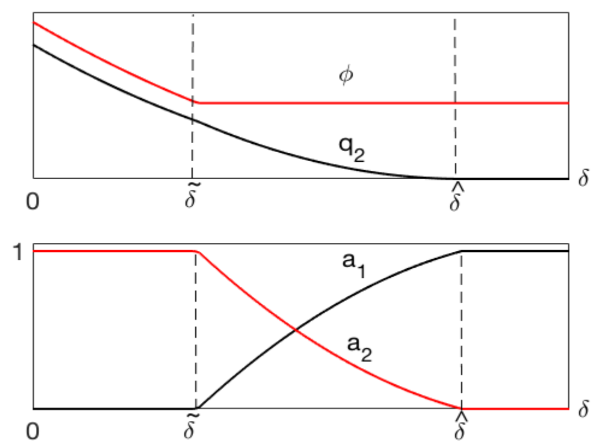

Figure 10: Model of theft, regimes of steady state

As Fig. 11 shows, steady state can either be on the linear or the nonlinear branch of the dynamical system $\Phi(\cdot)$. In the former case, $\bar{\phi} = \phi^F > \tilde{\phi}$ and steady state is the only equilibrium (any other path for ϕ_t is unbounded). In the latter case, $\phi^F < \bar{\phi} < \tilde{\phi}$, and we potentially have cyclic, chaotic or stochastic equilibria where ϕ_t oscillates around $\bar{\phi}$, which as usual happens when $F'\left(\bar{\phi}\right) < -1$. So the economy may have asset prices above their fundamental value and they may exhibit excess volatility but only if $\hat{a}_2 = 1$ in steady state, which requires $\delta < \tilde{\delta}$, and hence requires ρ not too big.

Now introduce banks that accept assets as demand deposits and issue notes as receipts. Let a_3 denote assets on deposit, which are safer than a_2, to capture the idea that having one's debit card of checkbook stolen or lost is less of a problem than having the same thing happen to other assets. Of course, one can imagine that with some probability banks abscond with the deposits, or otherwise fail, making them less than completely safe, but it is reasonable to assume they are relatively safe. Also, deposits may pay a return lower than ρ, because banks may have operating costs, and depositors may be willing to pay for safety. Let ι be the return on bank notes and a_3 the amount of deposits. Then bank profit is

$$\Pi\left(a_3\right) = a_3\left(\rho - \iota\right) - k\left(a_3\right), \tag{39}$$

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

Now $\hat{a}_j > 0\ \forall j$ is possible, because assets have heterogeneous attributes. Indeed, buyers may want $\hat{a}_2 > 0$ and $\hat{a}_3 > 0$ for diversification, but for now it suffices to make bank notes perfectly safe, and set $k\left(a_3\right) = 0$, although we return to a general cost function below. Therefore, for now a_3 strictly dominates a_2, and the economy looks similar to one without banking except we replace δ by 0. In terms of Fig. 11, this shifts up in the nonlinear branch of $\Phi\left(\cdot\right)$. This increases $\tilde{\phi}$ and $\bar{\phi}$, naturally, since agents can now keep assets in a safe place, the bank, and still use them in the DM – which is commonly understood as a (if not the) fundamental role of banking, even if it gets neglected in the theoretical literature.

Having banks, like reducing δ, increases DM output because it increases the size and number of trades. What does it do for volatility? Starting without banks, suppose steady state is on the linear branch of $\Phi\left(\cdot\right)$, so there is a unique equilibrium, $\phi_t = \phi^F\ \forall t$. Then, introducing banks, we can shift the nonlinear branch of $\Phi\left(\cdot\right)$ up by enough that the new steady state is on the nonlinear branch. Thus, the introduction of banking can make possible cyclic, chaotic and stochastic equilibria that were impossible without it. Of course, these are possible without banking, too, but it should be clear that if the economy has a unique equilibrium with banking, the same is true without banking. As an explicit example, consider

Example 7: *Let* $k(a_3) = 0$, $c(q) = q$,

$$u(q) = \frac{A}{1-\sigma}\left[(q+\varepsilon)^{1-\sigma} - \varepsilon^{1-\sigma}\right],$$

and use bargaining with $\theta = 1$. *Also set* $A = 0.15$, $\sigma = 3.1$, $\varepsilon = 0.16$, $\rho = 0.033$, $\beta = 0.8333$, $\delta = 0.85$ *and* $\alpha = 1$.

Without banks there is a unique equilibrium, the steady state $\bar{\phi} = \phi^F = 0.1650$. With banks there is a steady state $\bar{\phi} = 0.3183 > \phi^F$ plus a two-cycle where $\phi_L = 0.3193$ and $\phi_H = 0.3502$. See Fig. 11, where Φ_1 and Φ_0 are the dynamical systems with and without banks.

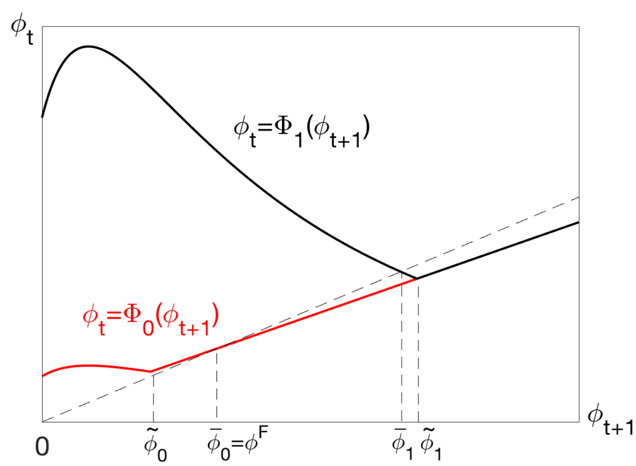

Figure 11: Model of theft, dynamic equilibrium

While this example makes a point, it is worth relaxing $k(a_3) = 0$ to see what else the model can generate. We now show it can generate concurrent circulation of assets and bank liabilities in the DM. So that $\hat{a}_3$ does not strictly dominate $\hat{a}_2$, we return to the cost function $k(a_3)$ and impose the Inada conditions $k'(0) = 0$ and $k'(1) = \infty$. Then banks FOC defines a supply curve that is decreasing in $\rho - \iota$, with $a_3 \to 0$ as $\iota \to \rho$ and $a_3 \to 1$ as $\iota \to 0$. In equilibrium ι depends on a_3, although individual banks take it as given. Equilibrium is characterized by (32)-(33) with

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

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

$$0 = \hat{a}_{3,t} \left\{ \beta \left(\phi_{t+1} + \iota_t \right) \left[1 + \delta \alpha \lambda \left(q'_{t+1} \right) + (1-\delta) \alpha \lambda \left(q_{t+1} \right) \right] - \phi_t \right\} \tag{40}$$

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

Example 8: *Let* $A = 2.5$, $\sigma = 2.5$, $\varepsilon = 0.001$ $\rho = 0.04$, $\beta = 0.8$, $\delta = 0.01$ *and* $\alpha = 1$. *Let* $k\left(a_3\right) = 0.03 a_3$.

There is a unique steady state in which $\bar{\phi} = 1.3125$, $\hat{a} = (0,0,1)$ and $\iota = 0.01$. There is also a two-cycle with $\phi_L = 1.2128$, $\hat{a}_L = (0,0,1)$, $\phi_H = 1.4760$ and $\hat{a}_H = (0.0384, 0.2293, 0.7323)$. In the L state, the price ϕ is low, all assets are deposited in banks, and only their liabilities are used in the DM; then in the H state, ϕ is high, assets are kept in all three forms, with both a_2 and a_3 used in the DM. Note that the value of deposits $\left(\phi_t + \iota_t\right) a_{3,t}$ is smaller in both L and H than in the steady state. Fig. 12 shows the price ϕ, deposits a_3, their value $(\phi + \iota) a_3$, and welfare $u(q) - c(q)$.

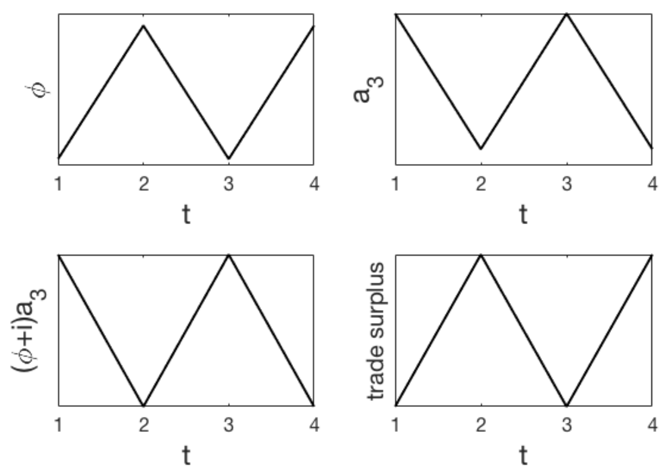

Figure 12: Model of theft, time series for a two-period cycle

We now switch from safety to secrecy, which is actually a similar idea. While secrecy has been discussed in literature, as mentioned above, our approach is somewhat different. Namely, as in Hu and Rocheteau (2015) or Lagos and Zhang (2019), e.g., we assume Lucas trees die – i.e., they disappear – with probability δ at the beginning of each CM.[22] To maintain stationarity, dead trees are replaced by new ones, distributed across agents as lump sum transfers from nature. Also, this is an aggregate shock (all or no assets survive each period) that cannot be diversified away. Moreover, assume information about the shock in the next CM is revealed in the current DM, before agents trade, which is a hindrance to having assets serve as a media of exchange. While this setup is extreme, in the sense that the asset value drops to 0 after a shock, this is merely to ease the presentation; in principle, all we need is that it drops.

Similar to the model with theft, the CM problem is

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

where T describes any transfer. Here the asset is the only DM means of payment, and it is only usable when it is revealed that it will survive in the next CM. Hence,

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

where, exactly as in the model with theft, $v\left(q_{t+1}\right) = \left(\phi_{t+1} + \rho\right)\hat{a}_t$ if $\left(\phi_{t+1} + \rho\right)\hat{a}_t < v\left(q^*\right)$ and $v\left(q_{t+1}\right) = v\left(q^*\right)$ otherwise.

Normalizing the asset supply to 1, we derive dynamical system $\phi_t = \Phi_0\left(\phi_{t+1}\right)$, where again the subscript 0 indicates there are no banks yet, and

$$\Phi_0\left(\phi\right) = \beta\left(1-\delta\right)\left(\phi + \rho\right)\left[1 + \alpha\lambda \circ v^{-1}\left(\phi + \rho\right)\right]. \tag{41}$$

Now consider banks that, as above, take assets as demand deposits and issue notes as receipts. These deposits however are not insured – they are claims to the asset, and if the asset disappears the claim is not worth anything. The role of banking here is not to provide insurance, which is not necessary (i.e., there is no demand for it) given that W is linear in wealth. In fact, this is not a model of safety, but of secrecy: while an agent holding an asset can see if it will die in

[22] For an individual, having one's asset disappear is similar to having it stolen, which is why we group these two models together. Moreover, they share the alternating CM-DM structure, the use of a generic trading mechanism $v\left(q\right)$, and other components.

the next CM, once he exchanges it for a note he cannot see this, and although the banker holding the asset can see it he may not inform the depositor. This is the idea in the literature, discussed above, of some assets being more informationally insensitive than others and the role of banks as secret keepers. Agents prefer to use bank notes as DM payment instruments, rather than the original assets, because the notes trade at the assets' expected value rather than its realized value, since that cannot be inferred from the note. In this way, bank provides a steadier source of liquidity.

With banks, the DM value is

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

where $v\left(q_{t+1}\right) = (1-\delta)\left(\phi_{t+1}+\rho\right)\hat{a}_t$ if $(1-\delta)\left(\phi_{t+1}+\rho\right)\hat{a}_t < v\left(q^*\right)$ and $v\left(q_{t+1}\right) = v\left(q^*\right)$ otherwise.[23] This leads to $\phi_t = \Phi_1\left(\phi_{t+1}\right)$, where

$$\Phi_1\left(\phi\right) = \beta\left(1-\delta\right)\left(\phi+\rho\right)\left\{1+\alpha\lambda\circ v^{-1}\left[\left(1-\delta\right)\left(\phi+\rho\right)\right]\right\}. \tag{42}$$

As the liquidity premium is decreasing, it it easy to see that Φ_1 lies above Φ_0 on the nonlinear branch, and Φ_1 reaches a higher steady state. It is also can be shown that the liquidity provided by bank notes in steady state is lower than that provided by the asset when the asset does not die, but of course is higher when it dies. On net, banking can improve welfare, but it can also engender instability. This is shown in Fig.13 for the following parameterization:

Example 9 *Same as Example 7 except* $A = 0.5$, $\sigma = 3.5$, $\varepsilon = 0.15$, $\rho = 0.5$, $\beta = 0.9$ *and* $\delta = 0.5$.

Without banking, the unique equilibrium is the steady state, where $\phi = 0.4091$ and $q = q^* = 0.6703$ if asset survives, while $q = 0$ if it does not. With banking, there is a steady state where $\phi = 0.7187$ and $q = 0.6093$ and welfare is higher,

[23] Notice that V can be written as $V_{t+1}\left(\hat{a}_t\right) = \alpha\left[u\left(q_{t+1}\right) - v\left(q_{t+1}\right)\right] + W_{t+1}\left[\left(1-\delta\right)\hat{a}_t\right]$. It looks as if banks can perfectly diversify asset portfolio to ensure $1-\delta$ fraction of the investment will survive. But this is not what they actually do – they just keep the realization of asset unrevealed and force the agents to use the expected value of the asset in the DM transaction. In the CM, agents still encounter an aggregate shock but the linearity of W implies that their expected utility is the utility of the expected value.

but there is also a two-cycle where $\phi_L = 0.6081$ and $\phi_H = 0.8514$. The time series (not shown) in this case is simple, since all variables move with ϕ. Thus, banking eliminates fundamental cycles induced by information about realized asset values, but introduces volatility as a self-fulfilling prophecy.

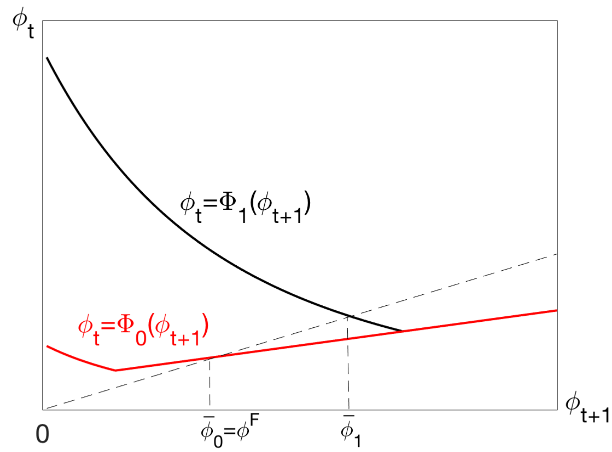

Figure 13: Model of secrecy, dynamic equilibrium

To summarize the results in the models of theft and secrecy, we have

Proposition 5 *When the steady state $\bar{\phi} = \phi^F$ is the unique equilibrium without banking, introducing banks can improve welfare, but may introduce nonstationary equilibria. When the steady state $\bar{\phi} = \phi^F$ is the unique equilibrium with banking, a steady state is the unique equilibrium without banking.*

Notice that in the model of theft, $\phi^F = \beta\rho/(1-\beta)$, whereas in the model of secrecy, $\phi^F = \beta(1-\delta)\rho/[1-\beta(1-\delta)]$ as the expected value of dividend is $(1-\delta)\rho$. The first part of Proposition 5 says banks may engender volatility. The second part says they cannot eliminate volatility, since if there is a unique equilibrium with $\phi_t = \phi^F$ $\forall t$ with banking, there is also a unique equilibrium with $\phi_t = \phi^F$ $\forall t$ without it.

The models of safety and secrecy deliver similar results and can be understood by similar economic intuition. First, in the presence of liquidity considerations, the asset-pricing (Euler) equations $\phi_t = \Phi\left(\phi_{t+1}\right)$ have two terms: one reflects the store-of-value component making price today monotone increasing in the price tomorrow; the other reflects the medium-of-exchange component making price today generally nonmonotone in the price tomorrow. As is well understood in monetary theory, if the second term is decreasing fast enough to dominate the first term, $\Phi'\left(\bar{\phi}\right) < 0$ and even $\Phi'\left(\bar{\phi}\right) < -1$ can arise, where the latter is a standard condition for the existence of cyclic and sunspot equilibria. In the theft model, without banks we have $\Phi_0(\phi)$ and with banks we have $\Phi_1(\phi) = \Phi_0(\phi)/(1-\delta)$ on the nonlinear branch. Hence, it is natural to have $\Phi_0'(\phi) > -1$ and $\Phi_1'(\phi) < -1$ at any given ϕ. In addition, the steady state moves from $\bar{\phi}_0$ without banking to $\bar{\phi}_1$ with banking, which can also make $\Phi_1'(\phi) < -1$ more likely.

In the first model, banks make the asset better as a store of value and as a medium of exchange by protecting from theft. In the second model banks do not make the asset better as a store of value, because there is no way to avoid the loss if the tree dies; banks do however, make it a better a medium of exchange, because it trades at its expected rather than its realized value. Hence, in the second model, based on secrecy, agents put relatively more weight on the nonmonotone medium-of-exchange component, making it more likely to get $\Phi_1'(\phi) < -1$. Heuristically, although the details are slightly different in the two models, again banking therefore makes it more likely that cycles and sunspots emerge.

Conclusion

This paper explored the idea that financial intermediaries are inherently unstable or fragile. The approach involved building formal models of these institutions, and then asking if they make it more likely that there will be multiple equilibria and/or excess volatility. We showed they do, in several different theoretical frameworks designed to capture the many and varied features of financial intermediation. Two models involved reputation, or trust, as seems natural in a theory of banking, but they differed in the fundamental reason for its emergence: one concerned insurance; the other featured fixed costs of investing. Another model was built to capture not banks but middlemen in OTC asset markets. Yet another concerned the use of bank liabilities as payment instruments. The analysis used tools from mechanism design, contract theory, search and bargaining, and monetary economics, and while many of the ingredients have been previously deployed, the ways in which we combine them are novel and generate new insights.[24]

Although the models differ economically and mathematically they have similar if not identical implications for multiplicity and volatility. This lends credence to the notion that financial intermediation engenders instability, as it appears to transcend technical modeling details. However, we again emphasize this does not make it a bad idea, since financial intermediation may well improve welfare.[25] We used examples a lot because the claim is only that financial intermediation *may* lead to instability, not that it *must*; future work may ask what happens at realistically calibrated parameters. To reiterate our other claim, it is not that we think actual data are best explained by cycles or sunspots, but that when rudimentary models have equilibria where liquidity, prices, quantities and welfare vary as self-fulfilling prophecies, it seems more likely to be possible in the real world.

One can naturally ask what the four types of models presented above have in common and why they are all in one paper. What they have in common is this: Building models of, and not just with, financial intermediation requires environments with explicit frictions, including limited commitment, spatial or temporal separation,

[24] As an example, Models 1 and 2 took textbook models of banks, as insurance providers and delegated investors, and embed them in infinite horizons with reputational considerations, which may be useful in other applications. As another, Model 4 showed how to get concurrent circulation of simple assets and bank liabilities as payment instruments in a popular model of monetary exchange. As yet another, Model 3 generalized previous search-based theories of middlemen, e.g., by giving end users heterogeneous investment projects.

[25] Rajan (2005) argues that volatility (which is bad) has emerged from financial innovation. We do not dispute this – it is very much consistent with our the findings – but tend to agree with Summers' comment on the argument: Financial innovations are like improvements in transportation technologies, which have an overwhelmingly positive impact on welfare, even if they may increase the possibility of, say, airline crashes. There is no serious suggestion afoot to ground planes as a way to prevent these accidents, although it would surely work. What we take away from this is that financial markets, like the airline industry, may need some regulation, but Draconian intervention can be counterproductive. Having said all that, given that there is already a lot in the current paper, analyzis of policy options must be delegated to future research. Indeed, Lacker (2015) argues that regulation has contributed at least in part to the instability of banking.

and imperfect information or communication. This can give rise to an endogenous role for intermediation, like it can for money and other institutions whose purpose is ameliorating said frictions. At the same time, frictions mean that there can be multiple Pareto-ranked equilibria and belief-based dynamics.[26] Our finding is that the same frictions that actuate endogenous intermediation actuate multiplicity and volatility. The reason to have four classes of models is to argue the conclusion is robust – it applies to all the models, even though their key frictions are different, because they are meant to capture different features of financial intermediation in the real world.

[26] This is related to what Shell (1992) calls the Philadelphia Pholk Theorem: in all models where equilibria are not efficient one can find multiple equilibria or excess volatility, where he was thinking of sunspots, but the reasoning also applies to cycles. It is hard to prove this, in general, because it concerns all models, not particular models, so corroboration consists of demonstrating it works a series of environments where equilibria can be nonoptimal. In fact, it is easy to prove that convex economies where equilibria are optimal cannot have sunspot equilibria: By way of contradiction, suppose there is an equilibrium where the allocation is random. Convexity of opportunities implies the average allocation is feasible, and strict convexity of indifference curves implies it is better. That contradicts equilibria being efficient.

Appendix A: Proofs of Nonobvious Results

Proposition 1: If $\hat{\phi} \leq 0$ then (12) 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 (12) for $\phi = \beta\mu v(bR) / (1-\beta)$ and substitute it into (10) to get $\lambda d = (1 - \beta + \beta\mu) v(bR) / (1-\beta)$. This implies d is increasing in b. But (11) implies d is decreasing in b, so if they have a solution $(\bar{b}, \bar{d})$ it is unique. ■

Proposition 3: First, for uniqueness, note that when $\pi = \bar{\pi}$ the equations for the R-curve and n-curve are defined by

$$\left(\frac{r+\delta}{1-\delta} + \alpha\theta_{ms}\right) R - \rho - \frac{\alpha n_b \theta_{mb} \tau (\bar{\pi} - R) + \alpha (n_b + n_m) \theta_{ms} R}{N} = 0 \quad (43)$$

$$\delta n + n(1-\delta)\frac{\alpha n_b \tau}{N} - (n_m - n)(1-\delta)\alpha\left(1 - \frac{n_b + n_m}{N}\right) = 0 \quad (44)$$

where

$$N = \frac{\alpha n_b \theta_{sb} \bar{\pi} + \alpha (n_m - n) \theta_{sm} R}{\kappa_s}.$$

In the region where $R > \bar{\pi}$, where $\tau = 0$, combine (43) and (44) to eliminate N,

$$\left(r + \delta + \frac{\theta_{ms}\delta n}{n_m - n}\right) R = \rho(1-\delta) \quad (45)$$

This implies

$$\frac{\partial R}{\partial n} = -\frac{\theta_{ms}\delta n_m}{(n_m - n)^2 (r+\delta) + (n_m - n)\theta_{ms}\delta n} < 0.$$

Thus we transform the system (43)-(44) to (45)-(44). As (45) is downward sloping and (44) is upward sloping, there exists at most one steady state with $R > \bar{\pi}$.

In the region where $R < \bar{\pi}$, where $\tau = 1$, combine (43) and (44) to get

$$\left(\frac{r+\delta}{1-\delta} + \alpha\theta_{ms}\right) R = \rho + \frac{n_b\theta_{mb}(\bar{\pi} - R) + (n_b + n_m)\theta_{ms} R}{(1-\delta) n_m (n_b + n_m - n)} \left[(n_m - n)(1-\delta)\alpha - n\delta\right].$$

This implies

$$\frac{\partial R}{\partial n} = -\frac{n_b\theta_{mb}(\bar{\pi} - R) + (n_b + n_m)\theta_{ms} R}{r + \delta + (\theta_{ms} + n_b\theta_{mb})(1-\delta)\alpha/N} \frac{\delta(n_b + n_m) + (1-\delta)\alpha n_b}{n_m (n_b + n_m - n)^2} < 0 \quad (46)$$

Again, since (46) is downward and (44) upward sloping, there is at most one steady state with $R < \pi$. Similarly, when $R = \bar{\pi}$ and $\tau \in (0,1)$, the n-curve is flat and R-curve is upward sloping. Hence, there again is at most one steady state.

For existence, first, it is easily verified that the R- and n-curve are upward sloping. At $n = 0$ the R-curve implies $R > 0$ and the n-curve implies $n > 0$. At $R = \infty$ the R-curve implies $n = n_m$ and the n-curve implies $n = \bar{n} \equiv \alpha n_m (1-\delta) / [\delta + (1-\delta)\alpha] < n_m$. Hence the curves cross at least once, and generically an odd number of times. Since we already established that there cannot be multiple steady states in the same regime , if there is a steady state at $R = \bar{\pi}$, there must exist two other steady states, one with $R < \bar{\pi}$ and one with $R > \bar{\pi}$. Routine calculation implies $\partial R / \partial \rho > 0$, and so there exist $\tilde{\rho}, \hat{\rho} \geq 0$ with the properties specified in Proposition 3. ■

Appendix B: Sunspot Equilibria

If a dynamical system allows for a two-state stationary sunspot equilibrium, is solves

$$\phi_{s,t-1} = \rho_s f\left(\phi_{s,t}\right) + (1-\rho_s) f\left(\phi_{-s,t}\right) \tag{47}$$

where $s = A, B$ denotes two states in the sunspot equilibrium, $\rho_s \in (0,1)$ is the probability of staying in the same state, and f is the function of the dynamical system in the deterministic case (i.e., (12) in Model 1 and (19) in Model 2). We seek a pair of probabilities $(\rho_A, \rho_B) \in (0,1)^2$ satisfying (47). Rewrite (47) as

$$\rho_A = \frac{f(\phi_B) - \phi_A}{f(\phi_B) - f(\phi_A)} \text{ and } \rho_B = \frac{\phi_B - f(\phi_A)}{f(\phi_B) - f(\phi_A)}$$

Consider wlog $\phi_B > \phi_A$. If f is decreasing on (ϕ_A, ϕ_B), the denominator is negative. The necessary and sufficient condition for $\rho_A, \rho_B \in (0,1)$ is $f(\phi_A) > \phi_B > \phi_A > f(\phi_B)$, which implies that f crosses the 45 degree line from above and $[f(\phi_A) - f(\phi_B)] / (\phi_A - \phi_B) < -1$. Therefore, in Model 1 where f is decreasing around the 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. The necessary and sufficient condition for $\rho_A, \rho_B \in (0,1)$ is $f(\phi_B) > \phi_B > \phi_A > f(\phi_A)$, which implies f crosses the 45 degree line from below on $[\phi_A, \phi_B]$. Therefore, in Model 2 where f is increasing, there exist sunspot equilibria around the stable steady state ϕ_1, and any $\phi_A \in (0, \phi_1)$ and $\phi_B \in (\phi_1, \phi_2)$ satisfy the condition and constitute a two-state stationary sunspot equilibria.

Appendix C: Bargaining in Model 2

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

$$W(\phi) = \max_{X,x,D,d} [U(X) - C(D)]^{\theta} [u(x) - c(d)]^{1-\theta} \tag{48}$$

$$\text{st } X + x = R(D + d) - \kappa \tag{49}$$

$$u(x) - c(d) \geq 0 \tag{50}$$

$$x_t \leq \phi_t. \tag{51}$$

As usual the last constraint 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 (51) binds, and there is a cutoff $\tilde{\phi}$ above which banking is viable and below which it is not.

Denote the solution ignoring (50) and (51) by (X^*, x^*, D^*, d^*). Further, consider the case $u(x^*) > c(d^*)$ and let $\phi^* = x^*$. Substituting (49) into the objective function and taking FOC's, we get

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

where η_1 and η_2 are multipliers. From this one can see the banker's surplus may not increase 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

$$\phi_{t-1} = \frac{\beta\mu}{\lambda}[U(X_t) - C(D_t)] + \beta\phi_t. \tag{52}$$

Now (52) can be written as

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

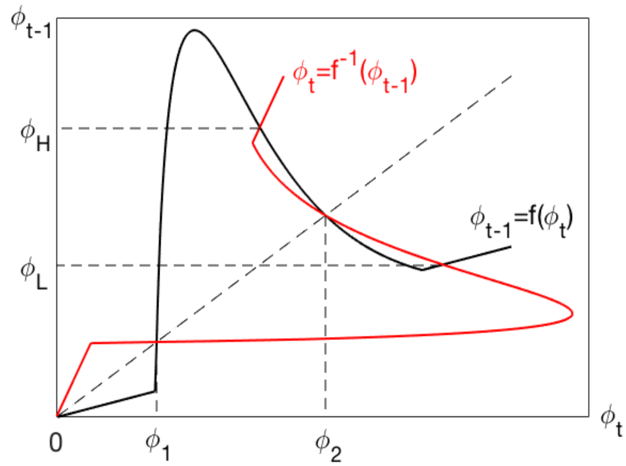

Figure AC: Delegated monitoring – Nash bargaining

Fig. AC shows the dynamical system for the following parameterization:

Example AC: *Let* $U(x) = u(x) = Ax$ *and* $C(d) = c(d) = Bd^{\gamma}/\gamma$*, where* $A = 1$*,* $B = 0.5$*,* $\gamma = 5, R = 2$*,* $k = 1.5$*,* $\theta = 0.01$*,* $\lambda = 0.01$*,* $\mu = 1$ *and* $\beta = 0.35$*.*

There are three steady states, $\phi = 0$ and $\phi_2 > \phi_1 > 0$, with f crossing the 45^o line first 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 Model 2, and since $f'(\phi_2) < -1$ so 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 Model 1.

Appendix D: Entry by Type M in Model 3

Here we consider entry by M with n_b and n_s fixed. The equations (23)-(27) are the same with entry by M, except now n_s is fixed while $n_{m,t}$ is endogenous. What changes is the participation condition: $V_{s,t} = \kappa_s$ is replaced by $V_{0,t} = \kappa_m$, assuming M acquires inventory after entry. Given this, (24) yields a simple expression for N_t in terms of R_t,

$$N_t = \frac{\alpha n_s \theta_{ms} R_t}{(1-\beta)\,\kappa_m}. \tag{53}$$

From (53), N_t depends only on R_t, while in other version, with entry by S, it depends on R_t and n_t. Substituting (53) into (26), after some algebra we get $R_{t-1} = G(R_t)$, where

$$G(R) \equiv \beta(1-\delta)\left\{\rho + R + \frac{(1-\beta)\kappa_m n_b \theta_{mb}}{n_s \theta_{ms} R}\int_R^\infty [1-F(\pi)]\,d\pi - (1-\beta)\kappa_m\right\}. \tag{54}$$

From (54), R_{t-1} depends only on R_t, while in other version, it depends on R_t and n_t.

These considerations make entry by M easier, since it delivers the univariate system $R_{t-1} = G(R_t)$, which determine the path for R_t , after which N_t follows from (53), n_t from (27), etc. If fact, given a fixed point $R = G(R)$, we have

$$\begin{aligned}
N &= \alpha n_s \theta_{ms} R_t / (1-\beta)\kappa_m \\
n_m &= \frac{\alpha n_s \theta_{ms} R_t}{(1-\beta)\kappa_m} - n_s - n_b \\
n &= \frac{n_s(1-\delta)\left[\alpha n_s \theta_{ms} R - (n_b + n_s)(1-\beta)\kappa_m\right]}{\delta n_s \theta_{ms} R + (1-\delta)\left[n_b \tau(R) + n_s\right](1-\beta)\kappa_m}
\end{aligned}$$

To guarantee the fixed point is a steady state we must check $n_m, n \geq 0$, both of hold iff $R \geq \underline{R} \equiv (n_s + n_b)(1-\beta)\kappa_m / \alpha n_s \theta_{ms}$ (we also need $n \leq n_m$ but that never binds). Hence, a solution to $R = G(R) \geq \underline{R}$ is a steady state with type M active; if there is we no such R, the only steady state has no intermediation.

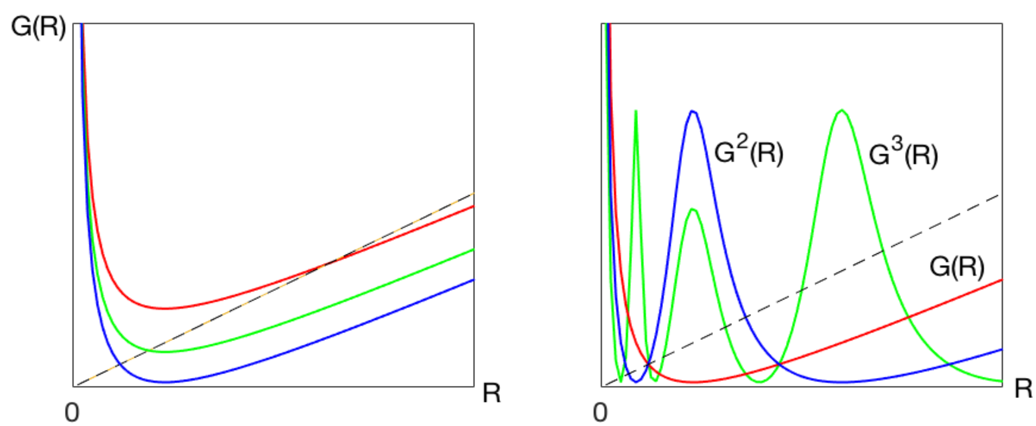

Figure AD: Model 3, cycles with entry by M

One can check $G(0) = \infty$, $G'(R) < 1$ and $G''(R) \geq 0$. Also, G is linear with slope $\beta(1-\delta)\,\forall R > \max(\pi)$. This is shown in the left panel of Fig. AD, from which it is clear that there exists a unique fixed point, say $\hat{R}$. For what it's worth, we can borrow with minor modification the intuition from Rocheteau and Wright (2005) for uniqueness in this version, vis a vis multiplicity in the baseline Model 3 with entry by S: with entry by S there are strategic complementarities, because M choosing to trade more with B encourages entry by S, and vice versa; that is absent with entry by M, because the agents choosing whether to trade are the same ones choosing to enter. In any case, we can have $\hat{R} > \max(\pi)$ on the linear increasing part of $G(R)$ or $\hat{R} < \max(\pi)$, on the nonlinear part of $G(R)$. If $G'(\hat{R}) < -1$ then $\hat{R}$ is locally stable, and there exist cycles and sunspots, as in Model 1. Is $G'(\hat{R}) < -1$ possible? Yes, in fact, there is a threshold, say ρ_1, such that $G'(\hat{R}) < -1$ iff $\rho < \rho_1$. We do not know if $\rho_1 > 0$ or $\rho_1 < 0$, in general, but all our examples gave $\rho_1 < 0$. Still we have to verify $R \geq \underline{R}$ to ensure that M enter the market, as discussed above. It $G'(\hat{R}) < -1$ and $\hat{R} \leq \underline{R}$ possible? Yes, as we now show by way of example.

Example AD: Consider $\alpha = 1$, $\delta = 0.01$, $\beta = 0.99$, $n_b = n_s = 1$, $\theta_{mb} = \theta_{ms} = 0.5$, $\kappa_m = 0.1$, $\rho = -0.1$, and use the $F(\pi)$ in (30), with $\pi_0 = 4.95$, $\pi_1 = 0.05$, $\pi_2 = 5.05$, $\pi_3 = 0.95$ and $\pi_4 = 10$. This is the example used in Fig. AD, where it can be easily checked that $G'(\hat{R}) < -1$ and $\hat{R} < \underline{R}$. Hence this example admits a two-cycle. Note that $\rho < 0$ in this example. If we lower ρ a little more, we can get higher-order cycles, including three-cycles, and hence chaotic dynamics. This is shown in the right panel of Fig. AD, where we plot $G^3(R)$ and see that there exist fixed points other than $\hat{R}$, namely a pair of three cycles. In our examples the dynamics do not involve regime switching: over the cycle, M and B always trade. The dynamics over a two cycle are similar to Fig. 9, from the model with entry by type S, so we do not repeat that discussion. However, here we can explicitly construct higher order cycles, and an example is shown in Fig. AD. Finally, one more result is that $\rho < 0$ implies M and B must trade for some π, $\Pr(R < \pi) > 0$, if M is in the market – just like in the other version, a buy-and-hold-forever strategy is never a good idea at $\rho < 0$.

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