Information Acquisition, Coordination, and Fundamentals in a Financial Crisis *

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Abstract

This paper reconciles the two explanations of a financial crisis, the self-fulfilling prophecy and the fundamental causes, in an empirically-relevant framework, by explicitly modeling the costly voluntary acquisition of information about fundamentals in a variant of Diamond and Dybvig (1983). The model exhibits strategic complementarity in information acquisition. In the "partial run" equilibrium investors engage in costly evaluation of projects, so that banks with lower-return projects fail. There also exist the classic "full-run" and "no-run" equilibria in which there is no project evaluation. Investors' coordination on a specific equilibrium is triggered by a self-fulfilling prophecy. So, financial crises are seen as both fundamentals-based and self-fulfilling prophecies-based phenomena.

Keywords: financial crisis, banks, self-fulfilling prophecy

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1 Introduction

Theoretical analysis of recent financial crises in Mexico in 1994, South-East Asia in 1997, Russia in 1998, Argentina in 2001-2002 emphasizes the international illiquidity of the domestic financial system. Chang and Velasco (2000, 2001) extend the Diamond and Dybvig (1983) closed-economy bank run model to an open economy setting and show how a sudden capital outflow brings about costly liquidation of investment projects rendering the domestic banks insolvent. Chang and Velasco's approach focuses on self-fulfilling prophecies as the main cause of financial crises. However, empirical studies of financial crises emphasize that normally banks or currencies with certain "fundamental" problems are the ones that suffer from a sudden loss of confidence by investors, and that financial crises are often preceded by shocks to fundamentals.

Our paper reconciles these two explanations of a financial crisis—the self-fulfilling prophecy and the fundamentals-based crises—in an empirically-relevant framework, by explicitly modeling the costly voluntary acquisition of information about fundamentals. Our framework is a variant of Diamond and Dybvig's model with an open-economy interpretation. While Diamond and Dybvig consider one bank in a closed-economy setting, we consider a continuum of countries, each with one bank. Our model allows for two types of banks: "good" banks with a high rate of return to illiquid assets (projects), and "bad" banks with a low return. We find conditions under which three different equilibria are possible: the "verification" equilibrium in which all global investors verify types of banks, and withdraw funds from the bad ones, leaving them insolvent, the no-run equilibrium in which all banks remain solvent, and the full-run equilibrium, in which investors withdraw funds from all the banks.[1] On the one hand, in the verification equilibrium only bad banks go bust, so the run on them has a fundamental cause. On the other hand, a switch from the no-run to the verification equilibrium can be triggered by a self-fulfilling prophecy. Therefore the financial crisis is inherently *fundamentals-based and panic-based* at the same time.

Our model exhibits strategic complementarity in information acquisition. The intuition behind this complementarity is that the value of information increases in the share of agents who acquire the information about fundamentals. In particular, the value of information exceeds its cost when all agents acquire the information, but not when other agents refrain from information acquisition.

A stylized fact that supports our model is the alternation of periods of lending booms and

[1] The last two equilibria are similar to the two equilibria of Diamond and Dybvig's model.

busts, with dramatically different approaches towards risk. During lending booms, investors' enthusiasm for particular segments of the domestic or the world economy, or for particular financial instruments, brings about a narrowing of spreads and lack of concern for credit quality, as funds flow indiscriminately to all borrowers in these segments. The busts are accompanied by the "flight to quality," and a widening of spreads, which are devastating to borrowers with particularly weak fundamentals.[2]

Our model is close in spirit to Hellwig and Veldkamp (2005) who also link strategic complementarities in information acquisition with actions. If an agent wants to do what others do, then he wants to know what others know. Hellwig and Veldkamp (2005) show that the complementarity in information acquisition creates the room for multiplicity of equilibria. For a range of information costs, there are two equilibria, one where no one buys the information, and one where everyone does. They discuss their idea in the context of several applications (an investment model with externalities, a 'beauty contest' game, and the costly planning problem (Reis, 2005)), but not financial crises.

Our approach is complementary to the recent 'global games' literature that eliminates the multiplicity of equilibria in a Diamond-Dybvig style coordination game in a way that preserves the panic-based nature of the bank runs, but also relates the probability of the run to fundamentals. Morris and Shin (2000) and Goldstein and Pauzner (2005) develop models in which agents receive a slightly noisy signal about fundamentals (the return to illiquid asset). This information heterogeneity allows the modelers to pin down the range of values of fundamentals in which a bank run takes place, calculate the unconditional probability of a run, and show that improvement in fundamentals reduces the likelihood of a run. At the same time, a run is panic-based, because agents demand early withdrawal from a bank just because they fear others would. Other important contributions to the 'global games' literature include Morris and Shin (1998) and Heinemann and Illing (2002) who reconciled the self-fulfilling prophecies and fundamentals approaches to currency crises, Morris and Shin (2004) who studied self-fulfilling debt crises, and Rochet and Vives (2004), who analyzed the role of the lender of last resort in a model of bank runs. However, further contributions to the literature suggested that information heterogeneity is not a panacea to achieve uniqueness of equilibrium. Angeletos and Werning (2005) introduce a financial market in a stylized

[2]Schadler et al.(1993) document periods of overlending and capital outflow in emerging markets. The Economist(1998) describes how changes in investors' sentiments made risk "a four-letter word" in the aftermath of the Russian default in September 1998.

'global' coordination game with imperfect private information so that the asset price acts as a public signal aggregating dispersed private information. They show that equilibrium multiplicity is still ensured with small noise. Angeletos, Hellwig and Pavan (2003) add endogenous defensive central bank policies to the model of speculative currency attack of Morris and Shin (1998) and show that self-fulfilling market expectations still determine the equilibrium: "In her attempt to fashion the equilibrium outcome, the policy maker reveals information that market participants can use to coordinate on multiple courses of action."

The limitation of the 'global games' approach is that it preserves the assumption that all information received by agents is exogenous (in a sense that an agent cannot choose what information to receive) and free. However, in real-world settings the information acquired by investors is potentially available to other investors and is costly.[3]

The remainder of the paper is structured as follows. Part 2 is a presentation of the basic setup of the model. Part 3 comprises the derivation of the model solution. Part 4 presents a modification of the basic model in which strategic complementarity in information acquisition gives rise to more than one equilibrium with verification. Part 5 concludes the analysis.

2 Model Setup

Consider a world economy populated by a continuum of agents (global investors) of measure one. All agents live for three periods: 0, 1, and 2. Each agent is endowed with one unit of divisible good in period 0. However, he derives his utility from consumption in periods 1 or 2 (depending on his type). In order to transfer wealth across time, he has two options. The first option is storage. The storage is liquid and risk-free, and its gross rate of return is one in both periods.[4]

Alternatively, the agent can use illiquid productive technologies (illiquid projects), which have a high expected return if left for two periods, but a low return if interrupted after one period. There is a continuum of country-specific illiquid projects, also of measure one (this is a departure from the original Diamond-Dybvig setup). The projects are risky: α projects yield the gross return

[3] Even if the data is available free of charge (for example, released by government statistics offices), investors need time (and other resources, e.g. computers) to process it. Furthermore, most of the economic and financial research is conducted by the private sector and is available for a fee.

[4] A possible interpretation of storage in the open-economy context is the investment in government securities of the OECD countries.

$R > 1$, and $(1-\alpha)$ projects yield $q < 1$. There is no aggregate uncertainty about the productivity: α is non-stochastic. If interrupted during period 1, the illiquid technology yields only $r < 1$. We assume also that $\alpha R + (1-\alpha)q > 1$, so illiquid projects have a higher expected return than the return on storage.

Productivity shocks are realized in period 1. In that period an agent can learn which country projects are highly productive, and which are not, at a cost $\epsilon > 0$ per unit of investment.

Similarly to the original Diamond-Dybvig setup, agents face a preference risk. With probability λ, their utility function is $u(C_1) = \frac{C_1^{1-\sigma}-1}{1-\sigma}$, i.e. they derive utility from consumption in period 1 only. Henceforth we will refer to them as impatient agents. With probability $(1-\lambda)$, their utility function is $u(C_2) = \frac{C_2^{1-\sigma}-1}{1-\sigma}$. We will refer to them as patient agents. We assume that σ, the coefficient of relative risk aversion, is greater than or equal to 1.[5] The preference shock is realized during the first period, i.e. after agents have made their investment decisions. Moreover, the shock is not publicly observable.

3 Model Solution

3.1 Social Optimum

The problem of the (world) social planner is to maximize the expected welfare of a representative agent.

We will focus on the range of parameter values under which the social planner should never interrupt illiquid technology investment in period 1, i.e. even inefficient projects should be completed and resources on verification should not be spent. (The restriction on parameter values that ensures this will be derived at the end of this subsection.) The social planner should use storage to provide for consumption of impatient agents.[6] This approach is consistent with the literature.

The planner maximizes:

$$EU = \lambda u(X) + (1-\lambda)u(Y), \tag{1}$$

subject to

$$\lambda X \leq b \tag{2}$$

[5]Virtually all empirical estimates of σ lie between 1 and 10 (Auerbach and Kotlikoff, 1987, p.50.)

[6]It is inefficient to interrupt an illiquid technology, because the return on storage is greater than the return on the interrupted illiquid technology, $r < 1$.

$$(1-\lambda)Y = \tilde{R}k + (b - \lambda X) \tag{3}$$

$$k + b = 1 \tag{4}$$

$$X \leq Y, \tag{5}$$

where b is the amount invested in storage, k is the amount invested in illiquid technology, X is the consumption of impatient agents, Y is the consumption of patient agents, and $\tilde{R} = \alpha R + (1-\alpha)q$ is the average return on illiquid projects. Maximization is with respect to X, Y, k and b.

The objective function (1) is the expected utility of an agent. Inequality (2) is the first-period resource constraint. It states that the consumption of impatient agents comes from storage, b. Equation (3) is the second-period resource constraint. It shows that the consumption of the patient agents comes from the illiquid technology, k, and the storage of the good that is available but not consumed in period 1, $(b - \lambda X)$. Equation (4) is the budget constraint of period 0. It demonstrates that the social planner must either store or invest all the endowment. Finally, inequality (5) is the incentive-compatibility constraint. The patient agent should not have the incentive to mimic the behavior of the impatient agents and attempt to acquire the consumption good in period 1.

Proposition 1: The problem (1)-(5) has the following solution:

$$b^* = \frac{\lambda \tilde{R}^{(\sigma-1)/\sigma}}{1 - \lambda + \lambda \tilde{R}^{(\sigma-1)/\sigma}} \tag{6}$$

$$k^* = 1 - b^* = \frac{1-\lambda}{1 - \lambda + \lambda \tilde{R}^{(\sigma-1)/\sigma}} \tag{7}$$

$$X^* = \frac{b^*}{\lambda} = \frac{\tilde{R}^{(\sigma-1)/\sigma}}{1 - \lambda + \lambda \tilde{R}^{(\sigma-1)/\sigma}} \tag{8}$$

$$Y^* = \frac{\tilde{R}(1-b^*)}{1-\lambda} = \frac{\tilde{R}}{1 - \lambda + \lambda \tilde{R}^{(\sigma-1)/\sigma}}, \tag{9}$$

where the asterisk denotes the socially optimal values of the variables.

The proof is straightforward and is omitted for brevity.

Proposition 1 says that the social planner should invest in storage just enough to satisfy the impatient agents and not store anything between periods 1 and 2. Over two periods the average return on the illiquid technology dominates the return on storage.

In the particular case of $\sigma = 1$ (the case of the logarithmic utility function) $b^* = \lambda$, $X^* = 1$, $k^* = 1 - \lambda$, $Y^* = \tilde{R}$. In words, the share of investment in storage should be equal to the share of impatient agents in the economy, and they should get exactly the return on storage. Patient agents earn the average return on the illiquid technology. The social planner does not redistribute investment earnings from the patient to impatient agents, or vice versa.

If $\sigma > 1$, that is, if agents are *more* risk-averse than the agents with logarithmic utility, the social planner should reduce the difference between the earnings of patient and impatient agents. Hence $X^* > 1$, and $Y^* < \tilde{R}$.

We derive the threshold value of the verification cost, ϵ, (the social planner verifies, if and only if $\epsilon < \epsilon^*$) in the following way. We are searching for the value of the verification cost, such that the social planner is indifferent between verifying and not verifying a unit of investment. When the social planner verifies one unit of investment (and interrupts low-return investments), he gets $(1-\alpha)r - \epsilon$ in period 1, and αR in period 2. To have an unchanged amount of consumption good in period 1 (to provide for impatient agents) when he verifies an extra unit of investment, he should reduce storage by $(1-\alpha)r - \epsilon$ and increase unverified investment by the same amount.[7] Indifference is achieved if he gets the same amount of consumption good in period 2 as well. Switching to verification of one unit gives him period-2 returns of $\tilde{R}[(1-\alpha)r - \epsilon] + \alpha R$, but he loses $\tilde{R}$. Therefore, the indifference condition is:

$$\tilde{R}[(1-\alpha)r - \epsilon^*] + \alpha R = \tilde{R} \tag{10}$$

Solving for ϵ yields:

$$\epsilon^* = (1-\alpha)\left[r - \frac{q}{\alpha R + (1-\alpha)q}\right]$$

The right-hand side of the last expression can be positive, or negative. We assume that the verification cost is always non-negative. Therefore, to ensure that verification is never socially optimal, we assume that

$$\epsilon \geq \max\left\{(1-\alpha)\left[r - \frac{q}{\alpha R + (1-\alpha)q}\right], 0\right\} \tag{11}$$

3.2 Decentralized Equilibria and Runs

Decentralization of the socially optimal allocation can be achieved in the same way as in the original Diamond-Dybvig model. Each bank issues demand deposits. These deposits pay $X^* = \frac{b^*}{\lambda}$

[7] A marginal reduction in storage is possible, because the social planner stores a part of the endowment and invests another part.

if withdrawn in the first period, provided that the bank is solvent. In the second period all remaining assets are liquidated and allocated among deposit holders on *pro rata* basis.

Each bank stores the b^* share of the period 0 deposit, and invests the rest in the illiquid technology. The amount of storage should suffice to just satisfy the liquidity needs of impatient agents. If there is no run, i.e., if in period 1 patient agents do not attempt to withdraw, then impatient agents get X^*, and patient agents get Y^*, i.e., the socially optimal allocation is attained.

The demand deposit contract is the optimal arrangement because the type of the agent is his private information. The bank is unable to condition the first-period payout on the type of the agent.

Given that agents are risk-averse, and the bank type may be revealed only in period 1, it is optimal for agents to spread their deposits across the banking system, i.e. to make an equal deposit in every bank.

The decentralized equilibrium is prone to runs. If a sufficient number of patient agents decide to withdraw in period 1, it is indeed optimal for *all* patient agents to withdraw in period 1. The run becomes self-fulfilling, because $X^* > r$, and hence the banks have to destroy illiquid investment to meet the unexpected withdrawal demand. Therefore the return on deposits in period 2 can fall below X^*.[8]

In this setup three different equilibria are feasible: a no-run equilibrium, or an equilibrium in which the socially optimal allocation is achieved, a "verification," or "partial run," equilibrium, and a "full-run" equilibrium. In the full-run equilibrium, agents do not verify the type of banks, but attempt to withdraw their deposits from all of them. Hence all the banks liquidate all their investment and shut down. In the verification equilibrium, all patient agents verify the type of the banks and withdraw from the inefficient ones. Hence the inefficient banks, though not the efficient ones, have to liquidate all their investment and shut down in the first period.

Proposition 2 below describes conditions for existence of equilibria. The proof is relegated to the Appendix.

[8] We acknowledge that the demand-deposit contract presented above decentralizes the socially optimal allocation only if runs never occur. In the case of a run autarky may be welfare superior to the use of a banking system. Goldstein and Pauzner (2005) present a demand-deposit contract that is optimal *given the probability of a run,* i.e. they construct a demand-deposit contract that trades off the benefits from liquidity shocks insurance against the costs of runs. Such a contract cannot be constructed in our model, because the probability of a run (endogenously determined in Goldstein and Pauzner, 2005) is indeterminate here.

Proposition 2: Under conditions (12)-(14) below there exist three Nash equilibria of the coordination game: the no-run equilibrium, the verification equilibrium, and the full-run equilibrium:

$$[b^* + k^* r](1-\alpha) > \epsilon \tag{12}$$

$$\frac{k^*}{1-\lambda}\alpha R - \epsilon > \alpha X^* \tag{13}$$

$$(1-\alpha)\left(X^* - \frac{k^*}{1-\lambda}q\right) < \epsilon \tag{14}$$

where b^*, k^* and X^* are determined by equations (6)-(9).

Remark: Conditions (12)-(14) do not depend on whether the sequential service constraint applies. This is true for two reasons. First, the sequential service constraint does not affect the *expected* return on a bank deposit in case of a run on this bank. The expected return depends only on the amount of resources available at the bank in period 1.[9] Second, given that agents diversify their portfolios and hold their deposits in a continuum of banks, by the law of large numbers, the return on a portfolio is non-stochastic in any of the three equilibria even if the sequential service constraint applies.

Conditions (12)-(13) ensure that if all patient agents play the verification equilibrium, it is not optimal for any agent to deviate. If a patient agent verifies the type of banks and withdraws from inefficient ones, his expected return is $\left[\alpha R\frac{k^*}{1-\lambda} + (1-\alpha)[b^* + k^* r] - \epsilon\right]$. If he neither verifies nor withdraws from any bank in period 1, the inefficient banks go bust and his return is $\left[\alpha R\frac{k^*}{1-\lambda}\right]$ (he earns the return on deposits in efficient banks only). Hence inequality (12) guarantees that the patient agent does not wait until period 2. Inequality (13) ensures that withdrawing from all the banks in period 1 would not benefit a patient agent either. Specifically, withdrawing from all banks in period 1 gives a patient agent $[\alpha X^* + (1-\alpha)[b^* + k^* r]]$ per unit of investment. But if he verifies the type of banks and withdraws from inefficient ones, he gets $\left[\alpha R\frac{k^*}{1-\lambda} + (1-\alpha)[b^* + k^* r] - \epsilon\right]$.[10] Intuitively, it is clear from (12)-(13) that the verification equilibrium exists only if the verification cost, ϵ, is not too large.

[9] The following example clarifies the idea. Assume that the demand deposit rate is X, and the amount of resources (per depositor) available at the bank in period 1 is $m < X$. Then, if the sequential service constraint is present, and all depositors run (which is the only equilibrium outcome, if there is a run), a depositor will get X with probability m/X and 0 with probability $1 - m/X$. Therefore, the expected return is m, the same as if the bank first collects all the withdrawal requests, and then makes an equal payment to every depositor.

[10] There are other possible strategies available to patient agents but all of these are necessarily dominated by the payoff from playing the equilibrium strategy (see the proof of Proposition 2).

Inequality (14) is the sole condition for the no-run Nash equilibrium—patient agents choose not to verify and not to withdraw from any banks. Intuitively, the existence of this equilibrium requires that the verification cost, ϵ, not be too small; otherwise patient agents could improve their situation by verifying and withdrawing from inefficient banks. All other potential strategies are necessarily dominated by the equilibrium strategy.

Finally, the full-run equilibrium always exists in this model. Other potential equilibria, such as verification in tandem with withdrawing from all banks or perhaps just efficient banks, are not possible (see the proof of Proposition 2).

Note that conditions (12)-(14) can be written as a single constraint on the magnitude of the verification cost:

$$\min\left[(1-\alpha)(b^* + k^* r), \alpha\left(\frac{k^* R}{1-\lambda} - X^*\right)\right] > \epsilon > (1-\alpha)\left(X^* - \frac{k^* q}{1-\lambda}\right) \tag{15}$$

If the verification cost is so high that it violates the left inequality then only the two classic equilibria exist: the full-run and no-run equilibria (with no verification in either case). If the verification cost is so low that it violates the right inequality then the only equilibria that exist are the verification equilibrium and the full-run equilibrium. Next we show that for a positive measure of parameter values the joint inequality (15) as well as (11) are satisfied, which means that all three equilibria co-exist for a positive measure of the parameter space.

3.3 Existence of the Three Equilibria

Given the large number of the parameters, we restrict our analysis to the simplest case, when $\sigma = 1$. Below we show that under that restriction, the intersection of (11) and (12)-(14) has positive measure. By continuity, the intersection of (11) and (12)-(14) has a positive measure at least for some values of $\sigma > 1$.

If $\sigma = 1$, (12)-(14) become:

$$[\lambda + (1-\lambda) r](1-\alpha) > \epsilon \tag{16}$$

$$\alpha R - \epsilon > \alpha \tag{17}$$

$$(1-\alpha)(1-q) < \epsilon \tag{18}$$

To ensure that (17) is satisfied it is sufficient to choose sufficiently large values of R. Inequalities (11), (16) and (18) can be rewritten as a single restriction on ϵ:

$$\max\left[1-q, r-\frac{q}{\alpha R+(1-\alpha)q}\right] < \frac{\epsilon}{1-\alpha} < \lambda+(1-\lambda)r \tag{19}$$

The last inequality is satisfied for a positive measure of ϵ, if

$$\max\left[1-q, r-\frac{q}{\alpha R+(1-\alpha)q}\right] < \lambda+(1-\lambda)r \tag{20}$$

It immediately follows from $r<1$, that $r-\frac{q}{\alpha R+(1-\alpha)q} < r < r+\lambda(1-r) = \lambda+(1-\lambda)r$. Hence inequality (20)is satisfied if q is sufficiently large (and $1-q$ is sufficiently small). The above analysis proves the following proposition:

Proposition 3: Suppose $\sigma = 1$. For any value of λ, α and r there exist $R_0 > 1$ and $q_0 < 1$, such that for any $R > R_0$ and for any $q > q_0$, a positive measure of ϵ satisfy (11) and (12)-(14).

Numerical example 1: If $\sigma = 1$, $R = 2, r = q = 0.9, \lambda = \alpha = 0.5$, then conditions (11) and (12)-(14) are satisfied for any $\epsilon \in (0.14, 0.50)$.

3.4 Implications of the Verification Equilibrium.

A first implication of our model is that the partial run, i.e. the verification equilibrium, is fundamentals-based and panic-based at the same time. During a partial run only inefficient banks suffer from the run and shut down in the first period. This does not mean that bad fundamentals of these banks *per se* cause the run. Their fundamentals are as bad as in the no-run equilibrium. However, in the partial run equilibrium it is optimal for the agents to investigate the fundamentals of the banks just because other agents do that.

Second, empirical studies show high correlation between banking crises and recessions/economic slowdowns. This has been sometimes interpreted as the evidence that banking crises are just a natural outgrowth of the business cycle (Gorton, 1988, Allen and Gale, 1998). An alternative view states that the causality goes from the banking crisis to the economic slowdown (Chang and Velasco, 1998). Our model is consistent with this latter view. In the verification equilibrium, the GDP (global income) is:

$$I_v = \alpha[b^*+(1-b^*)R]+(1-\alpha)[b^*+(1-b^*)r]-(1-\lambda)\epsilon = b^*+(1-b^*)(\alpha R+(1-\alpha)r)-(1-\lambda)\epsilon \tag{21}$$

In the no-run equilibrium the global income is:

$$I_{nr} = b^* + (1-b^*)\tilde{R} = b^* + (1-b^*)[\alpha R + (1-\alpha)q] \quad (22)$$

From equations (21) and (22) it follows that the global income is always greater in the no-run equilibrium than in the verification equilibrium.

Therefore the model explains the positive correlation of GDP and bank runs. But the causality goes from the bank run to GDP and not the other way around. The direction of causality is assured, because aggregate uncertainty is ruled out by assumption.

4 An Extension of the Model: The Case of "Good" and "Not-too-bad" Fundamentals.

We now consider a modification of the basic model in which the return on illiquid technology can be either "good," $R > 1$, or "not-too-bad," $q > 1$, but $q < R$. The rest of the assumptions still hold. We will show that now there is a possibility of a fourth equilibrium in which all patient agents verify the type of banks, but withdraw funds from the "good" banks only. In that case we still have a strategic complementarity in information acquisition, i.e., the value of information depends on the number of verifying agents, and so agents verify the type of banks as long as other agents do the same. However, the existence of that counterintuitive equilibrium does not refute the findings of the previous sections. The assumption $q > 1$ implies that even inefficient banks (banks with the lower return on illiquid asset) are good enough, as their return dominates the return on liquid technology (storage). The run on either type of banks arises as a pure coordination failure. In contrast to the model of this section, the assumption $q < 1$ in the basic model implies that fundamentals of the inefficient banks are "bad," as the return on storage is higher than the return on illiquid technology in these banks. Hence "bad" fundamentals in the basic model (but not the "not-too-bad" fundamentals in the model of this section) matter in a well-defined and intuitive way: when a partial run takes place, only "bad" banks are affected.[11]

Let us call the partial run equilibrium in which all patient agents verify the type of banks and withdraw from "not-too-bad" banks only, the type 1 partial run, and the equilibrium in which all

[11]We are grateful to the anonymous referee for pointing out this to us.

patient agents verify banks and withdraw from "good" banks only, the type 2 partial run.

Proposition 4: Under conditions (12)-(14) and (23)-(24) below there exist four Nash equilibria of the coordination game: the no-run equilibrium, the full-run equilibrium, the type 1 partial run equilibrium and the type 2 partial run equilibrium.

$$q > X^* + \frac{\epsilon}{1-\alpha} \tag{23}$$

$$[b^* + k^* r]\alpha > \epsilon \tag{24}$$

where b^*, k^* and X^* are determined by equations (6)-(9).

Conditions (23)-(24) ensure that if all patient agents verify the type of banks and withdraw from "good" ones only, it is not optimal to deviate and engage in indiscriminate withdrawal (condition (23)[12]) or not run at all (condition (24)). It is straightforward to show that condition (24) suffices to ensure that in case of type 2 partial run, it is not optimal to deviate and withdraw from "not-too-bad" banks only. It is also easy to show that withdrawal from "not-too-bad" banks is suboptimal when all other agents play other equilibria, i.e. full run, no-run, or type 1 partial run (see the proof of Proposition 4 in the Appendix for details).

Taking into account that $\left(X^* - \frac{k^* q}{1-\lambda}\right)$ can be smaller than 0, when $q < 1$, the conditions (12)-(14) and (23)-(24) can be written as a single constraint on the magnitude of the verification cost in the following way:

$$\min\left[\min[\alpha, (1-\alpha)](b^* + k^* r), (1-\alpha)(q - X^*), \alpha\left(\frac{k^* R}{1-\lambda} - X^*\right)\right] > \epsilon >$$
$$\max\left[(1-\alpha)\left(X^* - \frac{k^* q}{1-\lambda}\right), 0\right] \tag{25}$$

Numerical example 2: If $\sigma = 1, R = 2, q = 1.5, r = 0.9, \lambda = \alpha = 0.5$, then conditions (12)-(14) and (23)-(24) are satisfied for any $\epsilon \in (0, 0.25)$.

5 Conclusions

The paper presents a coordination game in which there is a strategic complementarity in acquisition of information about fundamentals. Our paper reconciles the two explanations of a financial crisis,

[12] Condition (23) also shows that the type 2 partial run equilibrium is feasible only if $q > 1$, as $X^* \geq 1$.

the self-fulfilling prophecy and the fundamental causes in an empirically-relevant framework, by explicitly modeling the costly voluntary acquisition of information about fundamentals. Agents verify the type of banks and withdraw funds from inefficient ones if and only if other agents do the same. Therefore runs on inefficient banks have a fundamental cause, although they are triggered not by an exogenous shock, but by a self-fulfilling prophecy.

An avenue for further research would be to introduce endogenous information acquisition in a 'global games' environment similar to Morris and Shin (2000) or Goldstein and Pauzner (2004) and check if (and if yes under what conditions) the model will possess multiple equilibria.[13]

[13]We are grateful to Alessandro Pavan who pointed out this possibility to us.

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Appendix

Proof of Proposition 2:

Consider first the equilibrium in which patient agents verify and withdraw from inefficient banks. Conditions (12)-(13) ensure that if all patient agents play the verification equilibrium, it is not optimal for any agent to deviate. In the equilibrium, a patient agent verifies the type of banks and withdraws from inefficient ones; his expected return is $\left[\alpha R\frac{k^*}{1-\lambda}+(1-\alpha)[b^*+k^*r]-\epsilon\right]$. Alternatively, if he does not verify and does not withdraw from any banks then inefficient banks go bust and his return is $\left[\alpha R\frac{k^*}{1-\lambda}\right]$ (he earns the return on deposits in efficient banks only). Hence inequality (12) guarantees that the patient agent does not wait until period 2. Inequality (13) ensures that an indiscriminate withdrawal from all the banks (and no verification) in period 1 would not benefit a patient agent either. In case of an indiscriminate withdrawal, the patient agent gets only $[\alpha X^*+[b^*+k^*r](1-\alpha)]$ per unit of investment. But if he verifies the type of banks and withdraws from inefficient ones, he gets $\left[\alpha R\frac{k^*}{1-\lambda}-\epsilon+[b^*+k^*r](1-\alpha)\right]$. There are three other possible strategies for a patient agent besides playing the equilibrium strategy, all of which involve verification: (i) no withdrawals (ii) withdraw from efficient banks only, and (iii) withdraw from all banks. It is readily verified that the payoffs in all of these are necessarily lower than the payoff of playing the equilibrium strategy.

Consider next the no-run equilibrium (and no verification). First, if a patient agent does not verify and waits until the second period to withdraw he earns $\left[\tilde{R}\frac{k^*}{1-\lambda}\right]$ per unit of investment, but attains only X^* if he withdraws in period 1. The former exceeds the latter for any $\sigma\geq 1$ and $\tilde{R}>1$, both of which are true by assumption. Second, if he verifies the type of banks and withdraws from inefficient ones, his gain, $\left[(1-\alpha)(X^*-\frac{k^*}{1-\lambda}q)\right]$, must be lower than the verification cost, ϵ, for the agent not to want to deviate. This condition is inequality (14). Third, if a patient agent verifies but does not withdraw in period 1 then clearly his payoff is lower than the equilibrium strategy since he pays the verification cost and receives the same return from banks. Finally, the agent could verify and run on all banks or just efficient banks. It is apparent that both of these strategies necessarily produce lower payoffs than the equilibrium strategy.

Consider the full-run equilibrium. The existence of the full-run equilibrium is ensured, because $X^*\geq 1>r$. This condition guarantees that if all patient agents decide to withdraw in the first period, neither efficient nor inefficient banks have enough resources to pay X^* to all the agents wishing to withdraw. Therefore the payout to the patient agents waiting until the period 2 is 0. In comparison, the return to the patient agents joining the full run is $b^*+k^*r>0$. Second, it follows that verifying but not running on the banks is also dominated by the equilibrium strategy. Third, if a patient agent verifies the type of banks during the full run he incurs the verification cost but gains nothing in payoff. Finally, it follows directly that the agent would be worse off by verifying and running on just the efficient or just the inefficient banks.

To complete the proof we show the impossibility of the three other potential equilibria: those in which the patient agents verify the type of banks in period 1, but 1) withdraw from the *efficient* banks only; 2) withdraw from all banks; 3) do not withdraw from either type of banks.

1)When all patient agents verify, but withdraw from efficient banks only, a patient agent will get $\alpha(b^* + k^*r) - \epsilon + (1-\alpha)\frac{k^*q}{1-\lambda}$. If, instead, a patient agent deviates and verifies and runs on all banks he gets $(1-\alpha)X^* + \alpha(b^* + k^*r)$. The latter is greater than the former since $\tilde{R} > 1 > q$. Thus, the conjectured equilibrium cannot be supported.

2)When all patient agents verify, but withdraw from all banks, each of them gets $b^* + k^*r - \epsilon$. The last expression is smaller than $b^* + k^*r$, the payoff an agent gets, if he does not verify, but withdraws indiscriminately while others withdraw indiscriminately as well. Hence there is an incentive to deviate from the equilibrium.

3)When all patient agents verify, but do not withdraw from any bank, each of them gets $\frac{\tilde{R}k^*}{1-\lambda} - \epsilon$. The last expression is smaller than $\frac{\tilde{R}k^*}{1-\lambda}$, the payoff an agent gets, if he deviates by not verifying and not withdrawing. Hence the conjectured equilibrium is not a Nash equilibrium. Q.E.D.

Proof of Proposition 4:

Proposition 4 asserts the existence of the three equilibria of the coordination game of the basic model, plus the fourth one, the type 2 partial run equilibrium. Hence, conditions (12)-(14) that ensure the existence of those three equilibria must hold. Furthermore, we have to show that: 1)If all patient agents play the type 2 partial run equilibrium, no deviation is profitable. 2)If all patient agents play any other equilibrium, a switch to the type 2 partial run equilibrium is not profitable.

1)If all patient agents play type 2 partial run equilibrium, the expected return for each of them equals $\alpha(b^* + k^*r) + (1-\alpha)q - \epsilon$. If a patient agent withdraws indiscriminately, his return equals $\alpha(b^* + k^*r) + (1-\alpha)X^*$. Hence no agent would deviate and withdraw indiscriminately, if and only if:

$$\alpha(b^* + k^*r) + (1-\alpha)q - \epsilon > \alpha(b^* + k^*r) + (1-\alpha)X^*$$

The last inequality simplifies to (23).

If all patient agents play type 2 partial run equilibrium, then the return for an agent who does not withdraw at all equals $\alpha * 0 + (1-\alpha)q$. Hence no agent would deviate to keep all the deposits in banks, if and only if:

$$\alpha(b^* + k^*r) + (1-\alpha)q - \epsilon > (1-\alpha)q$$

The last inequality simplifies to (24).

Finally, if all patient agents play type 2 partial run equilibrium, then the return for an agent who withdraws from "not-too-bad" banks only equals $(1-\alpha)X^* - \epsilon$. Hence no agent would deviate to withdraw from "not-too-bad" banks only, if and only if

$$\alpha(b^* + k^*r) + (1-\alpha)q - \epsilon > (1-\alpha)X^* - \epsilon$$

The last inequality holds whenever (23) holds.

2) If all patient agents do not verify the type of banks and do not withdraw, their expected return equals $\alpha R + (1-\alpha)q$. When an agent deviates, verifies the type of banks and withdraws from "good" banks, his return equals $\alpha X^* + (1-\alpha)q - \epsilon$. It is straightforward to verify that

$$R > \tilde{R} > \frac{\tilde{R}}{1-\lambda+\lambda\tilde{R}} > \frac{\tilde{R}^{\frac{\sigma-1}{\sigma}}}{1-\lambda+\lambda\tilde{R}^{\frac{\sigma-1}{\sigma}}} = X^*$$

Hence,

$$\alpha R + (1-\alpha)q > \alpha X^* + (1-\alpha)q - \epsilon$$

And no patient agent has an incentive to deviate from the no-run to the type 2 partial run equilibrium.

If all patient agents engage in indiscriminate withdrawal (full run equilibrium), their expected return equals $(b^* + k^* r)$. If a patient agent deviates, verifies the type of banks and withdraws from "good" ones, his return equals $\alpha(b^* + k^* r) + (1-\alpha) * 0 - \epsilon$, which is clearly smaller than $(b^* + k^* r)$. Hence no agent has an incentive to deviate from the full run to the type 2 partial run equilibrium.

Finally, if all agents play type 1 partial run equilibrium, their expected return equals $\alpha R + (1 - \alpha)(b^* + k^* r) - \epsilon$. If a patient agent deviates, verifies the type of banks but withdraws from "good" ones instead of "not-too-bad" ones, his expected return equals $\alpha X^* - \epsilon$, which is clearly smaller than $\alpha R + (1-\alpha)(b^* + k^* r) - \epsilon$. Hence no agent has an incentive to deviate from type 1 partial run to the type 2 partial run equilibrium. Q.E.D.