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Mandatory Disclosure and Financial Contagion*

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Abstract

This paper explores the desirability of forcing banks to disclose balance-sheet information they could reveal on their own but choose not to. In our benchmark model, mandatory disclosure can raise welfare, but only if markets would be frozen otherwise, i.e. if banks would be unable to raise external funds if no information were disclosed. Moreover, intervention in our model is only beneficial when banks are vulnerable to contagion due to their interconnectedness, meaning banks expect to incur losses when other banks' investments prove unprofitable. When we modify the model to allow banks to engage in moral hazard, mandatory disclosure can increase welfare even when markets aren't frozen. But, even in this case, intervention is only beneficial when banks are vulnerable to contagion. Finally, our model suggests mandatory disclosure serves as a substitute rather than a complement to other financial reforms such as leverage restrictions, as some have argued.

JEL Classification Numbers:

Key Words: Information, Networks, Contagion, Disclosure, Stress Tests

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Introduction

Economists studying the financial crisis of 2007 have argued that uncertainty about which entities incurred the bulk of the losses associated with the decline in U.S. house prices played an important role in fueling the crisis. For example, in his early analysis of the crisis, Gorton (2008) argued

> "The ongoing Panic of 2007 is due to a loss of information about the location and size of risks of loss due to default on a number of interlinked securities, special purpose vehicles, and derivatives, all related to subprime mortgages... The introduction of the ABX index revealed that the values of subprime bonds (of the 2006 and 2007 vintage) were falling rapidly in value. But, it was not possible to know where the risk resided and without this information market participants rationally worried about the solvency of their trading counterparties. This led to a general freeze of intra-bank markets, write-downs, and a spiral downwards of the prices of structured products as banks were forced to dump assets."[1]

Policymakers also seem to have ascribed an important role to uncertainty, as evidenced by the decision to release the Federal Reserve's stress test results showing expected losses at large US banks under specific stress scenarios. Such disclosure runs counter to the confidentiality usually accorded bank examinations. Bernanke (2013a) argued publicizing this information helped alleviate the crisis:

> "In retrospect, the [Supervisory Capital Assessment Program] stands out for me as one of the critical turning points in the financial crisis. It provided anxious investors with something they craved: credible information about prospective losses at banks. Supervisors' public disclosure of the stress test results helped restore confidence in the banking system and enabled its successful recapitalization."

Indeed, the disclosure of stress-test results during the crisis was viewed as so successful that policymakers eventually argued for releasing them routinely, e.g. Bernanke (2013b):

> "The disclosure of stress-test results, which increased investor confidence during the crisis, can also strengthen market discipline in normal times."

This paper investigates whether forcing banks to disclose their balance sheet information, either in crisis times or normal times, should be viewed as desirable. Specifically, we seek to understand why intervention is necessary at all: If disclosure is so useful, why don't banks hire auditors or release the information they provide bank examiners on their own? Although private monitoring may not have been feasible in the crisis of 2007 given the poor reputation of rating agencies, incentive problems for private monitors can in principle be addressed contractually. Any argument for ongoing intervention ought to explain why banks fail to release information even though doing so enhances welfare.

[1] Similar views were voiced by non-academics. For example, former Salomon Brothers vice chairman Lewis Ranieri, known as the "godfather" of mortgage finance, anticipated the role of uncertainty if house prices were to decline back in a February 24, 2007 *Wall Street Journal* article: "The problem ... is that in the past few years the business has changed so much that if the U.S. housing market takes another lurch downward, no one will know where all the bodies are buried. 'I don't know how to understand the ripple effects through the system today,' he said during a recent seminar."

We show that there may be scope for mandatory disclosure if banks are interconnected in a way that admits the possibility of contagion, meaning banks can suffer losses because of their exposure to other banks. During the recent crisis, banks with minimal exposure to subprime mortgages indeed appeared vulnerable to losses at other banks that heavily invested in subprime mortgages. When the potential for contagion is severe, compelling banks to disclose information can raise welfare. Intuitively, the possibility of contagion implies information about individual banks is systemically important, since one bank's performance matters for the health of other banks. Banks will not take into account the systemic value of their own information, and so they disclose less than is socially optimal.

Although we find that forcing banks to reveal information can raise welfare when banks are vulnerable to contagion, our analysis neither implies nor requires that mandatory disclosure is always desirable. To the contrary, our benchmark model is similar to work by Goldstein and Leitner (2013), Faria-e Castro, Martinez, and Philippon (2015), and Dang et al. (2014) in which suppressing information is optimal. As in these papers, our benchmark model implies that when all banks can raise funds without disclosing information, it would be optimal to prevent banks from revealing information if any were tempted to do so. This is because opacity can sustain risk-sharing between banks, in the spirit of Hirshleifer (1971). In our benchmark model, then, mandatory disclosure is desirable only when markets are frozen, i.e. when banks cannot raise funds in the absence of disclosure. Banks should be forbidden from disclosing in normal times the very same information they would be forced to disclose in crises.

Our benchmark model thus contradicts the argument in Bernanke (2013b) for imposing mandatory disclosure routinely. However, this model also abstracts from a need for market discipline that Bernanke (2013b) invokes to justify disclosure in normal times. We therefore consider a version of the model in which banks can engage in moral hazard. In this case, mandatory disclosure may be desirable even when markets aren't frozen. However, potential contagion remains necessary for disclosure to raise welfare. Essentially, when information has little systemic importance and agents capture most of the gains from revealing it, agents would voluntarily disclose if it were socially valuable to do so.

While our discussion is focused on stress tests and banks, our analysis would extend to any setting in which interconnectedness confers systemic importance to private information. One example is sovereign debt crises in which default by one sovereign prompts runs on debt issued by others. The analog to our results on the release of stress tests would be international agreements that force more transparency about sovereign financial positions.[2] Another example concerns the regulation of derivative trading. Some have argued trade in derivatives ought to be shifted from over-the-counter (OTC) to centralized exchanges because OTC trading often involves chains of indirect exposure to counterparty risk (i.e. balance sheet contagion).[3] Our results suggest mandatory disclosure may be a partial substitute to migration to exchanges by addressing some of the shortcomings of OTC markets.

The remainder of the paper is organized as follows. We first discuss how our work is related to the existing literature. We then describe our benchmark model in Sections 1 and 2. In Section 3, we show that with sufficient potential for contagion, mandatory disclosure can improve welfare relative to an

[2]For an early survey on contagion and sovereign debt, see Kaminsky, Reinhart, and Vegh (2003). On the lack of transparency by fiscal authorities, see Koen and van den Noord (2005).

[3]For a discussion, see Duffie and Zhu (2011) and Duffie, Li, and Lubke (2010) and the references therein.

equilibrium where all banks fail to disclose. To interpret our results, in Section 4 we explore the strategic interaction that underlies our model. Here, we argue our results reflect information externalities rather than coordination problems. In Section 5, we introduce moral hazard to show that mandatory disclosure can raise welfare in normal times, but only with sufficient potential for contagion. Given the important of contagion, in Section 6 we look at what forces influence the potential for contagion. Here, we argue that certain financial reforms can eliminate the need for mandatory disclosure. Section 7 concludes.

Related Literature

Our paper is related to several literatures, specifically work on (i) financial contagion and networks, (ii) disclosure, (iii) market freezes, and (iv) stress tests.

The literature on financial contagion is quite extensive. We refer the reader to Allen and Babus (2009) for a survey. Although we consider more than one channel for contagion, some of our discussion focuses specifically on balance sheet contagion in which banks are connected through liabilities to one another. This type of contagion was originally developed in Kiyotaki and Moore (1997), Allen and Gale (2000), and Eisenberg and Noe (2001) and more recently explored in Gai and Kapadia (2010), Battiston et al. (2012), Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015), and Elliott, Golub, and Jackson (2015). However, these papers are largely concerned with how the pattern of obligations across banks affects the extent of contagion, while our focus is on how disclosure policies can be used to mitigate the fallout from contagion given an existing network structure.

Our model is also closely related to work on disclosure. Verrecchia (2001) and Beyer et al. (2010) provide good surveys of this literature. A key result in this literature, established by Milgrom (1981) and Grossman (1981), is an unravelling principle whereby all private information will be disclosed because agents with favorable information want to avoid being pooled with inferior types and receive worse terms of trade. Beyer et al. (2010) summarize the various conditions subsequent research has established as necessary for this unravelling result: (1) disclosure must be costless; (2) outsiders know agents have private information; (3) outsiders interpret disclosure identically, i.e. outsiders have no private information (4) information is verifiable and cannot be misrepresented; and (5) agents cannot commit to a disclosure policy ex-ante before observing the relevant information. Violating any of these conditions can result in equilibria with incomplete disclosure. In our model, a non-disclosure equilibrium can arise even when all of these conditions are satisfied. We thus highlight a distinct reason for the failure of the unravelling principle due to informational spillovers.

Ours is not the first paper to explore disclosure in the presence of informational spillovers. One predecessor is Admati and Pfleiderer (2000). They also assume informational spillovers and generate non-disclosure equilibria.[4] But their equilibria crucially rely on disclosure being costly; when disclosure is costless in their model, equilibrium involves full disclosure. We generate non-disclosure even when disclosure is costless because our model features informational complementarities whereby determining any one bank's equity requires information from multiple banks, a feature with no analog in their

[4] Foster (1980) and Easterbrook and Fischel (1984) also argue that spillovers may justify mandatory disclosure, although these papers do not develop formal models to study this.

model. That said, informational spillovers can make mandatory disclosure welfare-improving in their model, although their results are not related to contagion. Another difference between their model and ours is that they assume agents commit to disclosure before learning any information, while agents in our model decide after becoming informed.

Beyond these papers, there is also a literature on the social value of information in the presence of externalities, e.g. Angeletos and Pavan (2007). However, such papers are less directly related to ours, not only because they abstract from disclosure but also because they assume recipients of information wish to coordinate their actions, a feature that is absent in our framework.

Our paper is also related to the literature on market freezes. The existing literature emphasizes the role of informational frictions. Some papers argue that agents who know they have limited information are reluctant to trade for fear of being exploited by more informed agents. Examples include Rocheteau (2011), Guerrieri, Shimer, and Wright (2010), Camargo and Lester (2011), Kurlat (2013), and Guerrieri and Shimer (2014). Others have argued that uncertainty about each agent's own liquidity needs and the liquidity needs of others encourages liquidity hoarding. Examples include Caballero and Krishnamurthy (2008), Diamond and Rajan (2011), and Gale and Yorulmazer (2013). Our framework combines private information about a bank's own balance sheet with uncertainty about other banks' balance sheets. Moreover, unlike these papers, we assume information is verifiable and can be disclosed.

Finally, there is a literature on stress tests. On the empirical front, Peristian, Morgan, and Savino (2010), Bischof and Daske (2012), Ellahie (2012), and Greenlaw et al. (2012) look at how the release of stress-test results in the US and Europe affected bank stock prices. These results are complementary to our analysis by establishing stress test results are informative. Several papers examine stress tests theoretically, e.g. Shapiro and Skeie (2012), Spargoli (2012), Bouvard, Chaigneau, and de Motta (2013), Goldstein and Leitner (2013), Goldstein and Sapra (2014), and Faria-e Castro, Martinez, and Philippon (2015). Some of these argue disclosure can be harmful, especially in normal times when markets aren't frozen. The benchmark version of our model shares this implication, for similar reasons to Goldstein and Leitner (2013) and Faria-e Castro, Martinez, and Philippon (2015). However, we show that if banks can engage in moral hazard, disclosure can be useful in normal times. In addition, our paper differs in focusing on the question of why banks must be compelled to disclose information they could reveal on their own. The above papers sidestep this question by assuming only regulators can disclose.

1 Information Structure

Consider an economy with n banks. In this section, we describe the information structure of our economy, i.e. the nature of uncertainty and what each of the n banks knows. In the next section, we describe the disclosure decisions of banks and how the information banks might release can be used.

Each bank can be one of two types, good and bad. A bank's type reflects the outcomes of a particular class of asset purchases the bank made before our model begins, e.g. mortgages. Good banks are those whose past asset purchases proved profitable *ex-post* and bad banks are those whose past purchases proved unprofitable. Let $S_i \in \{0, 1\}$ denote bank i's type, where $S_i = 0$ means bank i is bad and $S_i = 1$ means it is good. Thus, the relevant state in our model is the vector $S = (S_1, \ldots, S_n) \in \{0, 1\}^n$.

For any realization $s \in \{0,1\}^n$, let $\pi(s) \equiv \Pr(S = s)$ denote the probability that the realized state is s. Note that $\pi(s)$ governs both how many banks are likely to be bad as well as which ones. In what follows, we find it convenient to impose a symmetry assumption which ensures all banks are equally likely to be bad, but which places no restrictions on how many banks are likely to be bad in total:

A1. Symmetric Distribution of Types across Banks: Given s and s', if $\sum_{i=1}^n s_i = \sum_{i=1}^n s'_i$, then $\pi(s) = \pi(s')$. That is, two realizations with the same number of bad banks are equally likely.

A1 requires that two realizations with the *same* number of bad banks be equally likely, but imposes no restriction on the relative likelihood of realizations in with different numbers of bad banks. Let $b(S)$ denote the total number of bad banks, i.e. $b(S) = \sum_{i=1}^n (1 - S_i)$. Then A1 is compatible with any distribution $\Pr(b(S) = b) = q_b$ such that $q_b \geq 0$ and $\sum_{b=0}^n q_b = 1$. This is because for any such $\{q_b\}_{b=0}^n$, we can set $\pi(s) = q_{b(s)} \binom{n}{b(s)}^{-1}$ to ensure that $\Pr(b(S) = b) = q_b$ as well as to satisfy A1. In what follows, we use q_b to denote the probability that the number of bad banks is exactly b. To avoid trivial cases we assume $q_0 < 1$, i.e. each bank can be bad with positive probability.

Our specification encompasses several special cases. One is when bank types are independent and identically distributed. In this case, $q_b = \binom{n}{b}(1-q)^{n-b}q^b$, where q represents the probability that any given bank is bad. Thus, our model can capture the case where the assets banks purchased have idiosyncratic returns. But A1 is also consistent with the case where bank investments are correlated. Finally, A1 includes a case explored in several papers in which $q_b = 1$ for one value of b. That is, everyone knows exactly how many banks are bad but not which ones. A1 essentially rules out only *ex-ante* heterogeneity across banks in which some banks are known as more likely to be bad than others. While this restriction ignores some interesting issues, it greatly simplifies the analysis.

In what follows, we treat the distribution $\pi(s)$ as fixed. However, it is natural to think of the event that sets off a financial crisis as a shock to $\pi(s)$ that means more banks are likely to be bad, i.e. a shift in q_b towards higher b. This is consistent with the view cited in the Introduction that the 2007 financial crisis was set off by the fall in the price of subprime mortgage products and concern that many banks held such assets. Conversely, when we later examine whether mandatory disclosure is desirable in normal times, we will consider $\pi(s)$ for which banks typically tend to be good and q_0 tends to 1.

While the state of the economy is fully characterized by S, each individual bank i observes its own type S_i but not those of any other bank. That is, each bank gets to observe a single entry in the vector S. However, banks know the distribution $\pi(s)$ and can assign probabilities to other banks assuming particular types. In words, banks do not observe what assets other banks purchased, but they have some sense of what those might be. Formally, knowing its own type S_i and $\pi(s)$, the probability bank i should assign to the types of other banks, S_{-i}, can be readily deduced using Bayes' rule:

$$\Pr(S_{-i} = s_{-i} \mid S_i = s_i) = \frac{\pi(s_{-i}, s_i)}{\sum_{x \in \{0,1\}^{n-1}} \pi(x, s_i)} \tag{1}$$

Since A1 does not require that types be independent, a bank's beliefs about other banks' types can be informed by how its own assets performed, i.e. $\Pr(S_{-i} = s_{-i} | S_i = 0)$ can generally differ from

$\Pr(S_{-i} = s_{-i}|S_i = 1)$. We discuss the implications of positive and negative correlation across types in Section 4. But the results we focus on do not depend on how types are correlated.

2 Economic Environment

We now turn to the possibility of banks revealing their information and how this information might be used. The timeline of our model is as follows. First, nature chooses S according to $\pi(s)$. Each bank i learns its type S_i. Next, banks participate in a disclosure game in which banks simultaneously choose to reveal their types. Disclosures are verifiable, so banks must announce truthfully. Any bank that discloses its type incurs a cost. After banks make their disclosure decisions, outside investors observe the information that was disclosed and choose whether to lend funds to banks. Banks then use these funds to finance profitable projects. Once these projects pay off, banks distribute their earnings.

Given disclosure is costly, a bank will only reveal its type if it expects this will improve its terms of trade with outsiders. This requires that outsiders care about a bank's balance sheet in choosing whether to fund it. One scenario where this concern arises naturally is when banks face debt overhang as in Myers (1977), i.e. when banks have outstanding liabilities that are senior to any new claims they take on. When banks are subject to debt overhang, new investors understand that if a bank suffers losses elsewhere on its balance sheet, returns to the projects they are funding would go to more senior creditors. Good banks thus have an incentive to reveal to potential investors that their asset purchases were profitable to help reassure them. Philippon and Schnabl (2013) argue that debt overhang among banks was one reason why banks faced difficulty in raising new funds during the recent crisis. We therefore study an economy where banks face debt overhang to ensure disclosure is valuable.

The other key feature of our model is that we allow banks to be interconnected, so that banks are exposed to losses at other banks they are somehow connected to. Since banks do not know which other banks are bad, each bank will be uncertain about its full balance sheet when it contemplates disclosing how its asset purchases fared. Banks also understand that the value of the information they reveal may depend on what other banks they are connected to choose to reveal. As anticipated in the Introduction, interconnectedness will prove key for why mandating disclosure can be desirable.

2.1 Interconnectedness and Contagion

We begin our description with how we model contagion among interconnected banks. While contagion can occur in various ways, the literature on financial contagion has emphasized two: balance sheet contagion and fire sales. We want a framework that can potentially encompass both.

Balance sheet contagion refers to the case of mutual liabilities among banks so that banks which suffer losses default on other banks. As an example, consider the Caballero and Simsek (2012) model in which n banks are organized along a circle. Each bank owns some assets and a liability of size λ from the bank counter-clockwise to it, which means each bank also owes λ to the bank clockwise from it beyond any of its other obligations. Caballero and Simsek (2012) assume there is one bad bank, so any one bank is bad with probability $1/n$. The bad bank incurs large losses that force it to default on the bank to which it owes λ. This triggers a chain reaction in which the next k banks – all of which are good – default, where k depends on the size of the loss of the bad bank, the amount λ banks owe one another, and the amount of other assets banks own. In this case, a good bank can assure outsiders it did not buy impaired assets, but it does not know nor can it assure outsiders about its lending to other banks. That requires information from other banks, including those not directly connected to it.

Even when banks do not invest in other banks, they might be vulnerable to losses at other banks because of fire sales, i.e. if the banks that suffer losses liquidate their holdings and drive down the price of the assets held by others. As an illustration, suppose banks can buy two types of assets with borrowed funds, e.g. prime and subprime mortgages. Banks choose which assets to buy based on idiosyncratic factors captured by $\pi(s)$. Bad banks are those that bought both mortgages, while good banks only bought prime mortgages. If the value of subprime mortgages collapses, bad banks must liquidate both assets to repay their obligations. Greenwood, Landier, and Thesmar (2015) assume the price of any asset sold declines linearly in the amount bad banks sell. Shleifer and Vishny (1992) instead argue the price should fall only when the marginal buyer changes to someone who values the asset discretely less, e.g. a non-bank entity. This suggests the price of prime mortgages would fall only when the quantity of mortgages sold exceeds a threshold, i.e. if the number of bad banks $b(s)$ exceeds some threshold b^* that depends on how much the price of subprime mortgages falls and what portfolios bad banks hold. While a good bank can assure outsiders it did not buy subprime mortgages, it does not know how its mortgages will fare. But information from other banks can reveal the likely scale of fire sales.

For our purposes, it turns out there is no need to take a stand on whether banks are connected because they invest in one another or not. Instead, our results only depend on how much a bank suffers when other banks are bad, regardless of the reason why. Formally, let $e_i(s)$ denote the equity of bank i when $S = s$ before any bank raises funds to finance their respective project. We only need to know how $e_i(s)$ changes when banks other than bank i switch from being good to being bad. In particular, we will say banks are interconnected when $e_i(s)$ satisfies the following monotonicity restriction:

A2. Interconnectedness: For each i, $e_i(s_i, s'_{-i}) \geq e_i(s_i, s_{-i})$ whenever $s'_{-i} > s_{-i}$, and there exists some pair s_{-i} and s'_{-i} for which $e_i(s_i, s'_{-i}) > e_i(s_i, s_{-i})$.

Thus, we refer to banks as being interconnected if they incur losses when certain other banks are bad. By contrast, we will use the term contagion to mean that banks are both interconnected and can be bad. By way of analogy, the explosive potential of dynamite is only relevant if there is some spark to set it off. Likewise, as q_0 tends to 1 so that all banks are likely to be good, there would be little reason for concern about the balance sheets of good banks even when A2 implies banks are interconnected and so exposed to other banks. The measure of contagion we will use below captures this idea, and will tend to imply greater contagion both as bad banks inflict more collateral damage on other banks and as banks are more likely to be bad.

We assume that the functions $e_i(s)$ are common knowledge. That is, all agents understand how banks are connected in each realization s, and their only uncertainty is about s, i.e. how many banks are bad and which ones. So, in the case of balance sheet contagion, all agents know what banks owe one another but are unsure which banks purchased impaired assets. In the case of fire sales, all agents could deduce asset prices if they knew the portfolios of all banks, but they are initially unsure what those portfolios are. In what follows, it will be convenient to impose additional restrictions on $e_i(s)$ to aid tractability. These assumptions represent implicit restrictions on how banks are interconnected, e.g. what liabilities banks owe one another or how the portfolios of assets banks hold overlap in the case of fire sales. But given our setup, it is more convenient to frame these as restrictions on $e_i(s)$.

Our first restriction involves symmetry. For any $s = (s_1, \ldots, s_n)$, let $\vec{s}$ denote the vector in which bank types are rotated one position relative to s, i.e. $\vec{s} = (s_n, s_1, \ldots, s_{n-1})$. That is, in state $\vec{s}$, bank 2's type is the same as bank 1's type in state s, bank 3's type is the same as bank 2's type in state s, and so on, with bank 1's type the same type as bank n's type in state s. The symmetry we impose requires that e_i also be rotated, i.e. bank 2's equity in state $\vec{s}$ is the same as bank 1's equity in state s, bank 3's equity is the same as bank 2's equity in state s, and so on.[5]

A3. Rotational Symmetry in Equity: Given $s \in \{0,1\}^n$, if $\vec{s} = (s_n, s_1, \ldots, s_{n-1})$, then

$$e_i(\vec{s}) = \vec{e}_i(s) = \begin{cases} e_n(s) & \text{if } i = 1 \\ e_{i-1}(s) & \text{if } i = 2, \ldots, n \end{cases} \tag{2}$$

Assumption A3 invokes a weaker notion of symmetry than A1. In particular, A1 is akin to an anonymity condition in which a bank's identity is irrelevant, while A3 allows identity to matter in the sense that banks can be more exposed to certain banks than to others. That is, A3 only requires similarity in the pattern of obligations between adjacent banks or in the degree of overlap in asset holdings between adjacent banks, not that banks be equally obligated to all other banks or own the same portfolio as all other banks. Combining A1 and A3 implies that prior to raising outside funds, equity is distributed identically for all banks, even conditional on their own type:

Lemma 1: If A1 and A3 hold, then $\Pr(e_i = x)$ and $\Pr(e_i = x|S_i)$ are the same for all i.

An implication of Lemma 1 is that when banks choose whether to disclose their type, they face identical decision problems. Hence, we only need to solve a single bank's decision to analyze all n banks. However, since A3 allows banks to be differentially exposed to other banks, once a bank reveals its type, beliefs about remaining banks can be different. That is, while $\Pr(e_i = x|S_i)$ is the same for all i, $\Pr(e_i = x|S_j)$ for a fixed j need not be the same for all $i \neq j$.

Our next assumption concerns how equity varies with bank type. Absent contagion, good banks should have positive equity before raising funds. Thus, we assume that when all banks are good, $e_i > 0$ for all i. At the same time, we want losses at bad banks to be sufficiently large that such banks are rendered insolvent. In fact, we assume that losses are sufficiently large that bad banks will remain insolvent even if they raised funds from outsiders. Recall from our timeline that banks in our economy want to raise funds to run projects. We will assume these projects yield a riskless gross return R. Thus, we would require equity at bad banks to be negative even after earning R. Formally:

A4. Equity and Bank Types: If all banks are good, then $e_i(1, \ldots, 1) > 0$ for all i. If bank i is bad, then $e_i(0, s_{-i}) \leq -R$ for all s_{-i}.

[5] We could impose a weaker notion of symmetry in which the relevant invariance can hold for a more general permutation rather than a rotation, but the notation for this case is considerably more cumbersome with no additional insight.

Our last assumption is that no bank be marginal, meaning that its ability to meet its obligations does not depend on whether it undertakes a project that promises a return of R we introduce later. Either a bank has enough equity to discharge all its obligations or its equity is sufficiently negative that its earnings from operating a project would never be enough to render it solvent. Formally:

A5. No Marginal Banks: For all $s \in \{0,1\}^n$, either $e_i(s) \geq 0$ or $e_i(s) \leq -R$.

Condition A5 allows us to infer whether a bank can repay investors from the state S without knowing which banks raise external funds. This is because under A5, running a project never turns an insolvent bank solvent; a bank that defaults on other banks will do so even if it raised funds. To determine the ability of any bank to repay investors, then, it will suffice to know which banks are bad. A5 is somewhat restrictive, since in terms of economic primitives it limits the nature of interbank liabilities and how asset prices can change with the amount of assets insolvent banks sell. However, in Section 5 we show that we can replace A5 with an assumption that does not require such restrictions.

To recap, we allow for contagion by considering an environment in which a bank's equity before raising new funds falls if certain other banks are bad. In not specifying how banks are connected, we greatly simplify the exposition. But this also makes it hard to see what economic forces might increase contagion. However, we could infer these by explicitly modelling bank linkages. For example, in Section 6 we construct a model of balance sheet contagion. This model shows how linkages across banks shape the functions $e_i(s)$ and what restrictions on linkages correspond to conditions A2-A5.

2.2 Trade between Outsiders and Banks

Now that we described what determines each bank's initial equity $e_i(s)$ in each state s, we can turn to why equity matters. The idea is that outsiders will want to avoid investing in banks with sufficiently negative equity, so they will care about each bank's equity position.

Suppose each bank, regardless of its type, can earn a gross return $R > 1$ if it invests a single unit of resources. We assume bank assets are illiquid at the time banks can earn this return, so banks must borrow to initiate these investments. There is a group of outside investors who can supply such funds, who earn a gross return $\underline{r} < R$ on their own, and who collectively own more resources than banks can invest. Thus, there is scope for gains from trade between outsiders and banks. However, we assume banks already have existing liabilities before borrowing any additional resources to fund new projects, and that these liabilities must be senior to any new obligations banks takes on. Indeed, the fact that banks have existing liabilities is implicit in both channels for contagion we discussed: The reason bad banks get into trouble and must either default or sell assets is because they have existing liabilities. If outsiders believe $e_i < 0$, i.e. that prior to raising funds bank i's assets fall short of its existing liabilities, they would not want to invest knowing the returns to the project would go to others. This is the debt overhang problem discussed by Myers (1977). Without it, a bank could always finance its project by pledging the returns from the project to its lenders. Although we do not explicitly model why existing debt holders are granted non-negotiable seniority, previous work such as Hart and Moore (1995) offers conditions in which such contracts can be optimal even though they lead to debt overhang.

In what follows, we restrict outsiders to only offering debt contracts, i.e. they can provide any bank i with 1 unit of resources, and in exchange can demand a fixed repayment of r_i. Since equity contracts are junior to debt obligations, allowing these would lead to similar results. We assume all investors simultaneously offer a contract to each bank, and banks choose among the contracts offered. Investors thus engage in Bertrand competition. Although a complete description of equilibrium would specify the contracts investors offer, we will only refer to equilibrium terms rather than what investors do. Thus, if outsiders knew the initial equity of each bank, in equilibrium only banks for which $e_i(s) \geq 0$ would receive funding and each would be charged $\underline{r}$. If outsiders knew nothing other than the prior $\pi(s)$, by symmetry all banks generically receive the same terms. If outsiders had partial information about S, banks would generally receive different terms. What outsiders know about S emerges endogenously once banks choose whether to reveal their types in a disclosure game we now describe.[6]

2.3 Disclosure and Investment

We begin by describing the disclosure game and then the round of investment that follows it. Each bank i must decide whether to disclose its type S_i before observing S_{-i}. Disclosure involves hard information, i.e. announcements are verifiable so banks must report truthfully. Disclosure is also costly, reflecting the fact that information is costly to produce or communicate. For simplicity, we model disclosure costs as a utility cost $c > 0$ that is only incurred if S_i is disclosed. Note that this specification equates the private and social costs of disclosure. In principle this need not be restrictive, since differences between the two can be captured in the payoff to disclosure. That is, the cost of disclosure can equally be represented as a benefit from non-disclosure. Indeed, for reasons that will become clear below, the private and social benefits from disclosure will differ in our model.[7]

Bank i's strategy can be summarized as a rule $\sigma_i : S_i \to [0, 1]$ that assigns a probability of disclosure σ_i when its type is S_i. The outcome of the disclosure game is a vector of announcements $A = \{A_1, \ldots, A_n\}$, where $A_i = S_i$ if bank i announces its type and $A_i = \varnothing$ otherwise. Given a realization s and a strategy profile $\sigma = (\sigma_1, \ldots, \sigma_n)$, we can determine the distribution of announcements A that will be observed in that state, $\Pr(A|s, \sigma)$. Outsiders, however, face the opposite problem: Given announcements A and the equilibrium strategy profile σ, they form beliefs as to the likelihood of different realizations s, $\Pr(S = s|A, \sigma)$. It will be convenient to introduce a vector that summarizes which banks disclosed rather than *what* they disclosed. Thus, define $\alpha = (\alpha_1, \ldots, \alpha_n)$ where $\alpha_i = 1$ if $A_i = S_i$ and $\alpha_i = 0$ if $A_i = \varnothing$. Since disclosure is costly, we must subtract $c\alpha_i$ from bank i's payoff.

Banks might be willing to undertake costly disclosure to improve their equilibrium terms of trade. Define $I_i(A)$ as 1 if bank i obtains funding in equilibrium and 0 otherwise, and $r_i(A)$ as the rate bank i is charged in equilibrium. By disclosing it is good and changing A, bank i can potentially increase

[6] Other papers have also studied disclosure games that precede decisions, e.g. Alonso, Dessein, and Matouschek (2008), Hagenbach and Koessler (2010) and Galeotti, Ghiglino, and Squintani (2013). However, these papers are interested in economies where agents want to coordinate with one another but disagree on what action to coordinate on. By contrast, in our model agents communicate to an outside party rather than to other players and are not trying to coordinate.

[7] In general, the net private benefit from disclosure can be higher or lower than the net social benefit. If disclosing information erodes the rents banks earn, the private cost of disclosure will exceed the social cost. But if disclosure prevents risk-sharing its social cost will exceed its private cost. Our model features the latter but not the former.

the odds of being funded and reduce the expected interest rate it must pay.

Note that in equilibrium, $r_i(A)$ cannot exceed R or else bank i would never agree to borrow. To solve for the equilibrium $r_i(A)$, recall that under A5, a bank's equity prior to raising funds is either nonnegative or less than $-R$. Since $r_i \leq R$, a bank will repay its debt in full if its initial endowment $e_i \geq 0$ and nothing if $e_i \leq -R$. The expected payoff to funding bank i is thus

$$\Pr\left(e_i \geq 0 \,|A, \sigma\,\right) r_i\left(A\right) \tag{3}$$

Since e_i is a function of S, we can compute $\Pr\left(e_i \geq 0 \,|A, \sigma\,\right)$ from $\pi(s)$. Outsiders will fund bank i if (3) is at least $\underline{r}$. Competition will drive the expected return from lending to $\underline{r}$, i.e.

$$r_i\left(A\right) = \frac{\underline{r}}{\Pr\left(e_i \geq 0 \,|A, \sigma\,\right)} \tag{4}$$

Since $r_i\left(A\right)$ cannot exceed R, then we know that after observing the announcements A, outsiders will not finance a bank i for which

$$\Pr\left(e_i \geq 0 \,|A, \sigma\,\right) < \frac{\underline{r}}{R}$$

Hence, equilibrium investment $I_i\left(A\right)$ will be given by

$$I_i\left(A\right) = \begin{cases} 1 & \text{if } \Pr\left(e_i \geq 0 \,|A, \sigma\,\right) \geq \dfrac{\underline{r}}{R} \\ \\ 0 & \text{if } \Pr\left(e_i \geq 0 \,|A, \sigma\,\right) < \dfrac{\underline{r}}{R} \end{cases} \tag{5}$$

Equations (4) and (5) together fully characterize the terms each bank would receive given vector of announcements A. Since bank i retains the equity that remains after discharging its debts, and incurs a cost c if it chooses to disclose, its expected payoff if banks announce A is

$$E\left[\ \left(e_i\left(S\right) + (R - r_i)I_i\right)_+ \mid A, S_i\ \right] - c\,\alpha_i \tag{6}$$

where $(x)_+ \equiv \max\{x, 0\}$. Each bank will choose its disclosure given S_i to maximize the expected payoff (6) given other banks' disclosure strategies σ_{-i}. A bad bank gains nothing from disclosure, since A4 implies its equity is zero even if it gets funded. But a good bank may wish to disclose. Our model is thus a dynamic game in which banks choose whether to reveal their types and then investors choose offers. As in any dynamic game of incomplete information, investors' off-equilibrium beliefs matter. We will restrict how these beliefs are formed in the next section by choosing a particular equilibrium concept. With this restriction, offers can be derived from (4) and (5), and our model effectively collapses to a static game in which all that needs to be determined is whether good banks disclose.

2.4 Implications of Debt Overhang in our Model

Before we analyze the game we just described, we note that our formulation makes it easy to lose sight of the role of our two key assumptions – interconnectedness among banks and debt overhang. Without debt overhang, there would be no reason for banks to disclose S_i. If banks could pledge the returns from their project, outsiders would be willing to invest in them regardless of e_i. Interconnectedness is not essential for banks to be willing to disclose S_i, but how bank equity varies with S matters for payoffs, and thus affects the incentives for disclosure and its social desirability.

To help anticipate the way in which interconnectedness matters, it will help to take stock of the resource allocation problem in our model. In the environment we sketched out, banks have a fixed capacity for carrying out investment projects. Hence, any bank that fails to raise funds represents a lost opportunity for society to earn R rather than $\underline{r}$. An unconstrained planner would want all banks to obtain funding, even if contractual frictions prevent this from occurring in equilibrium.[8]

A planner can in principle overcome these contractual frictions by transferring resources to banks that cannot raise funds. Philippon and Schnabl (2013) pursue this line in a related model of debt overhang. They allow the planner to tax agents and transfer the resources it collects to banks, and find such an intervention can increase welfare.[9] Indeed, the US policy response to the crisis involved capital injections beyond just disclosure of stress tests. However, we only consider interventions that involve disclosure. This allows us to analyze the virtue of disclosing balance sheet information separately from the role this information might play in determining which banks ought to receive capital injections. If the goal of stress-tests was simply to lay the groundwork for capital injections, there would be no need to publicly disclose them. Yet in practice policymakers have argued that public disclosure is beneficial in and of itself. Indeed, the European Central Bank has released stress test results without implementing capital injections. In addition, disclosure has been advocated in normal times when transfers are not an issue, and so it is worth studying the merits of disclosure policy on its own.

How can information be used to increase the number of banks that carry out projects? If outsiders refuse to invest in banks absent any information, disclosure allows outsiders to invest in those banks that are solvent. But if outsiders are willing to fund banks even without disclosure, revealing that some banks have negative equity only discourages investment. Maximizing the number of banks funded can thus require either more disclosure or less. This feature arises because in our model it is optimal for all banks to be funded. In Section 5, we introduce a moral hazard problem that leads insolvent banks to divert funds to private uses. In that case, funding insolvent banks is no longer beneficial, and disclosure may be desirable when banks would be funded without disclosure because it reveals insolvent banks.

3 Equilibrium of the Disclosure Game

To solve for the equilibrium of the disclosure game at the heart of our model, we first need to settle on an appropriate notion of equilibrium. Recall that our model features a dynamic game of incomplete information. As usual in these games, off-equilibrium paths matter. In particular, what happens in

[8] This policy prescription is similar to what optimal policy would dictate if banks were illiquid rather than insolvent, even though A5 implies banks with negative equity are insolvent, not illiquid. In our setting it is optimal to keep insolvent banks operating because they can create surplus other banks by assumption cannot.

[9] The simplest way to enact this transfer is a cash injection to banks, coupled with a lump-sum tax on banks that is senior to all other claims. Philippon and Schnabl (2013) discuss various transfer schemes that have been used in practice, e.g. capital injections in which a bank promises to pay dividends in exchange for the resources it receives; asset purchases where the bank sells its assets; and loan guarantees, where a bank is assessed a fee based on how much the bank borrows and in turn new borrowers are guaranteed to be repaid.

equilibrium depends on what investors believe after observing announcements they should never observe in equilibrium. Without any restrictions, investor can hold implauisble beliefs in these cases. For example, suppose bank i is expected to never reveal its type. If it deviated and disclosed, outsiders could believe bank i is the opposite type to what it announces, even though announcements are verifiable. Outsiders could also arbitrarily change their beliefs about banks $j \neq i$, even though bank i knows nothing about these types.[10] To avoid this, we restrict attention to sequential equilibria as in Kreps and Wilson (1982). That is, we require each player's strategy to be optimal given the others' strategies, and for off-equilibrium beliefs to coincide with the limit of beliefs from a sequence in which players choose all strategies with positive probability but the weight on suboptimal actions tends to zero.

Since bad banks never opt to disclose given $c > 0$, each bank effectively only chooses the probability σ_i of disclosing when it is good. To confirm that a candidate profile σ is an equilibrium, we need to verify that each σ_i is optimal given σ_{-i}. In particular, given bank i's beliefs about the announcements other banks are likely to make knowing their strategies as well as its own type, i.e. $\Pr(A_{-i}|\sigma_{-i}, S_i)$, bank i's strategy σ_i must optimally balance the cost of disclosure c with how disclosure affects $\{I_i(A), r_i(A)\}$.

Since compelling banks to reveal information only matters when there is less then full disclosure in equilibrium, we first focus on equilibria with imperfect disclosure. More precisely, we consider non-disclosure equilibria where $\sigma_i = 0$ for all i. We derive conditions under which a non-disclosure equilibrium exists, and then ask whether forcing all banks to disclose in this case raises welfare. We then turn to equilibria with disclosure in Section 4. There, we consider both scenarios where non-disclosure equilibria don't exist and the possibility of multiple equilibria when non-disclosure equilibria do exist. For now, we merely observe that even if there were additional equilibria with some disclosure, our results would still tell us when it is possible to get inefficiently stuck in a non-disclosure equilibrium.

3.1 Existence of a Non-Disclosure Equilibrium

We begin with conditions for non-disclosure to be an equilibrium, i.e. when bank i agrees not to disclose it is good if it expects banks $j \neq i$ not to disclose that they are good. We show that a non-disclosure equilibrium exists if either the cost of disclosure or the potential for contagion are large.

To determine whether a non-disclosure equilibrium exists, we need to know what outsiders would do if bank i did not disclose its type in equilibrium and what they would do if bank i deviated and disclosed its type. If bank i did not disclose and this was an equilibrium, outsiders would always expect to observe $A_i = \varnothing$. As such, they would never update their prior beliefs as to whether bank i is good or bad. Under A1, the unconditional probability that any particular bank i is bad is given by

$$\Pr(S_i = 0) = \sum_{b=0}^{n} q_b \frac{b}{n} \tag{7}$$

A4 implies that when bank i is bad, it cannot pay back its investors. Outsiders assign complementary probability $\Pr(S_i = 1) = 1 - \Pr(S_i = 0)$ to bank i being good. In this case, the probability that bank

[10]This is referred to by Fudenberg and Tirole (1991) as signalling something you don't know.

i can pay back investors conditional on being good is given by

$$p_g = \Pr(e_i \geq 0 | S_i = 1) = \frac{\sum_{\{s: e_i(s) \geq 0\}} \pi(s)}{1 - \sum_{b=0}^{n} q_b b/n} \tag{8}$$

Combining these observations, the probability outsiders should assign to bank i paying back its obligation in an equilibrium in which no bank disclosed its type is equal to

$$0 \times \Pr(S_i = 0) + p_g \Pr(S_i = 1) \tag{9}$$

which is just $p_g \Pr(S_i = 1)$. Using (4) and (5), we can deduce that if bank i does not disclose, then outsiders would only agree to fund bank i when

$$p_g \geq \frac{1}{\Pr(S_i = 1)} \frac{\underline{r}}{R}$$

and if outsiders agree to fund bank i, they would demand an interest rate of $r_i = \frac{\underline{r}}{p_g \Pr(S_i=1)}$.

If bank i instead chose to deviate and disclose it is good, our restriction to sequential equilibria ensures outsiders would believe bank i is good. Since only bank i would be disclosing its type, the probability outsiders would assign to bank i repaying them is just p_g. Appealing once again to (4) and (5), we can deduce that if bank i were to disclose, outsiders would agree to fund bank i when

$$p_g \geq \frac{\underline{r}}{R}$$

and when outsiders agree fund bank i, they would demand an interest rate of $r_i = \frac{\underline{r}}{p_g}$. Given our assumption that $q_0 < 1$, each bank can be bad with positive probability, and so $\Pr(S_i = 1) < 1$. Hence, by disclosing it is good, bank i might be able to obtain funding that it would not be able to obtain otherwise, or obtain funding at better terms than it would otherwise. More precisely, when $p_g < \frac{\underline{r}}{R}$, outsiders will not invest in bank i whether it discloses or not, so there is no benefit to disclosure. But when $\frac{\underline{r}}{R} < p_g < \frac{1}{\Pr(S_1=1)} \frac{\underline{r}}{R}$, outsiders invest only if bank i discloses. When $p_g > \frac{1}{\Pr(S_1=1)} \frac{\underline{r}}{R}$, outsiders invest in bank i whether it discloses or not, but bank i will be charged a lower interest rate if it disclosed.

We can use these observations to infer when a non-disclosure equilibrium exists. If $p_g < \frac{\underline{r}}{R}$, non-disclosure is an equilibrium for any $c > 0$: Disclosure is costly but confers no benefit, so a bank should not disclose it is good if no other bank does. Note that non-disclosure is an equilibrium even if $c = 0$, although in this case all banks disclosing will also be an equilibrium.[11]

If $\frac{\underline{r}}{R} < p_g < \frac{1}{\Pr(S_1=1)} \frac{\underline{r}}{R}$, bank i will be able to raise funds from outsiders only if it discloses its type. Non-disclosure is an equilibrium only if a bank cannot expect to gain from raising funds. Revealing its type would secure the bank an expected profit of $p_g R - \underline{r}$ and incur a cost of c. Hence, non-disclosure is an equilibrium if the disclosure cost is sufficiently large, i.e. only if $c > p_g R - \underline{r}$.

[11]The case where $c = 0$ is noteworthy, since in that case our model satisfies all of the conditions Beyer et al. (2010) provide for full disclosure. Even in Admati and Pfleiderer (2000), which is similar in many respects to ours, there is full disclosure when $c = 0$. Our result is probably closest to Example 4 in Okuno-Fujiwara, Postlewaite, and Suzumura (1990), in which agents' choices are at a corner and so disclosure has no effect on actions.

Finally, if $p_g > \frac{1}{\Pr(S_i=1)}\frac{\underline{r}}{R}$, bank i will be able to raise funds whether it discloses its type or not, but it will be charged a lower rate if it discloses. Since each bank borrows one unit of resources, and since it only earns profits with probability p_g, these gains are equal to $p_g\left(\frac{\underline{r}}{p_g} - \frac{\underline{r}}{p_g \Pr(S_i=1)}\right)$. This expression reduces to $\frac{\Pr(S_i=0)}{\Pr(S_i=1)}\underline{r}$. This gain must be less than c for bank i to be willing not to disclose its type.

We collect these results together as the following Proposition:

Proposition 1: A non-disclosure equilibrium exists iff one of the following conditions is satisfied:

1. $p_g < \frac{\underline{r}}{R}$, in which case no bank is funded in equilibrium
2. $p_g \in \left[\frac{\underline{r}}{R}, \frac{1}{\Pr(S_i=1)}\frac{\underline{r}}{R}\right]$ and $c > p_g R - \underline{r}$, in which case no bank is funded in equilibrium
3. $p_g > \frac{1}{\Pr(S_i=1)}\frac{\underline{r}}{R}$ and $c > \frac{\Pr(S_i=0)}{\Pr(S_i=1)}\underline{r}$, in which case all banks are funded in equilibrium

Proposition 1 describes the existence of a non-disclosure equilibrium in terms of two parameters, p_g and c. Figure 1 illustrates graphically the region in (p_g, c)-space in which a non-disclosure equilibrium exists. As is clear from the figure, non-disclosure is an equilibrium when either c is large or p_g is small.

The fact that non-disclosure is an equilibrium when c is large is natural: Banks will not disclose if it is costly to do so. But the fact that the existence of non-disclosure equilibria can be reduced to just one other variable, p_g, requires some elaboration. The variable p_g is essentially a measure of potential contagion. Recall that p_g reflects the probability a good bank repays its debt.[12] Since a good bank is by definition one whose past asset purchases proved profitable, the reason it would be unable to repay is because of exposure to other bad banks. When p_g is close to 1, exposure to other banks is minimal and good banks will almost always repay. When p_g is instead close to 0, banks are likely to default even when they avoid investing in unprofitable projects, suggesting they are highly exposed to what happens at other banks. The reason non-disclosure equilibria become more likely when potential contagion is large is that when outsiders worry about contagion, a bank will not convince outsiders to invest in it by unilaterally revealing it is good, and so no bank disclosing can be an equilibrium.

Equation (8) reveals that two things are necessary for potential contagion, i.e. for p_g to be small. First, banks must be interconnected to ensure that good banks suffer losses when other banks are bad, i.e. $e_i(1, s_{-i}) < 0$ for some s_{-i}. Second, banks must be likely to be bad, i.e. $\Pr(S_i = 0)$ must be large, since dragging down the initial equity of a good bank requires that certain banks be bad. Thus, contagion can only occur when outsiders worry that banks hold bad assets. While a shock to $\pi(s)$ that increases $\Pr(S_i = 0)$ can set off a crisis in which outsiders fail to invest in banks, such a shock only affects p_g if banks are connected. If $e_i(1, s_{-i}) \geq 0$ for all s_{-i}, then p_g would equal 1 regardless of $\pi(s)$.

At the same time, (8) obscures the economic content of p_g. Consider once again the Caballero and Simsek (2012) model. Computing (8) reveals that $p_g = 1 - \frac{k}{n-1}$, since a good bank can repay outsiders if none of the k banks counterclockwise from it is bad. This analytical expression reveals the role of k,

[12] As such, p_g could be inferred from credit default swaps on banks known to be good, e.g. banks that market participants knew held no subprime mortgages. The idea of measuring contagion with conditional distributions is reminiscent of the CoVaR measure proposed by Adrian and Brunnermeier (2011). However, our measure is conditioned on the bank in question being good, while their measure is conditioned on banks other than the bank in question being in distress.

which recall depends on the losses of the bad bank, the amount λ banks owe one another, and how many assets banks own. More generally, to relate p_g to economic variables requires a model that specifies how banks are connected. We provide a more detailed example of such a model in Section 6.

3.2 Mandatory Disclosure and Welfare

We now turn to the question of whether starting from a non-disclosure equilibrium, forcing all banks to disclose their type can improve welfare. We do not claim such a policy is optimal. However, showing that mandatory disclosure improves welfare is sufficient to justify intervention. We focus on a rule that forces all banks to disclose both because it is easier to analyze and because it has been used in practice, i.e. stress test results are disclosed for all systemically important banks.

We begin with the case where $p_g < \frac{r}{R}$. We know from Proposition 1 that in this case no disclosure is an equilibrium for all $c \geq 0$ and that no bank receives funding in equilibrium. If we instead forced all banks to disclose, banks revealed to have positive equity would attract investment while the rest would not. The unconditional probability that a bank will be able to raise funds is just $\Pr(e_i \geq 0)$, and so the expected surplus that we could generate by forcing all banks to disclose their types is

$$n\left[\Pr(e_i \geq 0)(R - \underline{r}) - c\right] \tag{10}$$

Using the fact that $\Pr(e_i \geq 0) = p_g \Pr(S_i = 1)$, we infer that (10) is positive iff

$$c \leq p_g \Pr(S_i = 1)(R - \underline{r})$$

Hence, as long as disclosure isn't too costly, forcing disclosure can raise welfare.

Next, suppose $p_g > \frac{1}{\Pr(S_i=1)} \frac{r}{R}$. From Proposition 1 we know that in this case a non-disclosure equilibrium exists only if $c > \frac{\Pr(S_i=0)}{\Pr(S_i=1)} \underline{r}$ and that all banks are funded in equilibrium. Mandatory disclosure is then strictly welfare reducing, since it incurs disclosure costs cn but if anything only reduces the number of banks that undertake projects by revealing which banks have negative equity.[13]

The remaining case is when $p_g \in \left[\frac{r}{R}, \frac{1}{\Pr(S_i=1)} \frac{r}{R}\right]$. From Proposition 1, we know that in this case a non-disclosure equilibrium exists only if $c \geq p_g R - \underline{r}$ and that in equilibrium no bank is funded. The expected gain from forcing all banks to disclose is thus equal to (10), which is positive only if $c \leq p_g \Pr(S_i = 1)(R - \underline{r})$. Mandatory disclosure improves upon the equilibrium outcome if these two restrictions on c are compatible. We analyze this in the Appendix. The results imply the following:

Theorem 1: Suppose a non-disclosure equilibrium exists. Then

(i) $\exists p_g^*$ where $\frac{r}{R} < p_g < 1$ such that for all $p_g \in (0, p_g^*)$, mandatory disclosure improves welfare relative to the non-disclosure equilibrium for small c, but cannot improve welfare if $p_g > p_g^*$.

(ii) In a non-disclosure equilibrium, investors will fund banks iff $p_g \geq \frac{1}{\Pr(S_i=1)} \frac{r}{R}$. If investors fund all banks, mandatory disclosure cannot increase welfare for any $c \geq 0$.

[13]Our results when $p_g > \frac{1}{\Pr(S_i=1)} \frac{r}{R}$ are reminiscent of Jovanovic (1982) and Fishman and Hagerty (1989). They also consider models in which disclosure is costly and yields private gains but no social surplus and is thus undesirable.

Figure 2 provides a graphical representation of Theorem 1 in (p_g, c)-space. The region in which a non-disclosure equilibrium exists, depicted in light gray, is as in Figure 1. The region in which mandatory disclosure is superior to no trade is depicted in dark gray. The intersection of the two regions, depicted in blue, corresponds to parameter values for which it is possible to improve on a non-disclosure equilibrium. When p_g is low, intervention is warranted as long as disclosure costs are not too high. For intermediate degrees of contagion, intervention is warranted when disclosure costs are neither too high nor too low, since at low costs non-disclosure cannot be an equilibrium.

Theorem 1 is one of the key results in our paper. Part (i) establishes that severe contagion is a necessary condition for mandatory disclosure to be desirable, since whenever p_g is close to 1, such an intervention cannot improve welfare. Intuitively, contagion implies that each bank's private information can help outsiders to identify which banks are worth investing in. But banks only care about how disclosure affects whether banks invest in them. Without contagion, banks internalize most of the benefits of their disclosure, and so forcing a bank to disclose would not make it better off in equilibrium or else the bank would have already elected to disclose its type.[14]

Part (ii) of Theorem 1 implies mandatory disclosure can only be justified in crises, i.e. when in the absence of disclosure outsiders fail to invest in any bank. If banks could raise funds without any disclosure, mandating disclosure would only do harm. This result contradicts the argument for releasing stress test results routinely rather than during crises that we cite in the Introduction. However, it accords with recent work in Goldstein and Leitner (2013) and Faria-e Castro, Martinez, and Philippon (2015) that emphasize the costs of disclosure. In our model, disclosure can be beneficial in generating trade when no banks get funded, but it serves no useful purpose and can be detrimental when banks are already funded. This feature stems from the fact that in the model above there is no gain to identifying insolvent banks: These banks would obtain no funding, but the planner wants all banks to be funded. By contrast, Bernanke's argument for routine disclosure of stress tests results appeals to imposing market discipline against insolvent banks. Towards this end, we modify the model Section 5 to allow insolvent banks to engage in moral hazard. In that case, it may be desirable to identify insolvent banks. We show that the case for intervention will still require contagion. Essentially, without contagion, banks would choose to disclose on their own if disclosure is worth undertaking.

4 Beyond Non-Disclosure Equilibria

So far we have only considered equilibria without disclosure. This was natural given our focus on the desirability of mandatory disclosure. We now consider equilibria with some disclosure, i.e. where $\sigma_i > 0$ for at least one i. We emphasize two results. First, we argue that even though contagion implies banks have too little incentive to disclose their private but systemically important information, it is not the case that more disclosure is better. Specifically, we show that under certain conditions, starting with an equilibrium in which banks disclose some information, it will be possible to increase welfare by

[14] The reason mandatory disclosure cannot improve welfare when p_g is close to but still less than 1 is that mandatory disclosure forces both good and bad banks to disclose their types. While the private cost to a good bank of disclosing its type is c, expected disclosure costs per good bank exceeds c under mandatory disclosure.

preventing banks from disclosing information. This result complements Theorem 1 above which shows that starting with an equilibrium with no disclosure, compelling banks to reveal information need not make society better off. Second, we show that it is not the case that whenever intervention can increase welfare, an equilibrium in which some banks disclose must also exist. Hence, just because mandatory disclosure is beneficial does not imply that banks could coordinate on their own to all disclose without some enforcement mechanism. This is because although disclosure involves positive externalities, in a way we make precise, disclosure by one bank need not encourage others to disclose as well.

4.1 Equilibria with Modest Contagion and Small Disclosure Costs

In the previous section, we showed that a non-disclosure equilibrium exists only if either potential contagion or the cost of disclosure were large. Standard existence results ensure that our game always admits an equilibrium. Hence, when these conditions are violated, equilibrium must involve some amount of disclosure, i.e. $\sigma_i > 0$ for some i. Our next result shows that there are conditions in which any equilibrium involves some disclosure, and it is possible to improve upon this equilibrium not by forcing more information out but preventing any information from being disclosed. Specifically, suppose

$$p_g \Pr(S_i = 1) > \frac{r}{R} \tag{11}$$

As we argued in the previous section, this condition ensures outsiders invest in all banks when no information is disclosed. In other words, absent any disclosure, markets would not be frozen. Condition (11) highlights that both p_g and $\Pr(S_i = 1)$ must be large, i.e. contagion must be low and banks are likely to be good. As an aside, note that in the limit as the probability that any given bank is bad $\Pr(S_i = 0)$ tends to 0, other things equal $p_g \to 1$. Hence, (11) will be satisfied whenever there is little concern about banks holding bad assets, even if banks are deeply interconnected. In this case, if the cost of disclosure c were low enough so that at least one bank would opt to disclose in equilibrium, mandatory secrecy may be desirable.

Proposition 2: If $p_g > \frac{1}{\Pr(S_i=1)} \frac{r}{R}$ and $c < \frac{\Pr(S_i=0)}{\Pr(S_i=1)} \underline{r}$, then in any equilibrium $\sigma_i > 0$ for some i. In this case, forcing all banks to set $\sigma_i = 0$ increases total available surplus.

An implication of Proposition 2 is that in non-crisis times, forcing all banks to keep quiet can increase each bank's well-being ex-ante before they learn S_i. Intuitively, since in our setup all banks should be funded, when there is little concern among outsiders that any given banks is insolvent, the first best can be achieved without any disclosure. However, when c is low, good banks can benefit by revealing to outsiders that they are good and lowering the interest rate they pay. The problem with this is that outsiders would then infer that no news is bad news and refuse to fund a bank if it does not disclose its type. Forcing banks to keep quiet is a way of getting them to commit not to reveal their type if they learn they are good. Indeed, banks have indeed had a long tradition of secrecy in non-crisis times. For example, Gorton and Tallman (2015) document that prior to the establishment of the Federal Reserve, bank clearing houses went to great lengths to restrict what information was available about their member banks. As Prescott (2008)) observes, the Fed has maintained this secrecy by forbidding banks that do well on regulatory exams to release their results. He argues this custom can be optimal if banks have discretion on what to report to regulators, since disclosure may lead banks to volunteer less information. In our model, the virtue of opacity is instead due to the fact that it allows for insurance across banks, similarly to Goldstein and Leitner (2013) and Faria-e Castro, Martinez, and Philippon (2015). That is, if banks collude to never disclose their type, outsiders will fund all banks.

4.2 Multiple Equilibria

Proposition 2 above is concerned with the case where all equilibria involve non-disclosure, i.e. when contagion and disclosure costs are small and it is too tempting for a good bank to reveal its type and obtain better terms. However, equilibria with disclosure can arise even when non-disclosure is an equilibrium, i.e. when contagion and disclosure costs are large. In fact, in some cases a non-disclosure equilibrium exists and can be improved upon only if all banks disclosing is also an equilibrium. We pointed out one such case already, namely when $c = 0$ and disclosure is costless. In that case, a non-disclosure equilibrium represents a coordination failure in which no bank discloses only because it is pointless to do so when no other bank intends to disclose. This suggests mandatory disclosure may simply select a superior equilibrium. The next example illustrates that this is not true in general.

Example 1: Suppose there are 3 banks. Each is good with probability 0.9, independently of the others. Contagion is such that good banks default if even one other bank is bad. For example, fire sales might be such that if even one bank is forced to liquidate its assets, the price of the assets good banks hold falls enough to render all banks insolvent. Set the gross returns to outsiders and banks at $\underline{r} = 1$ and $R = 1.22$, respectively. These parameters ensure that a good bank will not be able to raise funds by revealing its type if the other two banks choose $\sigma_i = 0$, since

$$p_g R = (0.9)^2 \times 1.22 = 0.99 < 1 = \underline{r}$$

This ensures non-disclosure is an equilibrium. Finally, set $c = 0.16$. This ensures mandatory disclosure is preferable to the non-disclosure equilibrium where no bank is funded, since

$$(0.9)^3 \times 3(1.22 - 1) = 0.481 > 0.48 = 3c$$

We can verify numerically that a bank will be better off not disclosing its type for all values of σ_{-i}. For example, consider bank 1's best response to $(\sigma_2, \sigma_3) \in \{(0, 0), (0, 1), (1, 1)\}$. When neither bank discloses, bank 1 will prefer not to disclose since revealing its type is costly but will not convince outsiders to invest. When the two other banks both disclose if good, bank 1 will be able to raise funds even without disclosing when both other banks are in fact good. Since the cost of disclosure exceeds the gain from better terms, bank 1 again prefers not to disclose. When only one bank commits to disclosure, bank 1 must disclose its type to attract investment, but given the odds it will fail, it prefers not to disclose. The gain from disclosure for any pair $(\sigma_2, \sigma_3) \in [0, 1] \times [0, 1]$ is also negative. □

The fact that non-disclosure is the unique equilibrium in Example 1 suggests it will not be easy for banks to coordinate on mutual disclosure even though that would help all parties. Just as a cartel may find it hard to dissuade its members from cheating on quotas, banks may have a hard time enforcing disclosure by all. In principle, banks might be able to coordinate without resorting to an external enforcement entity like a government if banks could commit to punish one another. But the point remains that forcing banks to disclose may be more complicated than getting agents to coordinate, since non-disclosure may be a unique equilibrium even though it represents an inefficient outcome.

The fact that mandatory disclosure can make all banks better off but all banks disclosing is not an equilibrium may be surprising. In the remainder of this section, we show that this result reflects an important feature of our model: Although disclosure by one bank generates positive externalities for others, it will not in general encourage other banks to disclose. That is, disclosure decisions are generally not strategic complements.

To appreciate this point, we need to distinguish between the effect of a bank's *announcement* – observing $A_j = 1$ and thus learning bank j is good – and the effect of a bank's *strategy* – knowing bank j will disclose its type if good with a higher probability. The two are obviously related: A higher σ_j increases the odds we observe an announcement $A_j = 1$. But a higher σ_j also changes the informational content of observing $A_j = \varnothing$, since a higher σ_j implies a higher probability that bank j is bad when $A_j = \varnothing$. In general, the effect of an announcement that a bank is good on remaining banks is ambiguous. When types are positively correlated across banks, the announcement that some bank is good increases the probability that any remaining types are good. When types are negatively correlated, the opposite is true. For example, if we know there are exactly $b < n$ bad banks but not which banks are bad, an announcement that some bank is good would increase the odds each of the remaining banks is bad. By contrast, we show below that an increase in the probability σ_j always benefits remaining banks, although this does not mean they will be more inclined to disclose. The remainder of this section formally shows that both the effects of announcements and a higher probability of disclosing have ambiguous effects on the incentives for other banks to disclose.

4.3 The Effect of Announcements

As the above discussion suggests, the effects we are after – particularly those of announcements – depend on how bank types are correlated. This depends on the distribution $\pi(s)$. Formally, define an informational spillover as the effect of news that bank j is good on beliefs over good i. We will say that there are *positive informational spillovers* if, for any information set $\mathcal{I}$ that is compatible with some bank j being good, i.e. for which $\Pr(S_j = 1 \cap \mathcal{I}) > 0$, the distribution $\pi(s)$ implies

$$\Pr(S_i = 1 | A_j = 1 \cap \mathcal{I}) \geq \Pr(S_i = 1 | \mathcal{I}) \tag{12}$$

and if, in addition, there exists at least one set $\mathcal{I}$ for which inequality (12) is strict. Positive informational spillovers occur when bank types are positively correlated, so learning that one bank is good makes it more likely that other banks are also good. Analogously, we will say that there are *negative informational spillovers* if for any set $\mathcal{I}$ for which $\Pr(S_j = 1 \cap \mathcal{I}) > 0$,

$$\Pr(S_i = 1 | A_j = 1 \cap \mathcal{I}) \leq \Pr(S_i = 1 | \mathcal{I}) \tag{13}$$

and inequality (13) is strict for some $\mathcal{I}$. In this case, learning that one bank is good makes it less likely that other banks are good. Negative informational spillovers corresponds to the case where bank types are negatively correlated, as in the case when the total number of bad banks b is fixed so that when one bank is good some other bank must not be. Finally, we will say that there are *no informational spillovers* if for any set $\mathcal{I}$ for which $\Pr(S_j = 1 \cap \mathcal{I}) > 0$,

$$\Pr(S_i = 1 | A_j = 1 \cap \mathcal{I}) = \Pr(S_i = 1 | \mathcal{I}) \tag{14}$$

The absence of informational spillovers corresponds to the case where bank types are independent.

We begin with how news that $A_j = 1$ affects banks $i \neq j$. For simplicity, denote the investment in bank i as $I_i(A_i; A_j)$ rather than $I_i(A)$, even though investment depends on all announcements. This notation highlights the effect of bank j's announcement holding other announcements fixed.

The case of positive or no informational spillovers. In this case, news that one bank is good makes it easier for remaining banks to raise funds. Intuitively, if outsiders observe that $A_j = 1$, they would assign a higher probability that both bank i and any banks that bank i is exposed to are good, making them more likely to invest in bank i. This is confirmed in the following proposition:

Proposition 3: If informational spillovers are positive or absent, then $I_i(\varnothing; 1) \geq I_i(\varnothing; \varnothing)$ and $I_i(1; 1) \geq I_i(1; \varnothing)$, i.e. news that bank j is good encourages outsiders to fund bank i for any $A_i \in \{\varnothing, 1\}$.

Proposition 3 states that with positive or no informational spillovers, banks will be better off when another bank is revealed to be good. It does not tell us whether such news will encourage or discourage a bank to disclose its own type. To some extent, this is a moot question given our setup: By the time A_j is revealed, banks would have already made their disclosure decisions. However, banks choose their disclosure strategy anticipating what announcements will be made by others. What a bank's preferred action would be if certain other banks announced they were good is therefore relevant.

It turns out that whether news that another bank is good encourages or discourages other banks to disclose when they are good depends on whether a bank can raise funds when its type is uncertain. Our next result shows that if bank i expects not to raise funds if it does not reveal its type, then if some other bank is revealed to be good it will increase the gains to the bank i had it disclosed.

Proposition 4: Suppose informational spillovers are positive or absent. If $I_i(\varnothing; \varnothing) = I_i(\varnothing; 1) = 0$, then the gain to bank i from disclosure is weakly higher when $A_j = 1$ than when $A_j = \varnothing$.

Intuitively, if a bank cannot raise funds when outsiders are unsure of its type, disclosure may help it attract funds from outsiders. Since news that some other bank is good makes outsiders more optimistic about all banks, a good bank that reveals its type will earn higher profits if it attracts funds.

Proposition 4 tells us that if bank i cannot raise funds when its type is not known to outsiders, news that more banks are good would encourage bank i to disclose. However, Proposition 3 implies that as more banks are revealed to be good, bank i is more likely to obtain funding even if outsiders do not know its type. We now show that if bank i can raise funds even without revealing its type, news that more banks are good discourages bank i from disclosing.

Proposition 5: Suppose informational spillovers are positive or absent. If $I_i(\varnothing; \varnothing) = I_i(\varnothing; 1) = 1$, then the gain to bank i from disclosure is weakly lower when $A_j = 1$ than when $A_j = \varnothing$.

Intuitively, when a bank can raise funds even without disclosing its type, the gain from disclosure comes from reducing the interest it pays outside investors. But with positive informational spillovers, when others banks announce they are good, banks are charged lower rates. The more banks announce they are good, the lower the interest charges a bank can save by disclosing it is good.

Propositions 4 and 5 suggest banks may prefer to disclose if only a few banks are revealed as good but not to disclose if a large number of banks are revealed as good.[15] This suggests disclosure decisions cannot be characterized as either strategic complements or substitutes, since what a bank prefers depends on how many banks it expects will reveal themselves as good. We confirm this below when we show that the choices of σ_i cannot be generically described as either substitutes or complements.

The case of negative informational spillovers. With negative information spillovers, there is no analog to Propositions 3 and 4 above. To see why, let us return to the Caballero and Simsek (2012) model, and consider the effect of announcements by different banks on bank 1. If a bank in $\{n-k+1, n-k+2, ..., n\}$ is revealed to be good, outsiders will have more incentive to invest in bank 1; but if a bank in $\{2, 3, ..., n-k\}$ is revealed to be good, outsiders will have less incentive. Similarly, whether some other bank is revealed to be good makes bank 1 wish it had disclosed it is good when it cannot raise funds without disclosing depends on which bank is revealed as good. This reflects an important difference between negative and nonnegative informational spillovers. With nonnegative spillovers, news that some bank is good will be beneficial for bank i regardless of which bank it is: Outside investors raise their assessment that bank i is good as well as any banks that bank i is exposed to. With negative informational spillovers, which bank reveals itself to be good matters. Hence, there is no general results about announcement effects with negative informational spillovers.

However, we can still establish an analogous result to Proposition 5 even with negative informational spillovers. That is, news that a bank is good will have unambiguous implications when a bank can raise funds without revealing its type. The effect is now the opposite of what we found for nonnegative information spillovers, i.e. news that other banks are good encourages other banks to disclose:

Proposition 6: Suppose that informational spillovers are negative. If we have $I_i(\varnothing; \varnothing) = I_i(\varnothing; 1) = 1$ then the gain to bank i from disclosure is weakly higher when $A_j = 1$ than when $A_j = \varnothing$.

Intuitively, if a bank can raise funds without disclosing its type, the gain from disclosure comes from reducing the interest it has to pay. With negative spillovers, news that another bank is good will make outsiders more concerned that bank i is good. If they are still willing to invest in bank i, they will charge it a higher rate, and so the bank stands to gain more from disclosure.

[15] Propositions 4 and 5 omit case which $I_i(\varnothing; \varnothing) = 0$ and $I_i(\varnothing; 1) = 1$ (the case where $I_i(\varnothing; \varnothing) = 1$ and $I_i(\varnothing; 1) = 0$ is ruled out by Proposition 1). We show in the Appendix that in this case the gain to disclosure rises by no more than it would if $I_i(\varnothing; 1) = 0$ and falls no more than it would if $I_i(\varnothing; \varnothing) = 1$.

4.4 The Effect of Disclosure Strategies

So far, we have described the effect of news that a bank is good on other banks. This may seem like a natural way to describe interaction between banks that can be easily related to observable features like bank disclosures. But recall that the strategy each bank chooses is really the probability σ_i of announcing its type if it is good. It might seem as if the effect of increasing σ_i is similar to the effect of news that $A_i = 1$, since a high σ_i is just a promise to replace $A_i = \varnothing$ with $A_i = 1$ when bank i is good. But the two are not the same, since a commitment to a higher σ_j also changes the informativeness of $A_j = \varnothing$. Strategic interaction involves the how one bank's choice of σ_i affects other banks.

To appreciate the distinction, consider whether bank j choosing a higher σ_j would encourage outsiders to trade with banks $i \neq j$. Recall that if bank j is revealed to be good, outsiders will be more likely to trade with bank $i \neq j$ if informational spillovers are nonnegative, but they may be less like to trade with bank i if informational spillovers are negative. One might therefore expect that increasing σ_j will encourage trade with banks $i \neq j$ when informational spillovers are nonnegative. In fact, increasing σ_j encourages trade with other banks regardless of the nature of informational spillovers.

To see this, let us define $\mathcal{G}_i(\sigma)$ as the ex-ante expected total gains from trade between bank i and outsiders before S is revealed given the strategy profile $\sigma \equiv (\sigma_1, \ldots, \sigma_n)$. That is, given σ, we can compute the probability of observing different announcements A. Given each such announcement, outsiders will either fund bank i or not. If a bank is funded, outsiders incur an opportunity cost of $\underline{r}$, and the parties together receive R if bank i is solvent and 0 otherwise. Thus,

$$\begin{aligned} \mathcal{G}_i(\sigma) &= E\left[\left(1_{\{e_i \geq 0\}} R - \underline{r}\right) I_i(A) \,|\, \sigma\right] \\ &= \sum_{A \in \{\varnothing, 1\}^n} \left(\Pr(e_i \geq 0 | A, \sigma) R - \underline{r}\right) \, I_i(A) \, \Pr(A|\sigma) \end{aligned} \tag{15}$$

The higher is $\mathcal{G}_i(\sigma)$, the more outsiders and banks expect to jointly gain from being able to trade. However, since outsiders always earn the expected return $\underline{r}$, higher expected gains from trade imply that it will be bank i that is better off. Our next result shows an increase in σ_j will make bank i weakly better off ex-ante, regardless of the nature of informational spillovers.

Proposition 7: $\mathcal{G}_i(\sigma)$ is weakly increasing in σ_j for all $j \neq i$, i.e. the gains from trade outsiders expect to achieve are always weakly increasing in the probability that banks $j \neq i$ discloses its type.

The fact that Proposition 7 holds even when informational spillovers are negative may seem surprising at first. If news that some other bank is good causes outsiders to infer bank i is more likely to be bad, why wouldn't an increase in the probability that bank j announces it is good similarly discourage trade? The reason is that even though an announcement of $A_j = 1$ may discourage outsiders from trading with bank i, an announcement of $A_j = \varnothing$ may encourage trade. Essentially, outsiders want to trade with bank i only when its equity is positive, and a higher σ_j helps them identify when bank i is likely to repay. Thus, bank i is more likely to obtain its funding when such funding is profitable.

Proposition 7 highlights the externality behind our welfare results: When a bank discloses, it facilitates trade between outsiders and other banks, something it will not take into account when contemplating disclosure. This suggests too little disclosure. However, since investment also benefits senior debt holders, more disclosure is not always necessarily better.

While disclosure by one bank benefits others, it does not necessarily follow that banks will be able to coordinate to all disclose information. That hinges on whether a higher σ_j encourages other banks to disclose their own type. Above we argued that announcement effects suggest disclosure is not in general a strategic substitute or complement. The following numerical example illustrates that bank i's incentive to disclose is also not monotonic in the probability that other banks disclose.

Example 2: Consider Example 1 above, but with 10 banks. Each bank is good with probability 0.9 independently of other banks. Again, a good bank will default if even one bank is bad. Set the returns to outsiders and banks at $\underline{r} = 1$ and $R = 2.55$, respectively. These values ensure that if no other bank discloses its type, outsiders would not invest in a bank even if it disclosed its type. That is, if a bank unilaterally reveals it is good, outsiders expect to be repaid only if all other 9 banks are bad, which occurs with probability $(0.9)^9 = 0.387$, and $(0.9)^9 \times 2.55 = 0.99 < \underline{r}$. At the same time, if all other banks disclose, outsiders would trade with a bank of uncertain type since $0.9 \times 2.55 = 2.30 > \underline{r}$. We also set $c = 0.5$, although this choice has no bearing on the results we focus on.

Consider the case where all banks other than i disclose with the same probability σ^*. Since bank types are independent in this example, our discussion of announcement effects would suggest that increasing σ^* from 0 would encourage bank i to disclose, but that this effect should taper off at higher σ^* when bank i ought to be able to raise funds without disclosing its type. Figure 3 plots the gain to bank i from disclosing it is good as a function of σ^*, assuming outsiders expect bank i not to disclose. Bank i indeed gains less from disclosure when $\sigma^* = 0$ than when $\sigma^* = 1$. Moreover, the gains from disclosure seem to generally rise faster with σ^* at low values of σ^*. But as σ^* ranges from 0 to 1, the gains to disclosure rise and fall multiple times. This is because as we increase σ^*, outsiders grow more reluctant to invest in bank i unless enough other banks announce they are good. The local minima in Figure 1 occur at values of σ^* in which there are jumps in the threshold number of banks needed to induce outsiders to invest in bank i when it fails to disclose. $\square$

To recap, when one bank chooses a higher σ_j, other banks will be better off ex-ante, but they will not necessarily be more inclined to also disclose. Thus, even if all banks might be better off disclosing, without an enforcement mechanism they may not be able to coordinate among themselves to all disclose. In particular, non-disclosure can be the unique equilibrium even when mandatory disclosure is welfare improving. At its core, then, the problem that mandatory disclosure can correct is too little disclosure when each bank's private information has systemic importance rather than coordination failures.

5 Adding Moral Hazard

The model we presented up to now offers a stark conclusion: Mandatory disclosure can be desirable in crisis times when markets are frozen but not when banks can raise funds when no information is revealed. However, our model ignores various frictions that might justify intervention when markets operate normally. The argument for routinely disclosing strees tests in Bernanke (2013b) refer to a need for market discipline that is missing from our benchmark model. We now consider a version of the model in which banks can engage in a particular form of moral hazard. The key insight from this version is that mandatory disclosure can be desirable in normal times, but only when there is sufficient contagion. A secondary insight is to show that it is possible to relax assumption A5.

We introduce moral hazard in a particularly simple way by assuming banks can divert new funds they raise to achieve a private benefit. Diversion is meant to stand in for various actions banks can undertake that are not in the interest of investors. At the same time, we assume banks cannot divert the assets they already own, and that these can be seized by outsiders. Initial equity can thus mitigate moral hazard problems, since banks that engage in moral hazard can be deprived of equity.

We modify the model in Section 2 as follows. As before, nature chooses S, each bank i observes S_i, and banks play a simultaneous-move disclosure game. Investors observe announcements A and offer terms $\{I_i(A), r_i(A)\}$ to the different banks. If outsiders invest in banks, they give up the option to earn $\underline{r}$, i.e. there is a time limit on when they can exercise their outside option. After outsiders invest, banks learn the state S if they don't already know it from A. At this point, banks must decide whether divert the funds they raise from outside investors. That is, they can either initiate the project with return $R > \underline{r}$, or divert the funds and earn a private benefit v that accrues only to the bank.

The equity of each bank i prior to initiating their project depends on $e_i(S)$, which we continue to assume satisfies A2-A4. However, it will be useful to reframe A2 as follows. Let $\overline{e}$ denote the highest possible equity a bank can have, i.e.

$$\overline{e} \equiv \max_{\{s:\pi(s)>0\}} e_i(s) \tag{16}$$

A2 is equivalent to the restriction that there exists some s_{-i} for which $e_i(1, s_{-i}) < \overline{e}$. While we no longer impose condition A5, we do impose that v is neither too big nor too small:

A6. Binding Moral Hazard: The value of private benefits v satisfies

$$R - \underline{r} < v < R - \max\{\underline{r} - \overline{e}, 0\} \tag{17}$$

The first inequality in (17) implies that if bank i knew that its equity before undertaking the project $e_i(S) \leq 0$, it would divert funds, since the most it can earn from the project is $R - \underline{r}$. The second inequality implies that if a bank knew its equity $e_i(S) = \overline{e}$, it would initiate the project. Since the interest rates banks are charged in equilibrium depend on A, each bank will have a threshold level of equity $e_i^*(A) \in (0, \overline{e})$ as a function of A above which it prefer the project and below which it would divert. Note that the model in Section 2 is just a special case of this model in which $v = -\infty$.

After banks decide what to do with any funds they raised, payoffs are realized and banks pay their obligations. Outsiders who invested in banks but are not paid back can go after the equity banks have. We continue to assume that outsider claims are junior to any of the bank's other outstanding liabilities. Thus, if a bank has negative equity, outside investors will be unable to recover anything from it.

As in Section 3, we ask whether a non-disclosure equilibrium exists and if so when mandatory disclosure can improve upon it. Outside investors will expect a bank they fund to default with probability

$\Pr(e_i < e_i^*(A)|A, \sigma)$, although if $0 < e_i(S) < e_i^*(A)$ outsiders can still seize some of the bank's remaining equity. Bank i's payoff is no longer given by (6) but by

$$E[e_i(S) + I_i(A) \max\{R - r_i(A), v - e_i(S)\} \mid A, S_i] - c\alpha_i \tag{18}$$

We will not analyze the disclosure game under this new payoff function. Instead, we present an example which illustrates that mandatory disclosure can play a useful role when markets are not frozen, i.e. when outsiders invest in banks even when no bank is willing to reveal its type.

Example 3: Consider the case where the equity of a good bank before raising any funds is either negative or equal to $\overline{e}$. This condition is analogous to A5 in that we can determine whether a bank defaults based on the realization of S without knowing whether other banks are funded. In particular, the probability outsiders will be paid back by bank i is still given by $p_g \equiv \Pr(e_i \geq 0|S_i = 1)$. As before, when outsiders expect no bank to disclose, bank i will be funded regardless of whether it discloses if

$$p_g > \frac{1}{\Pr(S_i = 1)} \frac{\underline{r}}{R} \tag{19}$$

Non-disclosure would be an equilibrium in this case only if the cost of disclosure c exceeded the reduction in interest charges a bank could obtain from disclosure, i.e. if

$$c > \frac{\Pr(S_i = 0)}{\Pr(S_i = 1)} \underline{r} \tag{20}$$

Thus, when (19) and (20) both hold, there exists a non-disclosure equilibrium in which all banks are funded. In our benchmark model, if all banks could obtain funding without disclosure, mandatory disclosure could only make things worse. By contrast, now mandatory disclosure can prevent outsiders from investing in banks that divert resources for private gains. When $v < \underline{r}$, diversion is wasteful – surplus would have been larger if resources were invested in the alternative option available to outsiders – so avoiding it increases surplus. Here it is important that outsiders give up the right to exercise their outside option once they committed their funds to a bank, since it precludes banks from renegotiating with outsiders after learning S. Since the expected fraction of banks that divert is $1 - p_g \Pr(S_i = 1)$, mandatory disclosure increases surplus when there are enough banks that create waste, i.e.

$$[1 - p_g \Pr(S_i = 1)](\underline{r} - v) > c \tag{21}$$

Combining (20) and (21), there will exist values of c that satisfy both conditions whenever

$$p_g \Pr(S_i = 1) \leq 1 - \frac{\Pr(S_i = 0)}{\Pr(S_i = 1)} \frac{\underline{r}}{\underline{r} - v} \tag{22}$$

Condition (22) tells us that as long as $p_g \Pr(S_i = 1)$ is not too big, meaning that enough banks are likely to be insolvent, mandatory disclosure can increase surplus by preventing wasteful diversion. However, (19) implies that no disclosure with all banks obtaining funding is only an equilibrium if enough banks are solvent. Combining (19) and (22), there exist values of p_g such that both no disclosure with all obtaining funding is an equilibrium and mandatory disclosure increase surplus whenever

$$\frac{\Pr(S_i = 0)}{\Pr(S_i = 1)} < \left(1 - \frac{r}{R}\right)\left(1 - \frac{v}{\underline{r}}\right) \tag{23}$$

Under (23), there exist values of p_g – and thus patterns of interconnections among banks – such that even when banks can raise funds without disclosing any information, it would be desirable to force banks to provide information about their asset purchases. Intuitively, banks do not take into account that by committing to disclose when good they help investors avoid insolvent banks. □

Example 3 affirms the intuition in Bernanke (2013b) that it may be desirable to force banks to disclose information even in non-crisis periods. The benefit of disclosure in this case is not to stimulate trade, as is the case when markets are frozen, but to discourage socially wasteful investment, which can be viewed as the market disciplining role that Bernanke alludes to. However, the next result shows that contagion is still necessary for intervention to be desirable:

Theorem 2: Suppose A1 - A4, and A6 hold. If a non-disclosure equilibrium exists, then

(i) There exists a cutoff $e^* \in (0, \overline{e})$ such that if $\Pr(e_i > e^* \mid S_i = 1)$ is sufficiently close to 0 but strictly positive, mandatory disclosure can improve upon this equilibrium as $c \to 0$.

(ii) If $\Pr(e_i = \overline{e} \mid S_i = 1)$ is sufficiently close to 1, mandatory disclosure cannot improve welfare relative to the non-disclosure equilibrium for any $c \geq 0$.

In comparing this result to Theorem 1, recall that we can interpret our benchmark model as a special case of the model with moral hazard where $v = -\infty$. Imposing A6 allows us to drop A5, i.e. we do not need to assume that the distribution of equity before banks initiate projects exhibits a gap. Avoiding the gap also clarifies the role of contagion, since part (ii) of Theorem 2 makes clear that the condition which rules out a role for mandatory disclosure is that a good bank is very likely to have its equity equal to the maximum level $\overline{e}$, i.e. it is unlikely to be affected by exposure to other banks. The necessity of contagion is due to the fact that when information is valuable, banks have an incentive to reveal it. Contagion ensures that a bank's information is systemically important, so that banks fail to fully take the benefits of disclosure into account. A need for market discipline on its own may not justify forcing banks to disclose information they would otherwise choose not to reveal.

6 Balance Sheet Contagion

So far, we have described contagion through $e_i(s)$. This formulation makes it easy to lose sight of how contagion depends on economic primitives. We therefore conclude our discussion with an extended example to highlight how the relevant measure of contagion depends on the economic environment. A novel implication of this example is that it reveals how the justification for mandatory disclosure may vanish once other financial reforms are instituted. This runs counter to conventional wisdom expressed by some policymakers that mandatory disclosure complements other financial reforms.

Our example involves a model of balance sheet contagion in which contagion arises when banks whose balance sheets are impaired default on other banks whose balance sheets are not directly affected. Our formulation follows Eisenberg and Noe (2001). Each bank is endowed with $\overline{e} > 0$ worth of assets as well as a series of claims and obligations to other banks. Formally, we let Λ denote the $n \times n$ matrix of obligations between any pair of banks, so that Λ_{ij} corresponds to the amount bank i owes bank j. The diagonal terms are all zero. As in Example 5, we assume each bank has zero net position, i.e.

$$\sum_{j \neq i} \Lambda_{ij} = \sum_{j \neq i} \Lambda_{ji} \tag{24}$$

for each $i \in \{1, \ldots, n\}$. We take these claims as given, although in principle banks would choose the claims the obligations they want to enter in; this line is explored in Zawadowski (2013). To satisfy A3, we would need to assume the links implied by Λ represent a symmetric network. However, this assumption is not necessary for the main result we derive.[16]

Once again, let q_b denote the probability that exactly b banks are bad. In line with A1, given b, we assume each of the $\binom{n}{b}$ groups of b banks is equally likely to be those that are bad. What distinguishes bad banks is that they each incur a loss of magnitude $\phi > \overline{e}$. The simplest way to interpret ϕ is as an obligation to a senior claimant that has priority over any of the banks. As before, we let S_i reflect bank i's type, i.e. S_i is equal to 1 if bank 1 is bad and 0 otherwise.

Ignoring transfers between banks, a bad bank would see its equity position fall to a negative $\overline{e} - \phi$. However, the final equity position of a bank will depend on payments to and from other banks. Let $x_{ij}(S)$ denote the amount bank i pays bank j in state S. Following Eisenberg and Noe (2001), we define an equilibrium clearing payment as a set of payments $x_{ij}(S)$ in which each bank i pays all of his obligations ϕ and Λ_{ij} in full or else pays claims according to prescribed priority, and pays those with equal priority on a pro-rata basis, i.e. in proportion to its obligations to each of the banks.

Formally, define Λ_i as the total obligations of bank i to other banks, i.e.

$$\Lambda_i = \sum_{j=1}^{n} \Lambda_{ij}$$

The equilibrium payments $x_{ij}(S)$ in state S will solve the system of equations

$$x_{ij}(S) = \frac{\Lambda_{ij}}{\Lambda_i} \max\left\{0, \min\left\{\Lambda_i, \overline{e} - \phi S_i + \sum_{k=1}^{n} x_{ki}(S)\right\}\right\} \tag{25}$$

Hence, the equity position of each bank, before it attracts funds from outside investors, which the bank may not know, is given by

$$e_i(S) = \overline{e} - \phi S_i + \sum_{k=1}^{n} x_{ki}(S) - \sum_{j=1}^{n} x_{ij}(S) \tag{26}$$

[16] Caballero and Simsek (2012) consider a network that is not only symmetric but also circular, i.e. each bank is obligated to only one other bank. Barlevy and Nagaraja (2015) derive analytical expressions for the relevant measure of contagion in this case with a random number of bad banks. Since we consider a more general Λ we have no analytical expressions, but we can still derive comparative static results.

The expression in (26) confirms that this model gives rise to a reduced form in which we can assign an equity endowment to each bank in each state of the world. Moreover, we can now relate the endowment $e_i(S)$ to economic parameters such as the size of the loss ϕ at bad banks and the obligations Λ_{ij} among banks. To characterize this dependence, let us index the matrix of obligations across banks Λ by a scaling factor λ so that $\Lambda(\lambda) = \lambda\Lambda(1)$. That is, the scalar λ multiplies each entry of the baseline matrix $\Lambda(1)$. A higher λ increases obligations between all banks proportionately. The next proposition formalizes the way equity $e_i(S)$ depends on the magnitude of losses at bad banks ϕ and the magnitude of debt obligations across banks as scaled by λ.

Proposition 8: For every $x \in [0, \overline{e}]$, $\Pr(e_i \leq x | S_i = 1)$ is weakly increasing in ϕ and λ, i.e the distribution of equity is stochastically decreasing in ϕ and λ.

As Theorem 2 makes clear, the relevant measure of contagion that matters for the desirability of mandatory disclosure is the distribution of equity at good banks. Proposition 8 thus reveals what features exacerbate contagion and may create a role for policy intervention. In particular, contagion will be more severe the larger the losses ϕ of bad banks, as well as the greater the debt obligations λ between banks. The latter implies that restrictions on leverage that place limits on λ may reduce the need for mandatory disclosure. This implies that reforms such as leverage restrictions can obviate the justification for mandatory disclosure rules rather than complement these rules. Such a finding contradicts the claim among some policymakers that releasing stress test results naturally complements financial reforms that seek to restrict leverage among financial intermediaries.

7 Conclusion

One of lessons policymakers seem to have drawn from the recent financial crisis is that mandatory disclosure of bank balance sheets can be a useful tool. Specifically, a consensus has emerged that the release of stress test results for large banks played an important role in stabilizing financial markets in the US. Although the release of stress test results for European did not seem to have the same salutatory effect, for a variety of reasons, policymakers have continued conducting these tests and releasing their results. As crisis conditions mitigated in the US, policymakers continued to advocate for such disclosure, citing it as a naturally complement to existing regulatory policy.

This paper tackled the question of why it might be necessary to compel banks to disclose information rather than rely on them to disclose the information on their own. We argue that there can be a role for mandatory disclosure when there is sufficient contagion across banks. This, rather than markets being frozen or moral hazard problems that can arise with incomplete information, is what proves to be the decisive factor for whether such a policy can increase welfare. At the same time, even with contagion, our model does not imply that mandatory disclosure is always and everywhere desirable.

We conclude with a few comments and caveats about our analysis. First and foremost, our model does not imply mandatory disclosure constitutes an optimal policy. Our results establish conditions under which mandatory disclosure can increase welfare, but not how optimal disclosure policy ought to be structured. Goldstein and Leitner (2013) conduct an analysis of the latter, studying how to optimally release information assuming only the government can commit to such a disclosure rule. Their results suggest that even when disclosing information is desirable, some opacity might be optimal. This coincides with the fact that historically, the private sector solution implemented by clearinghouses often involved less transparency during crises, providing just enough information about the system as a whole to encourage investment in banks without revealing too much about individual banks. Questions about what type of information bank examiners should release are just as important as when there might be a need to compel information that isn't provided by the market.

Second, in our quest for analytical tractability, we have ignored various practical issues involved with the design of disclosure policy. For example, we invoked symmetry restrictions to simplify the analysis. But in practice banks differ in important ways, which raises the question of which banks should be forced to disclose information. Our analysis suggests that banks whose information is the most systemically important in terms of affecting other banks are those that are most likely to disclose too little. But demonstrating this requires working with asymmetric environments. Still another question is what type of information should be collected. Our specification assumes that the only relevant information are bank balance sheets, since once we know each bank's type the equity position of each bank is known. In practice, though, the linkages between banks may also be private information, raising the question of what optimal disclosure might be when information on both bank types and how banks are linked is initially private but might be elicited and made public.

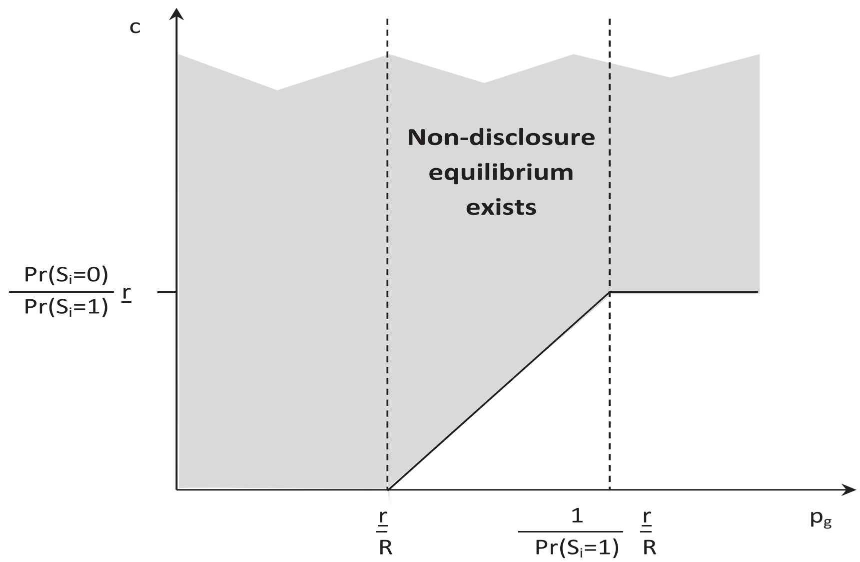

Figure 1: Values of (p_g, c) for which non-disclosure is an equilibrium

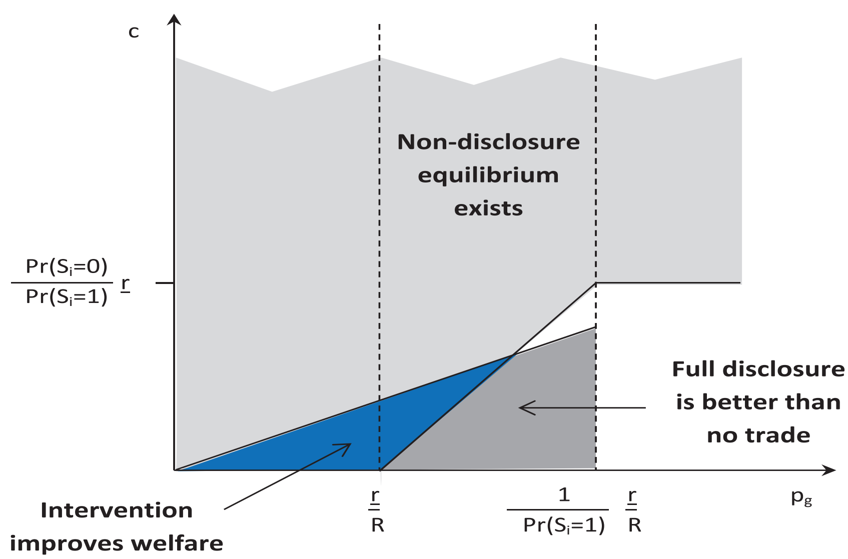

Figure 2: Values of (p_g, c) in which mandatory disclosure improves welfare

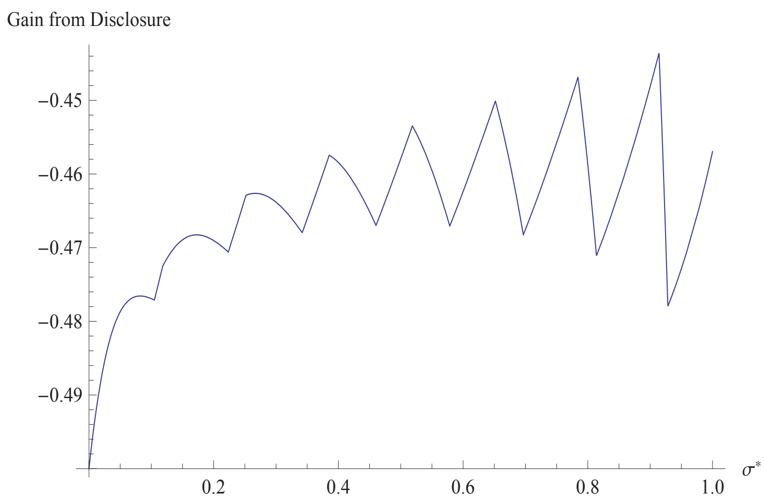

Figure 3: Gains from disclosure as a function of σ^* chosen by other banks

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Proofs

Proof of Proposition 1: Derivation in text.

Proof of Theorem 1: The cases where $p_g < \frac{r}{R}$ and $p_g > \frac{1}{\Pr(S_i=1)}\frac{r}{R}$ are described in the text. Note that part (ii) follows directly from the analysis fo the latter case supplied in the text. We therefore only need to consider the intermediate case where $p_g \in \left(\frac{r}{R}, \frac{1}{\Pr(S_i=1)}\frac{r}{R}\right)$. From Proposition 1, we know that in this case, a non-disclosure equilibrium involves no trade. The conditions for a non-disclosure equilibrium to exist and for mandatory disclosure to improve upon no trade can be summarized as

$$p_g \Pr(S_i = 1)(R - \underline{r}) \leq c \leq p_g R - \underline{r} \tag{27}$$

For this inequality to be valid, we need

$$p_g \Pr(S_i = 1)(R - \underline{r}) < p_g R - \underline{r}$$

which after rearranging implies

$$p_g \leq \frac{\underline{r}}{\Pr(S_i = 0)R + \Pr(S_i = 1)\underline{r}} \tag{28}$$

Define

$$p_g^* \equiv \min\left\{\frac{1}{\Pr(S_i = 1)}\frac{r}{R}, \frac{\underline{r}}{\Pr(S_i = 0)R + \Pr(S_i = 1)\underline{r}}\right\} \tag{29}$$

Note that both expressions on the RHS above are greater than $\frac{r}{R}$, so $p_g^* > \frac{r}{R}$ as claimed. If $p_g < p_g^*$, then either $p_g \leq \frac{r}{R}$, in which case a non-disclosure equilibrium exists and can be improved upon for any $c \geq 0$, or else (27) can be satisfied for a nonempty interval of values for c.

Finally, we need to show that $p_g^* < 1$. Since $R > \underline{r}$, we know the second expression is less than 1, which implies the minimum of it and another expression must also be less than 1. The claim follows.

Proof of Proposition 2: We know from Kreps and Wilson (1982) that the dynamic incomplete information game in which banks choose offers must have a sequential equilibrium. Since Proposition 1 rules out the possibility of a non-disclosure equilibrium, there must exist some i such that $\sigma_i > 0$.

To show that this equilibrium can be improved upon, note that if we force all banks to set $\sigma_j = 0$, we can ensure all banks raise funds. Hence, we maximize total surplus that can be created. In addition, we reduce the utility cost associated with disclosure, since $\sigma_j = 0$ implies $\alpha_j = 0$. Forcing all agents to hide their type thus allows us to make all agents at least as well off and some strictly better off than under the original equilibrium.

Prelude to proving Propositions 3-5: We begin with a lemma which shows that when informational spillovers are positive or missing, outsiders assign a weakly higher likelihood that bank 1 will repay if they know that bank 2 than if bank 2 made no announcement.

Appendix Lemma 1: For any information set $\mathcal{I} \equiv (\sigma, \{A_j\}_{j\neq 2})$ such that $\Pr(A_2 = 1|\mathcal{I}) > 0$ and $\Pr(A_2 = \varnothing|\mathcal{I}) > 0$, if informational spillovers are positive or missing, then

$$\Pr\left(e_1 \geq 0\,|A_2 = 1, \mathcal{I}\,\right) \geq \Pr\left(e_1 \geq 0\,|A_2 = \varnothing, \mathcal{I}\,\right) \tag{30}$$

Proof of Appendix Lemma 1: We first explain the need to restrict our result to information sets $\mathcal{I}$ for which $\Pr(A_2 = 1|\mathcal{I}) > 0$ and $\Pr(A_2 = \varnothing|\mathcal{I}) > 0$. Neither condition will necessarily hold for any information set. For example, if $\sigma_2 = 0$, bank 2 will never announce $A_2 = 1$. Even if $\sigma_2 > 0$, it will not always be possible for bank 2 to be good for an arbitrary information set $\mathcal{I}$. For example, if $q_0 = 0$, i.e. at least one bank is always bad, and $A_j = 1$ for all $j \neq 2$, then bank 2 must be bad. Likewise, there are conditions that would imply bank 2 must be good, and if $\sigma_2 = 1$ then we would never observe $A_2 = \varnothing$. Thus, we cannot consider arbitrary information sets.

The LHS of (30), $\Pr\left(e_1 \geq 0|A_2 = 1, \mathcal{I}\right)$, can be written as

$$\begin{aligned} &\Pr\left(e_1 \geq 0|S_1 = 1, A_2 = 1, \mathcal{I}\right)\Pr\left(S_1 = 1|A_2 = 1, \mathcal{I}\right) + \\ &\quad \Pr\left(e_1 \geq 0|S_1 = 0, A_2 = 1, \mathcal{I}\right)\Pr\left(S_1 = 0|A_2 = 1, \mathcal{I}\right) \end{aligned}$$

However, $\Pr\left(S_1 = 0|A_2 = 1, \mathcal{I}\right) = 0$, and A4 implies $\Pr\left(e_1 \geq 0\,|S_1 = 0, \mathcal{I}\,\right) = 0$. Hence, we have

$$\Pr\left(e_1 \geq 0\,|A_2 = 1, \mathcal{I}\,\right) = \Pr\left(e_1 \geq 0|S_1 = 1, A_2 = 1, \mathcal{I}\right)\Pr\left(S_1 = 1|A_2 = 1, \mathcal{I}\right)$$

Likewise, since A4 implies $\Pr\left(e_1 \geq 0\,|S_1 = 0, \mathcal{I}\,\right) = 0$, we can conclude that

$$\Pr\left(e_1 \geq 0\,|A_2 = \varnothing, \mathcal{I}\,\right) = \Pr\left(e_1 \geq 0|S_1 = 1, A_2 = \varnothing, \mathcal{I}\right)\Pr\left(S_1 = 1|A_2 = \varnothing, \mathcal{I}\right)$$

Consider first the case with no informational spillovers. Recall that this implies that for any information set $\mathcal{I}$, $\Pr\left(S_i = 1|A_j = 1, \mathcal{I}\right) = \Pr\left(S_i = 1|\mathcal{I}\right)$. If we set $\mathcal{I}$ to the empty set, then the conditional that there are no informational spillovers implies that S_i and S_j are independent. It follows that

$$\Pr\left(S_1 = 1|A_2 = 1, \mathcal{I}\right) = \Pr\left(S_1 = 1|A_2 = \varnothing, \mathcal{I}\right) = \Pr(S_1 = 1)$$

Since we are requiring that $\Pr(A_2 = 1|\mathcal{I}) > 0$, it follows that $\Pr(S_2 = 1) > 0$, since we cannot observe an announcement that bank 2 is good unless it truly is. Symmetry then implies $\Pr(S_1 = 1) > 0$.

Substituting our expressions into (30) and cancelling $\Pr(S_1 = 1)$ allows us to rewrite (30) as

$$\Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = 1, \mathcal{I}\right) \geq \Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = \varnothing, \mathcal{I}\right) \tag{31}$$

Let K denote the set of banks $j \geq 3$ that don't disclose their type, i.e. $K \equiv \{k \geq 3 : A_k = \varnothing\}$. We can write $\Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = 1, \mathcal{I}\right)$ as a sum over all possible realizations $(s_3, \ldots, s_n) \in \{0,1\}^{n-2}$:

$$\sum_{(s_3,\ldots,s_n)} 1_{\{e_1(1,1,s_3,\ldots,s_n)\geq 0\}} \prod_{k\in K} \Pr\left(S_k = s_k \left| \mathcal{I}\right.\right) \tag{32}$$

where $1_{\{e_1(s)\geq 0\}}$ is an indicator equal to 1 if equity is positive when the state $S = s$ and 0 otherwise. Similarly, we can write $\Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = \varnothing, \mathcal{I}\right)$ as

$$\begin{aligned} &\sum_{(s_3,\ldots,s_n)} 1_{\{e_1(1,1,s_3,\ldots,s_n)\geq 0\}} \cdot \Pr\left(S_2 = 1\right) \prod_{k\in K} \Pr\left(S_k = s_k | \mathcal{I}\right) + \\ &\sum_{(s_3,\ldots,s_n)} 1_{\{e_1(1,0,s_3,\ldots,s_n)\geq 0\}} \cdot \Pr\left(S_2 = 0\right) \prod_{k\in K} \Pr\left(S_k = s_k | \mathcal{I}\right) \end{aligned} \tag{33}$$

Since A2 implies $e_1\left(1,1,s_3,...,s_n\right) \geq e_1\left(1,0,s_3,...,s_n\right)$, it follows that for any vector $(s_3,\ldots,s_n)$, the expression $1_{\{e(1,1,s_3,\ldots,s_n)\geq 0\}}$ is greater than or equal to

$$\Pr\left(S_2 = 1\right) 1_{\{e(1,1,s_3,\ldots,s_n)\geq 0\}} + \Pr\left(S_2 = 0\right) 1_{\{e(1,0,s_3,\ldots,s_n)\geq 0\}}$$

Hence, the expression multiplying $\prod_{k\in K} \Pr\left(S_k = s_k | \mathcal{I}\right)$ in (32) exceeds the expression multiplying this same term in (33). From this, it follows that (31) holds, which in turn implies condition (30).

We now consider the case of positive informational spillovers. This implies that for any admissable information set $\mathcal{I}$, $\Pr\left(S_1 = 1 | A_2 = 1, \mathcal{I}\right) \geq \Pr\left(S_1 = 1 | A_2 = \varnothing, \mathcal{I}\right)$. Recall that we can rewrite (30) as

$$\begin{aligned} &\Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = 1, \mathcal{I}\right) \Pr\left(S_1 = 1 | A_2 = 1, \mathcal{I}\right) \geq \\ &\quad \Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = \varnothing, \mathcal{I}\right) \Pr\left(S_1 = 1 | A_2 = \varnothing, \mathcal{I}\right) \end{aligned} \tag{34}$$

Hence, to establish (30), it would suffice to show that

$$\Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = 1, \mathcal{I}\right) \geq \Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = \varnothing, \mathcal{I}\right) \tag{35}$$

since this would imply that the LHS of (34) is a product of two terms, each of which is greater than or equal to the respective term on the RHS of (34). Once again, rewrite $\Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = 1, \mathcal{I}\right)$ as a sum over all realizations $(s_3, \ldots, s_n) \in \{0,1\}^{n-2}$:

$$\sum_{(s_3,\ldots,s_n)} 1_{\{e(1,1,s,\ldots,s_n)\geq 0\}} \Pr\left(S_3 = s_3, \ldots, S_n = s_n | S_1 = 1, A_2 = 1, \mathcal{I}\right)$$

Similarly, we can write $\Pr\left(e_1 \geq 0 | S_1 = 1, A_2 = \varnothing, \mathcal{I}\right)$ as

$$\begin{aligned} &\sum_{(s_3,\ldots,s_n)} 1_{\{e_1(1,1,s_3,\ldots,s_n)\geq 0\}} \Pr\left(S_2 = 1, \ldots, S_n = s_n | S_1 = 1, A_2 = \varnothing, \mathcal{I}\right) + \\ &\sum_{(s_3,\ldots,s_n)} 1_{\{e_1(1,0,s_3,\ldots,s_n)\geq 0\}} \Pr\left(S_2 = 0, \ldots, S_n = s_n | S_1 = 1, A_2 = \varnothing, \mathcal{I}\right) \end{aligned}$$

To show that the first expression above is larger, consider state $\underline{S} = (1,0,...,0)$. If $e_1\left(\underline{S}\right) \geq 0$, then per assumption A2, we can conclude that $e_1(S) \geq 0$ for all S for which $\Pr(S|S_1 = 1) > 0$. In this case, both expressions above are equal to 1 and condition (35) holds trivially.

If instead $e_1(\underline{S}) < 0$, then we claim that for each state S where $e_1(S) \geq 0$, it must be the case that

$$\Pr(S|S_1 = 1, A_2 = 1, \mathcal{I}) \geq \Pr(S|S_1 = 1, A_2 = \varnothing, \mathcal{I})$$

To see this, observe that $e_1(S) \geq 0$ only if $S \geq \underline{S}$ per A4, which implies that $e_1(S) \geq 0$ only when $S_1 = 1$. Positive informational spillovers then implies that

$$\Pr(S|S_1 = 1, S_2 = 1, \mathcal{I}) \geq \Pr(S|S_1 = 1, S_2 = 0, \mathcal{I}) \tag{36}$$

as long as $\Pr(S_1 = 1, S_2 = 1, \mathcal{I}) > 0$. The latter follows from our restriction that $\Pr(A_2 = 1|\mathcal{I}) > 0$. But since $\Pr(S|S_1 = 1, A_2 = \varnothing, \mathcal{I})$ is a weighted average between $\Pr(S|S_1 = 1, S_2 = 1, \mathcal{I})$ and $\Pr(S|S_1 = 1, S_2 = 0, \mathcal{I})$, it follows that

$$\Pr(S|S_1 = 1, S_2 = 1, \mathcal{I}) \geq \Pr(S|S_1 = 1, A_2 = \varnothing, \mathcal{I})$$

The claim thus follows.

Proof of Proposition 3: Recall that $I_1(A_1, \ldots, A_n)$ is weakly increasing in $\Pr(e_1 \geq 0 \,|A, \sigma)$. But from Appendix Lemma 2, we know that

$$\Pr(e_1 \geq 0 \,|A_2 = 1, \mathcal{I}) \geq \Pr(e_1 \geq 0 \,|A_2 = \varnothing, \mathcal{I})$$

for any $\mathcal{I} = \{\sigma, \{A_j\}_{j \neq 2}\}$. Since this is true for any vector of announcements A, this includes vectors where $A_1 = \varnothing$ and $A_1 = 1$ (or, alternatively, $S_1 = 1$ if bank 1 never discloses it is good). From this, we can deduce that

$$\Pr(e_1 \geq 0 \,|A_1 = \varnothing, A_2 = 1, A, \{\sigma_j\}) > \Pr(e_1 \geq 0 \,|A_1 = \varnothing, A_2 = \varnothing, A, \sigma)$$

which implies $I_1(\varnothing, 1) \geq I_1(\varnothing, \varnothing)$, and

$$\Pr(e_1 \geq 0 \,|A_1 = 1, A_2 = 1, A, \sigma) > \Pr(e_1 \geq 0 \,|A_1 = \varnothing, A_2 = \varnothing, A, \sigma)$$

which implies $I_1(1, 1) \geq I_1(1, \varnothing)$, as claimed.

Proof of Proposition 4: Suppose $I_1^*(\varnothing; \varnothing) = I_1^*(\varnothing; 1) = 0$. If bank i disclosed it was good, its gain from disclosure would correspond to the expected profits is could retain using the funds it raises minus the cost of disclosure, i.e.

$$[\Pr(e_1 \geq 0|A_1 = 1, A_2, \mathcal{I}) R - \underline{r}] \, I_1(A_1 = 1, A_2, \mathcal{I}) - c \tag{37}$$

By Appendix Lemma 2, we know that

$$\Pr(e_1 \geq 0|A_2 = 1, A_2 = 1, \mathcal{I}) \geq \Pr(e_1 \geq 0|A_2 = \varnothing, A_2 = \varnothing, \mathcal{I})$$

In addition, Proposition 3 tells us that

$$I_1^*(1; 1) \geq I_1^*(1; \varnothing)$$

From these two inequalities, we can deduce that the gain (37) is higher given $A_2 = 1$ than $A_2 = \varnothing$.

Proof of Proposition 5: Suppose $I_1(\varnothing; \varnothing) = I_1(\varnothing; 1) = 1$. The gain in this case is the reduction in interest charges bank 1 would pay if it had equity net of the cost of disclosure c, i.e.

$$\Pr(e_1 \geq 0|A_1 = 1, \mathcal{I}) \left[\frac{\underline{r}}{\Pr(e_1 \geq 0|A_1 = \varnothing, \mathcal{I})} - \frac{\underline{r}}{\Pr(e_1 \geq 0|A_1 = 1, \mathcal{I})} \right] - c$$

This reduces to

$$\left[\frac{\Pr(e_1 \geq 0|A_1 = 1, \mathcal{I})}{\Pr(e_1 \geq 0|A_1 = \varnothing, \mathcal{I})} - 1 \right] \underline{r} - c \tag{38}$$

which is equal to

$$\left[\frac{\Pr(e_1 \geq 0|S_1 = 1, \mathcal{I})}{\Pr(e_1 \geq 0|A_1 = \varnothing, \mathcal{I})} - 1 \right] \underline{r} - c \tag{39}$$

However, since A4 implies $\Pr(e_1 \geq 0|S_1 = 0, \mathcal{I}) = 0$, it follows that

$$\Pr(e_1 \geq 0|A_1 = \varnothing, \mathcal{I}) = \Pr(e_1 \geq 0|A_1 = \varnothing, \mathcal{I}) \Pr(S_1 = 1|\mathcal{I})$$

Hence,

$$\frac{\Pr(e_1 \geq 0|S_1 = 1, \mathcal{I})}{\Pr(e_1 \geq 0|A_1 = \varnothing, \mathcal{I})} = \frac{1}{\Pr(S_1 = 1|\mathcal{I})}$$

With either positive informational spillovers or no informational spillovers, for any set $\mathcal{I}$, we have $\Pr(S_1 = 1|S_2 = 1, \mathcal{I}) \geq \Pr(S_1 = 1|S_2 = 0, \mathcal{I})$. From this, it follows that if $\Pr(S_1 = 1|A_2 = 1, \mathcal{I})$ is well-defined, we can deduce that

$$\Pr(S_1 = 1|A_2 = 1, \mathcal{I}) \geq \Pr(S_1 = 1|A_2 = \varnothing, \mathcal{I})$$

It follows that the gain from disclosure to bank 1 is lower when $A_2 = 1$ than when $A_2 = \varnothing$, as claimed.

Change in gain when $I_1(\varnothing; \varnothing) = 0$ and $I_1(\varnothing; 1) = 1$: From the proofs of Propositions 2 and 3, we can conclude that the gain from disclosure when $A_2 = \varnothing$ is equal to

$$[\Pr(e_1 \geq 0|A_1 = 1, A_2 = \varnothing, \mathcal{I}) R - \underline{r}] I_1(1, \varnothing) - c$$

and the gain from disclosure when $A_2 = 1$ is equal to

$$\left[\frac{\Pr(e_1 \geq 0|A_1 = 1, A_2 = 1, \mathcal{I})}{\Pr(e_1 \geq 0|A_1 = \varnothing, A_2 = 1, \mathcal{I})} - 1 \right] \underline{r} - c$$

We can use these expressions to compute the change in the gain from disclosure between $A_2 = \varnothing$ and $A_2 = 1$. If if $I(1; \varnothing) = 0$, the change in gain is equal to

$$\left[\frac{\Pr(e_1 \geq 0|A_1 = 1, A_2 = 1, \mathcal{I})}{\Pr(e_1 \geq 0|A_1 = \varnothing, A_2 = 1, \mathcal{I})} - 1 \right] \underline{r} \tag{40}$$

and if $I(1; \varnothing) = 1$ the change in gain is equal to

$$\frac{\Pr(e_1 \geq 0|A_1 = 1, A_2 = 1, \mathcal{I})}{\Pr(e_1 \geq 0|A_1 = \varnothing, A_2 = 1, \mathcal{I})} \underline{r} - \Pr(e_1 \geq 0|A_1 = 1, A_2 = \varnothing, \mathcal{I}) R \tag{41}$$

if $I(1; \varnothing) = 1$.

In the case of (40), we know from Appendix Lemma 2 that the expression is positive, i.e. in this case disclosure is a strategic complement.

In the case of (41), Recall that for $I_1(1;\varnothing)=1$, it must be the case that

$$\Pr\left(e_1 \geq 0 | A_1 = 1, A_2 = \varnothing, \mathcal{I}\right) \geq \frac{\underline{r}}{R}$$

Using this inequality, we can deduce that (41) is bounded below by

$$\frac{\Pr\left(e_1 \geq 0 | A_1 = 1, A_2 = 1, \mathcal{I}\right)}{\Pr\left(e_1 \geq 0 | A_1 = \varnothing, A_2 = 1, \mathcal{I}\right)}\underline{r} - \frac{\Pr\left(e_1 \geq 0 | A_1 = 1, A_2 = \varnothing, \mathcal{I}\right)}{\Pr\left(e_1 \geq 0 | A_1 = \varnothing, A_2 = \varnothing, \mathcal{I}\right)}\underline{r}$$

This is the change in gain if $I_1(\varnothing;\varnothing) = I_1(\varnothing;1) = 1$. Next, since we are given that $I_1(\varnothing,1) = 1$, it follows that

$$\Pr\left(e_1 \geq 0 | A_1 = \varnothing, A_2 = 1, \mathcal{I}\right) \geq \frac{\underline{r}}{R}$$

From this, we can conclude that (41) is bounded above by

$$\Pr\left(e_1 \geq 0 | A_1 = 1, A_2 = 1, \mathcal{I}\right) R - \Pr\left(e_1 \geq 0 | A_1 = 1, A_2 = \varnothing, \mathcal{I}\right) R$$

which is the change in gain if $I(\varnothing;\varnothing) = I(\varnothing;1) = 0$. Hence, in this case the change in gain is bounded by the two cases, and can in principle be either positive or negative.

Proof of Proposition 6: Set $i = 1$ and $j = 2$. Suppose $I_1(\varnothing;\varnothing) = I_1(\varnothing;1) = 1$. As in Proposition 3, the gain from disclosure is given by

$$\left[\frac{1}{\Pr\left(S_1 = 1 | \mathcal{I}\right)} - 1\right]\underline{r} - c$$

Since informational spillovers are negative, we know that

$$\Pr\left(S_1 = 1 | A_2 = 1, \mathcal{I}\right) \geq \Pr\left(S_1 = 1 | A_2 = \varnothing, \mathcal{I}\right)$$

Hence, the expected gain from disclosure to bank 1 is lower when $A_2 = 1$ than when $A_2 = \varnothing$.

Proof of Proposition 7: Define $\Sigma_i \equiv \{s | e_i(s) \geq 0\}$ as the set of states in which bank i is capable of paying back investors.

Consider a hypothetical decision maker who can either invest in bank i or not. If she invests, she receives R if the realization of S lies in Σ_i and 0 otherwise, while if she does not invest she receives $\underline{r}$ regardless of S.

Let the hypothetical decision maker observe a vector of signals A before choosing their investment decision. Consider the case where the hypothetical decision maker knows bank i is good, i.e. suppose $A_i = 1$. For any $j \neq i$, let the signal A_j be equal to 1 with probability σ_j if $S_j = 1$ and equal to $\varnothing$ otherwise, i.e. with probability 1 if $S_j = 0$ and with probability $1 - \sigma_j$ if $S_j = 1$. Let $I_i^D(A)$ denote the decision maker's investment decision after observing A, i.e. $I_i^D(A)$ is equal to 1 if the decision maker invests.

Since a signal with a value σ_j' represents a garbled version of a signal whenever $\sigma_j > \sigma_j'$, by the Blackwell's (1953) informativeness criterion, we know the hypothetical decision maker is weakly better off when σ_j is higher. Formally, if we define $1_{\{S\in\Sigma_i\}}$, then the expected payoff to the hypothetical decision maker is

$$E[I_i^D(A) R \; 1_{\{S\in\Sigma_i\}} + (1 - I_i^D(A))\underline{r}]$$

is weakly increasing in σ_j. Note that the hypothetical decision maker will invest after observing A if and only if

$$E[1_{\{S\in\Sigma_i\}} | A] R = \Pr(S \in \Sigma_i \; | A) R > \underline{r}$$

However, this is the same condition that determines whether in the decentralized market outsiders will be willing to trade. Hence, the payoff to the hypothetical decision maker is identically equal to the expected gains from trade $\mathcal{G}_i(\sigma)$.

Proof of Theorem 2: To prove part (i), recall that we defined $e^*(A)$ as the threshold level of equity given A above which bank i would be willing to invest rather than divert the funds they obtain. Define

$$e^* \equiv \min_A e_i^*(A) \tag{42}$$

as the lowest possible threshold. If $e_i < e^*$, bank i will not repay outsiders regardless of A. Recall that as long as the probability of repayment is less than $\frac{r}{R}$, there is no scope for trade between outsiders and banks. Thus, non-disclosure will be an equilibrium for any $c \geq 0$ when the probability that e_i falls below e^* is large enough. The condition for mandatory disclosure by all banks to improve upon no trade is given by

$$E[1_{e_i \geq e_i^*(S)}](R - \underline{r}) \geq c \tag{43}$$

That is, since mandatory disclosure reveals the state S, bank i will be funded if its equity exceeds $e_i^*(S)$, the level that ensures bank i will invest and not divert funds in state S. Since $\Pr(e_i > e^*|S_i = 1) > 0$ under assumption A6, it follows that $\Pr(e_i > e^*) > 0$, i.e. there exists a vector of announcements A that can occur with positive probability such that $\Pr(e_i > e_i^*(A)) > 0$. But this in turn implies there must exist a state of the world S such that $\Pr(e_i > e_i^*(S)) > 0$. Hence, $E[1_{e_i \geq e_i^*(S)}] > 0$, and so there exists a nonempty interval for c such that mandatory disclosure is preferable to the no trade equilibrium. This establishes the claim.

We now turn to part (ii). We consider three different cases, depending on whether none, all, or only some banks get funded in equilibrium.

Suppose first that in the non-disclosure equilibrium, outsiders invest in none of the banks. If $\Pr(e_i = \overline{e}|S_i = 1) \to 1$, then by disclosing its type bank i will be able to attract funds even if no other bank discloses its type. Hence, for a non-disclosure equilibrium to exist with no investment, it must be the case that the cost of disclosure c exceeds the expected value from disclosing and attracting funds. The latter is equal to

$$\rho_1 R + (1 - \rho_1)v - \underline{r} \leq c \tag{44}$$

where $\rho_1 = \Pr(e_1 > e_1^*(1, \varnothing, \ldots, \varnothing)|S_1 = 1)$ is the probability that a good bank will not default given the interest rate it is charged when it is the only bank that reveals its type (by symmetry, this will be the same for all banks). In the limit as $\Pr(e_i = \overline{e}|S_i = 1) \to 1$, it must also be the case that $\rho_1 \to 1$.

Next, the condition for mandatory disclosure to improve upon no trade is given by

$$\rho_2 \Pr(S_i = 1)(R - \underline{r}) \geq c \tag{45}$$

where $\rho_2 = E[\Pr(e_1 > e_1^*(S)|S_1 = 1)]$ is the expected probability that a good bank can be trusted to undertake the project when all information is revealed. In the limit as $\Pr(e_i = \overline{e}|S_i = 1) \to 1$, it must also be the case that $\rho_2 \to 1$. In the limit when $\rho_1 = \rho_2 = 1$, under A6 which implies $v < R$, conditions (44) and (45) are in contradiction, since $\Pr(S_i = 1) < 1$ given our assumption that $q_0 < 1$. Hence, mandatory disclosure cannot improve upon a non-disclosure equilibrium in the limit, and by continuity it cannot improve upon a non-disclosure equilibrium when $\Pr(e_i < \overline{e}|S_i = 1)$ is close to but strictly less than 1.

Next, suppose that in the non-disclosure equilibrium, outsiders invest in all of the banks. In this case, a bank will get funded whether it discloses or not, and the only benefit of disclosing is to reduce the interest charges. In equilibrium, the cost of disclosure c must exceed the reduction in interest rates, i.e.

$$c \geq \frac{\Pr(S_i = 0)}{\Pr(S_i = 1)} \underline{r} \tag{46}$$

The condition for mandatory disclosure to improve welfare is given by

$$(1 - \rho_2 \Pr(S_i = 1))(\underline{r} - v) \leq c \tag{47}$$

where as before $\rho_2 = E[\Pr(e_1 > e_1^*(S)|S_1 = 1)]$ is the expected probability that a good bank can be trusted to undertake the project when all information is revealed. In the limit as $\Pr(e_i = \overline{e}|S_i = 1) \to 1$, we still have that $\rho_2 \to 1$, and so (47) reduces to $\Pr(S_i = 0)(\underline{r} - v) > c$. Since A6 implies $v > R - \underline{r} > 0$ and since $\Pr(S_i = 1) > 0$, in the limit (46) and (47) are contradictory. hence, once again mandatory disclosure cannot improve upon a non-disclosure equilibrium in the limit, nor by continuity when $\Pr(e_i < \overline{e}|S_i = 1)$ is close to but strictly less than 1.

Finally, suppose that in the non-disclosure equilibrium some banks receive funding and some banks don't, i.e. outside investors are exactly indifferent. Consider the deterministic case where n_0 banks receive no funding and n_1 banks do receive funding, where $n_0 + n_1 = n$, and banks know whether they will receive funding or not. The condition for mandatory disclose to improve welfare is now

$$n_0 \rho_2 \Pr(S_i = 1)(R - \underline{r}) + n_1(1 - \rho_2 \Pr(S_i = 1))(\underline{r} - v) \leq nc \tag{48}$$

The conditions for the two types of banks to be willing to not disclose are the same as before. Hence, in the limit as $\Pr(e_i = \overline{e}|S_i = 1) \to 1$, each component in the sum will have to exceed c , and so the condition cannot be satisfied. This same sort of averaging argument holds in the case where a bank will be funded with some probability, since then the condition for a non-disclosure equilibrium to exist is a mixture of (44) and (46).

Proof of Proposition 8: We first define the shortfall D_{ij} in state S as the difference between what bank i owes bank j and what it actually pays bank j:

$$D_{ij} = \Lambda_{ij} - x_{ij} \text{ for all } i, j \in \{0, ..., n-1\} \tag{49}$$

Note that the RHS of (25) can be interpreted as an operator that maps payments x_{ij} into payments. We can express this operator as an alternative operator $F : \mathcal{D} \to \mathcal{D}$, where $\mathcal{D} \subset \mathbb{R}_+^n$ is the space of possible shortfalls given by $\mathcal{D} = \{D_{ij} \in [0\ ,\ \Lambda_{ij}]\ ,\ i, j \in \{0, ..., n-1\}\}$. This operator is defined by

$$(F)_{ij}(D) \quad = \quad \frac{\Lambda_{ij}}{\Lambda_i} \max\left\{\min\left\{\Lambda_i, \sum_{m \neq i} D_{mi} - \overline{e} + (1 - S_i)\phi\right\}, 0\right\} \tag{50}$$

The set of fixed points of the shortfall operator corresponds to the set of fixed points of the operator defined over payments. Either of these can be used to derive equity, and hence the distribution of equity we wish to characterize.

Our proof now proceeds as follows. First, we show that for each S the shortfall $D(S)$ are weakly increasing in ϕ and in λ. Next we argue that this implies that the distribution of equity is stochastically decreasing with ϕ and in λ for each S. Then the result follows since the distribution of S does not depend on (ϕ, λ).

We use the notation $F_{\phi,\lambda}$ to emphasize the dependence of the operator on the parameters (ϕ, λ). It is easy to show that F is monotone, i.e. $F_{\phi,\lambda}(D') \geq F_{\phi,\lambda}(D)$ if $D' \geq D$, where the comparison is component by component. Thus, by Tarski's fixed point theorem, there exists a smallest fixed point, which is obtained as $D^*(\phi, \lambda) = \lim_{n\to\infty} F^n(0)$. Additionally, F is monotone on (ϕ, λ), i.e. for each

$D \in \mathcal{D}$, $F_{\phi',\lambda'}(D) \geq F_{\phi,\lambda}(D)$, whenever $(\phi', \lambda') \geq (\phi, \lambda)$. Then it follows that the smallest fixed point $D^*(\phi, \lambda)$ is increasing in (ϕ, λ).

For any vector of shortfalls D, parameter (ϕ, λ) and state of the network S the implied equity of bank i is:

$$\begin{aligned} e_i(S) &= \max \left\{ 0,\ \pi - \phi S_i - \sum_{j=0}^{n-1} \Lambda_{ij} + \sum_{m=0}^{n-1} x_{mi}(S) \right\} \\ &= \max \left\{ 0,\ \pi - \phi S_i - \Lambda_i - \left(\sum_{m=0}^{n-1} D_{mi}(S) + \sum_{m=0}^{n-1} \Lambda_{mi} \right) \right\} \\ &= \max \left\{ 0, \pi - \phi S_i - \sum_{m=0}^{n-1} D_{mi}(S) \right\} \end{aligned}$$

where the last equality follows from our assumption that $\Lambda_i = \sum_m \Lambda_{mi}$.

Consider the equity corresponding to $D = D^*(\phi, \lambda)$. Equity at bank i is given by

$$e_i(\phi, \lambda; S) = \max \left\{ 0, \pi - \phi S_i - \sum_{m=0}^{n-1} D^*_{mi}(\phi, \lambda; S) \right\} \tag{51}$$

where $D^*_{mi}(\phi, \lambda; S)$ is the amount bank m falls short on bank i for the smallest fixed point for the state S and parameters (ϕ, λ). Using the monotonicity of $D^*(\phi, \lambda)$ it is immediate that $e_i(\phi, \lambda; S)$ is weakly decreasing in (ϕ, λ) for each S. While we have used the smallest fixed point in the definition (51), by Theorem 1 in Eisenberg and Noe (2001) every fixed point of $F_{\phi,\lambda}$ has the same implied equity values for each bank. Hence, the comparative static of equity must be the same for any fixed point.

Finally, the conditional probability of interest is given by

$$\Pr\left(e_i \leq x \,|\, S_i = 1\right) = \frac{\sum_{\{s \in \{0,1\}^n :\, s_i = 1\}} 1_{\{e_i(\phi,\lambda;s) \leq x\}} \Pr(S = s)}{\sum_{\{s \in \{0,1\}^n : s_i = 0\}} \Pr(S = s)} \tag{52}$$

Since $\Pr(S = s)$ is just constant for each s, it follows that $\Pr(e_i \leq x | S_i = 0)$ is decreasing in (ϕ, λ).