A micro-founded analysis of the design of interconnectedness based macroprudential regulation*

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Abstract

The social costs of a bank failure may exceed the private ones, especially if an initial default propagates through a network of contractual obligations. Even though banks account for private costs and benefits that their interconnectedness decisions carry, they may fail to consider external costs. I analyze under which conditions banks’ decisions are sub-optimal from a social point of view and how capital charges can contribute to align private and social incentives. Since this analysis is micro-founded, it sheds light on the impact of market frictions (asymmetric information and implicit government guarantees) on the design of interconnectedness based macroprudential regulation. I find that an asymmetrically informed regulator faces a steeper efficiency-financial stability tradeoff the stronger implicit guarantees are and/or the higher the correlation between credit and liquidity risk is. This uncovers non-trivial implications that complementary measures, such as resolution regimes and liquidity requirements, have on interconnectedness based capital regulation.

Keywords: Asymmetric Information, Counterparty Risk, Financial Crisis, Liquidity Coinsurance, Network Formation, Regulation.

JEL Codes: D82, D85, G01, G21, G28.

1 Introduction

The 2007/09 crisis exposed the limitations of the regulatory framework in place at the time. As a response, the aftermath of the crisis brought major regulatory changes with the objective of strengthening financial stability. In particular, the cross-border reach of certain institutions motivated the adoption of higher “loss absorbency requirements” (BCBS; 2011) to reduce the default probability of

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globally systemically important banks (G-SIBs), which will fully come into effect in January 2019. Table 1 displays the allocation across buckets of G-SIBs as of November 2013\(^1\).

Table 1: G-SIBs list as of November 2013

<table>
<thead>
<tr>
<th>Bucket</th>
<th>Institution</th>
<th>Bucket</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0%</td>
<td>Barclays, BNP Paribas, Citigroup, Deutsche Bank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5%</td>
<td>Bank of America, Credite Suisse, Goldman Sachs, Group Crédit Agricole, Mitsubishi UFJ FG, Morgan Stanley, Royal Bank of Scotland, UBS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

source: FSB (2013)

This allocation follows an indicator-based approach that takes into account (with equal weights) size, interconnectedness, importance to financial institution infrastructure, cross-border reach and complexity. The interconnectedness criteria, which is the focus of this paper, is measured by three (also equally weighted) indicators\(^2\): intra-financial system assets, intra-financial system liabilities and securities outstanding. The argument that justifies the adoption of this criteria is the following

"Financial distress at one institution can materially increase the likelihood of distress at other institutions given the network of contractual obligations in which these firms operate. A bank’s systemic impact is likely to be positively related to its interconnectedness vis-à-vis other financial institutions." (BCBS; 2011, p. 7)

Policies such as these are an example of the post-crisis macroprudential focus. That is, in addition to the pre-crisis microprudential approach designed to prevent banks from taking too much risk at an individual level, the macroprudential layer aims to ensure that banks do not take excessive risk at an aggregate level.

When the failure of one bank propagates through the network of obligations, the social costs of this event may exceed the private ones. The failure of a significant fraction of the financial sector may compromise the integrity of the payment system, for example. Even though banks take into account the private costs and benefits that their interconnectedness decisions carry, they may fail to consider the external costs imposed on the rest of society. In this paper, I analyze under which conditions banks’ interconnectedness decisions are sub-optimal from a social point of view and how capital charges can contribute to align private and social incentives. Since this analysis is micro-founded, it sheds light on the impact of market frictions (asymmetric information and implicit government guarantees) on the design of interconnectedness based macroprudential regulation.

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\(^1\)In addition to these four buckets, there is also a bucket left empty to provision for the case where 2.5% bucket institutions increase their systemic importance.

\(^2\)The detailed definition is presented in the appendix.
In my model, the negative externality stems from tail risk exposure. When a low probability high impact event occurs, the initial default may be propagated through the interbank network. However, tail risk exposure is not uniform across banks. While some banks are not exposed to this type of risk - *sound* banks, borrowing the terminology of Morrison and White (2005, 2011, 2013) - others have a critical exposure to it - *unsound* banks.\(^3\) This difference can be traced back to the bankers’ ability heterogeneity that is exogenously assigned.

Then, the objective of the regulator, in order to maximize total welfare, is to reduce default propagation by constraining unsound bankers’ choices. In frictionless markets, unsound bankers would either fail to attract depositors or would be screened out by the regulator. However, if explicit (and/or implicit) government guarantees exist, and tail risk exposure is private information unsound banks are allowed to persist. The assumption that the regulator is only able to observe the distribution but not each bank’s individual tail risk exposure can be motivated as follows. First, as previously argued by Blum (2008), very large banks are complex organizations, whose assets are opaque such that even supervisors may be unable to assess perfectly *ex ante* the exposure to low probability high impact events. Second, banks (especially ones of systemic importance) may choose optimally to misreport their true tail risk exposures (see Huizinga and Laeven; 2012) since not only it makes them subject to higher capital charges but also they may anticipate regulatory forbearance. A potential explanation for this response is the regulator’s desire to maintain a strong reputation of a good screener of unsound banks (as argued by Morrison and White; 2013) with the objective of avoiding contagion effects that would undermine the confidence in the stability of the financial system. Finally, also as argued by Blum (2008), if there is no asymmetry of information to begin with, then capital requirements can be replaced with quantitative risk restrictions since bank behavior is perfectly anticipated. In addition to this informational friction, unsound banks also benefit from implicit guarantees in default states. The existence of this distortion can be motivated by a time-inconsistent closure policy. That is, *ex ante* the regulator would like to close troubled institutions, but *ex post* the costs of a de-organized failure may greatly outweigh bailout costs\(^4\).

Anticipating that the regulator’s optimal response, banks choose to take on more risk. Here, I will assume that the probability of a bailout, and consequently its subsidy, is increasing in the number of interbank connections each bank has. This assumption can be motivated by the BCBS’s decision to include interconnectedness as a criteria to identify G-SIBs.

Given the inability to affect unsound bankers’ exposure to tail risk, the regulator is left with the alternative of constraining their interconnectedness. This constraint can be operationalized via capital charges increasing in it. Since capital is costly, they serve the purpose of increasing the cost

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\(^3\)One can think of sound banks as the ones with assets such as AAA-rated corporate bonds and unsound ones with assets such as AAA-rated tranches of Collateralized Debt Obligations (CDO). In good states of the world (i.e., pre-crisis periods) these two asset classes are perceived as of equal risk level, but in bad states of the world (i.e., crisis periods) their returns are significantly different. Griffin and Tang (2012) report that from a sample of securities initially AAA-rated before the crisis, 76.2% of corporate bonds retain the AAA-rating in 2010 comparing with only 26.9% of CDO notes. In fact, 45.2% were downgraded to junk and 4% to default rating. Alternatively, these 26.9% can be thought as being the sound assets and the 45.2% the unsound ones.

\(^4\)This argument has been proposed by Freixas (1999) for large banks, and by Acharya and Yorulmazer (2007, 2008) for banks with exposures to common shocks.
of establishing connections in the interbank market. In other words, these charges play the role of a Pigouvian tax. Nevertheless, the design of this policy instrument presents some challenges. First, interbank connections not only may reduce welfare by allowing an initial default to propagate, but also may increase it by allowing banks to insure against idiosyncratic liquidity shocks. Thus, even without asymmetric information, the regulator faces a tradeoff between efficiency and financial stability. In other words, total welfare is non-monotonic in interconnectedness. Second, banks respond optimally to the cost of regulation. Since banks’ decisions are strategic, the added cost brought about by regulation changes the incentives to participate in the interbank market. Third, this optimal response is affected by implicit guarantees that grant unsound bankers bailout subsidies in default states. That is, banks may choose to become more interconnected in order to increase the probability of a bailout. Finally, if the regulator is asymmetrically informed, capital charges cannot be conditioned on the bank’s type. This informational constraint then interacts with the implicit government guarantees friction. Even though the cost of regulation is uniform per connection, the additional value that each bank extracts from it is type dependent.

To address these challenges, I propose a three stage approach. At the first stage, nature determines bankers’ types. At the second, the regulator sets a per connection capital requirement. Finally, the interbank network emerges as the outcome of a network formation game where banks make their interconnectedness decisions taking their counterparties ability levels and capital requirements as given. Then, by solving the game by backward induction the regulator determines the capital requirement as the optimal solution to an unconstrained (constrained) optimization problem when she is symmetrically (asymmetrically) informed. When the regulator is asymmetrically informed, the constrains of the optimization problem correspond to the participation and incentive compatibility constraints in a standard principal-agent model. In this setting, the incentive compatibility constraints have the particular meaning of being the equilibrium network stability conditions of the pairwise stability concept (Jackson and Wolinsky 1996). That is, no bank has an incentive to deviate from the (constrained) socially optimal network given the capital requirements chosen by the regulator.

The main finding is that the more significant implicit government guarantees are, the steeper is the efficiency-financial stability tradeoff faced by an asymmetrically informed regulator. Not only undiscriminated higher capital requirements are required to induce unsound bankers to internalize contagion costs, but also it is increasingly more difficult for the constrained regulator to induce unsound banks to become less interconnected without affecting sound ones. Moreover, this difficulty is increasing in the correlation between liquidity and return shocks. The higher is the probability of an adverse liquidity shock (e.g., high depositor withdrawals or the need to refinance assets), the

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5 The Macroeconomic Assessment Group estimated the peak impact of the higher loss absorbency requirements at around .17%-.19% of GDP depending on the implementation period. A reversal to the baseline is expected after two to three years after the adjustment. See www.bis.org/publ/othp12.htm.

6 The policy counterpart is states as follows. “The assessment methodology provides a framework for periodically reviewing institutions’ G-SIB status. That is, banks have incentives to change their risk profile and business models in ways that reduce their systemic spillover effect. (...) banks can migrate in and out of G-SIB status, and between categories of systemic importance, over time” BCBS (2011, pp. 13-14).
more valuable interbank connections are for unsound bankers.

Even though the model is simple, it delivers some potentially important policy implications. First, an institutional framework that reduces implicit guarantees may improve financial stability through a direct and an indirect channel. Not only improved resolution regimes may reduce directly the impact of G-SIB failures, but also they can make the regulatory tradeoff between financial stability and efficiency less burdensome when the source of the negative externalities lies in banks’ interconnectedness decisions. Second, since this tradeoff is increasing in liquidity and return shock correlation, liquidity regulation may contribute to improve it. This finding sheds light on the effect that liquidity requirements such as the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR) have on the effectiveness of interconnectedness based capital requirements. Since these two instruments require banks to be better equipped to deal with liquidity shocks, they approximate the regulator’s ideal conditions of independence between credit and liquidity risk. In addition, the main message of the paper also applies to other forms of Pigouvian taxation that were adopted in several European countries to deal with systemic risk (see IMF 2010), and to other interconnectedness sensitive measures such as the Asset Value Correlation (AVC) multiplier that Basel III brings.

The rest of the paper is organized as follows. Section 2 discusses how this paper fits in the literature. Section 3 describes the basic setup. Section 4 presents the decentralized equilibrium outcome. Sections 5 and 6 compare the regulator’s problem under symmetry and asymmetry of information, respectively. Section 7 provides a discussion of the results. Section 8 discusses some policy implications in the context of the regulatory reform initiated after the crisis. Finally, section 9 concludes.

2 Related literature

This paper is related to several strands of literature. First, it is related with the literature on financial contagion, which gained momentum after the 2007/09 crisis. Allen and Babus (2009) provide a useful review. This paper follows in spirit the contagion propagation mechanism of Allen and Gale (2000). Allen and Gale (2000) develop a model where an unanticipated liquidity shock triggers an initial default that propagates through the interbank network of deposits. The authors show that a more complete network exhibits a higher degree of resilience. Even though my paper follows this “domino view” of the unravelling of financial distress, I focus on the gap between private and social incentives to establish endogenously these connections and how regulation can realign those incentives to induce the network that yields the socially optimal level of systemic risk. The discussion on the optimal financial network reverts back to Leitner (2005), who shows that the danger of contagion may motivate healthy banks to rescue counterparties in distress and consequently improve financial stability. In contrast to Leitner (2005), this paper concentrates on the role of the regulator to enhance welfare and not on the private incentives of “bail-ins”. It is also

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close to Castiglionesi and Navarro (2007) with some significant differences. While Castiglionesi and Navarro (2007) focus on a moral hazard problem, the focus of this paper is on adverse selection. Moreover, following their game theoretic approach, I model explicitly financial institutions’ response to regulation and determine the optimal policy menu. More recently, Allen et al. (2012), also within a network formation game context, show that banks’ private incentives to form financial connections may be misaligned with the social ones because financial institutions may not be able to select the composition of their portfolio explicitly leading to a suboptimal network. The market failure in my paper differs from theirs since in my setting banks fail to take into account the negative externality that their decisions impose on the deposit insurer/regulator. Bluhm et al. 2013 also study the effects of regulatory measures, such as systemic risk charges, on the endogenous formation of the financial network. The authors analyze the effect of macroprudential policy on the endogenous structure of the dynamic network within an agent-based model. The main difference is that in my paper the focus is on the design of a policy menu that induces banks to form the socially efficient network in the presence of asymmetric information. My paper follows a mechanism design approach to network formation related with Mutuswami and Winter (2002). This approach provides a unique perspective on the incentives that banks have to establish connections, which allows to analyze the importance of complementary instruments for the effectiveness of interconnectedness based capital requirements. Second, the paper is also related with the network based systemic risk contribution literature (e.g., Tarashev et al. 2009, Gai et al. 2011, Staum 2012 and Drehmann and Tarashev 2013). However, unlike these papers based on the Shapley (1950) value, the topology of the network is not assumed to remain fixed. This is particularly important when banks have different incentives to become interconnected and the regulator faces an informational disadvantage. Finally, the paper is also close to the literature on the effects of capital requirements under asymmetric information (e.g., VanHoose 2007 and references therein, Blum 2008, Vollmer and Wiese 2013) and incentive based regulation (e.g., Campbell et al. 1992, Chan et al. 1992, Giammarino et al. 1993).

3 The model

Consider an economy with three regions (indexed by \( i = 1, 2, 3 \)), each with a representative bank \((b_i)\) and a continuum of depositors fully covered by a common deposit insurer/regulator\(^8\). All agents are risk-neutral and time is divided into four dates. Depositors are endowed with 1 unit of the generic good at date \( t = 0 \) and nothing at subsequent dates. Bankers use their depositors’ endowments and their own capital \((k)\) to invest in an illiquid asset \((x)\) and in liquidity \((y)\). Investment occurs only at date \( t = 0 \), the events that take place in the subsequent three dates are as follows.

\(^8\)One can think about these three regions as three countries within Europe’s banking union that fall under the supervision of a single supervisory mechanism. However, in my model there is additionally common deposit insurance. The main result is established at each pair of banks level, the choice of a three bank system is only made for expositional purposes.
### 3.1 Return shocks

Asset allocation is determined by the bankers that simultaneously run and own the bank. There are two types of illiquid assets in the economy: sound and unsound (borrowing the terminology of Morrison and White; 2005, 2011, 2013). I assume that even though both types of assets have the same gross return at maturity in the good states of nature, equal to $R$, unsound assets default in bad states of nature earning 0 gross return with probability $1 - \beta$. For simplicity, I also assume that this probability is low and fundamental default events are independent. One can think of sound assets as AAA-rated corporate bonds and unsound ones as AAA-rated tranches of Collateralized Debt Obligations (CDO). In good states of the world (i.e., pre-crisis periods) these two asset classes are perceived as of equal risk level, but in bad states of the world (i.e., crisis periods) their returns are significantly different. The assumption that the gross return in the good states of nature is equal for both illiquid assets works against the main result of the model. As I discuss in section 7, even under these conditions, the design of macroprudential regulation is still affected by the market imperfections considered in this paper.

Following Giammarino et al. (1993), bankers have control over resources ($B$) that can either be appropriated to their own benefit without detection, or devoted to improve asset screening. Let $\theta_i \in \{\theta_H, \theta_L\}$ and $C(\theta_L) > C(\theta_H)$ denote the bankers ability and cost of screening determined by nature at $t = -1$, respectively. That is, high ability bankers have a comparative advantage in selecting sound assets. In addition to the remainder of resources not used in asset selection, bankers hold the bank’s profits. The decision whether or not to devote resources to asset screening involves a tradeoff between benefiting from an increased probability of success and having less resources that can be appropriated by the banker. This assumption captures the idea that some banks may choose to have a higher net exposure to tail risk than others. Since these events are extremely rare, tail risk exposures may not be observable ex ante by outsiders and thus cannot be contracted upon.

In frictionless markets, unsound bankers would either fail to attract depositors or they would be screened out by the regulator. However, since I assume that there is deposit insurance and that

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9This distinction in Morrison and White (2005, 2011, 2013) is motivated by differences in access to monitoring technologies. Also, notice that assuming that the probability of success is equal to one is without real loss of generality. All results follow from the difference between success probabilities and not from their levels.

This assumption can be further motivated by the contrasting resilience that financial institutions displayed during the 2007 crisis. As Senior Supervisors Group (2008) puts it, “firms that faced more significant challenges in late 2007 generally had not established or made rigorous use of internal processes to challenge valuations. They continued to price the super-senior tranches of CDOs at or close to par despite observable deterioration in the performance of the underlying RMBS collateral and declining market liquidity. Management did not exercise sufficient discipline over the valuation process: those firms generally lacked relevant internal valuation models and sometimes relied too passively on external views of credit risk from rating agencies and pricing services to determine values for their exposures. Given that the firms surveyed for this review are major participants in credit markets, some firms’ dependence on external assessments such as rating agencies’ views of the risk inherent in these securities contrasts with more sophisticated internal processes they already maintain to assess credit risk in other business lines. Furthermore, when considering how the value of their exposures would behave in the future, they often continued to rely on estimates of asset correlation that reflected more favorable market conditions.”

10This assumption seems reasonable since most countries either have some form of explicit (see Demirgüç-Kunt et al. 2008) or implicit (see Ioannidou and Penas 2010) deposit insurance. Also, I assume that deposit insurance is not fairly priced and the premium is normalized to 0.
the exposure to tail risk is private information (at the industry level), unsound bankers are allowed to persist. Moreover, given that the focus of this paper is on G-SIBs, I introduce implicit guarantees that affect the behavior of outsiders with respect to the bank. With this market distortion, unsound bankers benefit from bailout subsidies in default states. A reason why this subsidy may exist is due to a legal framework unfit to deal in a timely manner with failures of large and complex institutions in the midst of a crisis. When faced with a potential failure of a G-SIB, regulators (as seen during the recent crisis) may find (ex post) optimal to bailout troubled banks instead of letting them fail. The failure of such an institution may have serious negative effects in the real economy. Not only the regulator has to incur in deposit insurance costs, but also has to deal with other financial distress costs such as disruptions to the payment system. Ex ante the regulator would like to commit to a closure policy, but ex post it is optimal to bail-out systemically important institutions in distress. Thus, even though not explicitly modeled here, the existence of these subsidies can be motivated by a time-inconsistent closure policy (see Freixas; 1999; and Acharya and Yorulmazer; 2007). Also, bailouts may be more likely when institutions have significant linkages (e.g., the bailout of AIG - see Bernanke 2009). To incorporate this element on the model, I assume that these subsidies are increasing in interconnectedness. In spite of taking them as exogenously given, the model allows for a detailed analysis of the effects that ancillary measures, such as resolution regimes, that reduce this distortion have on the effectiveness of interconnectedness sensitive capital requirements.

As a baseline, \( \{b_1, b_3\} \) are governed by low ability bankers and \( b_2 \) by a high ability banker. The assignment of \( b_2 \) as the sound bank is without loss of generality, only the distribution of \( \Theta = (\theta_1, \theta_2, \theta_3) \) is relevant. The particular choice of the distribution of \( \Theta \) is relaxed in section 7. The next assumption summarizes the information set of each player.

**Assumption 1.** Banks are assumed to know the realization of \( \Theta \), but outsiders such as the regulator only observe (ex ante) the distribution of \( \Theta \).

The assumption that the regulator is not able to infer the skill of each banker from risk exposures can be motivated as follows. First, as previously argued by Blum (2008), very large banks are complex organizations, whose assets are opaque such that even supervisors may be unable to assess perfectly ex ante the exposure to low probability high impact events. Second, banks (especially ones of systemic importance) may choose optimally to misreport their true tail risk exposures (see Huizinga and Laeven; 2012) since not only it makes them subject to higher capital charges but also they may anticipate regulatory forbearance. One potential explanation for this response is the regulator’s desire to maintain a strong reputation of a good screener of unsound banks (as argued by Morrison and White; 2013) with the objective of avoiding contagion effects that would undermine the confidence in the stability of the financial system. Finally, also as argued by Blum (2008), if there is no asymmetry of information to begin with, then capital requirements can be replaced with quantitative risk restrictions since bank behavior is perfectly anticipated.

\[11\] The empirical evidence on this “Too-Interconnected-To-Fail” guarantee is limited. Akram and Christophersen (2010) find that more interconnected banks benefit from better rates in the interbank market, even after controlling for size and creditworthiness.
3.2 Liquidity shocks

Before these assets mature, however, each bank faces the need to refinance the illiquid share of its portfolio. As in Castiglionesi and Wagner (2012), the return at maturity of the illiquid asset is contingent on the survival to the regional liquidity shock that hits banks at the interim date. At date 1, bankers learn the liquidity needs of their assets. Let \( \gamma \in \{ \gamma_H, \gamma_L, \bar{\gamma} \} \) denote the set of shocks, with \( \bar{\gamma} = (\gamma_H + \gamma_L)/2 \). The motivation for these shocks is that illiquid assets may need to be refinanced in a given amount to ensure their return at maturity. For example, a loan to a non-financial company may require additional cash injections to insure the solvency of the firm at the maturity of the loan contract. Also as in Castiglionesi and Wagner (2012), these are “pure” liquidity shocks, that is, they are balanced at maturity.

Suppose that at the interim date, the bank faces a shock equal to \( \gamma_L \), then at maturity the asset returns (contingent on success) \( xR - (\bar{\gamma} - \gamma_L) \). If the absence of refinancing the asset defaults and the bank goes bankrupt. Alternatively, one can think of these shocks as stochastic depositor (in particular wholesale) withdrawals when banks choose to finance their long term assets with short term debt. Table 2 describes the distribution over the set of liquidity shocks \( \Omega \) (with typical element \( \omega \)).

| Table 2: Regional Liquidity Shocks |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Probability     | \( \omega \)    | \( b_1 \)      | \( b_2 \)      | \( b_3 \)      |
| \( \phi_1 \)    | \( \omega_1 \)  | \( \bar{\gamma} \) | \( \gamma_H \) | \( \gamma_L \) |
| \( \phi_2 \)    | \( \omega_2 \)  | \( \gamma_H \)  | \( \bar{\gamma} \) | \( \gamma_L \) |
| \( \phi_3 \)    | \( \omega_3 \)  | \( \gamma_H \)  | \( \gamma_L \)  | \( \bar{\gamma} \) |
| \( \phi_4 \)    | \( \omega_4 \)  | \( \bar{\gamma} \) | \( \gamma_L \)  | \( \gamma_H \) |
| \( \phi_5 \)    | \( \omega_5 \)  | \( \gamma_L \)  | \( \bar{\gamma} \) | \( \gamma_H \) |
| \( \phi_6 \)    | \( \omega_6 \)  | \( \gamma_L \)  | \( \gamma_H \)  | \( \bar{\gamma} \) |

That is, I assume that

**Assumption 2.** *Idiosyncratic liquidity shocks are uniformly distributed and are independent of return shocks.*

This assumption not only makes solving the model easier, but also establishes the most favorable conditions for the regulator with respect to interaction of credit and liquidity risk. As in the case of the equal gross return assumption, I show in the next sections that even under these conditions market frictions have an impact on regulatory design. In section 7, this assumption is replaced with a more realistic where liquidity and return shocks are correlated.

Therefore, the state space can be defined as follows

**Definition 1.** *(State Space)* The state space is given by the cartesian product of return and liquidity shocks \( \left( \hat{\Theta} \times \Omega \right) \) with typical element \( \left( \hat{\theta}, \omega \right) \), where \( \hat{\theta} \) is the set of realized asset returns conditional on the respective banker’s ability type.
3.3 Interbank credit lines

To face the liquidity shock banks can establish *ex ante* bilateral credit lines\(^\text{12}\) (see Cocco et al. 2009 and Castiglionesi and Wagner 2012). Modeling credit lines as established prior to the liquidity shock reflects the assumption that in order for banks to establish them they need to learn each others types. These credit lines are defined as directed, that is, a bank can be a potential borrower \((b_j \in \mathcal{B})\) without the requirement of being simultaneously a potential lender \((b_i \in \mathcal{L})\). For example, in states \((\cdot, \omega_2)\), through a credit line, \(b_1\) can obtain liquidity from \(b_3\)\(^\text{13}\). Upper (2011) reports that interbank loans can amount to several multiples of banks’ equity in some European countries. Another possible interpretation for these credit lines would over-the-counter (OTC) contracts that expose banks to the failure of their counterparties. The collection of all these credit lines constitutes the interbank network. In network theory terminology, the interbank market is a directed homogeneous network \((G)\).

**Definition 2.** (Interbank Network) An interbank network \(G\) is a subset of \((\mathcal{L} \times \mathcal{B})\) with typical element \((b_i, b_j)\) such that for all potential lenders \(b_i \in \mathcal{L}\), the section of \(G\) at \(b_i\) given by

\[
G (b_i) := \{b_j \in \mathcal{B} : (b_i, b_j) \in G\}
\]

is nonempty.

Even though these interbank credit lines allow banks to hedge liquidity shocks, the existence of unsound banks also exposes lenders to the potential of a default by contagion. A default by contagion occurs whenever the lender is unable to fulfill its obligations with its own depositors due to the failure of a borrower. Since the model assumes pure liquidity shocks, the liquidation value of the lender’s portfolio must be sufficient to repay retail depositors in order to remain solvent. Given that a bank can only be a lender if the liquidity shock at the interim date is less than \(\tilde{\gamma}\) when \(y = \tilde{\gamma}\),\(^\text{14}\) then the liquidation value \((1 - \tilde{\gamma}) R - (\tilde{\gamma} - \gamma_L)\) needs to be greater than \(r_d\) to ensure solvency.

**Assumption 3.** Defaults by contagion occur whenever a borrower defaults fundamentally and the default propagates through the interbank network, i.e.,

\[
(1 - \tilde{\gamma}) R - (\tilde{\gamma} - \gamma_L) - r_d < 0.
\]

Assumption 3 is a sufficient condition for the probability of default cascades to be positive. If defaults by contagion were not a concern, or at least the consequences of a fundamental default were not sufficiently severe, then there would be not much point in having interconnectedness sensitive regulation to begin with. Also, first round losses are only a fraction of the total impact imposed on

\(^\text{12}\)If there was a spot market for liquidity the results would remain qualitatively unaltered provided partial market discipline assumption holds.

\(^\text{13}\)Denote by \(\{(b_3, b_1)\}\) or graphically \(b_3 \rightarrow b_1\).

\(^\text{14}\)The liquidity allocation \(y = \tilde{\gamma}\) is optimal when banks are active in the interbank market as will be demonstrated shortly.
the lender. Second round effects may include a downward spiral in asset prices (fire-sales) and a rise in uncertainty with respect to lenders' resilience.

Since defaults can occur in equilibrium, and maintaining the assumption of market discipline\textsuperscript{15}, the interest rate on these credit lines is (counterparty) risk sensitive. However, implicit guarantees reduce the effectiveness of peer monitoring such that the interbank rate only reflects counterparty risk partially. For simplicity, I assume that the lender does not have any bargaining power. Any other interest rate within the banks’ reservation price range, for example resulting from Nash bargaining\textsuperscript{16}, would not change qualitatively the results. Note that the interest rate can only be observed by the regulator ex post (see Furfine 2001). Thus, the expected interbank interest rate is given by

\[
E[r_{IB}^i(G, s)] = \begin{cases} 
0 & \text{if } s = \text{sound} \\
\sum_{j \in G^{-}_i} \frac{\phi_{\omega}}{\phi(G_j)} \frac{1-\beta^*}{\beta^*} \left[ (1 + k^j - y^j) R - r_d - \delta k^j \right] & \text{if } s = \text{unsound} 
\end{cases},
\]

where $\beta^* > \beta$ is the perceived probability of success of unsound assets after implicit guarantees are accounted for, $G^{-}_i$ is the set of all banks that are potential lenders to bank $i$, $\delta$ is the opportunity cost of capital\textsuperscript{17} (assumed to be higher than return of the illiquid asset in the good states of nature - see Hellmann et al. 2000 and Blum 2008 for example) and $\phi_{\omega}$ is the probability of the state whose liquidity shock is hedged by the credit line with $j$. The full derivation of equation (1) is in the appendix.

### 3.4 Intermediation

In addition to bilateral liquidity coinsurance, the interbank network also allows for intermediation. For example, even in the absence of a credit line between $b_1$ and $b_3$, $b_1$ can still obtain the needed liquidity provided that both $b_1$ and $b_3$ have opposite credit lines with $b_2$. In describing how intermediation operates in this model it is helpful to define a path.

**Definition 3. (Path)** A sequence of credit lines $\{(b_i, b_j)_k\}_{k=1}^2$ forms a path between $b_i$ and $b_m$ if

\[
\exists \left\{(b_i, b_j)_1, (b_j, b_m)_2\right\} \subseteq G,
\]

with $b_i \neq b_j \neq b_m$.

In states where banks cannot obtain liquidity directly from their counterparties, survival to the liquidity shock can be achieved if a bank with excess liquidity can provide it, through an intermediary, to the bank with the liquidity shortage provided that they are connected through a path of length 2. Intermediation in the model can summarized by the following indicator functions

\textsuperscript{15}Empirical evidence on market discipline can be found in Cocco et al. (2009) for example.

\textsuperscript{16}For an example of how Nash bargaining can be used in a network context see Braun and Gautschi (2006).

\textsuperscript{17}Gandhi and Lustig (2013) find that investors require a lower return when they expect “Too-Big-To-Fail” institutions to be bailed out, such that $\delta$ will be approximately the same for sound and unsound banks when implicit guarantees are substantial.
\[ I^-(b_i|G) = \begin{cases} 1 & \text{if there is a path of exact length 2 from another node to } b_i \smallskip \text{otherwise} \end{cases} \quad (2) \]

\[ I^+(b_i|G) = \begin{cases} 1 & \text{if there is a path of length } \leq 2 \text{ from any two other nodes than } b_i \smallskip \text{otherwise} \end{cases} \quad (3) \]

Equations (2) and (3) summarize those cases where \( b_i \) receives liquidity from an intermediary and where \( b_i \) acts as an intermediary, respectively. In order for counterparty risk to be fully accounted for, I require that

**Assumption 4.** The interbank network is common knowledge.

This assumption is not strictly necessary. Intermediation fees can be derived based on only a limited knowledge of the network (see Caballero and Simsek 2013 for an exposition on how Knightian uncertainty can be accounted for in the context of a financial network). When banks dislike this uncertainty, it would be expectable a situation where intermediation breaks down in very complex environments.

When a bank intermediates a transfer of funds it has to borrow the needed liquidity from the surplus to then lend it to the deficit bank. By doing so, not only it faces counterparty risk but also has to support the cost brought about by its own intrinsic risk. Thus, under assumption 4, the intermediation fees owed to the lender reflect not only the intermediary’s bargaining power and the opportunity cost of the funds loaned, but also the counterparty risk along the credit path such that

\[
\epsilon = \begin{cases} 
\frac{1-2(\beta^*)^2+\beta^*}{(\beta^*)^2} \sum_{i \in \hat{I}} [(1 + k^i - y^i) R - r_d - \delta k^i] & \text{if 2 subsequent banks are unsound} \\
\frac{1-\beta^*}{\beta^*} \sum_{i \in \hat{I}} [(1 + k^i - y^i) R - r_d - \delta k^i] & \text{if 1 subsequent bank is unsound} 
\end{cases}
\]

where \( i \) is any unsound bank on the intermediation path \( \hat{I} \). For simplicity, the assumption that the borrower holds all the bargaining power is maintained.

**Assumption 5.** The intermediation fees are low enough such that are gains in borrowing funds through an intermediary. This is true given that a fundamental default is assumed to be a sufficiently low probability event, i.e., \( \beta^* \geq \frac{1+\sqrt{13}}{6} \).\(^{18}\)

Assumption 5 establishes that when \( \beta^* \) is high enough there are positive profits in using intermediation to offset a liquidity shock that exceeds its liquidity holdings, provided that all banks hold the

\(^{18}\)The full derivation of this assumption is in the appendix.
same amount of liquidity in equilibrium. Given that the intermediation fees are at least as high as
the interest rate on bilateral borrowing, assumption 5 also guarantees that there are gains in using
direct interbank credit lines. Since bankers with a high cost of asset selection exist, defaults may
occur in equilibrium. Moreover, since the model allows for intermediation, the default of a borrower
may lead to a default cascade - default of its (direct and indirect) interbank counterparties - in the
spirit of Allen and Gale (2000).

3.5 Bankers’ payoffs

Then, under assumptions 1-5, the conditional expected bankers’ profits are given by the following
equation

\[
\mathbb{E} [\pi_i (G, k, y, \theta, s)] = \begin{cases} 
(1 + k - y) R - r_d \phi_i (G) + \epsilon_i (G) - \delta k + B - C (\theta) 
\quad & \text{if } s = \text{sound} \\
(1 + k - y) R - r_d - \mathbb{E} [r^i_{IB} (G, s)] \beta \phi_i (G) + \epsilon_i (G) \beta - \delta k + B + (1 - \beta) \nu |G_i^-| 
\quad & \text{if } s = \text{unsound} 
\end{cases}, \quad (4)
\]

where \( \phi_i (G) \) is the network dependent probability of survival for bank \( i \) (increasing in the potential
borrower’s connections), \( \nu \) is the per connection expected bailout subsidy and \( \epsilon_i (G) \) are the net
intermediation proceeds (non-monotonic with respect to the whole network connectivity) given by

\[
\epsilon_i (G) = \epsilon \mathcal{I}^+ (b_i | G) - \epsilon \mathcal{I}^- (b_i | G),
\]

where \( \mathcal{I}^- (b_i | G) \) and \( \mathcal{I}^+ (b_i | G) \) are the indicator functions described in equations (2) and (3), respectively. Moreover, note that whenever \( \mathcal{I}^+ (b_i) = 1 (\mathcal{I}^- (b_i) = 1) \) an additional borrowing credit line
increases (decreases) expected profit in the amount of the intermediation fees. Implicit in equation
(4) is the assumption that bank shareholders have limited liability, which implies that profits have
a lower bound of 0 excluding the flow of unobserved resources that the banker has the ability to
divert and expected bailout subsidies. Also implicit in this equation is the assumption that the
budget constraint holds with equality, that is \( x + y = 1 + k \Leftrightarrow x = 1 + k - y \). The apparent
absence of the inflow of interbank interest proceeds in equation (4) reflects that the interbank interest
rate only compensates the lender for the counterparty risk assumed, which is a consequence of the
assumption that the lender does not have any bargaining power. Equation (4) also shows that the
implicit government guarantee affects banks’ risk taking via two channels: the funding (or supply
side) channel, by anticipating a bailout creditors of unsound bankers require a lower interest rate;
and the insurance (or demand side) channel, by expecting a subsidy in default states bankers are
more likely to choose to be exposed to tail risk.
3.6 Definition of Equilibrium

In addition to balance sheet structure, bankers’ profits are also determined by the equilibrium network. This equilibrium network is defined using the pairwise stability notion of Jackson and Wolinsky (1996).

**Definition 4.** *(Pairwise-stable network)* An interbank network $G$ is pairwise-stable (PWS) if

(i) for all $i, j$ $(i, j \in \{b_1, b_2, b_3\}$ and $i \neq j$) we have

$$\mathbb{E}\left[\pi_i (G, \cdot)\right] \geq \mathbb{E}\left[\pi_i (G \setminus (i, j), \cdot)\right],$$

(ii) for all $i, j$ $(i, j \in \{b_1, b_2, b_3\}$ and $i \neq j$) we have

$$\mathbb{E}\left[\pi_i (G, \cdot)\right] < \mathbb{E}\left[\pi_i (G \cup \{(i, j)\}, \cdot)\right] \Rightarrow \mathbb{E}\left[\pi_j (G, \cdot)\right] > \mathbb{E}\left[\pi_j (G \cup \{(i, j)\}, \cdot)\right].$$

Statement (i) requires that it is not possible, in equilibrium, for any of the two banks to have a profitable deviation by severing the connection. That is, the additional credit line established between $i$ and $j$ makes both banks at least as well off as without the liquidity insurance opportunity. Statement (ii), on its turn, requires that if one of the parties is strictly better off with the deviation, then it must be that the other party is strictly worse off. Thus, adding a credit line requires that both banks agree, but severing a connection can be done unilaterally.

Given the definition of the equilibrium interbank network, the equilibrium in the banking system can be defined as follows.

**Definition 5.** *(Equilibrium)* An equilibrium in the banking system is defined as a set of portfolio allocations, capital holdings and a set of PWS interbank networks.

3.7 Timeline

To summarize, the timeline of the model is displayed in figure 1.
4 Decentralized equilibrium

Within this framework, the optimization problem solved by bankers can be described as

\[
\max_{k,y,G(h)} \mathbb{E}[\pi_i(\cdot)]
\]

s.t.

\[
0 \leq y \leq 1
\]

\[
k \geq 0
\]

\[
G \in \mathbb{PS},
\]

where equations (6) and (7) are the feasibility and capital non negativity constraints, respectively. In addition to the balance sheet allocation, bankers also make network proposals that affect the equilibrium interbank network provided that \(G \in \mathbb{PS}\), where \(\mathbb{PS}\) is the set of PWS networks.

With respect to liquidity allocation, banks can choose to use their interbank connections to hedge the liquidity shock or to remain in autarky. When the autarky allocation is chosen, there is a trade-off between maintaining a more liquid portfolio and survive to all liquidity shocks or to survive only a few with a more profitable asset allocation. Equation (9) displays the optimal liquidity allocation in autarky. The details are provided in the appendix.

\[
y_{\text{autarky}}^{\text{autarky}} = \begin{cases} 
\bar{\gamma} & \text{if} \quad (1 - \tilde{\gamma}) R - (\tilde{\gamma} - \gamma_L) < r_d \leq (1 - \gamma_H) R + (\tilde{\gamma} - \gamma_L) \\
\gamma_L & \text{if} \quad r_d > (1 - \gamma_H) R + (\tilde{\gamma} - \gamma_L)
\end{cases}
\]
Moreover, I will assume that

**Assumption 6.** \((1 - \bar{\gamma}) R - (\bar{\gamma} - \gamma_L) < r_d \leq (1 - \gamma_H) R + (\bar{\gamma} - \gamma_L)\).

Assumption 6 ensures that the liquidity choice does not change regardless of interbank participation and is made for the sake of simplicity. This assumption does not change qualitatively the results of the model, but improves substantially tractability.

From the determined liquidity allocation, the intensity of the interbank connections can be assessed. Note \(y = \bar{\gamma}\) implies that each credit line amounts to \(\gamma_H - \bar{\gamma} = \bar{\gamma} - \gamma_L\), the remainder needed to cover the adverse liquidity shock \(\gamma_H\). Furthermore, when liquidity coinsurance is obtained through interbank market participation, the optimal liquidity choice is determined solely by the average liquidity shock. To see why this is true note that if assumption 5 holds, then there are gains in establishing credit lines to hedge adverse liquidity shocks. Without aggregate uncertainty, holding \(\bar{\gamma}\) units of liquidity is sufficient to ensure the survival of all banks provided that the interbank market can redistribute it efficiently. If this assumption holds, then complete self-insurance is not optimal. This is not without its empirical validation since banks establish relevant connections among themselves (see Cocco et al. 2009 and Upper 2011 for example).

**Lemma 1.** Under assumption 6, in any unregulated equilibrium banks choose to hold \(k^* = 0\) and the liquidity allocation is independent of the interbank network.

The sketch of the proof follows. The privately optimal capital level can be derived from the first order condition

\[
\frac{\partial \mathbb{E} [\pi (\cdot)]}{\partial k} = \begin{cases} 
R \phi (G) - \delta & \text{if } s = \text{sound} \\
R \phi (G) \beta - \delta & \text{if } s = \text{unsound} 
\end{cases}
\]

From the assumption that capital is costly \((\delta > R)\), it follows that \(\frac{\partial \mathbb{E} [\pi (\cdot)]}{\partial k} < 0\) regardless the type of illiquid asset chosen. Thus, without regulation, banks do not wish to hold any positive amount of capital in their balance sheets.

Then, after \(k^*\) and \(y^*\) have been determined, all that remains to be chosen by the banker is the quality of the illiquid asset. That is,

\[
\pi^*_i (G, k, y, \theta) = \max_s \pi_i (G, k, y, \theta, s).
\]

The choice of \(s\) depends not only on the ability of the banker but also on \(\nu\). To keep the model economically interesting, and match the resilience heterogeneity empirically verified during the crisis (see Senior Supervisors Group 2008), I assume

**Assumption 7.** Low ability bankers always choose unsound assets, that is,

\[
C (\theta_L) > (1 - \beta) [(1 - \bar{\gamma}) R - r_d - 2\nu] + \beta \mathbb{E} [r_{1B} (G_1, \text{unsound})].
\]

and
Assumption 8. High ability bankers always choose sound assets, that is,

\[ C(\theta_H) < (1 - \beta) [(1 - \tilde{\gamma}) R - r_d] + \beta \mathbb{E} [r_{IB}(G_1, \text{unsound})] - 2 (1 - \beta) \nu. \]

In other words, assumption 7 states that the cost of selecting high quality assets for a low ability banker exceeds the weighted average of the after guarantee added profits of liquidity insurance and the incremental costs of funding. Similarly, assumption 8 states that the selection costs for high ability bankers are lower than the weighted average of the added profits allowed by liquidity coinsurance and the incremental costs of funding net of the bailout subsidy. Combining lemma 1 with assumptions 1-8 leads to

**Proposition 1.** Without regulation, the complete network is PWS.

**Proof.** Note that \( \frac{\Delta \mathbb{E}[\pi_i(\cdot)]}{\Delta |G^-|} = [(1 - \tilde{\gamma}) R - r_d - \mathbb{E} [r^i_{IB}(\cdot)] \frac{\Delta \phi(G)}{\Delta |G^-|} + \frac{\Delta \lambda(G)}{\Delta |G^-|} > 0, \) where \(|G^-|\) is the number of incoming credit lines available to bank \( i. \) The sign of this variation stems from the assumption that the probability of survival is increasing in the number of credit lines the banks can draw upon, and from the potential intermediation gains that the bank can get from being located between two other institutions with opposite liquidity shocks. Even though the sign of \( \frac{\Delta \lambda(G)}{\Delta |G^-|} \) is network dependent, the intermediation proceeds have a low expected value if the intermediary has a low bargaining power. Thus, on the potential borrowers' side, the higher is the connectivity the higher is the expected profit. Moreover, since the potential lenders are risk neutral and the credit lines are priced according to the default risk of the counterparties, the borrowers' willingness to increase connectivity is not deterred by lenders. \( \square \)

The result that the complete network is pairwise-stable is not surprising. In the absence of extra costs inherent to the credit line, an additional connection will always increase the potential borrower's expected profit. This result is not general, though. Naturally, there may be circumstances where banks are underconnected (as shown by Acemoglu et al. 2013). However, in these cases capital charges are not desirable since they may inhibit the re-establishment of the interbank network.

5 Planner’s problem under symmetric information

In order to assess the need for regulatory measures such as the ones that motivate this paper, it is required to understand to which extent the decentralized equilibrium outcome derived in section 4 differs from the one that a symmetrically informed planner would choose. If that is the case, then intervention is required to correct the gap between private and social incentives.

I assume that the social planner wishes to maximize total welfare in the banking system. Following Giammarino et al. (1993) total welfare is expressed as the sum of the banks’ expected profits net of non-pecuniary benefits that are not socially valuable - \( \bar{\pi}^*(\cdot) \), minus expected financial distress costs (\( \mathbb{E} [\rho(G, \theta)] \)) augmented by the cost of the inefficiencies (\( \lambda > 0 \)) introduced by funding \( \rho(G, \theta) \) using taxation (see Freixas 1999 and Acharya and Yorulmazer 2007). Financial distress
costs, $\rho(G, \theta)$, include both deposit insurance costs and the costs associated with the disruption in the financial system brought by default events (i.e., disruptions in payment systems that are increasing in unsound banks’ incoming credit lines) net of the banks’ liquidation value in case of default ($\chi$). Formally,

$$\rho(G, \theta) = r_d \left( E[\# \text{defaults}|G, \theta] + 3 - \sum_{i=1}^{3} \phi_i(G) \right) + \min \{ \tilde{\nu}(G), \eta(\# \text{defaults}|G, \theta) - \chi \}, \quad (10)$$

where $\tilde{\nu}$ are the network dependent bailout costs to all stakeholders other than depositors in default states and $\eta$ is a discrete convex function. The convexity assumption reflects the idea that as more defaults pile on, costs are increasingly higher due to the loss of key parts of the banking infrastructure.

Thus, the planner’s problem under symmetric information is given by

$$\max_{G, y, k} \mathbb{W}(G, y, \theta) = \sum_{i=1}^{3} E[\tilde{\nu}_i^*(G, k, y, \theta)] - (1 + \lambda) E[\rho(G, \theta)] + 3r_d. \quad (11)$$

Notice that even though the regulator is still constrained by the distribution of bankers’ ability, under symmetric information, she can directly choose $k$, $y$ and $G$. Naturally, the planner can freely allocate liquidity across the system after the liquidity shock materializes. However, in order to provide a comparison with the decentralized equilibrium outcome I model the liquidity reallocation choice as an interbank network. In this context, the network is interpreted as the transfers the planner is willing to make after observing the liquidity but before the return shock materializes, conditional on the banker’s type.

This optimal solution can then be enforced by requiring bankers to hold minimum liquidity requirements (i.e., lower bounds on $y$) or by imposing quantitative restrictions on the number of interbank credit lines banks can establish with other banks in the system. Regardless of the particular choice of instruments that the regulator decides to use to implement problem (11)’s solution, it is evident that undifferentiated capital requirements are not the most effective among all the alternatives available. Even though the regulator wishes to limit the tail risk assumed by unsound bankers, imposing capital requirements on sound ones unambiguously decreases total welfare. Thus, this observation further motivates the assumption that an informational friction may condition regulatory design and consequently it deserves some consideration.

Even under perfect information the regulator faces a tradeoff when deciding to what extent she

\[19\] Alternatively, I could have considered the case where regulation acts directly by replacing unsound by sound bankers, or even more drastically withdraw their banking license.

\[20\] In my model, capital only plays the role of a Pigouvian tax. This can be motivated by the focus on tail risk, that is, in order to create a buffer against low probability high impact events banks would be required to hold a considerable amount of capital that might be unfeasible. Moreover, the regulator may have limited ability to determine the precise buffer that prevents failures when banks misreport their exposures. As argued by Huizinga and Laeven (2012), the evidence that financial reports may provide a distorted picture of banks’ resilience can be found in the result of the 2009 US stress tests. These tests revealed capital shortages even though reports gave the appearance that the minimum regulatory requirements were fulfilled.
should allow bankers to access the interbank infrastructure. In one hand, a more interconnected
interbank network increases banks’ profits in the good states of the world, but on the other hand it
also leads to defaults by contagion in bad states. This tradeoff becomes clear when taking discrete
differences in equation (11)

\[
\frac{\Delta W}{\Delta |G|} = \sum_{i=1}^{3} \frac{\Delta \mathbb{E} [\bar{\pi}_i (\cdot)]}{\Delta |G|} - (1 + \lambda) \frac{\Delta \mathbb{E} [\rho (\cdot)]}{\Delta |G|} \geq 0. \tag{12}
\]

Although equation (12) cannot be signed unambiguously, it is instructive to analyze how this
tradeoff is affected by changes in other parameters. Since the higher \( \lambda \) and the incremental financial
distress costs are, the lower are the net social benefits of more interconnectedness it is not surprising
that the regulator never allows unsound banks to borrow from other banks when these costs are
sufficiently high.

**Proposition 2.** When \( \lambda \) and/or \( \mathbb{E} [\rho (\cdot)] \) are high enough, then the complete network, \( G_1 \), is not socially optimal.

**Proof.** The proof follows directly from equation (12). Denoting \( G_1' \) as any network obtained from \( G_1 \)
when unsound banks are denied to participate in the interbank market reducing financial disruption
costs, the implicit condition in the Proposition is the following

\[
\sum_{i=1}^{3} \frac{\Delta \mathbb{E} [\bar{\pi}_i (\cdot)]}{\Delta |G|} - (1 + \lambda) \frac{\Delta \mathbb{E} [\rho (\cdot)]}{\Delta |G|} < 0 \iff
\]

\[
\iff \lambda > \frac{\sum_{i=1}^{3} \mathbb{E} [\bar{\pi}_i (G, \cdot) - \bar{\pi}_i (G', \cdot)]}{\mathbb{E} [\rho (G_1, \theta)] - \mathbb{E} [\rho (G_1', \theta)]} - 1.
\]

Figure 2: Complete network, \( G_1 \)

Comparing Propositions 1 and 2, it follows that when augmented financial distress costs are
high enough there is a misalignment between private and social incentives to establish connections.
Since bankers fail to take into account the negative externalities they imposed on the regulator,
they become overly interconnected from a social point of view. To eliminate this gap, following the policy under analysis, I assume that the regulator chooses interconnectedness sensitive capital requirements, which are studied in the next section.

6 Planner’s problem under asymmetric information

To accommodate regulatory design, I add a new date \( t = -1/2 \) to the model, when the capital charges are fixed by the regulator. Then, at the network formation stage banks treat them as an exogenous cost to form credit lines. Since it is not possible to induce low ability bankers to reveal their type without also affecting high quality bankers, the first best cannot be achieved under asymmetric information.

Given that the source of the externality is the interbank network, the Pigouvian tax (i.e., cost of the capital charge) implemented to solve this problem is also defined with respect to the network. Imposing interconnectedness based requirements creates a tradeoff between raising additional capital and benefitting from increased connectivity. This added cost can affect the interbank network that emerges as the equilibrium outcome. Thus, analyzing capital requirements within a network formation game allows to design a policy that takes into account how optimizing agents react to them. Following the spirit of the policy that motivates this paper, I consider a simple per incoming credit line capital requirement. That is, for each incoming credit line established by the potential borrower, the minimum amount of capital that banks must hold increases by \( \kappa \).

In contrast to sections 4 and 5, where the informational friction did not play any role, this section details the planner’s problem when exposure to tail risk is private information. Under asymmetric information, it is given as follows

\[
\max_{\kappa} \mathbb{W} = \sum_{i=1}^{3} \mathbb{E} \left[ \pi^*_i (G, \kappa, \gamma, \theta) \right] - (1 + \lambda) \mathbb{E} \left[ \rho (G, \theta) \right] + 3r_d \tag{13}
\]

\[
\text{s.t.}
\]

\[
\mathbb{E} \left[ \pi^*_i (G, \kappa, \gamma, \theta) \right] \geq 0 \tag{14}
\]

\[
\mathbb{E} \left[ \pi^*_i (G, \kappa, \gamma, \theta) \right] \geq \mathbb{E} \left[ \pi^*_i (G', \kappa, \gamma, \theta) \right] \tag{15}
\]

\( \forall i \in \{b_1, b_2, b_3\} \).

As is common in problems of this type, the first set of constraints in equation (14) is the set of individual rationality constraints (or participation constraints) and the second set in equation (15) comprises the incentive compatibility constraints. As shown by Myerson (1979), this representation is without loss of generality given the revelation principle. The individual rationality constraints state that under \( \kappa \) each bank is better off continuing its operations rather than exiting the market. In this case, the intersection of the second set of constraints has a particular meaning since it expresses that banks will only choose those networks that are pairwise-stable given \( \kappa \). Much like in similar
screening problems, banks are induced to reveal their type by self-selecting into the menu designed for their class of risk.

From the regulator’s standpoint, choosing \( \kappa \) involves a series of trade-offs. On one hand, by choosing higher capital requirements based on the number of incoming credit lines the regulator can reduce interconnectedness and thus reduce financial distress costs. On the other hand, reduced interconnectedness achieved through higher capital requirements also reduces liquidity coinsurance and increases capital costs leading to a decrease in banks’ profits.

When the regulator adopts a given \( \kappa \), she creates an undifferentiated added cost of adding an incoming credit line. However, banks do not benefit identically from increased interconnectedness. The heterogeneity in bankers’ ability, that is translated into individual risk taking, has an immediate implication for the marginal value of each connection in the interbank market. While sound banks’ profits increase by the full amount allowed by coinsurance in additional states of the world, unsound banks only benefit with probability \( \beta \) from the marginal return (net of interbank interest rate) of additional liquidity coinsurance and with probability \( 1 - \beta \) from the bailout subsidy. These differences can be analyzed in detail by decomposing the incremental profit allowed by each interbank connection both for sound and unsound banks. That is,

\[
\frac{\Delta \mathbb{E} [\pi^*_i (\cdot, \theta H)]}{\Delta [G^*_i]} = \left[ 1 + \left( |G^*_i - \gamma| \right) R - r_d \right] \phi_i (G) + \epsilon_i (G) - \delta \left( |G^*_i - \gamma| + 1 \right) \kappa + B - C (\theta) - \left[ 1 + |G^*_i - \gamma| \right] R - r_d \phi_i (G’) + \epsilon_i (G’) + \delta |G^*_i - \gamma| = \left[ (1 - \gamma) R - r_d \right] \Delta \phi_i + \Delta \epsilon_i - (\delta - R \Delta \phi_i) \kappa,
\]

and

\[
\frac{\Delta \mathbb{E} [\pi^*_i (\cdot, \theta L)]}{\Delta [G^*_i]} = \left[ 1 + \left( |G^*_i - \gamma| \right) R - r_d - \mathbb{E} [r^i_{IB} (G, s)] \right] \beta \phi_i (G) + \beta \epsilon_i (G) - \delta \left( |G^*_i - \gamma| + 1 \right) \kappa + B + \nu (1 - \beta) \left( |G^*_i - \gamma| + 1 \right) - \left[ 1 + \left( |G^*_i - \gamma| \right) R - r_d - \mathbb{E} [r^i_{IB} (G’, s)] \right] \beta \phi_i (G’) - \beta \epsilon_i (G’) + \delta |G^*_i - \gamma| = \left[ (1 - \gamma) R - r_d \right] \beta \Delta \phi_i - \Delta \mathbb{E} [r^i_{IB}] \beta \Delta \phi_i + \beta \Delta \epsilon_i + (1 - \beta) \nu - (\delta - R \beta \Delta \phi_i) \kappa.
\]

Then, it follows from equations (16) and (17) that sound and unsound bankers wish to establish an additional credit line if \( \kappa \) is low enough, i.e.,

\[
\frac{\Delta \mathbb{E} [\pi^*_i (\cdot, \theta H)]}{\Delta [G^*_i]} > 0 \iff \left[ (1 - \gamma) R - r_d \right] \Delta \phi_i + \Delta \epsilon_i - (\delta - R \Delta \phi_i) \kappa > 0 \iff
\]
\[ \iff \kappa < \{(1 - \bar{\gamma}) R - r_d \} \Delta \phi_i + \Delta \epsilon_i \} / (\delta - R \Delta \phi_i) \equiv \kappa_s (\Delta \phi_i; \delta, R, r_d), \]

and

\[ \frac{\Delta \E \left[ \pi^*_i (\cdot, \theta_L) \right]}{\Delta \left[ G^-_i \right]} > 0 \iff \{(1 - \bar{\gamma}) R - r_d \} \beta \Delta \phi_i - \Delta \E \left[ r^i_{IB} \right] \beta \Delta \phi_i + \beta \Delta \epsilon_i + (1 - \beta) \nu - (\delta - R \beta \Delta \phi_i) \kappa > 0 \iff \]

\[ \iff \kappa < \{(1 - \bar{\gamma}) R - r_d \} \beta \Delta \phi_i - \Delta \E \left[ r^i_{IB} \right] \beta \Delta \phi_i + \beta \Delta \epsilon_i + (1 - \beta) \nu \} / (\delta - R \beta \Delta \phi_i) \equiv \kappa_u (\Delta \phi_i; \delta, R, r_d, \nu). \]

More importantly, since the negative externality arises because unsound banks are overly connected the tradeoff between financial stability and efficiency depends strongly on how much sound and unsound banks value interbank connections. If sound banks value relatively more credit lines, then it is possible to induce unsound banks to reduce their interconnectedness without reducing the benefits of liquidity coinsurance that sound banks benefit, ceteris paribus. Even in this case there is a tradeoff between financial stability and efficiency. By reducing the extent to which unsound banks participate in the interbank market, and thus improving stability, efficiency is still reduced because all banks have to raise more capital. However, if unsound bankers value relatively more interbank connections, then the tradeoff becomes more onerous, given that now more efficiency needs to be foregone to improve financial stability. To understand under which conditions each scenario arises, one needs to inspect the difference between equations (16) and (17). That is,

\[ \frac{\Delta \E \left[ \pi^*_i (\cdot, \theta_H) \right]}{\Delta \left[ G^-_i \right]} - \frac{\Delta \E \left[ \pi^*_i (\cdot, \theta_L) \right]}{\Delta \left[ G^-_i \right]} = (1 - \beta) \{(1 - \bar{\gamma}) R - r_d + \kappa R\} \Delta \phi_i + \Delta \epsilon_i - \nu + \Delta \E \left[ r^i_{IB} \right] \beta \Delta \phi_i. \]

Thus, unsound banks value relatively more credit lines if

\[ (1 - \beta) \{(1 - \bar{\gamma}) R - r_d + \kappa R\} \Delta \phi_i + \Delta \epsilon_i - \nu + \Delta \E \left[ r^i_{IB} \right] \beta \Delta \phi_i < 0 \iff \]

\[ \iff \kappa < \{\nu - (1 - \bar{\gamma}) R - r_d \} \Delta \phi_i - \Delta \epsilon_i - \Delta \E \left[ r^i_{IB} \right] \Delta \phi_i / \beta \} / R \Delta \phi_i \equiv \bar{\kappa}. \]

Which implies that

**Proposition 3.** If \( \kappa_s > \bar{\kappa} \) the regulator can induce unsound banks to reduce their interconnectedness without affecting the extent to which sound banks benefit from participating in the interbank market, ceteris paribus.

**Proof.** The proof follows from equations (15), (16) and (17).

Under asymmetric information, the regulator cannot condition \( \kappa \) on bankers’ types. Thus, when \( \kappa \) is defined strictly on the number of connections established, the extent to which unsound banks
participate in the interbank market can only be reduced by choosing $\kappa$ high enough so that they do not wish to increase their interconnectedness. However, if unsound banks value relatively more credit lines, which occurs if $\kappa > \kappa_s$, then it is not possible to induce them to eliminate connections without also inducing sound banks to do the same.

Alternatively, the regulator can choose non contingent capital requirements, $\bar{\kappa}$. If the ratio of low to high ability bankers is low, then by choosing a capital requirement that drives unsound banks out of the system the regulator may increase financial stability. Thus, the question is whether there is a non contingent capital requirement that violates unsound bankers’ participation constraint without doing so for sound ones. That is,

$$
\mathbb{E} [\pi^* (G_1, \bar{\kappa}, \bar{\gamma}, \theta_H)] = 0 \iff \bar{\kappa} = \left[ (1 - \bar{\gamma}) R - r_d + B - C (\theta_H) \right] / (\delta - R), \quad (18)
$$

and

$$
\mathbb{E} [\pi^* (G_1, \bar{\kappa}, \bar{\gamma}, \theta_L)] = 0 \iff \bar{\kappa} = \left[ \left[ (1 - \bar{\gamma}) R - r_d - \mathbb{E} \left[ r^I_B (\cdot) \right] \right] \beta + B + 2\nu (1 - \beta) \right] / (\delta - R\beta). \quad (19)
$$

It follows from equations (18) and (19) that the ability of the regulator depends once again on the magnitude of the implicit guarantees. In other words,

**Proposition 4.** The regulator can drive unsound banks out of the system without violating sound bankers participation constraints if the magnitude of bailout subsidies is low enough.

**Proof.** Straightforward.

Propositions 3 and 4 show that, under asymmetric information, the regulator is constrained in her ability to induce banks to form the socially efficient interbank network. Moreover, this ability is affected by the magnitude of bailout subsidies. In its turn, the relevance of this distortion can be traced back to the particular institutional framework, which I discuss in the next section.

7 Discussion

In the previous section, I showed that when the informational friction interacts with implicit government guarantees the regulator faces a steeper efficiency-financial stability trade off. This is the case not only due to more capital being required to induce unsound banks to become less interconnected, but also because in this process sound banks’ interconnectedness may also be reduced. This last effect depends on the magnitude of $v$ as given by the condition in proposition #. It is instructive to ask then how likely is it to be met. Even though the magnitude of this implicit bailout subsidy is an empirical question, it is unreasonable to expect it to exceed the profit in the good state of the world. Nevertheless, even under the most favorable conditions assumed up until this point, the regulatory
tradeoff is still increasing in the importance of \( v \). In this section, relax some critical assumptions that have a direct implication on this tradeoff.

7.1 Correlated liquidity and return shocks

Proposition 3 was derived under the assumption that liquidity and return shocks are independent. However, it is more reasonable to assume that unsound banks face higher than average liquidity shocks with a higher probability than sound ones do (i.e., \( \text{prob}(\gamma = \gamma_H | s = \text{unsound}) > \text{prob}(\gamma = \gamma_H | s = \text{sound}) \) or \( \min \{ \phi_2, \phi_3, \phi_4, \phi_5 \} > \max \{ \phi_1, \phi_6 \} \)). This would correspond to a higher probability of bank runs, for example. If this is the case, then unsound banks’ additional benefit of an additional credit line may exceed the one of sound ones, violating the condition of this Proposition.

7.2 Risk aversion

The differences in (tail) risk taking were motivated by assuming that bankers have heterogenous ability levels. An alternative approach would be the case where bankers have heterogenous risk preferences. That is, less risk averse bankers may take on more risk if the return on the good states of the world exceeds the return on safer assets. If this is the case, the additional benefit brought about by enhanced liquidity insurance would be higher for unsound banks. Then, the constraints that the market frictions impose on the design of regulation would remain qualitatively unchanged.

7.3 Imperfect signals with respect to tail risk exposure

Even though the two extreme cases presented in this paper with respect to the ability of the regulator to observe tail risk exposures ex ante are not realistic, they provide useful benchmarks. A more realistic assumption is the case where the regulator is able to condition capital requirements on some ex ante imperfect signal of risk exposures, such as risk weighted assets. However, provided that the signal is noisy, such that unsound assets cannot be perfectly distinguished from sound ones, the main economic argument still holds. That is, the regulator still faces a tradeoff between constraining investment in sound assets and limiting the negative externality posed by unsound ones.

7.4 Network is observable but tail risk exposure is not

The assumption that the interbank network is perfectly observed by the regulator is undoubtedly a strong assumption. Moreover, it contrasts with the assumption that tail risk exposure is not observed by the regulator at an individual level. Even though interbank exposures may be hard to identify, tail risk exposure may be even harder to measure. The difference may lie on the fact that while connections may already be in place, tail risk may only manifest itself at some unknown point in the future.
7.5 Bankers’ ability distribution
Throughout the paper, I fixed the ability distribution. However, since all results are established based on the types of banks involved, the assumption regarding a particular distribution is without loss of generality.

8 Policy implications
8.1 Resolution regimes
The existence of G-SIBs poses a major threat to financial stability, such that no single approach is able to deal with it entirely. Therefore, a multilayered approach is required to address this externalities issue. In addition to the higher loss absorbency requirement extensively discussed in this paper, that reduce the probability of default of G-SIBs, the (Financial Stability Board; 2010) developed measures to improve resolution and recovery regimes with the objective of “reduce the extent or impact of failure of G-SIBs” (BCBS; 2011, p. 3).

The analysis carried out in this paper suggests that resolution regimes may play a larger role in financial stability, though. Since effective resolution frameworks reduce ex post costs of G-SIBs failures they lend credibility to closure policies, which reduces expected bailout subsidies. If these subsidies are related not only with size but also with interconnectedness, then this implies that unsound banks, the prospective recipients of these subsidies, value less their connections. Consequently, it becomes more effective for an informationally constrained regulator to induce unsound banks to become less interconnected using capital requirements. Therefore, not only resolution regimes complement capital charges by reducing the impact of G-SIB failures, but also they make capital requirements more effective in correcting the misalignment between private and social incentives when market frictions are relevant.

8.2 Bank levies
Following the proposals made at the G-20 meetings (IMF; 2010), since the beginning of 2011, the bank levies were introduced in several European countries, namely France, Germany, Portugal and the United Kingdom. The specific regime of the levy varies from country to country, though. While the chosen base of incidence in France was the minimum regulatory capital, Germany, Portugal and the UK targeted liabilities. However, even among those countries that chose to focus on liabilities there are significant differences not only on the structure of the rate but also the destiny of the proceeds. While Portugal, Sweden and the UK chose a flat rate for liabilities with the same maturity, Germany chose a variable rate depending on the amount. Furthermore, unlike Portugal and the UK that devoted the proceeds to the treasury, Germany allotted the capital raised by the tax to a stability fund.

\[\text{At the time, Sweden have already had enacted a 'Stability Fee' based on bank's liabilities.}\]
\[\text{In Germany, 'relevant liabilities' under 10 billion EUR are subject to 0.02%, under 100 billion EUR to 0.03% and over 100 billion EUR to 0.04%. In the United Kingdom, short-term liabilities (less than one year) over 20 billion GBP are subject to a 0.07% rate and 0.035% for longer maturities. Unlike the UK, Germany and Portugal chose to tax the notional amount of financial derivatives held by banks. Furthermore, unlike Portugal and the UK that devoted the proceeds to the treasury, Germany allotted the capital raised by the tax to a stability fund.}\]
The effects of these levies are quite similar to interconnectedness based capital requirements, they are essentially a Pigouvian tax. Both instruments create a cost when banks wish to become more interconnected. Thus, the results of this paper also apply to these instruments.

8.3 Basel III’s Asset Value Correlation (AVC)
Basel III brings major changes to the regulatory landscape. In particular, Basel II’s Counterparty Credit Risk (CCR) regulatory capital is enhanced by introducing a 1.25 multiplier (denoted as Asset Value Correlation - AVC) on exposures to large financial institutions (with total assets equal or greater to US $10 billion) in their calculation of risk-weighted assets (RWA) for banks using the internal ratings-based approach. This creates an incentive for banks to reduce their exposures to G-SIBs, and consequently reduce the impact of failures of these institutions. Much like resolution regimes, the AVC multiplier may contribute to reduce bailout subsidies, albeit at a lesser extent.

8.4 Liquidity regulation
As discussed in subsection 7.1, liquidity and credit risk may interact with the market frictions constraining regulatory design. Thus, liquidity regulation (such as the Liquidity Coverage Ratio and the Net Stable Funding Ratio) may contribute to reduce the regulatory tradeoff brought by interconnectedness based regulation.

9 Conclusion
The main point of this paper is that a micro-founded analysis can contribute substantially for the design of macroprudential regulation, especially when certain types of market frictions are present. In particular, it emphasizes that any type of regulation that aims to affect interconnectedness must be designed taking into account how it affects the incentives that lead regulated entities to become interconnected in the first place. Doing so, uncovers the effects that market frictions have on shaping these incentives and provides a guide to what complementary instruments can be used to align them with social costs and benefits.

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**Appendix**

A.1. Details of the interconnectedness criteria of “higher loss absorbency requirements” (excerpt from the rules text p. 7)

**Intra-financial system assets**

This is calculated as the sum of:

- lending to financial institutions (including undrawn committed lines);
- holdings of securities issued by other financial institutions;
- net mark to market reverse repurchase agreements;
- net mark to market securities lending to financial institutions; and
- net mark to market OTC derivatives with financial institutions.

**Intra-financial system liabilities**

This is calculated as the sum of:

- deposits by financial institutions (including undrawn committed lines);
- securities issued by the bank that are owned by other financial institutions;
- net mark to market repurchase agreements;
- net mark to market securities borrowing from financial institutions; and
- net mark to market OTC derivatives with financial institutions.

The scores for the two indicators in this category are calculated as the amounts of their intra-financial system assets (liabilities) divided by the sum total intra-financial system assets (liabilities) of all banks in the sample.
A.2. Derivation of the interbank interest rate

Thus, \( \beta \left[ \pi^r + \frac{1-\beta}{\beta} \pi^r \right] = \pi^r \), where \( \pi^r \) are the profits upon survival (or the opportunity cost of defaulting by contagion).

A.3. Derivation of assumption 5

If there are 2 subsequent risky banks on the intermediation path (i.e., the original lender is safe), the original lender’s expected profit is

\[
\beta^2 \left[ \epsilon_{safe} + (1 - y) R - r_d + B - C(\theta) + (1 - \beta^2) [B - C(\theta)] \right] = \epsilon_{safe} + (1 - y) R - r_d + B - C(\theta) \Leftrightarrow \\
\Leftrightarrow \epsilon_{safe} = \frac{1-\beta^2}{\beta^2} [(1 - y) R - r_d].
\]

Similarly when the intermediary is safe or there is only 1 subsequent risky bank the lender’s expected profit is

\[
\beta^2 \left[ \epsilon_{safe, interm.} + (1 - y) R - r_d + B \right] + (1 - \beta^2) B =
\]
\[
\begin{align*}
&= \beta \left[ \epsilon_{safe} + (1 - y) R - r_d \right] + B \Leftrightarrow \\
\Leftrightarrow \epsilon_{safe} &= \frac{1 - \beta}{\beta} [(1 - y) R - r_d]. \\
\text{or} \\
&= \beta \left[ \epsilon_{risky} + (1 - y) R - r_d + B - C(\theta) \right] + (1 - \beta) [B - C(\theta)] = \\
&= \epsilon_{risky} + (1 - y) R - r_d + B - C(\theta) \Leftrightarrow \\
\Leftrightarrow \epsilon_{risky} &= \frac{1 - \beta}{\beta} [(1 - y) R - r_d].
\end{align*}
\]

Note that in this derivation \( k \) is set to 0. Since capital is costly, setting \( k = 0 \) yields a sufficient condition for intermediation to be beneficial for borrower.

**A.4. Derivation of the liquidity allocation in autarky**

- expected profit in autarky of \( y = \gamma_L \)
  
  \[
  [(1 - \gamma_L) R - r_d] \frac{1}{3};
  \]

- expected profit in autarky of \( y = \tilde{\gamma} \)
  
  \[
  [(1 - \tilde{\gamma}) R - r_d] \frac{2}{3} + \frac{1}{3} (\tilde{\gamma} - \gamma_L);
  \]

- expected profit in autarky of \( y = \gamma_H \)
  
  \[
  (1 - \gamma_H) R - r_d + \frac{1}{3} (\gamma_H - \gamma_L) + \frac{1}{3} (\gamma_H - \tilde{\gamma}).
  \]

Comparing all equations above and given assumption 3, it can be showed that

\[
y_{\text{autarky}} = \begin{cases} 
\tilde{\gamma} & \text{if } (1 - \tilde{\gamma}) R - (\tilde{\gamma} - \gamma_L) < r_d \leq (1 - \gamma_H) R + (\tilde{\gamma} - \gamma_L) \\
\gamma_L & \text{if } r_d > (1 - \gamma_H) R + (\tilde{\gamma} - \gamma_L)
\end{cases}.
\]