A microfounded design of interconnectedness based macroprudential regulation

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Abstract

The failure of large, complex and interconnected banks has severe consequences to the real economy. To address the challenges posed by globally systemically important banks (G-SIBs), the Basel Committee on Banking Supervision designed an “additional loss absorbency requirement” for these institutions. Motivated by this measure, which reflects concern over contagion and ineffective market discipline, I develop a micro-founded analysis of interconnectedness based capital charges. These charges increase the costs of establishing interbank connections, which leads to a non-monotonic welfare effect. While reduced interconnectedness decreases welfare by restricting banks’ ability to insure against liquidity shocks, it also increases it by reducing contagion in default states. Thus, the regulator faces a trade-off between efficiency and financial stability. I show that the trade-off implied by the optimal charges is steeper the stronger G-SIBs implicit support is when banks’ tail risk exposure is private information. This underscores the importance of complementary measures, such as resolution regimes, that mitigate these frictions.

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

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

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1 Introduction

The 2007-2009 financial crisis exposed the limitations of the regulatory framework in place at the time. The crisis also confirmed that not all financial institutions are equally important for the stability of the financial system, some emerged clearly as of systemic importance. Therefore, not surprisingly, the aftermath brought a major regulatory reform for all institutions and in particular for those deemed to be systemically important. To address the challenges posed by these institutions, the Basel Committee on Banking Supervision (BCBS) designed an “additional loss absorbency requirement” (see BCBS 2011) targeted at globally systemically important banks (G-SIBs), which requires banks to hold more capital according to their systemic importance. Among other criteria, banks receive this classification based on their interconnectedness. That is, the G-SIB status depends, at some extent, on how exposed to losses other institutions are to them. The argument for 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)

The adoption of this criterium reveals regulatory concern over contagion and also suggests that market discipline alone is unable to mitigate this problem. As seen during the crisis, in a situation were the threat of contagion materializes the entities which were entrusted of preserving financial stability are prompted to intervene exposing taxpayers, even if only temporarily, to potentially large losses. However, when banks make their decisions, namely with respect to how interconnected they are with the rest of the financial system, they do not take into account these costs. Therefore, regulation is required to ensure that private and social incentives are aligned. Motivated by this instrument of macroprudential policy, I analyze a microfounded design of interconnectedness based capital requirements.

As with any other instrument, this one implies a trade-off between efficiency and financial stability. These capital charges increase the cost of establishing interbank connections, which results in a non-monotonic welfare effect. Decreased interconnectedness reduces welfare by limiting banks’ ability to rely on outside sources of financing to face idiosyncratic liquidity shocks, which in its turn reduces their ability to allocate funds to illiquid positive net present value projects. Notwithstanding, reduced interconnectedness also limits the spread of financial distress across the interbank network, which is welfare improving. Not all banks pose an equal threat to financial stability, though. Tail risk (i.e., low probability high impact default events) exposure is likely to be heterogenous. As such, the efficiency - financial stability
trade-off is bank dependent and is less steep the more exposed to tail risk a bank is.

In frictionless markets, banks with a substantial exposure to tail risk could easily be removed by the supervisor or simply be driven out of the system by market discipline, which would mitigate their negative impact on financial stability. However, market frictions are pervasive in the financial sector, namely: i) tail risk exposure is banks’ private information; and ii) systemic banks benefit from implicit government support. Consequently, the design of interconnectedness based capital charges requires an understanding on how these market frictions affect the trade-off above mentioned. I find that the more significant government guarantees are, the steeper is the efficiency-financial stability trade-off faced by an asymmetrically informed regulator. This finding underscores the importance of an integrated macroprudential policy since complementary measures, such as resolution regimes, that mitigate market frictions increase the effectiveness and efficiency of interconnectedness based capital charges. That is, not only capital requirements and resolution mechanisms are complementary but they are also mutually reinforcing.

In my model, banks invest their own and their depositors’ funds in a mixed portfolio of liquid and illiquid assets. These illiquid assets are \textit{ex ante} positive net present value projects, but need to be refinanced before maturity in an idiosyncratic amount. To insure against this liquidity shock, banks can either invest a higher fraction of available funds in liquidity or establish interbank credit lines with counterparties with negatively correlated liquidity shocks. These connections allow for a more efficient liquidity allocation, but also enable financial distress to be propagated through the network. This is the case when the borrower is exposed to tail risk, or in the terminology of Morrison and White (2005) it is \textit{unsound}. If this event materializes, losses on interbank exposures may compromise the solvency of the lenders and prompt public sector intervention when financial stress is large enough, which potentially carries significant financial and economic costs.

Given the dual role of interbank connections, the socially optimal network must balance efficiency with resilience to contagion. In order for this goal to be achieved, unsound banks should be restrained from participating in the interbank network, while sound ones should not. In frictionless markets, this goal could easily be achieved since lending conditions would reflect completely counterparty risk and/or unsound banks would be removed by prompt corrective action. However, if the regulator is asymmetrically informed, then unsound banks cannot be preemptively excluded from the system. Moreover, the existence of implicit government support dampens counterparties’ incentives to exert effective market discipline and induces lending conditions’ insensitivity to tail risk exposure. Consequently, with market frictions, in the decentralized equilibrium unsound banks choose to establish excessive interbank connections given that they fail to internalize the costs incurred by the regulator to
re-establish the normal functioning of the financial system after a tail risk event.

To align the social and privately optimal networks, the regulator can use interconnectedness based capital requirements. However, the implementation of this instrument involves three challenges. First, the interbank network is an equilibrium outcome determined by banks’ costs and benefits of establish interbank connections. Since capital charges introduce a cost in establishing connections, the impact on the network depends on how banks respond individually to this change in incentives. Therefore, the optimal capital charges need to induce a new welfare superior equilibrium. Second, tail risk exposure is private information. 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. Also, 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 as 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. Moreover, 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 consequence of this informational friction, capital charges cannot be conditioned on a bank’s true tail risk exposure, which requires that the design of this capital instrument must be incentive compatible. Third, the same guarantees that impair market discipline also grant systemic unsound banks a subsidy in default states providing an added incentive for risk taking, which in its turn incentivizes interconnectedness. By increasing its interconnectedness, banks may also increase their systemic importance and with it benefit from more substantial subsidies in default states.

To address these challenges, I propose a three stage approach. At the first stage, nature determines bankers’ types, which determines banks’ tail risk exposure. 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 own type and capital requirements as given. Then, by solving the game by backward induction the regulator determines the capital charge as the optimal solution to an unconstrained (constrained) optimization problem when she is symmetrically (asymmetrically) informed. When the regulator is asymmetrically informed, the constraints 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).

I find that the resulting optimal interconnectedness based capital charges are characterized by a trade-off between efficiency and financial stability, which is steeper in the severity of asymmetric information and implicit government support. 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 asymmetrically informed regulator to induce unsound banks to become less interconnected without affecting sound ones. Moreover, this difficulty is also increasing in the correlation between liquidity and credit shocks. If unsound banks are also more likely to be hit by a negative liquidity shocks, these banks value more their interbank connections than their sound counterparts. In addition, differences in risk aversion can also drive a wedge between the interbank connections' valuation. If unsound banks are less risk averse, and consequently have a more aggressive risk culture which cannot be contracted, they will value relatively more interbank connections. Thus, correlation between liquidity and credit risk and more aggressive risk cultures play an analogous role to implicit guarantees in constraining the regulator’s ability to limit the participation of unsound banks in the interbank market.

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 trade-off between financial stability and efficiency less burdensome when banks’ interconnectedness decisions generate negative externalities. Second, since this trade-off is increasing in liquidity and return shock correlation, liquidity requirements such as the Net Stable Funding Ratio (NSFR) brought by Basel III can improve the effectiveness of interconnectedness based capital requirements. Third, the main message of the paper also applies to other forms of Pigouvian taxation that were adopted via banking levies in several european countries to deal with systemic risk (see IMF 2010).

The rest of the paper is organized as follows. Section 2 presents a brief summary of Basel III’s systemic risk charges and discusses the model’s results in light of the regulatory reform initiated after the crisis. Section 3 discusses how this paper fits in the literature. Section 4 describes the basic setup. Section 5 presents the decentralized equilibrium outcome. Sections 6 and 7 compare the regulator’s problem under symmetry and asymmetry of information, respectively. Section 8 discusses the results. Section 9 analyzes the model’s policy implications. Finally, section 10 concludes.
2 G-SIBs “additional loss absorbency requirement”

Basel III’s “additional loss absorbency requirement” follows an indicator based approach that takes into account (with equal weights) size, interconnectedness, importance to financial institution infra-structure, cross-border reach and complexity. G-SIBs are then allocated across four buckets as follows

<table>
<thead>
<tr>
<th>Bucket</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5%</td>
<td>HSBC, JP Morgan Chase</td>
</tr>
<tr>
<td>2.0%</td>
<td>Barclays, BNP Paribas, Citigroup, Deutsche Bank</td>
</tr>
<tr>
<td>1.5%</td>
<td>Bank of America, Credite Suisse, Goldman Sachs, Group Crédit Agricole,</td>
</tr>
<tr>
<td></td>
<td>Mitsubishi UFJ FG, Morgan Stanley, Royal Bank of Scotland, UBS</td>
</tr>
<tr>
<td>1.0%</td>
<td>Bank of China, Bank of New York Mellon, BBVA Groupe, Group BPCE, Industrial</td>
</tr>
<tr>
<td></td>
<td>and Commercial Bank of China Limited, ING Bank, Mizuho FG, Nordea, Santander,</td>
</tr>
<tr>
<td></td>
<td>Société Générale, Standard Chartered, State Street, Sumitomo, Mitsui FG,</td>
</tr>
<tr>
<td></td>
<td>Unicredit Group, Wells Fargo</td>
</tr>
</tbody>
</table>

source: FSB (2013)

Importantly, this allocation is not static, it is subject to periodical revisions. Thus, banks have an incentive to re-optimize their risk profile. When considering their interconnectedness decisions, banks internalize the costs stemming from higher capital requirements. This observation implies that capital charges have an impact on the equilibrium interbank network, which can best be analyzed using a network formation game.

3 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

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1The interconnectedness criteria, which is the focus of this paper, is measured by three (also equally weighted) indicators: intra-financial system assets, intra-financial system liabilities and securities outstanding. See appendix and BCBS (2011) for further details.

2“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).

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 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 market frictions. 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, Drehmann and Tarashev 2013 and Bluhm and Krahnen 2014). 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.
4 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 of measure one fully covered by a common deposit insurer/regulator.\textsuperscript{4} All agents are risk-neutral and time is divided into four dates. Each bank is owned and operated by a banker. To capture heterogeneity in risk-taking, I assume that nature draws banker $i$’s ability, $\theta_i$, from $\{\theta_L, \theta_H\}$ at $t = -1$. Ability then determines the cost to the banker of selecting the type of illiquid asset ($x$). Illiquid asset’s types and the events that take place at subsequent dates are described as follows.

4.1 Return shocks

At $t = 0$, depositors are endowed with a unit of the generic good and nothing at subsequent dates. Also at this date, bankers use their depositors’ endowments and their own capital ($k$) to invest in a portfolio of illiquid ($x$) and liquid ($y$) assets. While liquidity is the standard storage technology, yielding one unit of the generic good per unit invested in the preceding date, the illiquid asset returns a stochastic amount at $t = 2$ per unit invested at $t = 0$.

This stochastic return is conditioned by the illiquid asset’s type, though. This asset can either be sound or unsound (borrowing the terminology of Morrison and White 2005). Even though both types of assets have the same gross return at maturity in good states of nature, equal to $R (> 1)$, unsound assets default in bad states of nature earning zero gross return with probability $1 - \beta$. This probability is assumed to be low and fundamental defaults independent across banks. 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.\textsuperscript{5}

These assets are assumed to be ex ante identical. Bankers can, however, learn the type of the illiquid assets at a cost. Following Giammarino et al. (1993), bankers have control

\textsuperscript{4}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.

\textsuperscript{5}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. It establishes the best possible conditions for the regulator. As I discuss in section 8, even under these conditions, the design of macroprudential regulation is still affected by the market imperfections considered in this paper.
over resources \( (B) \) that can either be appropriated to their own benefit without detection, or devoted to improve asset screening. Let \( C (\theta_i) \) (with \( C (\theta_L) > C (\theta_H) \)) denote the cost of screening determined by ability \( \theta_i \). That is, high ability bankers have a comparative advantage in selecting sound assets.\(^6\) 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 trade-off between benefiting from an increased probability of success and having less resources that can be appropriated by the banker. Since these events are extremely rare, tail risk exposure may not be observable \( \text{ex ante} \) by outsiders and thus cannot be contracted upon.

In frictionless markets, unsound bankers would either fail to attract funds or they would be screened out by the regulator. However, market frictions allow unsound bankers to persist. Creditors may be insured either explicitly, via deposit insurance,\(^7\) or implicitly through implicit government guarantees. In addition to providing G-SIBs with a funding advantage, implicit government support provides unsound bankers with 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 (\( \text{ex post} \)) optimal to bailout troubled banks instead of letting them fail. \( \text{Ex ante} \) the regulator would like to commit to a closure policy, but \( \text{ex post} \) 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). Furthermore, bailouts may be more likely when

\(^6\)This 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.”

\(^7\)This 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.
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, which reduce this distortion have on the effectiveness of interconnectedness sensitive capital requirements.

As a baseline, \( b_1 \) and \( b_3 \) are assumed to be 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 8. The next assumption summarizes the information set of each player.

**Assumption 1.** Banks know their own type, but outsiders only observe (ex ante) the distribution of \( \Theta \).

The assumption that the regulator is not able to infer *ex ante* the ability 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.

### 4.2 Liquidity shocks

Before these illiquid assets mature, however, each bank faces the need to refinance the illiquid share of its portfolio. The return at maturity of the illiquid asset is contingent on the survival to the regional liquidity shock that hits banks at \( t = 1 \).

Let \( \gamma \in \{\gamma_H, \gamma_L, \bar{\gamma}\} \) denote the amount of the liquidity need revealed to the bankers at the interim date, with \( \gamma_H > \gamma_L \) and \( \bar{\gamma} = (\gamma_H + \gamma_L) / 2 \). This shock can be thought as

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8The 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.
refinancing need which must be met to ensure illiquid asset’s stochastic 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, these are “pure” liquidity shocks, that is, they are balanced at maturity. Suppose that at \( t = 1 \), the bank faces a shock equal to \( \gamma_L \), then the asset at maturity returns \( xR - (\bar{\gamma} - \gamma_L) \) in success states. In 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>
<thead>
<tr>
<th>Probability</th>
<th>( \omega )</th>
<th>( \gamma )</th>
<th>( \gamma_H )</th>
<th>( \gamma_L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi_1 )</td>
<td>( \omega_1 )</td>
<td>( \bar{\gamma} )</td>
<td>( \gamma_H )</td>
<td>( \gamma_L )</td>
</tr>
<tr>
<td>( \phi_2 )</td>
<td>( \omega_2 )</td>
<td>( \gamma_H )</td>
<td>( \bar{\gamma} )</td>
<td>( \gamma_L )</td>
</tr>
<tr>
<td>( \phi_3 )</td>
<td>( \omega_3 )</td>
<td>( \gamma_H )</td>
<td>( \gamma_L )</td>
<td>( \bar{\gamma} )</td>
</tr>
<tr>
<td>( \phi_4 )</td>
<td>( \omega_4 )</td>
<td>( \gamma )</td>
<td>( \gamma_L )</td>
<td>( \gamma_H )</td>
</tr>
<tr>
<td>( \phi_5 )</td>
<td>( \omega_5 )</td>
<td>( \gamma_L )</td>
<td>( \bar{\gamma} )</td>
<td>( \gamma_H )</td>
</tr>
<tr>
<td>( \phi_6 )</td>
<td>( \omega_6 )</td>
<td>( \gamma_L )</td>
<td>( \gamma_H )</td>
<td>( \bar{\gamma} )</td>
</tr>
</tbody>
</table>

Table 2: Regional Liquidity Shocks

That is, I assume that

**Assumption 2.** Idiosyncratic liquidity shocks are independent, 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. In section 8, this assumption is replaced with a more realistic where liquidity and credit shocks are allowed to be correlated.

Combining credit and liquidity shocks, the state space is defined as follows

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

To face the liquidity shock banks can establish *ex ante* bilateral credit lines\(^9\) (see Cocco et al. 2009). 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 \((\bar{\omega}_2, \omega_2)\), through a credit line, \(b_1\) can obtain liquidity from \(b_3\).\(^10\)

This credit lines can be substantial. 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 be 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 \(\mathcal{G} := (\mathcal{L} \times \mathcal{B})\) 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 \(\bar{\gamma}\) when \(y = \bar{\gamma}\),\(^11\) the liquidation value \((1 - \bar{\gamma})R - (\bar{\gamma} - \bar{\gamma}_L)\) needs to be greater than \(r_d\) to ensure solvency. To make the model consistent with the policy that motivates it, I assume that

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

\[
(1 - \bar{\gamma})R - (\bar{\gamma} - \bar{\gamma}_L) - r_d < 0.
\]

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\(^9\)If there was a spot market for liquidity the results would remain qualitatively unaltered provided partial market discipline assumption holds.

\(^10\)Denote by \(\{(b_1, b_1)\}\) or graphically \(b_3 \rightarrow b_1\).

\(^11\)The liquidity allocation \(y = \bar{\gamma}\) is optimal when banks are active in the interbank market as will be demonstrated shortly.
Assumption 3 is a sufficient condition for the probability of default cascades to be positive. This is undoubtedly a strong assumption, but the model’s qualitative results only requires that regulator’s costs in case of default are positively related with unsound banks’ interconnectedness. Even though first round losses may only have a limited impact on the financial stability, as argued by Glasserman and Young (2014) for example, second round effects may include a downward spiral in asset prices (fire-sales) and a rise in uncertainty with respect to lenders’ resilience which may be compromise financial stability. Since G-SIBs additional capital charges specifically identify interconnectedness as a relevant factor, this assumption stems directly from the policy under analysis. Moreover, it can be argued that there is a precedent for considering interconnectedness as relevant concern to entities entrusted of safeguarding financial stability. As Bayazitova and Shivdasani (2012) show, interconnectedness was an actual determinant when approving TARP’s Capital Purchase Program (CPP) applications. Bayazitova and Shivdasani find that the ratio of the notional value of the bank’s derivates to total assets and the wholesale debt ratio leads to an increase in the probability of a CPP application to be approved by the U.S. Treasury.

In the absence of market frictions, the interest rate on these credit lines would reflect the true exposure to tail risk. However, the expectation of government support in states where tail risk materializes dampens market discipline. Moreover, since tail risk exposure is private information the interest rate is assumed to capture the expected counterparty risk instead of actual counterparty risk. The resulting implicit support adjusted probability of success, $\beta^*$, can be though of as a rating agency credit grade that incorporates support perspectives (e.g., Fitch support ratings). Thus, the knowledge of $\beta^*$ eliminates the need to ascertain tail risk exposure in setting the interbank interest rate. Thus, assuming, for the sake of simplicity, that the borrower holds all the bargaining power,$^{12}$ the expected interbank interest rate is given by

$$r_{IB}^{i,j}(G) = \sum_{j \in G_i^-} \frac{\phi_j^J}{\phi_i(G)} \frac{1 - \beta^*}{\beta^*} \left[ \left( 1 + k_j^y - y_j^i \right) R - r_d - \delta k_j^y \right],$$

where $G_i^-$ is the set of all banks that are potential lenders to bank $i$, $\delta$ is the opportunity cost of capital$^{13}$ (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), $\phi_j^J$ is the probability of the

$^{12}$Any other interest rate within the banks’ reservation price range, for example resulting from Nash bargaining. For an example of how Nash bargaining can be used in a network context see Braun and Gautschi (2006).

$^{13}$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.
state whose liquidity shock is hedged by the credit line with $j$ and $\phi_i (G)$ is $i$'s probability of survival to the liquidity shock given $G$. The full derivation of equation (1) is in the appendix.

4.4 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 $\{(b_i, b_j)\}_{k=1}^{2}$ forms a path between $b_i$ and $b_m$ if

$$\exists \, \{(b_i, b_j)_{1}, (b_j, b_m)_{2}\} \subseteq G,$$

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

$$T^-(b_i|G) = \begin{cases} 1 & \text{if there is a path of exact length 2 from another node to } b_i \\ 0 & \text{otherwise} \end{cases} .$$  \hspace{1cm} (2)

$$T^+(b_i|G) = \begin{cases} 1 & \text{if there is a path of length } \leq 2 \text{ from any two other nodes than } b_i \\ 0 & \text{otherwise} \end{cases} .$$  \hspace{1cm} (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 involved in intermediation to be 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. If this is the case, interconnectedness based capital requirements are counterproductive since banks are underconnected.

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 expected 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 expected counterparty risk along the credit path such that

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

where $i$ is any unsound bank on the intermediation path $\mathcal{I}$. 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., $\beta^* \geq \frac{1+\sqrt{13}}{6}$.

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 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).

### 4.5 Bankers’ payoffs

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

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

\[\text{where } i \text{ is any unsound bank on the intermediation path } \mathcal{I}. \text{ For simplicity, the assumption that the borrower holds all the bargaining power is maintained.}\]

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\end{cases}\]

\[\text{where } i \text{ is any unsound bank on the intermediation path } \mathcal{I}. \text{ For simplicity, the assumption that the borrower holds all the bargaining power is maintained.}\]
\[
\mathbb{E} [\pi_i (G, k, y, \theta, s)] = \begin{cases} 
\left[ (1 + k - y) R - \delta r_d - \delta r_{ij}^d (G) \right] \phi_i (G) + \epsilon_i (G) - \delta k + B - C (\theta) & \text{if } s = \text{sound} \\
\left[ (1 + k - y) R - \delta r_d - \delta r_{ij}^d (G) \right] \beta \phi_i (G) + \epsilon_i (G) \beta - \delta k + B + (1 - \beta) \nu |G_i^-| & \text{if } s = \text{unsound}
\end{cases}
\]

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 zero 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 \( x + y = 1 + k \iff x = 1 + k - y \). Moreover, the apparent absence of the inflow of interbank interest proceeds in equation (4) reflects the fact 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.

### 4.6 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 \( G \in \mathcal{G} \) is pairwise-stable *(PWS)* if
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.

### 4.7 Timeline

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

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

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

s.t.

$$1 \geq y \geq 0$$ (6)

$$k \geq 0$$ (7)

$$G \in \mathcal{PS},$$ (8)

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 $G \in \mathcal{PS}$, where $\mathcal{PS}$ 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.
Moreover, I assume that

\[ (1 - \bar{\gamma}) R - (\bar{\gamma} - \gamma_L) < r_d \leq (1 - \gamma_H) R + (\bar{\gamma} - \gamma_L). \]

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 and its interbank connections. That is,

\[
\pi_i^* (G, \theta) = \max_s \pi_i (G, k^*, y^*, \theta, s).
\]
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 heterogeneity in resilience empirically verified during the crisis (see Senior Supervisors Group 2008), I assume that

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

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

and

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

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

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 $\frac{\Delta \mathbb{E}[\pi^*_i(J)]}{\Delta |G^-|} = [(1 - \gamma) R - r_d - \mathbb{E} [r_{IB} (\cdot)]] \frac{\Delta \phi(G)}{\Delta |G^-|} + \frac{\Delta v(G)}{\Delta |G^-|} > 0$, 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 $\frac{\Delta \phi(G)}{\Delta |G^-|}$ 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.

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.

6 Planner’s problem under complete information

In order to assess the need for regulatory measures such as the ones that motivate this paper, an understanding to which extent the decentralized equilibrium outcome derived in section 5 differs from the one that a symmetrically informed planner would choose is required. If that is the case, then intervention is needed 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 - \( \pi^* (\cdot) \), 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,

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

where \( \tilde{\nu} \) are the network dependent bailout costs to all stakeholders other than depositors in default states and \( \eta \) are the network dependent financial disruption costs, which are assumed to be convex in the number of defaults. The convexity assumption reflects 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

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

s.t.

\[
\mathbb{E} [\pi_i^* (G, \kappa, \theta)] \geq 0.
\]
Notice that even though the regulator is still constrained by the distribution of bankers’ ability,\(^{15}\) under symmetric information, she can directly choose \(k, y\) and \(G.\)^{16} 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 consideration.

Even under complete information the regulator faces a trade-off when deciding to what extent she 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 trade-off becomes clear when taking discrete differences in equation (11)

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

Although equation (12) cannot be signed unambiguously, it is instructive to analyze how this trade-off 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.

\(^{15}\) 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.

\(^{16}\) 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.
when these costs are sufficiently high.

**Proposition 2.** When $\lambda$ is high enough, implicitly defined as

$$
\lambda > \sum_{i=1}^{3} \frac{\mathbb{E} [\tilde{\pi}_i (G_1, \cdot) - \tilde{\pi}_i (G'_1, \cdot)]}{\mathbb{E} [\rho (G_1, \theta)] - \mathbb{E} [\rho (G'_1, \theta)]} - 1,
$$

then any network $G'_1$ obtained from the complete network $G_1$ in which unsound banks are, at some extent, denied participation in the interbank market is welfare superior.

**Proof.** The proof follows directly from equation (12). Denoting $G'_1$ as any network obtained from $G_1$ in which unsound banks are, at some extent, denied participation in the interbank market, which reduces expected financial disruption costs, the implicit condition in the Proposition is the following

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

$$
\iff \lambda > \sum_{i=1}^{3} \frac{\mathbb{E} [\tilde{\pi}_i^* (G_1, \cdot) - \tilde{\pi}_i^* (G'_1, \cdot)]}{\mathbb{E} [\rho (G_1, \theta)] - \mathbb{E} [\rho (G'_1, \theta)]} - 1.
$$

$\square$

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.

7 Planner’s problem under asymmetric information

To accommodate regulatory design, I add a new date \( t = \frac{1}{2} \) 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 unsound banks’ participation in 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 to the banker a trade-off between raising additional capital and benefiting 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 5 and 6, 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

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

s.t.

\[
\mathbb{E} [\pi_i^* (G, \kappa, \theta)] \geq 0 \quad (14)
\]

\[
\mathbb{E} [\pi_i^* (G, \kappa, \theta)] \geq \mathbb{E} [\pi_i^* (G', \kappa, \theta)] , \quad (15)
\]

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

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,

\[
\frac{\Delta \mathbb{E} [\pi^*_i (\cdot, \theta_0)]}{\Delta [G^*_i]} = \left[ (1 + \left| G^*_i \right| + 1) \kappa - \bar{\gamma} \right] R - r_d - r_{IB}^{i,j} (G) \phi_i (G) + \epsilon_i (G) - \delta \left( \left| G^*_i \right| + 1 \right) \kappa + B - C (\theta) - \left[ (1 + \left| G^*_i \right| \kappa - \bar{\gamma} \right] R - r_d - r_{IB}^{i,j} (G') \phi_i (G') + \epsilon_i (G') + \delta \left| G^*_i \right| \kappa - B + C (\theta) = (1 - \bar{\gamma}) R - r_d \Delta \phi_i - \Delta r_{IB}^{i,j} \Delta \phi_i + \Delta \epsilon_i - (\delta - R \Delta \phi_i) \kappa,
\]

and
\[ \frac{\Delta E \left[ \pi_i^* (\cdot, \theta_L) \right]}{\Delta \left| G_i^- \right|} = \left[ 1 + \left( \left| G_i^- \right| + 1 \right) \kappa - \gamma \right] R - r_d - r_{IB}^i (G) \beta \phi_i (G) + \beta \epsilon_i (G) - \delta \left( \left| G_i^- \right| + 1 \right) \kappa + B + \nu (1 - \beta) \left( \left| G_i^- \right| + 1 \right) - \left[ 1 + \left( \left| G_i^- \right| + 1 \right) \kappa - \gamma \right] R - r_d - r_{IB}^i (G) \beta \phi_i (G') - \beta \epsilon_i (G') + \delta \left| G_i^- \right| \kappa - B - (1 - \beta) \nu \left| G_i^- \right| = \left[ (1 - \gamma) R - r_d \right] \beta \Delta \phi_i - \beta \Delta r_{IB}^{i,j} \Delta \phi_i + \beta \Delta \epsilon_i + (1 - \beta) \nu - (\delta - R \beta \Delta \phi_i) \kappa. \]

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.,

\[ \frac{\Delta E \left[ \pi_i^* (\cdot, \theta_B) \right]}{\Delta \left| G_i^- \right|} > 0 \iff \left[ (1 - \gamma) R - r_d \right] \Delta \phi_i - \Delta r_{IB}^{i,j} \Delta \phi_i + \Delta \epsilon_i - (\delta - R \Delta \phi_i) \kappa > 0 \iff \kappa < \left\{ \left[ (1 - \gamma) R - r_d \right] \Delta \phi_i - \Delta r_{IB}^{i,j} \Delta \phi_i + \Delta \epsilon_i \right\} / (\delta - R \Delta \phi_i) \equiv \kappa_u \left( \Delta \phi_i; \delta, R, r_d \right), \]

and

\[ \frac{\Delta E \left[ \pi_i^* (\cdot, \theta_L) \right]}{\Delta \left| G_i^- \right|} > 0 \iff \left[ (1 - \gamma) R - r_d \right] \beta \Delta \phi_i - \Delta E \left[ r_{IB}^{i,j} \right] \beta \Delta \phi_i + \beta \Delta \epsilon_i + (1 - \beta) \nu - (\delta - R \beta \Delta \phi_i) \kappa > 0 \iff \kappa < \frac{\left\{ \left[ (1 - \gamma) R - r_d \right] \beta \Delta \phi_i - \beta - \Delta r_{IB}^{i,j} \Delta \phi_i \Delta \phi_i + \beta \Delta \epsilon_i + (1 - \beta) \nu \right\}}{\delta - R \beta \Delta \phi_i} \equiv \kappa_u \left( \Delta \phi_i; \delta, R, r_d, \nu \right). \]

More importantly, since the negative externality arises because unsound banks are overly connected the trade-off 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 to sound banks, \textit{ceteris paribus}. Even in this case there is a trade-off 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 trade-off 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,

\[
\frac{\Delta \mathbb{E} [\pi^*_i (\cdot, \theta_H)]}{\Delta |G^-_i|} - \frac{\Delta \mathbb{E} [\pi^*_i (\cdot, \theta_L)]}{\Delta |G^-_i|} = (1 - \beta) \{[(1 - \bar{\gamma}) R - r_d + \kappa R] \Delta \phi_i + \Delta \epsilon_i - \nu\} + \Delta r_{iB}^{ij} \Delta \phi_i \Delta \phi_i.
\]

Thus, unsound banks value relatively more credit lines if

\[(1 - \beta) \{[(1 - \bar{\gamma}) R - r_d + \kappa R] \Delta \phi_i + \Delta \epsilon_i - \nu\} + \beta \Delta r_{iB}^{ij} \Delta \phi_i < 0 \Leftrightarrow \]

\[\Leftrightarrow \kappa < \{[\nu - (1 - \bar{\gamma}) R - r_d] \Delta \phi_i - \Delta \epsilon_i - \beta \Delta r_{iB}^{ij} \Delta \phi_i / (1 - \beta)\} / R \Delta \phi_i \equiv \bar{\kappa}.
\]

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 \(\bar{\kappa} > \kappa_s\), then it is not possible to induce them to eliminate connections without also inducing sound banks to do the same. \(\square\)

Proposition 3 shows 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.
8 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 because more capital is 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 \( \nu \) as given by the condition in Proposition 3. It is instructive to ask 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 trade-off is still increasing in the importance of \( \nu \). In this section, I relax some critical assumptions that have a direct implication on this trade-off.

8.1 Correlated liquidity and return shocks

Proposition 3 was derived under the assumption that liquidity and return shocks are independent. However, it may be 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 can be the case if assets with higher exposure to credit shocks also need to be refinanced with a higher probability. Alternatively, correlation between credit and (funding) liquidity risk can be motivated with reference to a business model where banks fund long-term assets exposed to tail risk with short-term liabilities. Maturity mismatch of this type would lead unsound bankers to value comparatively more an additional interbank credit line. Thus, correlation between liquidity and credit risk plays an analogous role to implicit guarantees in constraining the regulator’s ability to limit the participation of unsound banks in the interbank market.

8.2 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.
8.3 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 trade-off between constraining investment in sound assets and limiting the negative externality posed by unsound ones.

8.4 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.

8.5 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.

9 Policy implications

9.1 Resolution regimes

The existence of G-SIBs poses a major challenge 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 \textit{ex post} costs of G-SIBs failures they lend credibility to closure policies, which reduces expected bailout subsidies (which corresponds to $\nu$ in the model). 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.

9.2 Bank levies

Following the proposals made at the G-20 meetings (IMF; 2010), since the beginning of 2011, bank levies were introduced in several European countries,\textsuperscript{17} namely France, Germany, Portugal and the United Kingdom. For example, in Germany ‘relevant liabilities’ under 10 billion EUR are subject to a 0.02\% rate, under 100 billion EUR to 0.03\% and over 100 billion EUR to 0.04\%. Since an increase in interconnectedness increases the liabilities base, this type of levy in effect introduces a cost to interconnectedness. Therefore, it is similar to interconnectedness based capital requirements and the results of the paper also apply to it.

9.3 Liquidity regulation

As discussed in subsection 8.1, liquidity and credit risk may interact with market frictions in a way that affects adversely the regulatory trade-off. Maturity mismatch between assets and liabilities can be a potential source of this correlation. If that is the case, a liquidity requirement such as the Net Stable Funding Ratio (NSFR) brought by Basel III can improve the effectiveness of interconnectedness based capital requirements. This would correspond to setting a lower bound to $y$ in the context of the model. In its turn, this would make defaults by contagion less likely, or alternatively it would reduce expected external costs imposed on the social planner in consequence of a default.

\textsuperscript{17}At the time, Sweden had already in place a ‘Stability Fee’ based on bank’s liabilities.
10 Conclusion

The 2007-09 subprime crisis targeted a major regulatory reform. In addition to strengthening microprudential standards, the new regulatory framework brought a series of macroprudential instruments that aim to contain systemic risk at socially acceptable levels.

Motivated by contagion concerns, one class of these new instruments targets the connections established among financial institutions. Yet, interconnectedness is in itself an equilibrium outcome and as such is affected by any instrument made contingent on it. In this paper, I analyze a microfounded design of interconnectedness based capital requirements that not only explicitly accounts for the endogenous response of the regulated institutions, but also accounts for the impact of asymmetric information and implicit government guarantees in the optimal design of the instrument. I find that the resulting optimal interconnectedness based capital charges are characterized by a trade-off between efficiency and financial stability, which is steeper in the severity of asymmetric information and implicit government support. 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 asymmetrically informed regulator to induce unsound banks to become less interconnected without affecting sound ones. This finding underscores the importance of complementary measures, such as credible resolution regimes, that mitigate these frictions. Not only improved resolution regimes may reduce directly the impact of G-SIB failures, but also they can make the regulatory trade-off between financial stability and efficiency less burdensome when banks’ interconnectedness decisions generate negative externalities.

The model has some limitations, though. First, in order to focus on the impact of market frictions, the liquidity allocation is assumed to be independent of the interbank network. A more realistic model could include the joint determination of the liquidity choice and interbank connections. Second, the model only considers a three bank network. Even though the main contribution of the paper is established at each connection level, an agent based model with full determination of the equilibrium interbank network could provide new insights to inform regulatory design. Finally, the link between interconnectedness based capital requirements and liquidity and credit risk correlation deserves more attention that is outside of the scope of this paper.

References


URL: [http://dx.doi.org/10.1016/j.jfi.2013.08.001](http://dx.doi.org/10.1016/j.jfi.2013.08.001)

Financial Stability Board (2010). Reducing the moral hazard posed by systemically important financial institutions: interim report to G20 leaders.

Financial Stability Board (2013). 2013 update of group of global systemically important banks (g-sibs).


Senior Supervisors Group (2008). Observation on risk management practices during the recent market turbulence.


URL: http://www.sciencedirect.com/science/article/pii/S1572308913000533


**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

\[ r_{iB}^{\text{ij}} = \frac{1 - \beta^*}{\beta^*} \mathbb{E} \left[ \pi_{\text{lender}} \right], \]

where \([\pi_{\text{lender}}]\) are the lenders’ profits on survival stages (or the opportunity cost of defaulting by contagion).

A.3. Derivation of assumption 5
If there are 2 subsequent banks on the intermediation path, then the original lender’s expected profit is
\[ \beta^2 \left[ \epsilon_s + (1 - y) R - r_d \right] = \epsilon_s + (1 - y) R - r_d \Leftrightarrow \epsilon_s = \frac{1 - \beta^2}{\beta^2} [(1 - y) R - r_d]. \]
Similarly when there is only 1 subsequent bank, the lender’s expected profit is
\[ \beta^* \left[ \epsilon_s + (1 - y) R - r_d \right] = \epsilon_s + (1 - y) R - r_d \Leftrightarrow \epsilon_s = \frac{1 - \beta^*}{\beta^*} [(1 - y) R - r_d]. \]
Finally, a bank wishes to establish an intermediation relation if after the intermediation fees and interest rate on the interbank loan are paid its profit is still non negative. That is are the ones that
\[ [(1 - y) R - r_d] \left( 1 - \frac{1 - \beta^*}{\beta^*} - \frac{1 - \beta^2}{\beta^2} \right) \geq 0 \Leftrightarrow \beta^* \geq \frac{1 + \sqrt{13}}{6}. \]
Note that in this derivation \( k \) is set to 0 and \( y \) is the same for all banks. Since capital is costly, setting \( k = 0 \) yields the 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 \( y = \bar{\gamma} \)

\[ [(1 - \bar{\gamma}) R - r_d] \frac{2}{3} + \frac{1}{3} (\bar{\gamma} - \gamma_L); \]

- expected profit in autarky of \( y = \gamma_H \)

\[ (1 - \gamma_H) R - r_d + \frac{1}{3} (\gamma_H - \gamma_L) + \frac{1}{3} (\gamma_H - \bar{\gamma}). \]

Comparing all equations above and given assumption 3, it can be showed that
\[ y^{\text{autarky}} = \begin{cases} \bar{\gamma} & \text{if} \quad (1 - \bar{\gamma}) R - (\bar{\gamma} - \gamma_L) < r_d \leq (1 - \gamma_H) R + (\bar{\gamma} - \gamma_L) \\ \gamma_L & \text{if} \quad r_d > (1 - \gamma_H) R + (\bar{\gamma} - \gamma_L) \end{cases}. \]