

Distress Dispersion and Systemic Risk in Networks*

Jessie Jiaxu Wang
W. P. Carey School of Business
Arizona State University

This version: August 2015

First version: April 2014

ABSTRACT

I develop a model in which heterogeneity in financial distress endogenously generates inefficiencies in network formation, creating excessive systemic risk. Financial firms face costly liquidation and strategically trade assets, thereby forming links. A link with a distressed firm can be socially costly as it raises system-wide liquidation risk. When firms are highly dispersed in financial distress, the *network composition* is distorted in two ways: it features too many links with distressed firms and too few risk-sharing links among non-distressed firms. This inefficiency arises from an externality when bilateral trading terms are not contingent on links faraway in the network. Using insights from the model, I discuss policy implications for financial stability. I also show empirical evidence that the distress dispersion across financial firms provides a novel indicator for systemic risk.

JEL Classification: D85, G01, G20, G28

Keywords: Financial network formation, systemic risk, financial distress, network externality

*Email: Jessie.Jiaxu.Wang@asu.edu. I am grateful to Laurence Ales, Burton Hollifield, Lars-Alexander Kuehn, and Chester Spatt for invaluable advice and guidance. I thank Toni Ahnert, Daniel Andrei, Bruce Carlin, Ben Craig, Huberto Ennis, Brent Glover, Rick Green, Borys Grochulski, Pierre Liang, Martin Oehmke, Ned Prescott, Vincenzo Quadrini, Bryan Routledge, Alireza Tahbaz-Salehi, Andrew Winton, Ariel Zetlin-Jones, Marius Zoican, conference and seminar participants at 2014 MFA, FMA, USC Ph.D. Conference, 2014 Cleveland Fed OFR Financial Stability Conference, CMU, Richmond Fed, RPI, Case Western Reserve, Arizona State, Rutgers, Columbia, Georgia State, Minnesota, Cornell, Tulane, UCLA, Treasury OFR, and Johns Hopkins for helpful comments.

1 Introduction

The interconnectedness of financial institutions is a key feature of the modern financial system. Linkages are formed by a diverse range of transactions and contracts that connect firms to each other. A growing literature identifies these linkages as a major source of systemic risk (e.g. [Allen and Gale \(2000\)](#), [Brunnermeier \(2009\)](#), and [Acemoglu, Ozdaglar, and Tahbaz-Salehi \(2015\)](#)). The insights are evident in the financial crisis: initial losses caused the financial distress of a few firms, which then spread via the links that connect the distressed firms with otherwise healthy ones, resulting in systemic failures. Yet, these studies analyze contagion in given network structures and do not consider firms' strategic formation of links.

In this paper, I focus on endogenous linkage formation which allows firms to strategically build connections for profit and risk diversification purposes. A recent literature examines linkage formation among homogeneous firms and concludes that either over- or under-connections prevail in the financial system (e.g. [Castiglionesi and Navarro \(2011\)](#) and [Farboodi \(2014\)](#)).¹ In contrast, this paper studies the linkage formation among firms differing in financial distress levels. Such framework provides novel implications for efficiency and systemic risk by generating over- and under-connections simultaneously.

I show that the endogenously formed network features inefficiency and leads to systemic risk measured by the probability of joint failures. A link between two non-distressed firms creates value from risk-sharing, whereas a link with a distressed firm can be socially costly as it raises systemic risk through balance sheet interdependence. I find that, when firms are highly dispersed in financial distress, the *network composition* is distorted in two ways: there are too many links with distressed firms and too few risk-sharing links among non-distressed firms. The inefficiency arises as firms write bilateral contracts that are not contingent on the entire network structure. Hence, the non-distressed firms have incentives to link with distressed firms for profit, while failing to internalize negative spillovers. Such inefficient network generates contagion and loss in risk-sharing, creating excessive systemic risk. By embedding heterogeneity as a new dimension of links, my model provides unique predictions on the efficiency of network composition.

In my model, financial firms face costly liquidation risks and strategically trade assets,

¹For example, [Castiglionesi and Navarro \(2011\)](#) show that decentralized network is under-connected when counterparty risk is high. [Farboodi \(2014\)](#) illustrates over-connection in an endogenous core-periphery network.

thereby forming a network. There are a finite number of firms financed by short-term debt and each invests in a long-term asset. A random fraction of the asset is liquid and can be used to repay debt. As in [Allen, Babus, and Carletti \(2012\)](#), if the amount of liquid asset falls short of the debt level, a costly liquidation is triggered.² To hedge the idiosyncratic liquidation risk, firms can strategically enter into bilateral forward contracts to trade liquid assets. A two-sided link in a network is formed when both parties decide to purchase a fraction of each other’s liquid asset claims. Firms *differ ex ante* in how liquid their assets are expected to be and thus in the liquidation probability. This generates the key feature of the model: cross-sectional heterogeneity in financial distress levels. Difference in asset liquidity also implies a price of trade in each contract. Motivated by the incomplete contract literature, I assume that prices in the bilateral trades are not contingent on the entire network structure. Specifically, I consider *local contingency*, that is, prices are contingent on which firms the two parties directly trade with. Given the network formed, the liquid asset holding of a firm depends not only on who its direct counterparties are, but rather on the entire network structure.³ As a benchmark for efficiency, I solve for the optimal network that minimizes total bank liquidations.

The pairwise stable network formed in equilibrium can be inefficient relative to the optimal benchmark: there can be excess links with distressed firms and insufficient risk-sharing links among non-distressed firms. When distress dispersion is high across firms, the optimal network requires that the non-distressed firms form risk-sharing links and that the most distressed firm be isolated. In contrast, the equilibrium network with four or more firms shows that the distressed firm is always connected with the most liquid firm. This suboptimal link between the liquid and the distressed firm (“*distress link*” hereafter) transmits risky assets in the network and leads to systemic risk, measured by the chances that all firms fail at the same time.

The inefficiency is caused by network externalities. Linking with a distressed firm potentially avoids liquidation, thus is *ex ante* profitable for the most liquid firm. However, when a firm is too distressed, linking with it can be socially costly because distressed assets are then shared jointly by all connected firms and so the balance sheets of other banks in the network are contaminated. Essentially, a liquid firm forming a distress link imposes a network externality.

²A firm with a low level of liquid asset has difficulty in repaying short-term debt and hence is *distressed*.

³Following [Cabral, Gottardi, and Vega-Redondo \(2014\)](#), I model this balance sheet interdependence as an iterative swap process which represents asset securitization.

This externality in turn reduces risk-sharing participation among non-distressed firms. As such, two forces reinforce and lead to inefficiency: the transmission of distressed assets that should have been isolated and the insufficient risk-sharing among non-distressed firms.

The necessary ingredients for the externalities are interconnectedness, distress heterogeneity, and local contingency. Interconnectedness transmits risky assets, thus enabling the spillover. Firm heterogeneity generates distress dispersion and different incentives to form links. When there are only two firms or multiple identical firms, there is no externality. However, when there are multiple firms differing in distress levels, the most liquid firm can profit from trading with the distressed firm and can shift risks away to its direct and indirect counterparties. It therefore has a greater incentive to link with the distressed firm than is socially desirable. But interconnectedness and heterogeneity are not enough. The externalities fail to be internalized because of local contingency. Firms that bear the externalities cannot jointly give incentives to the liquid firm via contingent payments. This failure occurs as long as one of the indirect counterparties of the most liquid firm cannot condition payments on the distress link.

While the prior literature largely focuses on the average soundness of the financial sector,⁴ my second primary result identifies a novel indicator for the level of network inefficiency: the distress dispersion across financial firms. In my model, inefficiency arises when the distress dispersion is sufficiently high and increases with the level of dispersion thereafter. This positive relation owes to the disparity between individual and social incentives to form a distress link. When distress dispersion is higher, the cross-sectional distribution has more distressed firms in the left tail and more liquid ones in the right tail. It is precisely then that the most liquid firm has an incentive to form the socially costly distress link.

Using insights from the model, I discuss policy implications for financial stability. The links with distressed firms in the model can be interpreted as acquisitions of distressed firms. This interpretation is reasonable because distressed financial firms are commonly acquired by healthier institutions in the same industry.⁵ More than 1000 distressed financial firms were

⁴Atkeson, Eisfeldt, and Weill (2014) measure the median Distance to Insolvency of largest financial firms based on the Leland's model of credit risk. Gilchrist and Zakrajsek (2012) show that the average credit spreads on outstanding corporate bonds has predictive power for economic activity. Rampini and Viswanathan (2014) argue that the net worth of (representative) financial intermediaries is an important state variable affecting the cost of financing.

⁵Acharya, Shin, and Yorulmazer (2010) argue that if a bank needs to restructure or be sold, the potential buyers are generally other banks. Almeida, Campello, and Hackbarth (2011) document that distressed firms

acquired during 2000-2013, including Countrywide Financial and Riggs Bank.⁶ Despite the fact that acquisitions are a prevailing regulatory approach to improve financial stability,⁷ my findings imply that excess acquisitions may emerge precisely when more banks are distressed, thus increasing systemic risk rather than reducing failures. Based on this result, regulators can restore efficiency by supervising the acquisitions of distressed firms and using the purchase and assumption (P&A) method for distress resolution.

Finally, I provide empirical evidence that the distress dispersion across financial institutions provides a novel indicator for systemic risk. Following [Laeven and Levine \(2009\)](#), I measure distress by estimating Z-scores of financial firms. The time series of distress dispersion shows large variations over time. It also has a countercyclical pattern and appears to lead recessions. Consistent with the model predictions, the empirical dispersion series significantly comoves with future economic activities and systemic risk, bank failures, acquisitions of distressed firms, and interbank risk sharing. Moreover, I run forecasting regressions to evaluate whether the dispersion series conveys new information about aggregate indicators beyond what is contained in the average distress and existing systemic risk measures. The estimates confirm that the dispersion series has high predictive power for future systemic risk.

This paper builds on network theory and its applications in economics and finance.⁸ Pioneered by [Allen and Gale \(2000\)](#), a growing literature argues that certain financial network structures can lead to risks of contagion.⁹ While powerful for analyzing how risks propagate under different connection properties, this stream of research treats the network structures as given. My paper studies network formation, hence contributes to the analysis of how links evolve in response to changes in policies or aggregate conditions.

The main contribution of this paper is to embed distress heterogeneity in linkage formation and to study the implications on efficiency and systemic risk. As such, my paper belongs to

are acquired by liquid firms in their industries for financial synergies. Such acquisitions are more likely when industry-level asset specificity is high and firm-level asset specificity is low, which applies to the financial sector.

⁶The asset size of these acquisitions was \$2.2 trillion, about half the size of all current banking deposits.

⁷[White and Yorulmazer \(2014\)](#) provide a summary of resolution options for bank distress/failure. An acquisition “imposes the least cost since the franchise value is preserved, there is no disruption to the bank’s customers or the payment system itself, and there are no fiscal costs.” For this reason, acquisition is the primary choice by resolution authorities whenever there are willing acquirers.

⁸See surveys by [Jackson \(2003, 2008\)](#) and [Allen and Babus \(2009\)](#).

⁹See [Eisenberg and Noe \(2001\)](#), [Dasgupta \(2004\)](#), [Nier, Yang, Yorulmazer, and Alentorn \(2007\)](#), [Gai, Haldane, and Kapadia \(2011\)](#), [Greenwood, Landier, and Thesmar \(2015\)](#), [Caballero and Simsek \(2013\)](#), [Acemoglu, Ozdaglar, and Tahbaz-Salehi \(2015\)](#), [Elliott, Golub, and Jackson \(2014\)](#), and [Glasserman and Young \(2015\)](#).

the recent research on financial network formation, which examines how inefficient networks form due to various frictions.¹⁰ [Castiglionesi and Navarro \(2011\)](#) show network fragility when undercapitalized banks gamble with depositors' money. [Di Maggio and Tahbaz-Salehi \(2014\)](#) emphasize the role of secured interbank lending in overcoming moral hazard. [Zawadowski \(2013\)](#) studies a type of risk shifting stemming from banks' underinsurance of counterparty risk. [Castiglionesi and Wagner \(2013\)](#) show conditions when banks underinsure each other using credit lines. [Gofman \(2011\)](#) highlight that bargaining friction and intermediation lead to welfare loss.

In the network formation literature, my paper is closest to [Farboodi \(2014\)](#) who illustrates that a core-periphery intermediation structure arises inefficiently due to a lending constraint and the opportunity to earn intermediation rent. While my paper also generates excessive systemic risk due to certain types of inefficient links, I differ by studying linkage formation among firms differing in financial distress. Inefficiency arises from the incentive of liquid firms to link with distressed firms for profit under contract incompleteness. Moreover, I model links on the asset side of the balance sheet. The resulting asset cross-interdependence structure can be used to regulate bank acquisitions. Finally, the finding that the distress dispersion is a critical state variable allows for a closer link to the data in forecasting systemic risk.

The key friction underlying the network inefficiency here is the failure to offer incentives conditional on the entire network structure. In this sense, my paper is related to the literature on incomplete contracts.¹¹ From [Hart and Moore \(1988\)](#), agents cannot write contracts contingent on states that cannot be clearly specified, even if the states are perfectly foreseeable. The reason is that the states written in the contracts must be verifiable in court. In my setting, given that the links entered by other firms are not specifiable or verifiable, bilateral prices are contingent only on who the two firms directly trade with. This assumption is in line with [Acemoglu, Ozdaglar, and Tahbaz-Salehi \(2014\)](#) who show that inefficient networks can emerge in interbank lending markets with contingency debt covenants.

Finally, this paper adds to the studies on the trade-off between diversification and contagion. [Banal-Estanol, Ottaviani, and Winton \(2013\)](#) evaluate conglomeration with default costs facing

¹⁰See [Lagunoff and Schreft \(2001\)](#), [Castiglionesi and Navarro \(2011\)](#), [Gofman \(2011\)](#), [Babus \(2013\)](#), [Blume, Easley, Kleinberg, Kleinberg, and Tardos \(2013\)](#), [Acemoglu, Ozdaglar, and Tahbaz-Salehi \(2014\)](#), [Zawadowski \(2013\)](#), [Castiglionesi and Wagner \(2013\)](#), [Cabrales, Gottardi, and Vega-Redondo \(2014\)](#), [Di Maggio and Tahbaz-Salehi \(2014\)](#), and [Farboodi \(2014\)](#).

¹¹See for example [Hart and Moore \(1988, 1999\)](#), [Tirole \(1999\)](#), [Maskin and Tirole \(1999\)](#), and [Segal \(1999\)](#).

this trade-off. I follow [Cabralés, Gottardi, and Vega-Redondo \(2014\)](#) and study the trade-off in a network setting. [Acharya \(2009\)](#), [Wagner \(2010\)](#), and [Ibragimov, Jaffee, and Walden \(2011\)](#) show that diversification may lead to greater systemic risk as banks tend to over-diversify by holding similar portfolios. While these papers assume costly joint failures among ex ante homogeneous agents, my paper complements by showing that links among heterogeneous firms can result in both *over* and *under* diversification.

The rest of the paper proceeds as follows. Section 2 lays out the model environment and defines the equilibrium. Section 3 demonstrates the network inefficiencies. Section 4 examines the role of distress dispersion. Section 5 discusses the policy implications in the context of acquisitions of distressed firms. Section 6 presents empirical evidence, and Section 7 concludes.

2 Model

This section describes a model of network formation in which financial firms strategically trade assets via bilateral forward swap contracts.

2.1 Environment

Consider a four-date economy with a finite number of levered financial firms, denoted by $i = 1, \dots, N$. All agents are risk neutral and there is no discounting.

Figure 1 shows the model timeline. At date 0, each firm borrows 1 unit of short-term debt from a continuum of creditors and invests in an asset with fixed return R . The asset has liquidity risk. A random component a_i becomes liquid at date 2 and can be used to repay debt, whereas the rest $R - a_i$ is illiquid and matures at date 3. Given this financing structure, a maturity mismatch arises. A firm can be interpreted as a financial institution, e.g., an investment firm investing in a certain class of securities, or a commercial bank issuing an unsecured loan.

At date 1, firms learn the vector ν , a public signal about how much liquid asset each firm expects to receive. Then they simultaneously decide to enter into bilateral forward swap contracts for risk-sharing purpose, thus forming links. Each forward swap contract promises a claim to a fraction of each other's liquid assets.

At date 2, firms observe the amount of their liquid assets, given by $a_i = \nu_i + \sigma\varepsilon_i$. The

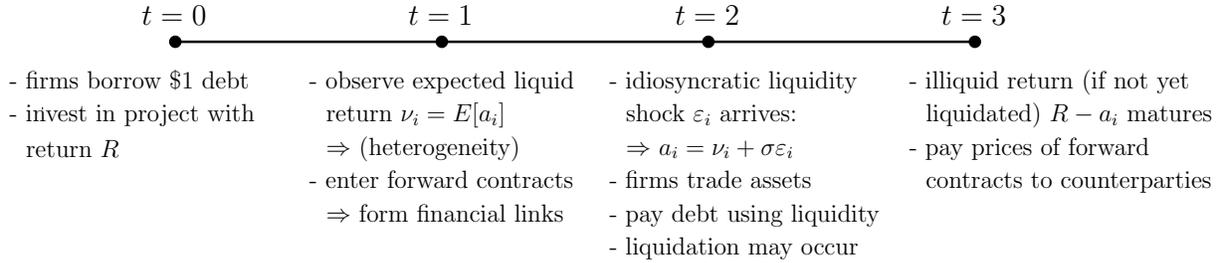


Figure 1. Model Timeline.

idiosyncratic shock ε_i is i.i.d. standard normal and is independent of ν_i .¹² Firms fulfill the forward swap contracts. Based on the overall linkage structure, firms obtain potentially diversified liquid asset holdings, which they use to repay short-term debt.¹³ If the liquid asset holdings fall short of debt, the firm liquidates its illiquid asset with a fixed cost c , for instance by selling at a discount to industry outsiders as in [Shleifer and Vishny \(1992\)](#).¹⁴

At date 3, if not liquidated, the illiquid component $R - a_i$ of the asset matures. Using this return, the payments associated with the forward swap contracts are paid in full.

Firms differ at date 1 in the amount of expected liquid asset ν . This generates heterogeneity in financial distress. I follow [Roy \(1952\)](#) and define a distress statistic, z_i , as the number of standard deviations that firm i is expected to be away from liquidation ($z_i \equiv \frac{\nu_i - 1}{\sigma}$). A firm with high z_i has highly liquid asset and low financial distress. We say such a firm is *liquid*. In contrast, a firm is *distressed* if it has a low z_i . To highlight the role of heterogeneity, let the vector z have mean \bar{z} and be equally spaced with step size $\delta \geq 0$, i.e.

$$z_i = \bar{z} + \frac{N + 1 - 2i}{2} \delta, \quad i = 1, \dots, N. \quad (1)$$

\bar{z} measures the average distance from liquidation. Let $\bar{z} > 0$ so that firms invest in positive NPV projects on average. δ is proportional to the cross-sectional standard deviation of z_i and proxies for the degree of distress dispersion.¹⁵

¹² a_i being negative means further liquidity input is needed in the asset investment.

¹³Introducing debt roll-over, renegotiation, or endogenous default boundary do not change the qualitative features. To separate from risk-shifting due to agency conflict between shareholders and depositors ([Jensen and Meckling \(1976\)](#)), limited liability is not particularly imposed for firm owners.

¹⁴[James \(1991\)](#) finds using US data 1985-1988 that substantial value is preserved if a failed bank is sold to another bank, but lost if liquidated by the FDIC. The cost can result from deadweight loss in liquidation due to asset specificity, loss of franchise value, or disruption of credit and payment services associated with relationship banking (see [White and Yorulmazer \(2014\)](#)).

¹⁵I rank firms by z_i merely for expository purpose. Distress is modeled as exogenous, while in reality firms choose liquidity holding and risk-taking which endogenously determine distress levels. [Acharya, Shin, and Yorulmazer \(2010\)](#) argue that liquid banks hoard cash for potential gains from asset sales. This implies that an otherwise endogenous setting would generate even bigger heterogeneity during an aggregate liquidity shortage.

2.2 Network Formation

At date 1, firms strategically decide to enter into bilateral forward swap contracts. In this network formation game, a *strategy* of firm i includes links $l_i = (l_{i1}, \dots, l_{i,i-1}, l_{i,i+1}, \dots, l_{iN})$ and prices $p_i = (p_{i1}, \dots, p_{i,i-1}, p_{i,i+1}, \dots, p_{iN})$. Firm i proposes to buy $l_{ij} \in \{0, \bar{l}\}$,¹⁶ where $\bar{l} \in (0, 1)$, fractions of liquid asset from firm j at date 2, offering to pay a unit price p_{ij} at date 3. The prices can be made contingent on the links. Similar to the simultaneous announcement game in Myerson (1991), each firm simultaneously proposes to contract with other firms.

A contract is signed (a two-sided link is formed) when both firms decide to swap asset claims at the offered prices. Let the matrix L represent the linkage structure; its element satisfies

$$L_{ij} = L_{ji} = \min\{l_{ij}, l_{ji}\}. \quad (2)$$

Firms i and j are directly linked ($L_{ij} = \bar{l}$) only if $l_{ij} = l_{ji} = \bar{l}$. This specification ensures that no firms end up being a net asset seller or buyer so each firm still holds one unit of liquid asset. It also captures an important aspect of the OTC derivatives market: firms have large gross notional positions and small net positions. After the asset swaps, each firm holds a non-negative share of its own asset, i.e. $L_{ii} = 1 - \sum_{j \neq i} L_{ij} \geq 0$. As such, L is a symmetric, doubly stochastic matrix by construction.¹⁷ When $L_{ii} = 1$, firm i is isolated.

The set of N firms and the links between them define the network. Depending on the distress level of the two connecting firms, the network is composed of *risk-sharing links* which connect two non-distressed firms, and *distress links* which connect a liquid and a distressed firm.

2.3 Payoffs and Firm Value

Firms' liquid asset holdings, denoted by vector $h_i(a, L)$, depend on not only their direct counterparties, but rather how firms are interconnected. As such, the linkage creates cross-interdependence from the asset side of firms' balance sheets. I model links via asset swaps because prior studies highlight that correlated portfolio exposures are the main source of systemic risk in the financial sector.¹⁸ In addition, asset swaps simplify the calculation of final asset holdings and systemic

¹⁶From Lemma 1, all results would remain if instead firms have a continuum strategy space, i.e. $l_{ij} \in [0, 1)$.

¹⁷A square matrix is doubly stochastic if all its entries are non-negative and the sum of the entries in each of its rows or columns is 1.

¹⁸See for example Elsinger, Lehar, and Summer (2006) and DeYoung and Torna (2013).

risk by avoiding kinks in standard cascade models (e.g. [Elliott, Golub, and Jackson \(2014\)](#)).¹⁹

At date 3, firms deliver payment transfers according to the forward swap contracts. Their final payoffs Π are thus given by the liquid asset values a , the network L , and the prices p ,

$$\Pi_i(a, L, p) = \underbrace{h_i(a, L) + R - a_i - 1}_{\text{asset net of debt}} - \underbrace{\mathbb{1}_{(h_i(a, L) < 1)} c}_{\text{liquidation cost}} - \underbrace{\sum_{j \neq i} (p_{ij} - p_{ji}) L_{ij}}_{\text{net payments from swaps}} \quad (3)$$

Expected firm value at date 1 equals the expectation of $\Pi_i(a, L, p)$,

$$V_i(z, L, p) = \mathbb{E}_1 [h_i(a, L)] + R - \nu_i - 1 - \Pr(h_i(a, L) < 1) c - \sum_{j \neq i} (p_{ij} - p_{ji}) L_{ij}. \quad (4)$$

2.4 Bilateral Prices and Asset Swaps

The key features of a network formation game are the payoff functions and the payment transfers. To further specify these terms in my framework, I next discuss assumptions on the bilateral prices and the asset swap process.

Local Contingency Who have the power to decide on a link between two firms is crucial to linkage formation. The bilateral prices allow for transfer payments among firms, which in turn define the decision power to form links. Given that a link L_{ij} “alters the payoffs to others, it seems reasonable to suppose that other firms, especially the [direct counterparties of] firms i and j should have some say in the formation of a link between i and j ” ([Goyal \(2009\)](#)). Following this spirit, I assume that prices are set under local contingency.

Assumption 1 (Local Contingency) *The bilateral price p_{ij} is contingent on the direct links entered by the two firms. Let L_i be the i -th row of L , then*

$$p_{ij}(L_i, L_j, L_k) = p_{ij}(L_i, L_j, \hat{L}_k), \quad \forall k, \forall \hat{L}_k \neq L_k. \quad (5)$$

In words, firm i offers prices p_{ij} based on its own links L_i and the links of its direct counterparty L_j . Even if firm i foresees that it indirectly connects to a third firm k ($L_{ij} > 0, L_{jk} > 0$), the price it offers cannot vary with the links of firm k .

Assumption 1 is the key friction in the model. The motivation lies in an inherent feature of the financial industry: when firms write bilateral contracts in an interconnected setting, it

¹⁹The asset swaps may capture in a broad sense cross holdings of deposits in [Allen and Gale \(2000\)](#).

is difficult for institutions to specify in every contract detailed contingencies for every possible network structure. One reason is that institutions do not publicly disclose the identities of their counterparties. As in [Hart \(1993\)](#), even if the bilateral relations they form could be foreseeable by other institutions, “they might be difficult to specify in advance in an unambiguous manner. [Hence], a contract that tries to condition on these variables may not be enforceable by a court.” This is essentially an example of *incomplete contracts*.²⁰

Price Offering Rules In each bilateral contract, what matters for firm payoffs is the net transfer payment $(p_{ij} - p_{ji})L_{ij}$. The same net payment can be achieved by a continuum of gross payments; hence, to ensure a unique set of equilibrium prices, I assume that buyer i proposes price p_{ij} to j as a *take-it-or-leave-it offer*. The proposed price cannot be lower than firm j ’s reservation price p_{jj} . Formally,

$$p_{ij} \geq p_{jj}, \quad \forall i \neq j, \quad (6)$$

where p_{jj} equals j ’s outside option when it cannot form any links, i.e.

$$p_{jj}(z_j) = V_j(z, L, p | L_j = 0). \quad (7)$$

Asset Swap Process I model the cross-interdependence of liquid asset holdings $h(a, L)$ by an iterative asset swap process: firm i swaps liquid asset with its direct counterparties iteratively. Given the linkage matrix L , the vector of asset holdings after the first round of swap is $h^{(1)} = La$. Applying L to $h^{(1)}$ gives the second round of swap, $h^{(2)} = Lh^{(1)} = L^2a$, where L^2 denotes $L \times L$. Specifically, I assume that the iteration goes on for infinitely many rounds.

Assumption 2 (Iterative Swap Process) *Firms swap liquid assets according to the linkage matrix L iteratively for infinite rounds. The final asset holdings h are given by*

$$h(a, L) = \lim_{K \rightarrow \infty} L^K a. \quad (8)$$

This iterative process is instantaneous and does not affect the payment of prices. It captures the securitization process such as the origination and trades of asset-backed securities.²¹

²⁰An alternative motivation relates to transaction costs à la [Williamson \(1975\)](#). As the size and complexity of the network builds up, it would be prohibitively costly to include every possible structure in every contract by every firm. This is consistent with the fact that we do not observe such types of contracts in practice.

²¹“The possibly iterative procedure through which each firm exchanges assets on its whole array of asset holdings can be viewed as a securitization process of the firm’s claims” ([Cabrales, Gottardi, and Vega-Redondo \(2014\)](#)).

Under Assumption 2, final holdings h depend on the liquid returns of both *direct and indirect* counterparties. Take for instance a network with $N = 3$ and $L_{12} = L_{23} = \bar{l}$, $L_{13} = 0$. After the first round, $h_1^{(1)} = (1 - \bar{l})a_1 + \bar{l}a_2$. After infinite rounds, $h_1 = h_2 = h_3 = \frac{1}{3}a_1 + \frac{1}{3}a_2 + \frac{1}{3}a_3$; hence, firm 1 holds $\frac{1}{3}$ shares of a_3 even if it does not directly link with firm 3. The following lemma formalizes this property of the final asset holdings.

Lemma 1 (Complete risk-sharing) $\lim_{K \rightarrow \infty} L^K$, $\forall L$ is doubly stochastic and coincides with complete risk-sharing among all firms connected in the same component.²² I.e. the holdings of each firm are equally weighted by the liquid assets of all firms directly or indirectly connected to it.

From Lemma 1, it is the linkage structure (whether $L_{ij} = 0$ or $L_{ij} > 0$) rather than the amount of swap that determines the final holdings of each firm. As such, the results would still hold if instead $l_{ij} \in [0, 1)$, that is, if we allow firms to make linkage decisions in a continuum space. This rationalizes the simplification that l_{ij} is a binary variable. Moreover, the holding of own asset $L_{ii} = 1 - \sum_{j \neq i} L_{ij} \geq 0$ implies that the maximum number of links a firm can form is $1/\bar{l}$. If $1/\bar{l}$ is very large, the number of possible network structures increases exponentially with N .²³ To maintain tractability, in what follows I restrict the number of links a firm can form.²⁴

Assumption 3 (Chain Networks) each firm can form a maximum of two links, i.e. $\bar{l} = \frac{1}{2}$.

The possible topology for the minimal networks therefore limits to an arbitrary collection of circles and chain networks.²⁵ The number of firms here can be interpreted as the longest diameter in an otherwise general network, such as the core-periphery structure empirically observed in the Fed funds market (Bech and Atalay (2010)), municipal bonds (Li and Schurhoff (2014)), and derivative securities (Hollifield, Neklyudov, and Spatt (2014)), as well as theoretically analyzed in Farboodi (2014) and Chang and Zhang (2015).

2.5 The Equilibrium

Upon knowing the distress vector z , firms simultaneously choose linkage decisions l and price offerings p to maximize their firm values $V(z, L, p)$. Next I formally define the equilibrium by

²²A component of a network is a maximally connected collection of firms: each firm in the component can reach any other firm in the same component following one or more links.

²³The number of possible network structures among N heterogeneous firms is $2^{\frac{N(N-1)}{2}}$.

²⁴A similar assumption on maximum number of links is made in Allen, Babus, and Carletti (2012).

²⁵A chain in a network is a sequence of firms and links that start with firm i and end with another firm j .

extending the notion of *pairwise stability* in Jackson and Wolinsky (1996). I embed bilateral prices along the lines of transfer payments in Bloch and Jackson (2007).

Definition 1 *The equilibrium of a network formed by bilateral forward swap contracts is characterized by the linkage structure L^e and the set of bilateral prices p^e , such that*

- *Optimality: each firm i takes as given other firms' strategies $(l_j, p_j), \forall j \neq i$, and chooses its own strategy (l_i, p_i) to optimize its firm value, i.e.*

$$V_i(z, L^e, p^e) = \max_{(l_{ij} \in \{0, \bar{l}\}, p_{ij})_{j \neq i}} V_i(z, L, p), \quad (9)$$

subject to (2), (4), and constraints (5) - (8).

- *Pairwise stability: denote $L^e_{-\{ij\}}$ as the matrix L^e by deleting L^e_{ij} , and similar notations apply to the prices. Then $\forall L^e_{ij} > 0$ and $\forall \hat{p} \neq p^e$,*

$$V_i(z, L^e, p^e) \geq V_i\left(z, L^e_{-\{ij\}}, L_{ij} = 0, p^e_{-\{i, i, j, \cdot, j\}}, \hat{p}_i, \hat{p}_i, \hat{p}_j, \hat{p}_j\right), \quad (10)$$

$$V_j(z, L^e, p^e) \geq V_j\left(z, L^e_{-\{ij\}}, L_{ij} = 0, p^e_{-\{i, i, j, \cdot, j\}}, \hat{p}_i, \hat{p}_i, \hat{p}_j, \hat{p}_j\right); \quad (11)$$

and $\forall L^e_{ij} = 0$ and $\forall \hat{p} \neq p^e$

$$V_i\left(z, L^e_{-\{ij\}}, L_{ij} = \bar{l}, p^e_{-\{i, i, j, \cdot, j\}}, \hat{p}_i, \hat{p}_i, \hat{p}_j, \hat{p}_j\right) > V_i(z, L^e, p^e), \quad (12)$$

$$\Rightarrow V_j\left(z, L^e_{-\{ij\}}, L_{ij} = \bar{l}, p^e_{-\{i, i, j, \cdot, j\}}, \hat{p}_i, \hat{p}_i, \hat{p}_j, \hat{p}_j\right) < V_j(z, L^e, p^e). \quad (13)$$

- *Feasibility:*

$$L \times \mathbb{1}_{N \times 1} = L^\top \times \mathbb{1}_{N \times 1} = \mathbb{1}_{N \times 1}. \quad (14)$$

The pairwise stability concept states that two firms i and j connect only if both decide to connect and both prefer no other bilateral prices to each of their counterparties; two firms do not connect only if, for all possible bilateral prices to each of their counterparties, at least one firm has no incentive to connect. Pairwise stability naturally applies to this setting as the goal here is to understand which networks are likely to arise and remain stable.

2.6 Discussions

Synergy from links The two types of links, risk-sharing links and distress links, generate different sources of synergy. A risk-sharing link always generates a positive surplus by reducing the volatility of liquid assets. For instance, a link between two *ex ante* identical non-distressed firms reduces the liquidation probability of each firm.²⁶ In comparison, a distress link has an extra source of synergy from the distress heterogeneity. Take two firms with $\nu_i = 1.5$, $\nu_j = 0.8$. Even when $\sigma = 0$, there is gain as the liquidation of firm j can be avoided surely. More generally, the surplus from the reduction of total liquidation costs of firms i and j is shown to increase with their distress dispersion $|z_i - z_j|$.²⁷ Note that only firms liquid enough are able to profit from such a link. This can be seen as when $z_j < -1$, the surplus is positive only if $z_i > 0 - z_j > 1$.

Payment seniority In the model, debt is paid at date 2 using liquid holdings after asset trades. Payments for the forward swap contracts are paid in full at date 3 using yields from the long-term assets. This specification assumes that short-term creditors have seniority over the OTC derivative counterparties. The motivation is that derivatives seniority here would create additional inefficiency in risk-sharing similar to that in Bolton and Oehmke (2014). Following the example above, let instead $\nu_1 = 1.2$, $\nu_2 = 0.8$, and $\varepsilon_i = \varepsilon_2 = 0$. When net payment is transferred at date 3, both firms avoid liquidation. But whenever firm 2 has to transfer a positive net payment to firm 1 at date 2, firm 2 incurs liquidation. So my specification helps to isolate from other inefficiency channels associated with the derivatives payments.

Algorithm for linkage formation There are multiple ways to determine which network emerges given a set of contingent transfer payments (prices). I illustrate the following one. Under rational expectations, firms form a common belief about the equilibrium linkage structure L^b . Based on this belief, firms simultaneously submit strategies $l_i(L^b)$ and $p_i = \left(p_{ij}(z, L_i^b, L_j^b) \right)_{j \neq i}$. Given the strategies, the realized equilibrium network is consistent with the initial belief $L^e = L^b$. An alternative guess-and-verify approach is described in Bloch and Jackson (2007).

²⁶The total expected liquidation costs of two stand alone firms are $2\Pr(a_i < 1)c = 2\Phi(-z_i)c$. In a forward swap contracts, total expected costs for two connected firms are $2\Phi(-2z_i)c$. The total surplus equals $2(\Phi(-z_i) - \Phi(-2z_i))c > 0$.

²⁷The synergy equals the reduction of liquidation costs of the two firms $\Phi(-z_i)c + \Phi(-z_j)c - 2\Phi(-z_i - z_j)c$. The derivative of synergy with respect to $|z_i - z_j|$, holding the sum $|z_i + z_j|$ fixed, is positive.

3 Network Inefficiency

In this section, I examine the efficiency of the equilibrium network relative to a benchmark that minimizes total liquidation costs. I show that the equilibrium network is inefficient when the dispersion of financial distress is high: there are more distress links and fewer risk-sharing links.

3.1 Optimal Network

Under the model specifications for links and the asset swap process, the optimal network is chosen to minimize total liquidation costs (i.e. to maximize total values).

Definition 2 *The optimal network L^* minimizes total expected liquidation costs, i.e.*

$$L^* = \arg \min_{L_{ij} \in \{0,1\}} \sum_i \Pr(h_i < 1) c, \quad (\text{P1})$$

subject to the conditions of two-sided links $L_{ij} = L_{ji}$, iterative procedure (8), and feasibility (14).

Next I solve P1 and characterize the properties of L^* in the space of \bar{z} and δ .

Proposition 1 (Optimal Network) $\exists \bar{z}_1, \bar{z}_2, \bar{z}_1 > \bar{z}_2 \geq 0, \exists$ *cutoff function $\delta_1(\bar{z}) > 0$ such that*

- $\forall \bar{z} \geq \bar{z}_1, \delta \geq 0$ *or* $\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta \in [0, \delta_1(\bar{z})]$, *all firms are connected in one component; formally, either $L_{ij}^* > 0$ or there exists a path between i and j , i.e. $L_{ik_1}^*, \dots, L_{k_m j}^* > 0$;*
- $\forall \bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z})$, *the distressed firm N is isolated ($L_{NN}^* = 1$), whereas all other firms are connected in one component.*

Proposition 1 states that the optimal network is characterized by the two moments of distress distribution, $\{\bar{z}, \delta\}$. All firms diversify maximally by connecting in one component in an economy with high enough \bar{z} (low average distress), or with low \bar{z} and low enough distress dispersion δ . In contrast, when distress dispersion δ is high and \bar{z} is not sufficiently high, the most distressed firm N should be isolated, whereas all other firms are connected in one component. These patterns are shown in Figure 2 for $N = 4, 5$.²⁸ The intuition for Proposition 1 is the trade-off between

²⁸The cutoff value \bar{z}_2 is zero for $N = 4$, and is positive for $N \geq 5$. For $\bar{z} < \bar{z}_2$, there are regions when L^* isolates more than one firm: in Panel B Figure 2, both firms 4 and 5 are isolated in the hump-shaped region in the lower left corner. As δ increases further, L^* switches from isolating two firms to one firm. This is because the total expected liquidity of the first $N-1$ firms increases with δ which mechanically results from the structure in equation (1). In Appendix 8, we show a general analysis for $N > 5$ and figures for $N = 6, 7, 8$.

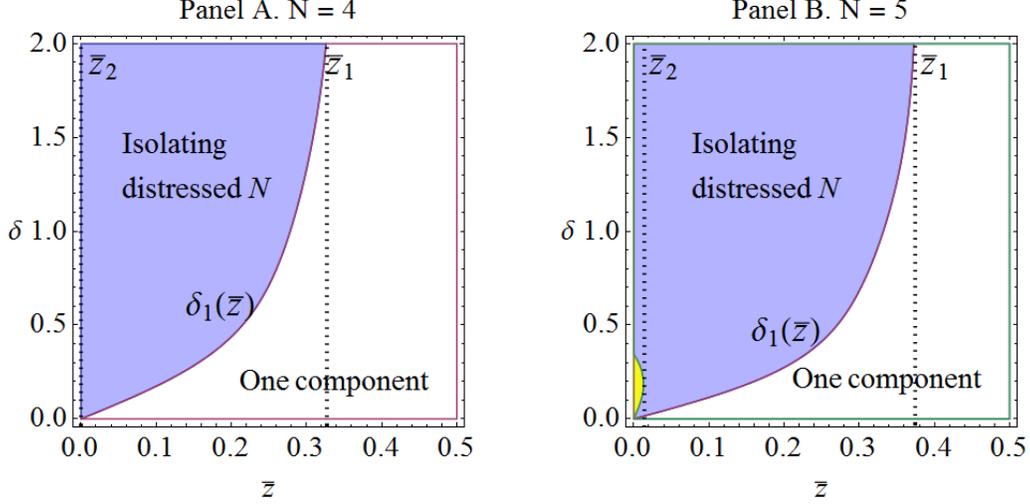


Figure 2. Optimal Network. This figure shows the optimal risk-sharing network characterized in Proposition 1 for $N = 4$ and $N = 5$. The horizontal and vertical axes represent the mean and dispersion of firm distress statistic z . In the white region, all firms are linked in one component. In the dark region ($\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z})$), firm N is isolated.

diversification and risks of contagion.²⁹ In an economy with high dispersion δ and low average \bar{z} , firm N is heavily distressed seen from equation (1). The contamination cost of linking firm N with all other firms dominates the risk-sharing benefit, which rationalizes isolating it to be socially optimal.

The model specifications on links and asset swaps do not deviate the optimal network from the best possible risk-sharing outcome. In Online Appendix A.1, I show that under the iterative swap procedure, the asset holdings implied by the optimal network, $h^* = (L^*)^\infty$, are equivalent to the optimal allocations if the social planner were to directly choose asset holdings for each firm. Hence, total liquidation costs achieve the minimum as long as the network is optimal.

3.2 Excess Distress Link

The question I address next is whether the optimal network can be decentralized in the network formation, and if not, in which ways the equilibrium network is inefficient.

Proposition 2 (Excess Distress Link) *For $N = 4$, $L_{12}^e = L_{23}^e = L_{14}^e = \bar{l}$: all firms are connected in one chain in equilibrium and firm 4 is linked with firm 1.*

²⁹The trade-off between risk-sharing and contagion is in line with Cabrales, Gottardi, and Vega-Redondo (2014), who find that, when shock distribution has thin tails, firms should be connected in one component, whereas when shock distribution has fat tails, maximum segmentation into small components is optimal.

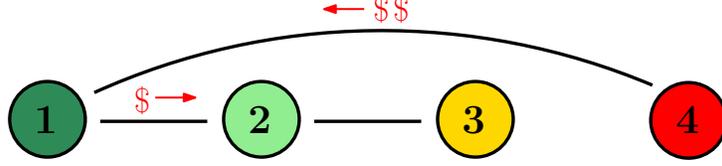


Figure 3. Equilibrium Network ($N = 4$). This figure shows the equilibrium four-firm chain network. Firms are ranked by the level of distress, and firm 4 is distressed. A solid line represents a link between two firms. A \$ arrow indicates the direction of net payment transfers via bilateral prices.

Proposition 2 states that for all parameter values, all firms are connected in one component in equilibrium including the most distressed firm via a distress link. Comparing propositions 1 and 2, when \bar{z} is low and dispersion δ is high, the optimal network has no distress link ($L_{NN}^* = 1$); however, the equilibrium network is inefficient and features excess distress link ($\sum_{i \neq N} L_{iN}^e > 0$).

Figure 3 illustrates the intuition. Under reservation prices $p_{ij} = p_{jj}$, firm 1 deviates to link with firm 4 to obtain a large profit. Then firm 2 tends to sever the 1 – 2 link as the cost of indirectly holding a fraction of a_4 gets high. To prevent 2 from disconnecting, firm 1 offers a premium price p_{12} by sharing part of the profit. This net transfer, $p_{12} - p_{21}$, equates the value of firm 2 to its outside option: the best it gets upon withdrawing. This results in over-connection at equilibrium: the distressed firm 4 should have been isolated but is linked with the rest. Firm 2 cannot afford to pay a premium price high enough to prevent 1 from connecting with 4. This is because the benefit of isolating 4 is shared by both 2 and 3, and so firm 2 would be worse-off paying the required premium on its own.

3.3 Risk Sharing Loss

As the chain network gets longer, the excess distress link can crowd out valuable risk-sharing links, thus giving rise to an additional channel of inefficiency from the loss of risk-sharing.

Proposition 3 (Risk Sharing Loss) For $N = 5$, there is excess distress link ($\sum_{i \neq N} L_{iN}^e > 0$, $\sum_{i \neq N} L_{iN}^* = 0$) when $\bar{z} \in [\bar{z}_2, \bar{z}_1]$, $\delta > \delta_1(\bar{z})$. In particular $\exists \eta(\bar{z})$ as a cutoff function such that

- $\forall \delta \in [\delta_1(\bar{z}), \eta(\bar{z})]$, all firms are connected in one chain, so there is over-connection;
- $\forall \delta > \max\{\delta_1(\bar{z}), \eta(\bar{z})\}$, non-distressed firms are not connected in one chain: the network has inefficient composition due to both excess distress link and insufficient risk-sharing.

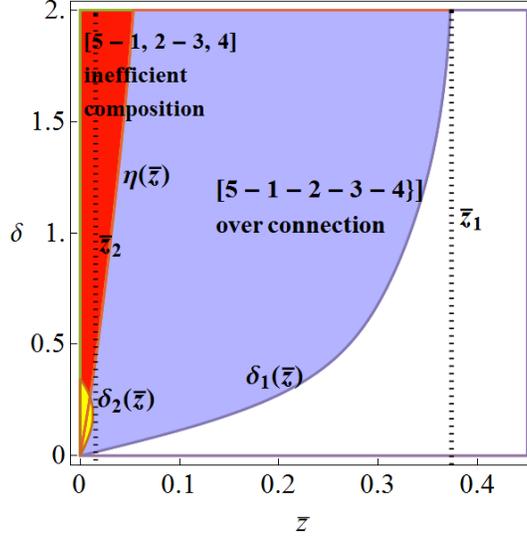


Figure 4. Equilibrium Network ($N = 5$). This figure shows the equilibrium five-firm network. The horizontal and vertical axes represent the mean and dispersion of firm distress statistic z . In blue and red regions, the optimal network isolates firm 5. Blue (lighter) region denotes over-connection, and red (darker) region denotes inefficient network composition.

Proposition 3 formalizes two channels of inefficiency: over-connection from the excess distress link and under-connection from risk-sharing loss. When \bar{z} is low and dispersion δ is high, the distressed firm, which should be isolated, is linked by firm 1 via the excess distress link. This occurs in the colored regions in Figure 4 where $\bar{z} \in [\bar{z}_2, \bar{z}_1]$ and $\delta > \delta_1(\bar{z})$. Particularly, if dispersion is in a middle range ($\delta \in [\delta_1(\bar{z}), \eta(\bar{z})]$), all firms are linked in one component, so inefficiency only results from over-connection. As we move to the upper left region ($\delta > \max\{\delta_1(\bar{z}), \eta(\bar{z})\}$), some risk-sharing links sever: a non-distressed firm becomes isolated or the non-distressed firms separate into multiple components. The externality from the distress link crowds out potential gains from risk-sharing. In this case, the equilibrium features inefficient composition with over- and under-connections simultaneously.

Without loss of generality, firms start from an ordered chain $1-2-3-4-5$ when $\delta = 0$.³⁰ As dispersion increases, firm 5 becomes distressed. The $4-5$ link terminates and the distress link $1-5$ forms: equilibrium network $\overbrace{1-2-3-4,5}$ thus generates over-connection. As dispersion rises further, the required premium price to keep firm 2 connected is higher and firm 1 is better off cutting the $1-2$ link. Firm 3 then optimizes by disconnecting the $3-4$ link. The equilibrium

³⁰I solve the equilibrium starting from each possible order in the chain. I confirm that the equilibrium is the same for large enough δ because the deviation incentives (endogenous outside options) for each firm is the same across different orders.

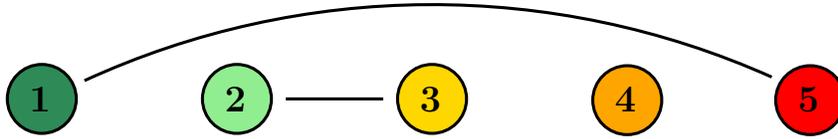


Figure 5. Inefficient Network Composition ($N = 5$). This figure shows the equilibrium connection structure $\overline{1, 2 - 3, 4, 5}$ with inefficient network composition that features both over- and under-connections.

therefore becomes $\overline{1, 2 - 3, 4, 5}$, as shown in Figure 5.

3.4 The Key Friction

The inefficiency is caused by network externalities. Due to local contingency in Assumption 1, the liquid firm 1 fails to internalize the negative externalities to its direct and indirect counterparties. When Assumption 1 is relaxed, bilateral prices $p_{ij}(z, L)$ can induce the efficient network, which indicates that the incomplete contingency on the network structure is the mere underlying friction.



Figure 6. Complete Contingent Contracts ($N = 4$).

Recall the $N = 4$ case. When δ is high, linking with the distressed firm 4 by 1 imposes an externality to both 2 and 3. To prevent this distress link, firms 2 and 3 need to jointly offer incentives to 1. In Online Appendix A.2, I formally show that, if and only if $L_{14}^* = 0$, there exist unique premium prices p_{21}^* and p_{32}^* such that $L_{14}^e = 0$. In particular, p_{32}^* is a function of L_{14} , implying that firm 3 pays a premium to firm 2 when $L_{14} = 0$. Essentially, the price offered by firm 3 is contingent not only on the link between 2 and 3, but also on the links of the counterparty's counterparty (see Figure 6).

4 The Distress Dispersion

In this section, I investigate factors that indicate the level of network inefficiency. While prior literature has largely focused on the first moment of financial distress, I show that heterogeneity in firm distress measured by the dispersion δ is a critical indicator for inefficiency. Both inefficiency indicators, value loss and systemic risk, increase with dispersion δ . Using comparative statics, I explain this positive relation by associating the network inefficiency to changes in the

network composition.

4.1 Measures of Inefficiency and Dispersion

In the model, I measure network inefficiency by value loss and systemic risk. Define *value loss*, ΔV , as the difference in total expected firm values between the optimal and the equilibrium networks. Then let $\Delta V\%$ be the *percentage value loss*, which is simply the percentage of value loss over total optimal firm values.

$$\Delta V = \sum_{i=1}^N V_i(z, L^*, p^*) - \sum_{i=1}^N V_i(z, L^e, p^e); \quad \Delta V\% = \frac{\Delta V}{\sum_{i=1}^N V_i(z, L^*, p^*)}. \quad (15)$$

Under the feasibility condition of asset swaps in equation (14), value loss equals the increment of total liquidation costs. Next, I characterize the properties of value loss as a function of the two moments of firm distress distribution, (\bar{z}, δ) .

Proposition 4 (Value Loss) *Value loss decreases with average \bar{z} and increases with dispersion δ . It increases with δ faster when \bar{z} is lower. Formally, $\frac{\partial \Delta V}{\partial \bar{z}} \leq 0$, $\frac{\partial \Delta V}{\partial \delta} \geq 0$, and $\frac{\partial^2 \Delta V}{\partial \bar{z} \partial \delta} \leq 0$.*

From Proposition 4, value loss is bigger when the average distress is higher or when the dispersion is higher. In such scenarios, firm N is so distressed that linking it with other firms generates large contagion risk. Consequently, the cost from such a distress link causes higher loss in total firm values.

Next I explore an alternative measure for inefficiency: *systemic risk* denoted as \Pr_{sys}^L . It is defined as the probability that all firms liquidate at the same time. In a network where all firms are linked in one component, systemic risk equals the liquidation probability of one firm because all firms hold exactly the same diversified asset, i.e.

$$\Pr_{sys}^{\text{all connect}} = \Pr\left(\frac{1}{N} \sum_{i=1}^N a_i < 1\right). \quad (16)$$

In a network that isolates the distressed firm, systemic risk is the probability that the isolated firm liquidates at the same time when all non-distressed firms in one connected component liquidate,

$$\Pr_{sys}^{\text{isolate } N} = \Pr\left(\frac{1}{N-1} \sum_{i=1}^{N-1} a_i < 1\right) \times \Pr(a_N < 1). \quad (17)$$

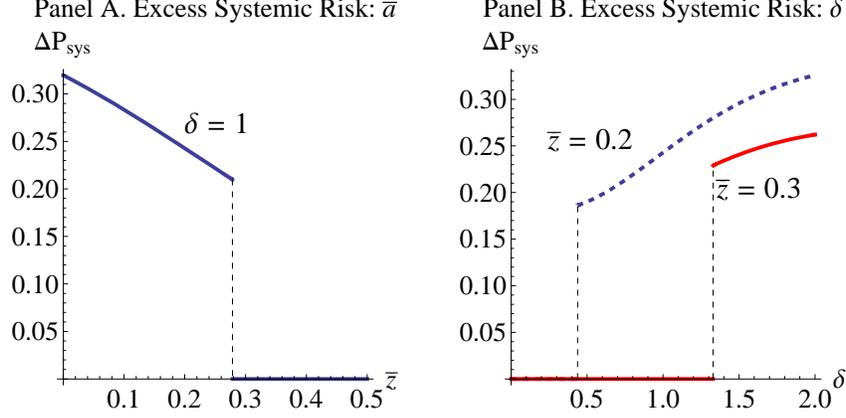


Figure 7. Excess Systemic Risk. This figure plots the excess systemic risk against average \bar{z} and dispersion δ for the equilibrium four-firm chain network.

Define *excess systemic risk*, $\Delta Pr_{sys} = Pr_{sys}^{L^e} - Pr_{sys}^{L^*}$, i.e. the difference between systemic risk at the equilibrium network compared to the optimal network. In the example of $N = 4$, the excess systemic risk is positive whenever the network is inefficient. That is, $\Delta Pr_{sys}(N = 4) > 0$ in the inefficient region ($\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z})$).³¹

Figure 7 plots excess systemic risk as a function of the mean (Panel A) and dispersion of z (Panel B). Excess systemic risk is positive when the average distress is sufficiently high and firm distress is dispersed. ΔPr_{sys} decreases with \bar{z} ; and as long as the dispersion δ is high enough, it increases with δ at a steeper rate when \bar{z} is lower. The similarity of these patterns with Proposition 4 suggests that excess systemic risk serves as an alternative measure for inefficiency.

4.2 Comparative Statics: dispersion, inefficiency, and network composition

The above analysis shows that firm distress dispersion δ is a key indicator for both measures of inefficiency. To inspect the mechanism, I analyze how the equilibrium network responds to changes in \bar{z} and δ , relative to the optimal network. Especially, I look at the two inefficiency measures, ΔV and ΔPr_{sys} , together with changes in the network composition in terms of distress links and risk-sharing links.

In the first comparative statics, I lower the level of \bar{z} in two cases when δ takes a low and a high value. When firms are similar in financial distress (δ is low), all firms linking in a single component is optimal and pairwise stable. As we lower \bar{z} , the optimal network remains

³¹For example, when $\bar{z} = 0.2$ and $\delta = 1.5$, $\Delta Pr_{sys} = 0.34 - 0.05 = 0.29$.

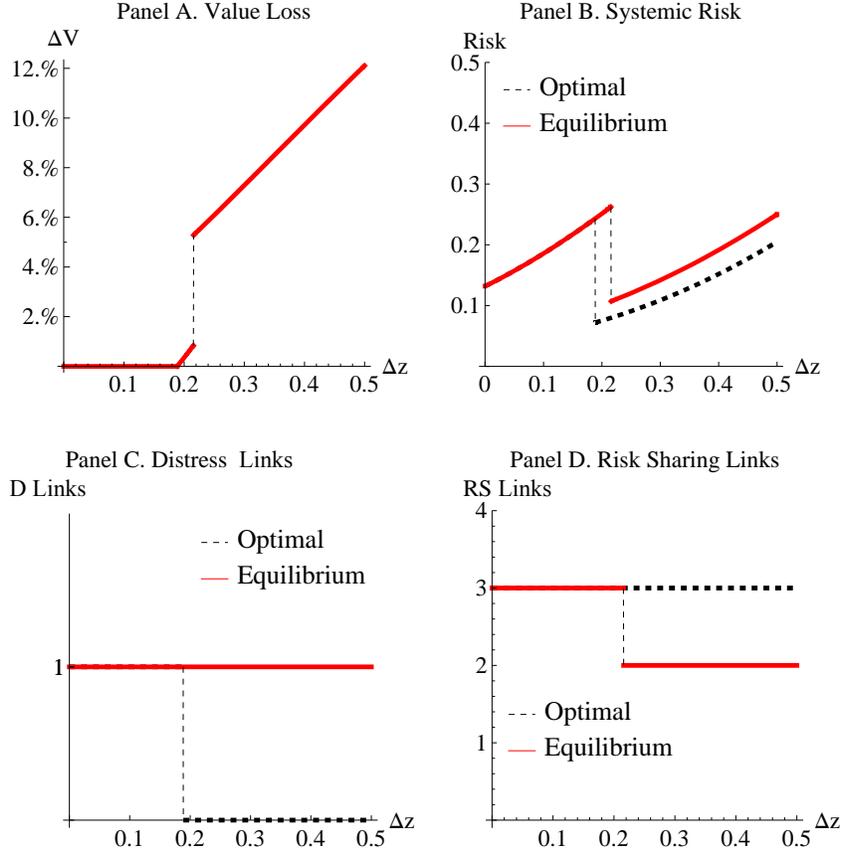


Figure 8. Increase in Average Distress under High Distress Dispersion. This figure shows the properties of the five-firm chain network with high δ when we lower \bar{z} . The horizontal axis $\Delta\bar{z}$ is the reduction in \bar{z} . I plot the values in the equilibrium network (solid) and the optimal network (dashed).

unchanged and is also stable. Consequently, both ΔV and ΔPr_{sys} equal zero.

Results are different when firms are dispersed in financial distress (δ is high): a decrease in \bar{z} affects the optimal and the equilibrium network differently. Figure 8 plots the value loss (Panel A), systemic risk (Panel B), distress links (Panel C), and risk-sharing links (Panel D) as functions of the reduction in \bar{z} in a five-firm network, starting from $\delta = 1$ and $\bar{z} = 0.5$.³² As \bar{z} reduces, both value loss ΔV and excess systemic risk ΔPr_{sys} (the difference of the solid and the dashed curves in Panel B) rise. Corresponding to where the inefficiency occurs, Panels C and D show that the equilibrium network has one extra distress link between 1 and 5, and one fewer risk-sharing link between 1 and 2. This exercise has two implications. First, comparing the two

³²I consider a chain network 1 – 2 – 3 – 4 – 5 of which the optimal and equilibrium networks are analyzed in Subsection 3.3 and in Figure 4. In particular, I set $A = 4$, $c = 2$, so that when $\delta = 1$ and $\bar{z} = 0.5$, the average liquidation cost amounts to 8% of total firm value.

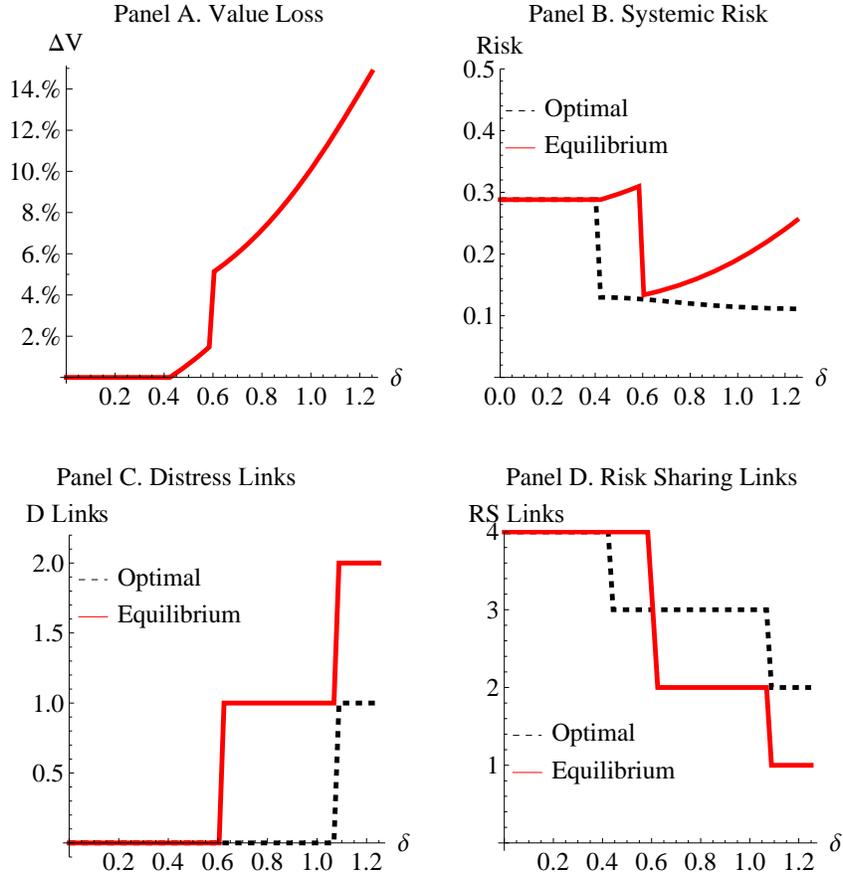


Figure 9. Increase in Dispersion. This figure shows the properties of the five-firm chain network when we raise dispersion δ while adjusting \bar{z} so total firm values at L^* remain constant. I plot the values in the equilibrium network (solid) and the optimal network (dashed).

cases when δ takes a low and a high value, δ only matters to inefficiency when it is sufficiently large. Second, the observed positive relation of inefficiency and δ is associated with changes in the network composition.

In the second comparative statics, I study how the equilibrium network changes with dispersion. However, when firms form links optimally, increasing dispersion alone increases total firm values, as the total liquidation costs decrease monotonically.³³ For this reason, in the following exercise, I increase δ while also adjusting \bar{z} such that the total firm values in the optimal network remains constant. This allows me to conduct a “fair” comparison across states when identical firm values can possibly be achieved. Figure 9 plots the inefficiency measures and linkages of the

³³When all firms are linked in a single component, total liquidation costs equal $N\Phi[\sqrt{N}(-\bar{z})]c$, independent of δ . When the most distressed firm is optimally isolated, total liquidation costs, $(N-1)\Phi[\sqrt{N-1}(-\bar{z}-\frac{1}{2}\delta)] + \Phi[-\bar{z}-\frac{1-N}{2}\delta]$, decrease monotonically with δ . With no linkages, however, liquidation costs increase monotonically with dispersion δ as more firms are distressed.

same chain network as before. From Proposition 4, both measures of inefficiency (see in Panels A and B) increase with dispersion. When δ is large enough, inefficiency becomes positive and increases thereafter. Particularly, systemic risk at equilibrium increases with δ , except for the drop when the 1-2 risk-sharing link severs, which reduces asset correlations.

These patterns are due to over-connection at high values of dispersion and wrong network composition when dispersion gets even higher. This can be seen by comparing the number of distress links and risk-sharing links in Panels C and D. The optimal network isolates firm 5 before it becomes distressed, so the only jump on the dashed curve in Panel C is when firm 4 falls into distress. In comparison, firms 4 and 5 are always connected at equilibrium (see the two steps in the solid curve), which results in over-connection. Shown in Panel D, when δ is high, the optimal network has one more risk-sharing link than the equilibrium network (dashed minus solid curves). The severance of the 1-2 risk-sharing link implies wrong network composition, which creates an extra channel for inefficiency.

To summarize, the above two comparative statics conclude that a decrease in \bar{z} when δ is high, or an increase in δ (together with a decrease in \bar{z}) is associated with: (1) *higher value loss and higher systemic risk*, (2) *more distress links*, (3) *fewer risk-sharing links*. In both exercises, the cross-sectional distribution of firm distress has high dispersion.

5 Policy Implications on the Acquisitions of Distressed Firms

In this section, I apply the model to a case where links with distressed firms are interpreted as acquisitions. There are two reasons for this particular application. First, in the data, a major example of the links with distressed firms is acquisitions. [Acharya, Shin, and Yorulmazer \(2010\)](#) and [Almeida, Campello, and Hackbarth \(2011\)](#) provide evidence that liquid firms acquire distressed firms for potential gains from asset sales or advantageous bargaining position. Second, compared with OTC derivative contracts that are challenging to supervise, acquisitions in the financial sector are subject to regulatory approval, which makes it relevant for policy interventions.

Based on the model result, regulations that prevent the inefficient distress links can generate social gains. I begin by proposing one such regulation using an acquisition tax to supervise acquisitions. Then I study an extension of the model that allows for the analysis of optimal

government policies both before and after the linkage formation. Results indicate that the too-connected-to-fail problem arises if the excess acquisition is not effectively prevented *ex ante*. In this case, liquidating the distressed firm is too costly due to spillovers to its existing counterparties. Using the extended model, I discuss, respectively, the options of government bailout, subsidized acquisition, and pushed acquisitions. I find that these are *ex post* optimal remedies, thereby rationalizing the government interventions observed during the crisis.

5.1 Acquisition Tax

Current authorities consider acquisition as the primary approach to resolve firm distress as it incurs the least fiscal cost. However, my results imply that acquisitions of distressed firms should rather be regulated accounting for the externalities in the financial linkage formation. If the regulators are able to provide incentives by imposing taxes, then a tax formula that varies with the distress distribution can induce the optimal level of acquisitions and restore the efficient network. Next I formally characterize the tax rate.

Proposition 5 (Acquisition Tax) *In an N -firm chain, the optimal network can be decentralized by a tax τ imposed to firm 1 upon its acquisition of the distressed firm N ,*

$$\tau = \left[N\Phi \left[\sqrt{N}(-\bar{z}) \right] - (N-2)\Phi \left(\sqrt{N-1}(-\bar{z} - \frac{1}{2}\delta) \right) - \Phi(-z_1) - \Phi(-z_N) \right] c. \quad (18)$$

where $\Phi(\cdot)$ is the CDF of the standard normal distribution. Furthermore, $\tau > 0 \iff L_{NN}^* = 1$. τ satisfies $\frac{\partial \tau}{\partial \delta} > 0$ and $\frac{\partial \tau}{\partial \bar{z}} < 0$.

Proposition 5 states that the acquisition tax is positive if and only if the most distressed firm should be isolated in the optimal network. Moreover, the acquisition tax increases with the average and dispersion of distress. The intuition is as follows. The acquisition tax equals precisely the negative externalities to all other non-distressed firms $i = 2, \dots, N-1$. Hence, it exactly aligns the individual motivation with the social incentive for acquisition. Accounting for negative spillovers, the acquisition tax is a function of the cross sectional distribution of firm distress in terms of $\{N, \bar{z}, \delta\}$. When dispersion is higher, the negative externalities are bigger; hence, we require bigger incentive to correct for the externality. A similar argument holds for the relation with the average distress. Note that the tax is only imposed conditional on the

excess acquisition. Therefore, no tax will be physically collected from the acquirers because the inefficient acquisition is effectively prevented.

The model provides a sharp theoretical guidance on how to regulate acquisitions. In particular, the novel insight of considering firm distress distribution complements the current metrics in regulatory decisions. The concern towards “financial stability” was included for the first time for processing firm acquisitions by the Dodd-Frank Wall Street Reform and Consumer Protection Act in Section 604(d). This section amended Section 3(c) of the Bank Holding Company Act of 1956 and it requires the Fed to consider “the extent to which a proposed acquisition, merger or consolidation would result in greater or more concentrated risks to the stability of the United States banking or financial system.” In the orders on approving recent acquisitions, for instance Capital One’s acquisition of ING Bank, the Fed illustrates the new financial stability metrics in response to Dodd-Frank’s mandate, including size, substitutability, interconnectedness, complexity, and cross-border activity.³⁴ The discussion regarding the interconnectedness factor, however, only covers the degree of interconnectedness of the resulting firm, rather than considering the entire linkage structure and possible externalities through indirect linkages.

The key issue is how to implement such acquisition tax. From equation (18), the regulators need to account for the distribution of financial distress. One feasible approach detailed in Section 6 is to estimate quarterly Z-scores of all financial firms. Among the limitations of this measurement are the low frequency and the opacity of balance sheets. Using exclusive regulatory data, the banking supervisors can potentially achieve better estimates by using observations with higher frequency or alternative models such as CAMELS ratings.

Once the excess acquisitions are prevented, alternative resolution methods in case of failure include liquidation or the Purchase and Assumption (P&A) transactions. The Federal Deposit Insurance Corporation Improvement Act of 1991 mandates the FDIC to choose the resolution method least costly to the Deposit Insurance Fund. To comply with this mandate, the FDIC chose P&A transactions as the resolution method for a great majority of failing banks (about 95%).³⁵ My results hence indicate that P&As are preferred to relying on private sector solutions

³⁴www.federalreserve.gov/newsevents/press/orders/2012orders.htm

³⁵For detailed institutional background on bank failures see [White and Yorulmazer \(2014\)](#), [Granja, Matvos, and Seru \(2014\)](#), and the the Guidance for Developing Effective Deposit Insurance Systems from FDIC, at <http://www.fdic.gov/deposit/deposits/international/guidance/guidance/FailedResolution.pdf>.

which give rise to network externalities and the potential build-up of systemic risk.

5.2 *Ex post* Policies

Several acquisition cases observed during the recent financial crisis render the baseline model counterfactual, including the acquisitions of Bear Stearns, Merrill Lynch, and National City. These cases differ from the baseline setting in several dimensions: links with the target institutions were formed before the distress conditions were fully disclosed. Additionally, government interventions such as bailout or pushed/subsidized acquisitions took place. For example, counterparties did not immediately pull back from trading with Bear Stearns after the failure of its two funds in 2007. When Bear Stearns suffered severe financial distress on March 2008, the Fed provided assistance in the form of a non-recourse loan of \$29 billion to JP Morgan to make the acquisition. To rationalize the observed government interventions of such kind, I next consider extensions of the baseline model, and the key deviation is that the timing of the network formation does not coincide with the observation of distress.

Suppose the linkage cannot be severed once formed at $t = 1$ after ν is learned. Further, assume that the liquid return a_i satisfies

$$a_i = \nu_i + \theta_i + \sigma\varepsilon_i, \quad i = 1, \dots, N, \quad (19)$$

where the additional term θ_i is realized after links are formed. Hence, ν_i and θ_i jointly determine the amount of liquid value firm i expects to receive. Let θ be a vector with $\theta_i = 0, \forall i = 1, \dots, N-1$, and $\theta_N = -k\bar{z}\sigma$.³⁶ Further let $\bar{z} \in [\bar{z}_2, \bar{z}_1]$ and $\delta > \delta_1(\bar{z})$ such that the distress firm N should be isolated (Proposition 1). Nonetheless, in the absence of the acquisition tax, all firms are connected at equilibrium (Proposition 2). Now, assume firm N receives a second bad liquidity shock θ_N with $k > N$ such that it drags down the average distress of all firms below zero. In this case, the links do not generate positive risk-sharing surplus, thus total liquidation costs are higher than without any links among firms.

5.2.1 Government Bailout

Next I analyze conditions when government bailout is *ex post* optimal and how total costs compare to those under the *ex ante* optimal policies (imposing acquisition tax). For this purpose, let

³⁶In practice, distress signals are released gradually. The negative θ_N captures persistence in liquidity conditions.

us enable the option of government bailout in the form of costly liquidity injection. Specifically, let $B\sigma$ denote the amount of government liquidity injection to the heavily distressed firm N . Since all firms are connected and each has the same diversified asset holdings, they share the same probability of liquidation $\Phi\left[-\frac{1}{\sqrt{N}}(N\bar{z} - k\bar{z} + B)\right]$. Here, the total costs incurred include expenses both in liquidation and bailout.³⁷

I find that positive government bailout is *ex post* optimal in an over-connected network as long as the liquidation cost is not very small. The formal analysis is provided in Internet Appendix A.3, Proposition 7. When the liquidation cost satisfies $c > \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$, a positive government bailout that matches at least the total expected liquid value shortfall ($B^* > (k - N)\bar{z}$) is *ex post* optimal. This lower bound of liquidation cost is smaller when the distressed firm has more counterparties or when asset volatility is lower. Now, suppose the second shock θ_N to firm N is not sufficiently bad, the lower bound of liquidation cost that justifies government bailout will be higher.³⁸ In other words, the worse shock the connected banking system gets, the more likely government bailout is *ex post* optimal. This relation is consistent with the empirical observation that bailout only occurs in rare occasions with severe distress.

Despite the fact that government bailout can be *ex post* optimal, it is likely to be more costly than preventing the excess acquisition *ex ante*. I show that, as long as the bailout cost is not sufficiently low, total costs from *ex post* government bailout is higher than regulating the links *ex ante* using the acquisition tax (see Proposition 8 in Internet Appendix A.3). This result captures one critical aspect of inefficiency in the current policy making: the time-inconsistency problem.³⁹ When a liquid firm observes the distress of some institution, it acquires the distressed target while generating externalities. Precisely owing to the excess acquisition link, liquidation of the distressed firm gets too costly. In consequence, government bailout becomes *ex post* optimal and *ex ante* inefficient.

³⁷The total costs incurred equal $N\Phi\left[-\frac{1}{\sqrt{N}}(N\bar{z} - k\bar{z} + B)\right] + B\sigma$.

³⁸Formally, if $0 \leq k \leq N$ in $\theta_N = -k\bar{z}\sigma$ instead, the average distress $\frac{1}{\sqrt{N}}(N - k)\bar{z}$ is then positive. And the lower bound for liquidation cost is higher than the case of $k > N$, i.e. $c \geq \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} e^{\frac{(N-k)^2\bar{z}^2}{2N}} > \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$.

³⁹For other discussions on the time-inconsistency issue, see Acharya and Yorulmazer (2007), Spatt (2009), Chari and Kehoe (2013), and Gimber (2013).

5.2.2 Government Subsidized Acquisition

Back to the Bear Stearns case, instead of injecting capital directly, the Fed provided assistance to the acquirer JP Morgan in the form of a non-recourse loan.⁴⁰ With a slight variation, the extended framework can explain this behavior. I show that, when there exist healthier institutions currently not connected with the distressed firm, government subsidized acquisition can reduce total liquidation costs.

Consider another group of connected firms that are separate from the existing firms. Suppose there are N firms $i = N + 1, \dots, 2N$ with the same average $\bar{z} > 0$ and dispersion $\delta = 0$, such that a complete risk-sharing network optimally emerges.⁴¹ Let the additional signal θ_i be $\theta_{N+1} = \hat{k}\bar{z}\sigma$ and $\theta_i = 0, \forall i = N + 2, \dots, 2N$, so the $(N + 1)$ th firm gets a positive shock in the liquid return. The question I address next is whether firm $N + 1$ has the incentive to acquire the distressed firm N after the realization of θ , and whether the *ex post* acquisition is socially optimal.

The answer to this question depends on how the liquidity surplus of firm $N + 1$ compares with the liquidity shortage of firm N . In Corollary 1 of Internet Appendix A.3, I show that the *ex post* distressed acquisition is efficient and it occurs at equilibrium if and only if the average distress is above zero ($\hat{k} > k - 2N$). However, if the adverse liquidity shock k is considerably large ($k \geq \hat{k} + 2N$), the acquisition has negative surplus, and firm $N + 1$ does not have incentive to acquire. In this case, subsidized acquisition in the form of liquidity injection to the acquirer is *ex post* optimal as long as the liquidation cost is not very small ($c > \frac{\sqrt{\pi}\sigma}{\sqrt{N}}$). The intuition is that risk-sharing among the two groups of firms reduces total liquidation costs only when the total expected liquidity is positive. And both acquisition subsidy and government bailout can push the average liquidity above zero. I find that the required optimal government subsidy is lower when the positive liquidity shock of the potential acquirer (\hat{k}) is higher. This result rationalizes the observation that the subsidized acquirers during the financial crisis, for instance JP Morgan and PNC (respectively acquirers of Stearns and National City), are relatively more liquid firms.

Comparing the two types of *ex post* policy remedies, the government subsidized acquisition generates lower total costs than government bailout, thus is always preferred. This result holds

⁴⁰On March 14, 2008, the New York Fed agreed to provide a \$25 billion collateralized loan to Bear Stearns for up to 28 days, but later decided that the loan was unavailable to them.

⁴¹The results are robust to $\delta > 0$. I leave the robustness on the number of firms in the two groups to the next subsection.

even when the acquisition alone is socially costly. Nonetheless, if the excess link with the distressed firm was prevented in the first place, liquidation would not be as expensive; hence, neither subsidized acquisition nor bailout would be necessary.

5.2.3 Government Pushed Acquisition

I have shown that when the two groups of firms have the same cardinality, the acquisition link forms at equilibrium if and only if it generates value gains. However, this “if and only if” condition does not hold when the cardinality of the two groups differs. Specifically, if the additional healthier group has fewer firms, the acquisition might not occur even if it is *ex post* socially valuable, which motivates direct government interventions.

The relative cardinality of the two groups determines the sign of the bilateral surplus and implies whether the *ex post* acquisition occurs at equilibrium or not. When the potential acquirer in the second group has more counterparties, there are more firms to share the cost of the acquisition than there are in the original distressed group to share the benefit. The bilateral surplus from the acquisition is greater than the social surplus, hence the acquisition link forms *ex post* whenever it is socially valuable. When the cardinality of the two groups are the same, the sign of the bilateral surplus matches that of the social surplus, and we are back to the special case in Section 5.2.2.

If instead the distressed firm N has more counterparties, the bilateral acquisition surplus is smaller than the social surplus. Especially, the bilateral surplus can be negative even when the social surplus is positive. Hence, the *ex post* socially valuable acquisition does not occur at equilibrium. In such circumstances, government pushed acquisition is socially value improving (see Proposition 9, Internet Appendix A.3).

There are many ways in which a government intervention can take place. One approach is by exerting pressure to the potential acquirers. Examples include the Fed pressuring Bank of America to acquire the distressed Merrill Lynch.⁴² The regulators can also aim to correct the sign of the bilateral surplus by subsidizing the acquirer using fund collected from the counterparties of the distressed firm. Alternatively, the regulators can provide a coordination device for collective

⁴²As discussed in Spatt (2010), “secretary of the Treasury Henry Paulson indicated to [Bank of America CEO] Lewis that banking supervisors would question his suitability to lead Bank of America if BoA backed out of the merger and then needed more federal support, while federal authorities agreed to provide ‘ring-fencing’ of difficult to value Merrill Lynch assets if Bank of America went ahead with the merger.”

decision making: let the potential acquirer and all the counterparties of the distressed firm bargain over the payments. One such example is the initiation of collective bailout of LTCM by the New York Fed in 1998.⁴³

6 Empirical Evidence

In this section, I document evidence that the distribution of distress across financial institutions provides a novel measure for systemic risk and aggregate failures in the financial sector. I establish this result by first examining how the cross-sectional mean and dispersion of distress correlate with indicators for aggregate systemic risk, liquidation costs, distress links through acquisitions, and interbank risk-sharing. I then confirm the findings using predictive regressions.

6.1 Measurement

The sample of financial institutions I consider includes bank holding companies and all Federal Deposit Insurance Corporation (FDIC) insured commercial banks and savings institutions. The quarterly accounting data of bank holding companies for the period of 1986-2013 are taken from FR Y-9C filings provided by the Chicago Fed. The quarterly accounting data for commercial banks (Call Reports) and savings institutions (Thrift Financial Reports) are taken from the FDIC's Statistics on Depository Institutions, available for 1976-2013. Next, I discuss the method for estimating the distress measure Z-scores and identifying the acquisitions of distressed firms.

6.1.1 Z-score

The quarterly accounting data provide the basis for measuring financial distress and identifying acquisitions of distressed institutions. I measure financial distress by estimating the Z-score, which has been widely used in the recent literature (e.g. [Stiroh \(2004\)](#), [Boyd and De Nicolo \(2005\)](#) and [Laeven and Levine \(2009\)](#)) as an indicator for a institution's distance from insolvency ([Roy \(1952\)](#)). The Z-score is defined as the return on assets plus the capital-asset ratio divided by the standard deviation of return on assets. Simply put, it equals the number of standard deviations that an institution's return on assets has to drop below the expected value before

⁴³On Sept 23 1998, the New York Fed arranged a meeting for a group of LTCM's major creditors at one of its conference rooms. During this historic meeting, the creditors worked out a restructuring deal that recapitalized LTCM and avoided its bankruptcy.

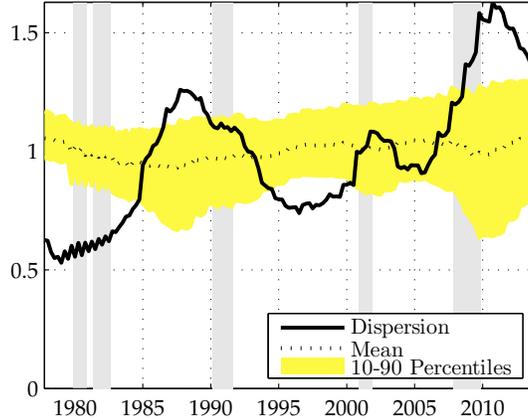


Figure 10. Log Z-score Moments across Financial Institutions. This figure plots the quarterly time series of dispersion, mean, and the 10-90 percentile range of log Z-score across all financial institutions over the period of 1978-2013. The series are normalized such that both the dispersion and the mean are centered around one. Shaded bars indicate NBER recessions.

equity is depleted. For this reason, the Z-score provides a good proxy for financial distress, which is denoted by the state variable z_i in my model.

The Z-score combines accounting measures of profitability, leverage and volatility. In particular, it is estimated according to the formula

$$\text{Z-score}_{i,t} = \frac{\frac{1}{T} \sum_{\tau=0}^{T-1} ROA_{i,t-\tau} + \frac{1}{T} \sum_{\tau=0}^{T-1} CAR_{i,t-\tau}}{\sigma_{i-T+1}^t(ROA_i)}, \quad (20)$$

where $ROA_{i,t}$ and $CAR_{i,t}$ are respectively the return on assets (net income over total assets) and capital asset ratio (total equity capital over total assets) for firm i in quarter t . In my analysis, the Z-score is computed considering a rolling window of eight observations, i.e. $T = 8$. The estimated Z-score is highly skewed; hence, I follow [Laeven and Levine \(2009\)](#) and [Houston, Lin, Lin, and Ma \(2010\)](#) and adopt the natural logarithm of the Z-score as the distress measure.

The time series of the mean and dispersion of log Z-score are estimated by taking the average and standard deviation across all financial firms in each quarter. Figure 10 plots the quarterly series of dispersion, mean, and the 10-90 percentile range of log Z-score over the period of 1978-2013. For the purpose of visualization, the series are normalized such that both the dispersion and the mean are centered around one. The shaded bars indicate NBER recession dates.

From Figure 10, we can make the following observations. First, relative to the cross-sectional

mean, the dispersion of log Z-score displays a fair amount of variation and has an increasing overall trend. Second, the dispersion series demonstrates a countercyclical pattern: it increases during the Savings and Loan crisis, the Dot-com crash and the recession afterwards, as well as during the 2007-2009 financial crisis. Based on the comparative statics in Section 4.2, precisely during the crises spell, network inefficiency is more pronounced, which potentially aggravates the crises and increases systemic risk. Finally, the dispersion series appears to lead recessions. Take the most recent crisis for instance, the dispersion starts to increase since 2005, and by the time financial firms enter the crisis in the 3rd quarter of 2007, they already show significant dispersion in financial distress. These features combined suggest that the time series of dispersion can potentially signal economic changes and systemic risk, which I will test at the end of this section.

While the Z-score provides a quantitative measure for distress, it is worth noting a few limitations. First, the quarterly accounting data are an endogenous outcome of certain degrees of risk diversification, thus are not exogenous to firms as assumed in my model. Nonetheless, the Z-score gives the best available proxy for the distress shock in the static framework because it is estimated using past data, which are taken as given by firms to make decisions onwards. The Z-score indicates firm stability well also because, as shown by [Acharya, Shin, and Yorulmazer \(2010\)](#), initially liquid firms tend to hoard liquidity or deleverage for potential gains from asset sales, whereas risk management tools for an initially distressed firm are limited. Hence, the ranks of the estimated Z-score across firms can reflect the ranks of initial distress. The second limitation pertains to the estimation of Z-score using accounting data. It omits off-balance sheet activities, and thus possibly gives a biased measure of firm risk. However, off-balance sheet usages are only relevant for a few institutions, hence do not necessarily affect the entire distribution.

6.1.2 Acquisitions of Distressed Firms

Based on the above measure, an acquisition of a distressed firm occurs when the target has a low Z-score. This enables us to proxy for the acquisition links with the distressed firms in the model. The acquisition transactions are taken from the Chicago Fed Mergers and Acquisitions dataset. The dataset records all the acquisition transactions of banks and bank holding companies since

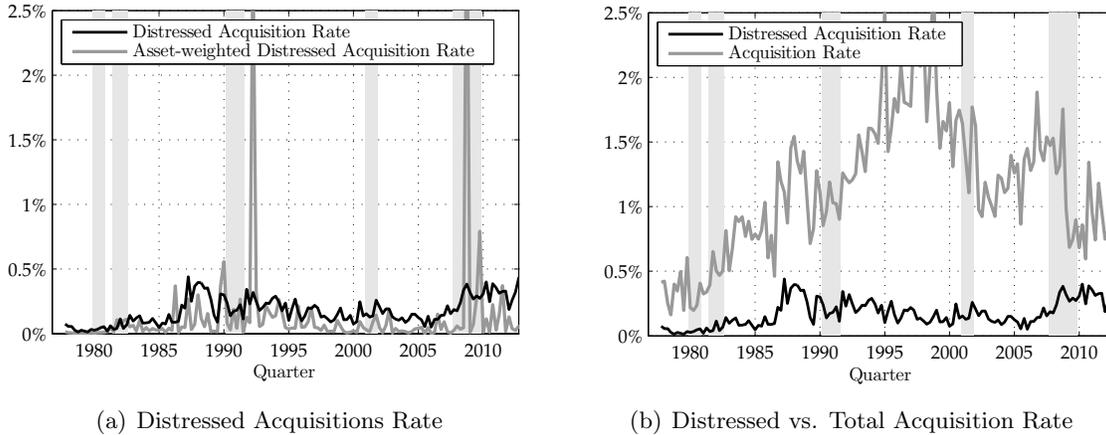


Figure 11. Distressed Acquisitions Rate. This figure plots the quarterly (asset-weighted) distressed acquisition rate for 1978-2013 (left) and compares the distressed acquisition rate to the total acquisition rate (right). Shaded bars indicate NBER recessions.

1976, keeping track of both the target and acquirer entities at the merger completion date. I drop the observations that are failures or restructurings.⁴⁴ I then match the dataset with quarterly accounting data using RSSD ID of the target firm two quarters ahead.⁴⁵ Around 86% (17,930) of the observations are matched. Out of the matched sample, I identify a *distressed acquisition* if the target firm reports a negative net income two quarters prior to the acquisition completion date, or if the target firm has a log Z-score of below 2.35 (two standard deviations below the sample mean) at least once, two to four quarters before the acquisition completes.

Using this strategy, around 20% (3,153) of the matched sample acquisitions are classified as distressed acquisitions, whereas the rest mostly took place during the merger wave in the 2000s after the Gramm-Leach-Bliley Act, which enabled mergers among investment banks, commercial banks, and insurance companies. Among the identified distressed acquisitions, some notable examples include Countrywide by Bank of America, Riggs and Sterling by PNC, and Wachovia by Wells Fargo.

Figure 11(a) plots the quarterly percentage of distressed acquisitions over total number of

⁴⁴Failures refer to transactions with Termination Reason Code = 5. Restructurings occur when the target entities and the acquirer entities have exactly the same entity name but different Federal Reserve RSSD IDs.

⁴⁵To match as many entities as possible, in this step, I include the FR Y-9LP and FR Y-9SP filings for bank holding companies. However, since these non-consolidated parent banks only report semiannually, I do not include them when computing the Z-score distributions. I match the quarterly accounting dataset two quarters ahead because the merger date in Chicago Fed M&A dataset represents the completion date and is usually later than the last quarter when the non-survivor firm files quarterly report.

Table 1. DISTRESSED ACQUISITION LIKELIHOOD AND LOG Z-SCORE

	Pr(Completing an Acquisition of a Distressed Firm)				
	(1)	(2)	(3)	(4)	(5)
Log Z-score	0.153*	0.145*	0.142*	0.284**	0.317***
	[0.070]	[0.070]	[0.067]	[0.094]	[0.094]
Firm Controls		yes	yes	yes	yes
Year Fixed-Effects			yes		yes
2006-2013				yes	yes
Observations	57,035	57,035	57,035	14,490	14,490
Firm Fixed-Effects	yes	yes	yes	yes	yes

Notes: This table reports the results from a fixed-effects logit regression. The sample includes commercial banks, savings institutions and bank holding companies. The dependent variable Pr(Completing an Acquisition of a Distressed Firm) takes the value of one if institution i completes an acquisition of a distressed firm at time $t + 4$, and zero otherwise. Firm controls include quarterly CAR, ROA, and asset size. Regression coefficients are reported with standard errors in the square bracket. *, **, *** denote statistical significance at the 5%, 1%, and 0.1% level.

financial institutions as well as the distressed acquisition rate weighted by the asset size of the targets. From the plots, the distressed acquisition rates are countercyclical. Two periods with clustered acquisitions are the Savings and Loan crisis and the 2007-2009 financial crisis. The asset-weighted acquisition rate displays significant spikes (some spikes reach as high as 3%, while the plots are trimmed at 2.5%).⁴⁶ Panel 11(b) compares the distressed acquisition rate to the total acquisition rate. The insignificant comovement between the two curves shows that variations in distressed acquisitions are unlikely driven by merger waves.

6.1.3 Model Assumptions on Distressed Acquisitions

To confirm the assumption made in the model that more liquid firms acquire the distressed firms, I match the quarterly firm-level data with the acquisition dataset using the acquirer entities and acquisition completion dates, and perform fixed-effects logit regressions. The dependent variable is a dummy indicating whether a firm conducts a distressed acquisition at a certain quarter. I assume that an acquisition takes on average four quarters to complete, so it starts four quarters prior to the merger completion date recorded in the Chicago Fed dataset. The independent variable of interest is the firm's estimated log Z-score. Results reported in Table 1 confirm that a firm with higher log Z-score has a higher likelihood of acquiring a distressed firm. For a one-

⁴⁶The spikes include one in the 2nd quarter of 1992 due to the acquisition of Security Pacific, one in 2007-2008 mostly due to the acquisitions of Lasalle bank (10/01/2007), Countrywide (01/11/2008), National City (10/24/2008), and Wachovia (12/31/2008).

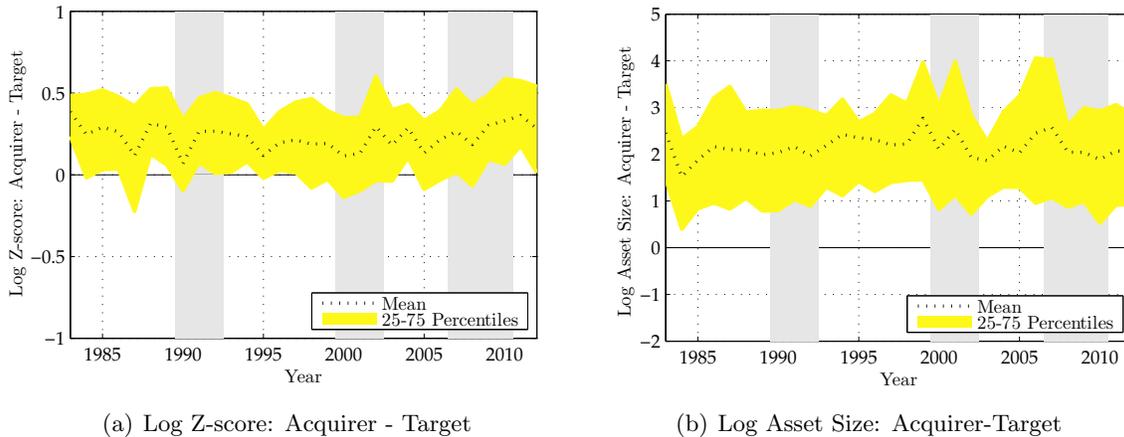


Figure 12. Log Z-score and Asset Size: Acquirer - Target. This figure plots the distribution of log Z-score and log asset size of the acquirer-target wedge for the identified 3,153 distressed acquisitions in 1983-2013. Shaded bars indicate NBER recessions.

standard-deviation increase in log Z-score (.58), the log odds ratio of a distressed acquisition increases by 0.09 ($=0.153 \times 0.58$). The economic and statistical significance of the coefficient is robust to including firm-level controls, year fixed effects, and only considering the post-2006 period.

Among the identified 3,153 distressed acquisitions, a clear pattern emerges among the acquirer-target pairs: the acquirer has higher Z-score and bigger asset size relative to the target. The results are depicted in Figure 12. The plots show the distributions of the acquirer-minus-target log Z-score (Panel 12(a)) and log asset size (Panel 12(b)). Both distributions are significantly above zero, implying that more stable firms acquire smaller and distressed targets.

In the theoretical analysis, a link with the distressed firm is modeled as a bilateral forward swap contract, which increases the financial distress of the acquirer and thus negatively affects its Z-score. To confirm this assumption, I perform fixed-effects regressions of growth rate in log Z-score on target log Z-score, and the dummy variables representing acquisition and distressed acquisition, controlling for firm-level characteristics. The regression results summarized in Table 2 show strong support for the model assumption. The estimates suggest that the effect of the log Z-score of the targets on the growth rate of Z-score of the acquirers is positive and significant. The economic magnitude of the effect is sizable: a one-standard-deviation decrease in target log Z-score decreases future log Z-score of the acquirer by 0.16, more than four times the magnitude

Table 2. EFFECT OF TARGET LOG Z-SCORE ON ACQUIRERS' FUTURE Z-SCORE

	$\log z_{i,t+1} - \log z_{i,t}$						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Target Log Z-score	0.248*** [0.060]	0.310*** [0.064]			0.326* [0.130]	0.291** [0.095]	0.250*** [0.060]
Acquisition Dummy			0.624*** [0.186]	0.884*** [0.206]			
Distressed Acquisition Dummy		-1.268** [0.447]		-1.373** [0.464]			
Observations	1,326,071	1,326,071	1,326,071	1,326,071	435,635	98,737	1,326,071
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Fixed-Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NBER Recessions					Yes		
Top Firms (A>\$1B)						Yes	
Year-quarter Dummy							Yes

Notes: This table reports the coefficients from a fixed-effects regression. The sample includes commercial banks, savings institutions and bank holding companies. The dependent variable $\log z_{i,t+1} - \log z_{i,t}$ is the growth rate of log Z-score for firm i at quarter t . The target log Z-score is the level of log Z-score of the target firm at the acquisition completion date if firm i has an acquisition at quarter t . The dummy variables take 1 (and 0 otherwise) if firm i has an acquisition or a distressed acquisition at quarter t . Firm controls include total assets, total equity, net income, and current level log Z-score. Regression coefficients are reported with standard errors in the square bracket. *, **, *** denote statistical significance at the 5%, 1%, and 0.1% level.

of its average level. Results in columns (3) - (4) show that, while in general completing an acquisition has a positive impact on the future Z-score of the acquirer, completing an acquisition of a distressed target has a significantly negative impact on the future Z-score of the acquirer. These findings are robust to controlling for recession periods, restricting to only top firms with asset size larger than \$1 billion, and including year-quarterly dummy.

6.2 Model Predictions

As shown in the comparative statics in Section 4.2, an increase in dispersion (together with a decrease in average Z-score) is associated with *higher systemic risk, more liquidations, more (excess) distress links through acquisitions, and fewer risk-sharing links*. Next, I illustrate that patterns in the data provide suggestive evidence for these model-predicted relations.

6.2.1 Aggregate Indicators

The goal is to provide aggregate level evidence that distress dispersion is indicative of economic activity and financial stability. To measure macroeconomic activity, I use the *Chicago Fed*

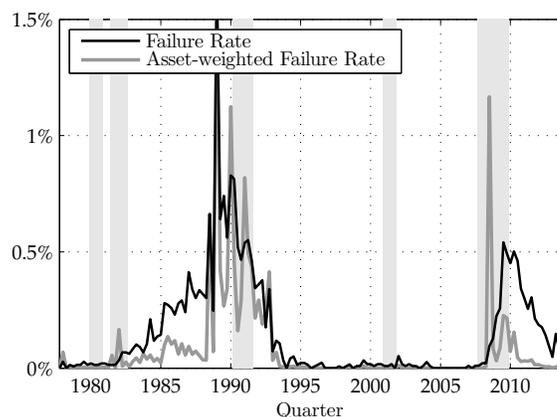


Figure 13. Bank Failure Rates. This figure plots the quarterly failure rate and asset-weighted failure rate of commercial banks and savings institutions for 1978-2013. Shaded bars indicate NBER recession dates.

National Activity Index (CFNAI),⁴⁷ which is adopted in [Giglio, Kelly, and Pruitt \(2015\)](#) to evaluate the predictive power of various systemic risk measures. As an indicator for systemic risk, I take the Chicago Fed’s *National Financial Conditions Index (NFCI)*.

Failures are aggregated from the FDIC Failure and Assistance Transaction Reports of all commercial banks and savings institutions in 1976-2013. I append this sample using the failures of bank holding companies, i.e. those in the Chicago Fed Mergers and Acquisitions dataset with Termination Code = 5 (failure). In total, I obtain 3,473 failures with an asset value of 1.84 trillion in 2010 dollars. I construct the quarterly failure rates (numbers of failures over the numbers of total financial institutions) as well as the failure rates weighted by the failing institution’s asset size. As depicted in [Figure 13](#), failure rates are strongly countercyclical: the majority of bank failures took place during the Savings and Loan crisis and the 2007-2009 crisis.

Regarding the linkage composition, the model predicts that non-distressed firms that do not engage in distressed acquisitions withdraw from risk-sharing contracts as a consequence of network externalities. Direct evidence on this prediction would be obtained if full information on individual level linkage is available. Instead, I consider the lending and interbank lending behavior of small to medium-sized commercial banks as proxies for risk-sharing contracts since

⁴⁷The CFNAI is designed to gauge overall economic activity and related inflationary pressure. It includes the following subcomponents: production and income (P&I), sales, orders, and inventories (SO&I), employment, unemployment, and hours (EU&H), and personal consumption and housing (C&H).

these institutions are more likely to be the non-distressed and non-acquirer firms in the model. In particular, using data from the Fed’s H.8 release, I construct the fractions of bank credit and Fed funds and reverse Repos with banks over total assets for small to medium-sized (beyond top 25) commercial banks.

6.2.2 Univariate Correlations

Table 3 provides the summary statistics of the above series as well as their univariate correlation coefficients with the mean and dispersion of financials’ log Z-scores. Both the mean and dispersion series are rescaled such that the two series are centered around one. The distress dispersion displays higher variation over time and does not significantly correlate with the mean of distress, thereby confirming that dispersion provides new information not captured by the mean.

Well aligned with the theoretical findings, dispersion series correlate negatively with the economic activity index CFNAI and positively with the systemic risk index NFCI. In other words, high dispersions relate to bad economic times and low financial stability. As the model predicts, the failure rates and distressed acquisition rates are significantly higher when the dispersion is higher or when the average Z-score is lower. Additionally, the distressed acquisitions as a fraction of total acquisitions correlate even more significantly with the log Z-score moments, ruling out the possibility that the variations in distressed acquisitions are due to changes in total acquisition rates. These patterns all corroborate that high dispersion is associated with more distressed acquisitions and consequently, more failures. Last but not least, indicators for lending and interbank lending have negatively significant correlation with dispersion. Small and medium-sized commercial banks reduce interbank lending and exposures with other banks in the Fed Funds and Reverse Repos market, with significance at the 0.001 level. This finding supports that certain risk-sharing contracts terminate as dispersion increases.

6.2.3 Predictive Regressions

Evidence from the univariate correlations provides a strong indication that the distress dispersion comoves with aggregate indicators. However, contemporaneous correlations do not necessarily imply that the distress dispersion is able to forecast systemic risk. Hence, the next goal is to

Table 3. SUMMARY STATISTICS AND UNIVARIATE CORRELATIONS

	Mean	StDev	Sacf	Correlations w/ log Z-score	
				Mean	Dispersion
Mean of Log Z-score	1.00	0.03	0.90		
Dispersion of Log Z-score	1.00	0.22	0.97	-0.13	
A. Economic activity and systemic risk					
Chicago Fed National Activity Index (CFNAI)	-0.11	0.72	0.80	-0.03	-0.30**
National Financial Conditions Index (NFCI)	-0.34	0.54	0.84	-0.25**	0.37***
B. Bank failures					
Failure Rate (%)	0.18	0.25	0.72	-0.60***	0.45***
Asset-weighted Failure Rate (%)	0.11	0.25	0.34	-0.38***	0.17*
C. Distressed acquisitions					
Distressed Acquisition Rate (%)	0.21	0.09	0.64	-0.41***	0.60***
Distressed over Total Acquisition Rate	0.19	0.13	0.71	-0.44***	0.68***
D. Lending and interbank lending					
Small Comm. Bk Credit over Assets	0.88	0.02	0.94	-0.26**	-0.73***
Small Comm. Bk Fed Funds Loan over Assets	0.02	0.01	0.85	-0.09	-0.53***

Notes: This table reports summary statistics for the quarterly cross-sectional mean and dispersion of log Z-score, indicators for economic activity and systemic risk (A), bank failures (B), distressed acquisitions (C), and lending and interbank lending (D). Group A series are from FRED. Series in groups B and C are aggregated based on data from the FDIC and the Chicago Fed. Group D series are constructed from the Fed's Z.1 and H.8 release. Data availability on bank holding companies restricts the analysis to 1986-2013. Sacf is the first-order sample autocorrelation coefficient. The last two columns report the correlation coefficients between cross-sectional mean and dispersion of log Z-score and each series in groups A-D. *, **, *** denote statistical significance at the 5%, 1%, and 0.1% level.

evaluate whether the distress dispersion has predictive power of aggregate indicators by providing additional information beyond what is contained in the average distress and existing systemic risk measures.

To this end, I run forecasting regressions of the above introduced aggregate indicators on the dispersion and mean of log Z-score controlling for moments including the term spread used in Giglio, Kelly, and Pruitt (2015), the leverage of both financial business and the security broker-dealers as in Adrian, Etula, and Muir (2014), and the growth rate of non-financial corporate liability as a measure of aggregate credit creation. The forecasting horizons range from one to four quarters and the data cover the years 1986-2013. To overcome correlation and autocorrelations in the time series, I calculate Newey-West standard errors.

Table 4 reports the coefficient estimates on the dispersion and mean of log Z-score, the values of R^2 when I run the regressions with and without the dispersion series. The regression results

Table 4. PREDICTIVE REGRESSIONS USING DISTRESS DISPERSION

Quarters	1	2	3	4	1	2	3	4
Forecasting	A. CFNAI				NFCI			
Dispersion	-2.09***	-4.04***	-5.85***	-7.50***	1.52**	2.77**	3.83**	4.72**
Mean	2.75	6.74	8.66	7.92	-8.95***	-17.80***	-25.73***	-32.32***
R^2	44.85	52.03	54.05	52.48	53.22	53.40	52.24	50.56
R^2 w/o disp	28.15	34.78	36.47	34.74	37.54	39.28	39.42	38.86
Forecasting	B. Failure Rate(%)				Asset-weighted Failure Rate(%)			
Dispersion	0.53***	1.03***	1.56***	2.07***	0.24*	0.48*	0.77*	1.04*
Mean	-3.81***	-7.91***	-12.21***	-17.12***	-2.68**	-5.41**	-7.92**	-11.29**
R^2	58.98	68.10	70.03	71.31	16.97	26.79	32.53	37.64
R^2 w/o disp	50.16	58.46	59.91	60.99	11.07	18.68	22.29	26.14
Forecasting	C. Acquisition Rate(%)				Distressed over Total Acquisition Rate			
Dispersion	0.16*	0.33*	0.50*	0.68*	0.29***	0.63***	1.00***	1.34***
Mean	-1.45**	-2.66**	-3.81**	-4.43**	-1.19*	-2.16*	-3.24**	-3.90*
R^2	47.31	57.25	64.90	67.04	53.90	63.06	72.20	75.26
R^2 w/o disp	41.24	49.52	56.12	57.55	43.64	48.92	54.41	56.11
Forecasting	D. Sml Bk Credit over Assets				Sml Bk Fed Funds over Assets			
Dispersion	-0.04**	-0.08**	-0.12**	-0.16**	-0.01*	-0.02*	-0.03**	-0.04***
Mean	-0.02	-0.01	-0.01	-0.04	0.05	0.08	0.09	0.07
R^2	69.85	70.68	71.18	71.44	57.07	63.49	64.71	63.93
R^2 w/o disp	62.69	63.39	63.83	63.76	54.04	59.60	59.48	56.94

Notes: This table summarizes the ability of distress dispersion to forecast future economic activity, systemic risk, failure rates, distressed acquisition rates, and bank lending behavior. Aggregate indicators in groups A-D are regressed respectively on the cross-sectional dispersion and mean of log Z-score controlling for the term spread, the leverage of financial business and security broker-dealers, and the growth rate of real non-financial corporate liability. Forecasting horizons range from one to four quarters and the data cover the years of 1986-2013. The table reports the regression coefficients of the dispersion and mean of log Z-score, the R^2 , as well as the R^2 when the regressions are run without the dispersion series. *, **, *** denote statistical significance (based on Newey-West standard errors) at the 5%, 1%, and 0.1% level.

echo those from the correlations and indicate striking predictive power of the dispersion series to forecast economic activity and systemic risk, failures, distressed acquisitions, and interbank lending. The predictive power is evidenced by both the economic significance of the regression coefficients and the differences in the R^2 s with and without dispersion in the regressors. For example, the estimates in the forecasting regression of CFNAI imply that (holding the *mean* fixed) a one-standard-deviation increase in *Dispersion* (=0.22) relates to a 0.46 ($= 0.22 \times 2.09$) decrease in CFNAI. Notably, the national activity index CFNAI, the credit and loans and the

interbank lending of small and medium-sized commercial banks all respond negatively to an increase in distress dispersion, but not to changes in the mean of distress. Overall, these results paint a clear picture: the second moment of the cross-sectional distress distribution conveys new information about future activities in the financial sector in terms of systemic risk, failures, acquisitions, as well as interbank lending behavior.

7 Conclusion

Given the importance of financial interconnectedness, policies on financial stability and distress resolution should not analyze institutions in isolation. This paper has developed a network formation model to highlight a novel channel of systemic risk due to externalities via financial links.

Adding to the recent literature on financial network formation, this paper embeds firm heterogeneity in financial distress and examines how the linkage formation affects efficiency and systemic risk. I have shown that, when firms display high distress dispersion, the equilibrium network features too many links with the distressed firms and too few risk-sharing links among liquid firms. The reason is that the relatively more liquid firms have incentives to connect with distressed firms for profit while shifting risks away to their direct and indirect counterparties via the links. Particularly, these liquid firms fail to internalize the negative externalities when prices in the bilateral contracts cannot be contingent on the overall network structure. The inefficient link with the distressed firm not only generates risks of contagion but also crowd out valuable risk-sharing links, thereby increasing systemic risk. Notably, this inefficiency is shown to be more severe when institutions are more dispersed in financial distress.

While detailed data on the precise linkages among financial institutions are yet to be collected,⁴⁸ this paper draws a relation between the degree of network inefficiency and the cross-sectional distribution of fundamentals, thus contributing to the measurement and forecast of systemic risk. The test can be extended along the lines of [Giglio, Kelly, and Pruitt \(2015\)](#) by comparing the distress dispersion to existing systemic risk measures such as CoVaR ([Brunnermeier and Adrian \(2011\)](#)) and Marginal and Systemic Expected Shortfall ([Acharya, Pedersen,](#)

⁴⁸For current challenges in measuring linkages and systemic risk, see for example [Bisias, Flood, Lo, and Valavanis \(2012\)](#), [Hansen \(2013\)](#), and [Yellen \(2013\)](#).

Philippon, and Richardson (2010)). Additionally, my model predicts that links between firms with different distress levels respond differently to an aggregate dispersion increase. With possibly better data access in the future, more work is needed to test these qualitative predictions.

My model provides new insights on policies for financial stability. The links with distressed firms in the model can be interpreted as acquisitions of such firms. In this context, my results call for regulations to eliminate the network inefficiencies associated with acquisitions of distressed firms. The task of the regulators is to oversee the acquisitions of distressed firms, especially those by highly interconnected acquirers when the distress dispersion is high across institutions. Rather than relying on acquisitions as the preferred private sector solution, regulators should instead adopt resolution methods such as purchase and assumption (P&A) for these distressed targets in case of failure.

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8 Appendix: Proofs and Additional Lemmas

Proof of Lemma 1

Before showing the properties of the asset composition matrix $\lim_{K \rightarrow \infty} L^K$, we first analyze features of the matrix L .

Claim 1 *The linkage matrix L has all real eigenvalues: the largest is 1 and all others lie within the unit circle.*

Proof L is symmetric so all its eigenvalues are real. L is doubly stochastic, so $L \times \mathbb{1}_{N \times 1} = \mathbb{1}_{N \times 1}$ and thus $\lambda = 1$ is its eigenvalue with eigenvector $\mathbb{1}_{N \times 1}$. Suppose for contradiction that there exists an eigenvalue $\lambda > 1$. Then there exists a non-zero vector x such that $Lx = \lambda x > x$. Given the rows of L are non-negative and sum to 1, each element of vector Lx is a convex combination of the components of x . This implies that $\max[Lx] \leq \max[x]$, which contradicts with $\max[\lambda x] > \max[x]$. Hence all eigenvalues cannot exceed 1 in absolute value.

Lastly, we show that $\lambda = -1$ is not an eigenvalue of L . It is equivalent to show that the matrix $L + I$ is non-singular. All the off-diagonal elements of $L + I$ are within 0 and 1, and all the diagonal elements are within 1 and 2. The largest element for any column or row is on the diagonal, so there are no columns or rows that are zero or linearly dependent. Therefore $\det(L + I) > 0$, and $\lambda = -1$ cannot be an eigenvalue. This concludes the proof of Claim 1.

Next we apply Claim 1 to show the limiting properties of $L^\infty = \lim_{K \rightarrow \infty} L^K$. Given L is a doubly stochastic matrix, $L \times \mathbb{1}_{N \times 1} = \mathbb{1}_{N \times 1}$, $L^\top \times \mathbb{1}_{N \times 1} = \mathbb{1}_{N \times 1}$. Then $L^K \times \mathbb{1}_{N \times 1} = L^{K-1} \times L \times \mathbb{1}_{N \times 1} = L^{K-1} \times \mathbb{1}_{N \times 1} = \mathbb{1}_{N \times 1}$. Similarly $L^{\top K} \times \mathbb{1}_{N \times 1} = \mathbb{1}_{N \times 1}$, so L^∞ is also a doubly stochastic matrix.

Since the eigenvalues of L , denoted by $\{\lambda_1, \lambda_2, \dots, \lambda_M\}$, are real, there exists an orthogonal matrix Q with $Q' = Q^{-1}$ such that $L^\infty = Q\Lambda Q^{-1}$, $\Lambda = \text{diag}(\lambda_1, \lambda_2, \dots, \lambda_M)$ and the columns of Q are eigenvectors of unit length corresponding to $\lambda_1, \lambda_2, \dots, \lambda_M$. Without loss of generality, we rank the eigenvalues $\lambda_i \geq \lambda_{i+1}$, then

$$L^\infty = Q\Lambda Q^{-1} \dots Q\Lambda Q^{-1} = Q\Lambda^\infty Q^{-1} = Q \begin{bmatrix} \lambda_1^\infty & 0 & \dots & 0 \\ 0 & \lambda_2^\infty & \dots & \dots \\ \dots & \dots & \dots & \dots \\ 0 & \dots & \dots & \lambda_M^\infty \end{bmatrix} Q^{-1} = Q \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 0 & \dots & \dots \\ \dots & \dots & \dots & \dots \\ 0 & \dots & \dots & 0 \end{bmatrix} Q^{-1},$$

where the last step follows from $\lambda_1 = 1$ and $\lambda_i < 1, \forall i \neq 1$. Let the first column of Q , which is the unit length eigenvector corresponding to $\lambda_1 = 1$ be x_1 , then

$$L^\infty x_1 = x_1, \quad x_1^\top x_1 = 1.$$

Since each entry of L^∞ is positive, the above relations imply that the unit length eigenvectors satisfy $x_{11} = x_{12} = \dots = x_{1M} = \frac{1}{\sqrt{M}}$. We have

$$L^\infty = Q \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 0 & \dots & \dots \\ \dots & \dots & \dots & \dots \\ 0 & \dots & \dots & 0 \end{bmatrix} Q^{-1} = \begin{bmatrix} x_{11}^2 & x_{11}x_{12} & \dots & x_{11}x_{1M} \\ x_{12}x_{11} & x_{12}^2 & \dots & \dots \\ \dots & \dots & \dots & \dots \\ x_{1M}x_{11} & \dots & \dots & x_{1M}^2 \end{bmatrix} = \begin{bmatrix} \frac{1}{M} & \frac{1}{M} & \dots & \frac{1}{M} \\ \frac{1}{M} & \frac{1}{M} & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \frac{1}{M} & \dots & \dots & \frac{1}{M} \end{bmatrix}.$$

Hence L^∞ coincides with complete risk-sharing regardless of the initial entries of L_{ij} in L . **Q.E.D.**

Proof of Proposition 1

We start by analyzing the risk-sharing decision of $N = 2$.

Lemma 2 *The risk-sharing surplus for $N = 2$ is positive if and only if $\bar{z} > 0$; when $\bar{z} > 0$, the risk-sharing surplus increases monotonically with δ .*

Proof The total liquidation costs for two separate firms $\{z_1, z_2\} = \{\bar{z} + \frac{1}{2}\delta, \bar{z} - \frac{1}{2}\delta\}$ is $\Pr(a_1 < 1) c + \Pr(a_2 < 1) c = \Phi[-\bar{z} - \frac{1}{2}\delta] c + \Phi[-\bar{z} + \frac{1}{2}\delta] c$. The total liquidation costs when the two firms fully share risk is $2\Phi[-\sqrt{2}\bar{z}] c$. The bilateral risk-sharing surplus is the difference between the above two, $\Phi(-\bar{z} - \frac{1}{2}\delta)c + \Phi(-\bar{z} + \frac{1}{2}\delta)c - 2\Phi(-\sqrt{2}\bar{z})c$. Function $\Phi(x)$ monotonically increases with respect to x and is convex $\forall x < 0$. Hence, $\bar{z} > 0, \delta > 0 \iff \Phi[-\bar{z} - \frac{1}{2}\delta] c + \Phi[-\bar{z} + \frac{1}{2}\delta] c > 2\Phi[-\bar{z}] c > 2\Phi[-\sqrt{2}\bar{z}] c$. When $\bar{z} > 0, \delta > 0$, the first derivative with respect to δ is $-\frac{1}{2}\Phi'[-\bar{z} - \frac{1}{2}\delta] c + \frac{1}{2}\Phi'[-\bar{z} + \frac{1}{2}\delta] c = \frac{c}{2} (\Phi'[-\bar{z} + \frac{1}{2}\delta] - \Phi'[-\bar{z} - \frac{1}{2}\delta]) > 0$. This concludes the proof of Lemma 2.

Next we analyze the optimal risk-sharing policy for $N \geq 3$. Total default probability in a full risk-sharing network with all N firms is

$$\sum_{i=1}^N \Pr(h_i < 1) = N\Phi[\sqrt{N}(-\bar{z})]. \quad (21)$$

Total default probability when the first $N - k$ firms fully share risk and firms $N - k + 1$ to N each stays separate is

$$\sum_1^{N-k} \Pr(h_i < 1) + \sum_{N-k+1}^N \Pr(a_i < 1) = (N-k)\Phi\left[\sqrt{N-k}(-\bar{z} - \frac{N-k}{2}\delta)\right] + \sum_{N-k+1}^N \Phi\left[-\bar{z} - \frac{N+1-2i}{2}\delta\right]. \quad (22)$$

Take the limit when $\delta \rightarrow \infty$, equations (21) and (22) become respectively $N\Phi[-\sqrt{N}\bar{z}]$ and k . This shows that when δ is very large, full risk-sharing is optimal with high values of \bar{z} , and isolating firm N is optimal with low values of \bar{z} .

Next we focus on the regions when the tradeoff is between full risk-sharing and isolating firm N . Equating (21) and (22) for $k = 1$ defines a cutoff function $\delta_1(\bar{z})$. Applying the implicit function theorem, the curve is well-defined for $\bar{z} < \bar{z}_1$ and $\frac{\partial \delta_1(\bar{z})}{\partial \bar{z}} \geq 0$. $\forall \bar{z} \geq \bar{z}_1$ and $\forall \delta > 0$, $\sum_{i=1}^N \Pr(h_i < 1) < \sum_{i=1}^{N-1} \Pr(h_i < 1) + \Pr(a_N < 1)$, so full risk-sharing is optimal.

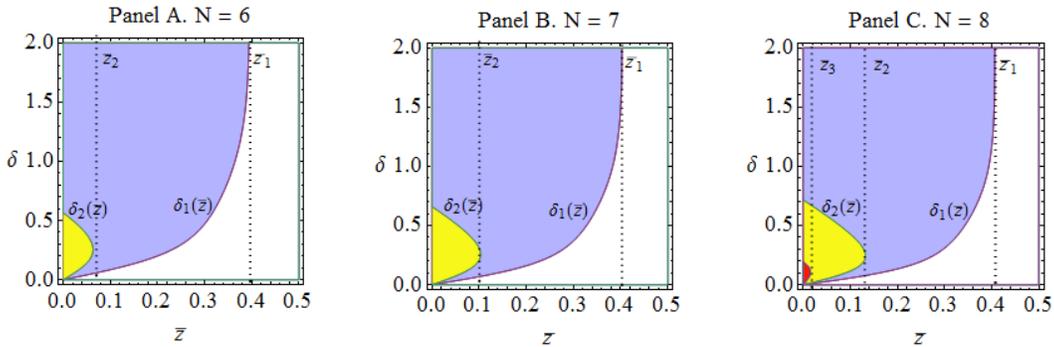


Figure 14. Optimal Network for $N = 6, 7, 8$. This figure shows the optimal risk-sharing network for $N = 6, 7, 8$. The white, blue, yellow and red regions indicate respectively isolating 0,1,2,3 firms.

Equating (22) for $k = 1$ and $k = 2$ gives the curve $\delta_2(\bar{z})$ which divides the regions between optimally isolating firm N only and isolating both firms $N - 1$ and N . We can show that $\exists \bar{z}_2$ so that $\bar{z}(\delta_2) < \bar{z}_2$. This implies that for $\bar{z} > \bar{z}_2$, isolating firm N is always preferred to isolating two firms. **Q.E.D.**

Proof of Proposition 2

It is equivalent to show that (1) in region $(\bar{z} > \bar{z}_1, \delta < \delta_1(\bar{z}))$, there exist bilateral prices that decentralize $L^* = [4 - 1 - 2 - 3]$; (2) in region $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z}))$, the stable network is $L^e = [4 - 1 - 2 - 3]$ and there do not exist bilateral prices that decentralize $L^* = [1 - 2 - 3, 4]$.

In what follows, denote \bar{V}_i^L the value of firm i in network L before paying prices to counterparties, V_i^L the value of firm i in network L under contingent bilateral prices, and V_i^a the autarky value of firm i without any linkages. The bilateral contingent prices with local contingency are denoted as follows, $(p_{41} - p_{14})|_{L_{12}=0}$, $(p_{41} - p_{14})|_{L_{12}=\bar{l}}$, $(p_{21} - p_{12})|_{L_{14}=L_{23}=0}$, $(p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}}$, $(p_{21} - p_{12})|_{L_{14}=\bar{l}, L_{23}=0}$, $(p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}}$, $(p_{32} - p_{23})|_{L_{12}=0}$, $(p_{32} - p_{23})|_{L_{12}=\bar{l}}$.

Within each pair reservation prices are paid so $(p_{41} - p_{14})|_{L_{12}=0} = V_1^a - V_4^a$, $(p_{32} - p_{23})|_{L_{12}=0} = V_2^a - V_3^a$, $(p_{21} - p_{12})|_{L_{14}=L_{23}=0} = V_1^a - V_2^a$.

(1) In region $(\bar{z} > \bar{z}_1, \delta < \delta_1(\bar{z}))$, $L^* = [4 - 1 - 2 - 3]$ and $\sum_1^4 \bar{V}_i^{4-1-2-3} \geq \sum_1^3 \bar{V}_i^{1-2-3} + V_4^a$. In order to decentralize the full risk sharing network, prices satisfy

$$V_1^{4123} = \bar{V}_1^{4123} + \bar{l}(p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}} + \bar{l}(p_{41} - p_{14})|_{L_{12}=\bar{l}} \geq \max[V_1^a, V_1^{14}, V_1^{123}, V_1^{412}] \quad (23)$$

$$V_2^{4123} = \bar{V}_2^{4123} - \bar{l}(p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}} + \bar{l}(p_{32} - p_{23})|_{L_{12}=\bar{l}} \geq \max[V_2^{23}, V_2^a, V_2^{234}] \quad (24)$$

$$V_3^{4123} = \bar{V}_3^{4123} - \bar{l}(p_{32} - p_{23})|_{L_{12}=\bar{l}} \geq \max[V_3^a, V_3^{34}] \quad (25)$$

$$V_4^{4123} = \bar{V}_4^{4123} - \bar{l}(p_{41} - p_{14})|_{L_{12}=\bar{l}} \geq \max[V_4^a, V_4^{34}] \quad (26)$$

(25) and (26) binding give $(p_{32} - p_{23})|_{L_{12}=\bar{l}}$ and $(p_{41} - p_{14})|_{L_{12}=\bar{l}}$. Plugging these prices into the binding equation in (24) (and combining with $V_2^{23} = \max[V_2^{23}, V_2^a, V_2^{234}]$) gives $(p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}}$, the required premium price for firm 1 to pay firm 2 in order to prevent 2 from deviating. As a result, $V_1^{4123} = \sum_1^4 \bar{V}_i^{4123} - V_3^a - \bar{V}_2^{23} - \bar{l}(V_2^a - V_3^a) - V_4^a$, where $\bar{V}_2^{23} + \bar{l}(V_2^a - V_3^a)$ is precisely the outside option of firm 2. Simple algebra gives $V_1^{4123} > \max[V_1^a, V_1^{14}, V_1^{123}, V_1^{412}]$. This shows that paying the premium $(p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}}$ to prevent 2 from withdrawing is always a dominating strategy for firm 1 in this region. Therefore, the equilibrium replicates the optimal connection $L^e = L^* = [4 - 1 - 2 - 3]$.

(2) In region $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z}))$, $L^* = [1 - 2 - 3, 4]$ and $\sum_1^4 \bar{V}_i^{4-1-2-3} < \sum_1^3 \bar{V}_i^{1-2-3} + V_4^a$. To decentralize $L^* = [1 - 2 - 3, 4]$, we require that firm 2 transfer premium $\bar{l}(p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}}$ to prevent 1 from linking with 4. Suppose such prices exist, we have

$$V_1^{123} = \bar{V}_1^{123} + \bar{l}(p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}} \geq V_1^{4123}, \quad (27)$$

$$V_2^{123} = \bar{V}_2^{123} - \bar{l}(p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}} + \bar{l}(p_{32} - p_{23})|_{L_{12}=\bar{l}} \geq V_2^{4123}, \quad (28)$$

Given (27) and (28), $V_1^{123} + V_2^{123} = \bar{V}_1^{123} + \bar{V}_2^{123} + \bar{l}(p_{32} - p_{23})|_{L_{12}=\bar{l}} = \bar{V}_1^{123} + \bar{V}_2^{123} + \bar{V}_3^{4123} - V_3^a$. From analysis in (1), $V_1^{4123} + V_2^{4123} = \sum_1^4 \bar{V}_i^{4123} - V_3^a - V_4^a$.

Next we show that $V_1^{123} + V_2^{123} < V_1^{4123} + V_2^{4123}$ hence there do not exist bilateral prices that satisfy the inequalities in (27) and (28). $V_1^{123} + V_2^{123} - (V_1^{4123} + V_2^{4123}) = \sum_1^3 \bar{V}_i^{123} + V_4^a - (\bar{V}_3^{123} - \bar{V}_3^{4123}) - \sum_1^4 \bar{V}_i^{4123} = -\frac{1}{2}\delta - \Phi[-\bar{z} + \frac{3}{2}\delta] - 2\Phi[-\sqrt{3}\bar{z} - \frac{\sqrt{3}}{2}\delta] + 3\Phi[-2\bar{z}]$. When evaluated at $\delta = 0$, the function is negative and has negative derivatives $\forall \delta > 0, \bar{z} > 0$. Therefore firm 2 is worse off providing premium price. Furthermore, we confirm that $L^e = [4 - 1 - 2 - 3]$ is stable following the analysis above. Therefore, the equilibrium network fails to replicate the optimal connection $L^* = [4, 1 - 2 - 3]$. **Q.E.D.**

Proof of Proposition 3

It is equivalent to show that (1) in region $(\bar{z} > \bar{z}_1, \delta \geq 0 \cup \bar{z} \in [\bar{z}_2, \bar{z}_1], \delta < \delta_1(\bar{z}))$, there exist bilateral prices that decentralize $L^* = [5 - 1 - 2 - 3 - 4]$; (2) in region $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z}))$, the optimal network $L^* = [1 - 2 - 3 - 4, 5]$ cannot be decentralized. Instead, the stable network is $L^e = [5 - 1 - 2 - 3 - 4]$ when $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta \in [\delta_1(\bar{z}), \eta(\bar{z})])$, and $L^e = [5 - 1, 2 - 3, 4]$ when $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \eta(\bar{z}))$.

We follow the same notation as in the proof of proposition 2. The bilateral contingent prices with local contingency are denoted as follows, $(p_{51} - p_{15})|_{L_{12}=0}, (p_{51} - p_{15})|_{L_{12}=\bar{l}}, (p_{21} - p_{12})|_{L_{15}=L_{23}=0}, (p_{21} - p_{12})|_{L_{15}=0, L_{23}=\bar{l}}, (p_{21} - p_{12})|_{L_{15}=\bar{l}, L_{23}=0}, (p_{21} - p_{12})|_{L_{15}=L_{23}=\bar{l}}, (p_{32} - p_{23})|_{L_{12}=L_{43}=0}, (p_{32} - p_{23})|_{L_{12}=0, L_{34}=\bar{l}}, (p_{32} - p_{23})|_{L_{12}=\bar{l}, L_{34}=0}, (p_{32} - p_{23})|_{L_{12}=L_{34}=\bar{l}}, (p_{43} - p_{34})|_{L_{23}=0}, (p_{43} - p_{34})|_{L_{23}=\bar{l}}$.

(1) In region $(\bar{z} > \bar{z}_1, \delta \geq 0 \cup \bar{z} \in [\bar{z}_2, \bar{z}_1], \delta < \delta_1(\bar{z}))$, $L^* = [5 - 1 - 2 - 3 - 4]$ and $\sum_1^5 \bar{V}_i^{5-1-2-3-4} \geq \sum_1^4 \bar{V}_i^{1-2-3-4} + V_5^a$. To decentralize the full risk sharing network, prices satisfy

$$V_1^{51234} = \bar{V}_1^{51234} + \bar{l}(p_{21} - p_{12})|_{L_{15}=L_{23}=\bar{l}} + \bar{l}(p_{51} - p_{15})|_{L_{12}=\bar{l}} \quad (29)$$

$$V_2^{51234} = \bar{V}_2^{51234} - \bar{l}(p_{21} - p_{12})|_{L_{15}=L_{23}=\bar{l}} + \bar{l}(p_{32} - p_{23})|_{L_{12}=L_{34}=\bar{l}} \geq \max \{V_2^{234}, V_2^{23}, V_a^2\} \quad (30)$$

$$V_3^{51234} = \bar{V}_3^{51234} - \bar{l}(p_{32} - p_{23})|_{L_{12}=L_{34}=\bar{l}} + \bar{l}(p_{43} - p_{34})|_{L_{23}=\bar{l}} \geq \max \{V_3^{34}, V_3^a\} \quad (31)$$

$$V_4^{51234} = \bar{V}_4^{51234} - \bar{l}(p_{43} - p_{34})|_{L_{23}=\bar{l}} \geq \max \{V_4^{34}, V_4^a\} \quad (32)$$

$$V_5^{51234} = \bar{V}_5^{51234} - \bar{l}(p_{51} - p_{15})|_{L_{12}=\bar{l}} \geq V_5^a \quad (33)$$

Within each pair, reservation prices are paid so $(p_{51} - p_{15})|_{L_{12}=0} = V_1^a - V_5^a$, $(p_{21} - p_{12})|_{L_{15}=L_{23}=0} = V_1^a - V_2^a$, $(p_{32} - p_{23})|_{L_{12}=L_{43}=0} = V_2^a - V_3^a$, $(p_{43} - p_{34})|_{L_{23}=0} = V_3^a - V_4^a$. (32) and (33) binding give $\bar{l}(p_{43} - p_{34})|_{L_{23}=\bar{l}}$ and $\bar{l}(p_{51} - p_{15})|_{L_{12}=\bar{l}}$. Plugging these prices into the binding equation in (31) gives $\bar{l}(p_{32} - p_{23})|_{L_{12}=L_{34}=\bar{l}}$.

Next we consider the outside option of firm 2, $\max \{V_2^{234}, V_2^{23}, V_a^2\}$. Plugging into (30) we have,

$$\bar{l}(p_{21} - p_{12})|_{L_{15}=L_{23}=\bar{l}} = \sum_2^4 \bar{V}_i^{51234} - \max \{V_4^{34}, V_4^a\} - \max \{V_3^a, V_3^{34}\} - \max \{V_2^{234}, V_2^{23}, V_a^2\}.$$

where $V_2^{234} = \bar{V}_2^{234} + \bar{l}(p_{32} - p_{23})|_{L_{12}=0, L_{34}=\bar{l}}$, and $(p_{32} - p_{23})|_{L_{12}=0, L_{34}=\bar{l}}$ satisfies $V_3^{234} = \bar{V}_3^{234} - \bar{l}(p_{32} - p_{23})|_{L_{12}=0, L_{34}=\bar{l}} + \bar{l}(p_{43} - p_{34})|_{L_{23}=\bar{l}} \geq \max \{V_3^{34}, V_3^a\}$. Thus $V_1^{51234} = \bar{V}_1^{51234} + \sum_2^4 \bar{V}_i^{51234} - V_4^a - \max \{V_3^a, V_3^{34}\} - \max \{V_2^{234}, V_2^{23}, V_a^2\} + \bar{V}_5^{51234} - V_5^a$. Simple algebra gives that $V_1^{51234} > V_1^{51}$ and $V_1^{51234} > V_1^{1234}$ in region (1). This shows that paying the premium $\bar{l}(p_{21} - p_{12})|_{L_{15}=L_{23}=\bar{l}}$ to prevent 2 from withdrawing is always a dominating strategy for firm 1 in region (1), thus the equilibrium replicates the optimal connection $L^e = L^* = [5 - 1 - 2 - 3 - 4]$.

(2) In region $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z}))$, $L^* = [1 - 2 - 3 - 4, 5]$ and $\sum_1^5 \bar{V}_i^{5-1-2-3-4} < \sum_1^4 \bar{V}_i^{1-2-3-4} + V_5^a$. To decentralize L^* , we require that firm 2 transfer premium $\bar{l}(p_{21} - p_{12})|_{L_{15}=0, L_{23}=\bar{l}}$ to prevent 1 from linking with 5. Suppose such prices exist, there must be

$$V_1^{1234} = \bar{V}_1^{1234} + \bar{l}(p_{21} - p_{12})|_{L_{15}=0, L_{23}=\bar{l}} \geq V_1^{51234}, \quad (34)$$

$$V_2^{1234} = \bar{V}_2^{1234} - \bar{l}(p_{21} - p_{12})|_{L_{15}=0, L_{23}=\bar{l}} + \bar{l}(p_{32} - p_{23})|_{L_{12}=L_{34}=\bar{l}} \geq V_2^{51234}, \quad (35)$$

However, simple algebra shows that $V_1^{1234} + V_2^{1234} < V_1^{51234} + V_2^{51234}, \forall \bar{z}, \forall \delta$. Hence there do not exist bilateral prices that satisfy (34) and (35), and thus the equilibrium fails to replicate the optimal connection $L^* = [5, 1 - 2 - 3 - 4]$. Next we analyze which if network $[5 - 1 - 2 - 3 - 4]$ is pairwise stable. Potential deviations are $[5, 1 - 2 - 3 - 4]$, $[5 - 1 - 2 - 3, 4]$, $[5 - 1 - 2, 3, 4]$, $[5 - 1, 2, 3, 4]$. (The rest deviations are easily eliminated.) In the entire region $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z}))$,

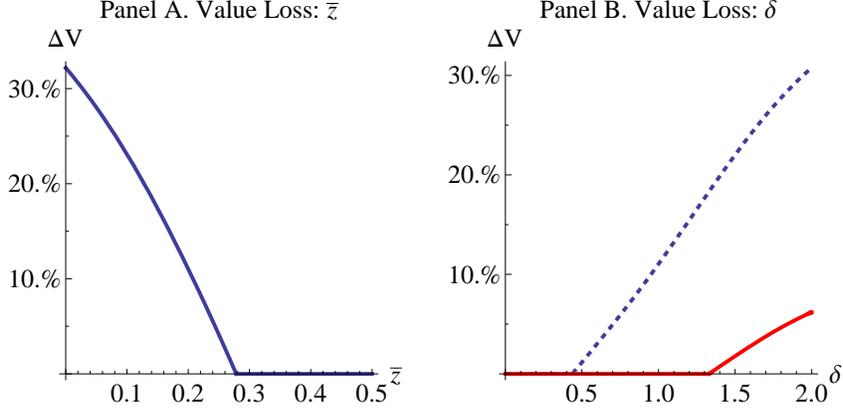


Figure 15. Percentage Value Loss. This figure plots the percentage value loss against \bar{z} and δ for the equilibrium four-firm chain network. The left panel plots V^{loss} against \bar{z} when $\delta = 1$. For $\delta > 0$, the value loss is positive until \bar{z} is large enough. The right panel plots V^{loss} as a function of δ for $\bar{z} = 0.2$ (dashed) and $\bar{z} = 0.3$ (solid). It shows that V^{loss} increases with δ and the slope is steeper when \bar{z} is smaller. The negative cross-derivative implies that the impact of heterogeneity in network inefficiency is more pronounced during episodes of banking distress.

we can easily eliminate $[5, 1-2-3-4]$, $[5-1-2-3, 4]$, $[5-1-2, 3, 4]$. However, this statement is not true for $[5-1, 2, 3, 4]$.

In region ($\bar{z} \in [\bar{z}_2, \bar{z}_1]$, $\delta \in [\delta_1(\bar{z}), \eta(\bar{z})]$), where the cutoff function $\delta = \eta(\bar{z})$ satisfies $V_1^{51234} = V_1^{51}$, we can show that $V_1^{51234} \geq V_1^{51}$, so equilibrium network is $L^e = [5-1-2-3-4]$.

In region ($\bar{z} \in [\bar{z}_2, \bar{z}_1]$, $\delta > \eta(\bar{z})$), we can show that $V_1^{51} \geq V_1^{51234}$, so equilibrium network is $L^e = [5-1, 2-3, 4]$. Similar logic applies to other cases when the starting chain is $[5-1-2-3-4]$, $[5-1-3-2-4]$, $\{5-1-4-3-2\}$, $[5-1-4-2-3]$. Detailed analysis on each of the cases is available upon request. **Q.E.D.**

Proof of Proposition 4

I prove this proposition in a four-firm network setting. The inefficiency occurs in the region ($\bar{z} \in [1, \bar{z}_1]$, $\delta > \delta_1(\bar{z})$), where $L^* = \{4, 1-2-3\}$ and $L^e = \{4-1-2-3\}$. The value loss equals the difference of the total firm values at L^* compared to L^e ,

$$V^{loss} = \sum_{i=1}^3 V_i^{1-2-3} + V_4^a - \sum_{i=1}^4 V_i^{4-1-2-3} = 4\Phi[2(-\bar{z})] - 3\Phi\left[\sqrt{3}\left(-\bar{z} - \frac{1}{2}\delta\right)\right] - \Phi\left[-\bar{z} + \frac{3}{2}\delta\right].$$

The value loss has the following properties. First, directly from proposition 2, $V^{loss} > 0$, $\forall \bar{z} \in [1, \bar{z}_1]$, $\delta > \delta_1(\bar{z})$. Second,

$$\frac{\partial V^{loss}}{\partial \delta} = \frac{3}{2} \frac{1}{\sqrt{2\pi}} \left(\sqrt{3} e^{-\frac{3}{2}\left(-\bar{z} - \frac{1}{2}\delta\right)^2} - e^{-\frac{1}{2}\left(-\bar{z} + \frac{3}{2}\delta\right)^2} \right) > 0, \quad \forall \bar{z} \in [0, \bar{z}_1], \delta > \delta_1(\bar{z}).$$

So V^{loss} increases with δ . Third, the value loss decreases with \bar{z} ,

$$\frac{\partial V^{loss}}{\partial \bar{z}} = -8\Phi'[2(-\bar{z})] + 3\sqrt{3}\Phi'\left[\sqrt{3}\left(-\bar{z} - \frac{1}{2}\delta\right)\right] + \Phi'\left[-\bar{z} + \frac{3}{2}\delta\right] < 0.$$

Finally, the cross-derivative of value loss with respect \bar{z} and δ is negative

$$\frac{\partial^2 V^{loss}}{\partial \delta \partial \bar{z}} = \frac{3}{2} \Phi''\left[-\bar{z} + \frac{3}{2}\delta\right] - \frac{9}{2} \Phi''\left[\sqrt{3}\left(-\bar{z} - \frac{1}{2}\delta\right)\right] < 0,$$

which means that the value loss increases faster with δ when \bar{z} is lower. **Q.E.D.**

Proof of Proposition 5

I show that the acquisition tax τ aligns the social incentive for acquisition with that of firm 1. τ equals precisely the negative externality imposed by the acquisition behavior of acquiring firm 1 to all the other non-distressed banks, $i = 2, \dots, N-1$. Under the required tax payment τ , the value of 1 upon acquisition is

$$V_1(\tau) = V_1^{12..N} - \tau = \sum_{i=1}^N V_i^{12..N} - \sum_{i=2}^{N-1} V_i^{12..N-1} - V_N^a.$$

Bank 1 chooses to acquire if and only if $V_1(\tau)$ is larger than the value of not acquiring, i.e.,

$$V_1(\tau) = \sum_{i=1}^N V_i^{12..N} - \sum_{i=2}^{N-1} V_i^{12..N-1} - V_N^a \geq V_1^{12..N-1}.$$

Recall from the social surplus function, linking N into the network is optimal if and only if

$$\sum_{i=1}^N V_i^{12..N} \geq \sum_{i=1}^{N-1} V_i^{12..N-1} + V_N^a.$$

This further gives that

$$L_{1N}^e = 1 \iff V_1(\tau) \geq V_1^{12..N-1} \iff L_{1N}^* = 1.$$

To obtain the expression of τ , we plug in the following values

$$\begin{aligned} \sum_{i=2}^{N-1} V_i^{12..N-1} &= (N-2)(1+\bar{z}) - (N-2)\Phi\left[\sqrt{N-1}\left(-\bar{z} - \frac{1}{2}\delta\right)\right]c; \\ \sum_{i=2}^N V_i^{12..N} &= N(1+\bar{z}) - N\Phi\left[\sqrt{N}(-\bar{z})\right]c - \left(1+\bar{z} + \frac{N-1}{2}\delta\sigma - \Phi\left[-\bar{z} - \frac{N-1}{2}\delta\sigma\right]c\right); \\ V_N^a &= 1+\bar{z} + \frac{1-N}{2}\delta\sigma - \Phi\left[-\bar{z} - \frac{1-N}{2}\delta\right]c, \end{aligned}$$

we obtain that τ is a function of $\{N, \bar{z}, \delta\}$.

$$\tau = \left(N\Phi\left[\sqrt{N}(-\bar{z})\right] - (N-2)\Phi\left[\sqrt{N-1}\left(-\bar{z} - \frac{1}{2}\delta\right)\right] - \Phi(-z_1) - p_N \right) c.$$

Whenever the most distressed firm should be optimally isolated, we have $\sum_{i=1}^{N-1} V_i^{12..N-1} + V_N^a - \sum_{i=1}^N V_i^{12..N} > 0$, which implies $\tau > 0$. Further, τ increases with dispersion δ , decreases with mean \bar{z} . To see this, we take the derivatives of \bar{z} , δ , and the cross-derivative of \bar{z} and δ and some algebra gives $\frac{\partial\tau}{\partial\bar{z}} < 0$ and $\frac{\partial\tau}{\partial\delta} > 0$ and $\frac{\partial^2\tau}{\partial\delta\partial\bar{z}} < 0$.

$$\begin{aligned} \frac{\partial\tau}{\partial\bar{z}} &= \sqrt{N-1}(N-2)\Phi'\left[\sqrt{N-1}\left(-\bar{z} - \frac{1}{2}\delta\right)\right]c \\ &\quad + \Phi'\left[-\bar{z} - \frac{1-N}{2}\delta\right]c + \Phi'\left[-\bar{z} - \frac{N-1}{2}\delta\right]c - N\sqrt{N}\Phi'\left[\sqrt{N}(-\bar{z})\right]c < 0, \\ \frac{\partial\tau}{\partial\delta} &= \frac{1}{2}\sqrt{N-1}(N-2)\Phi'\left[\sqrt{N-1}\left(-\bar{z} - \frac{1}{2}\delta\right)\right]c \\ &\quad + \frac{N-1}{2}\left(\Phi'\left[-\bar{z} - \frac{N-1}{2}\delta\right] - \Phi'\left[-\bar{z} - \frac{1-N}{2}\delta\right]\right)c > 0. \end{aligned}$$

And $\frac{\partial^2\tau}{\partial\delta\partial\bar{z}} < 0$. **Q.E.D.**

Online Appendix to Distress Dispersion and Systemic Risk in Networks

In this Online Appendix, I provide technical results on the optimal risk sharing allocation, the multiple equilibria, results under full contingent contracts, and a model extension with government bailout. I also provide additional empirical results.

A Technical Appendix

A.1 Optimal Risk Sharing Allocation

This section provides technical results for subsection 3.1. I show that the asset holdings implied by the optimal network L^* are equivalent to the allocations if the social planner were to allocate asset allocations directly.

Definition 3 Let \mathcal{H} be an asset holding matrix such that firms' liquid asset holdings are $h = \mathcal{H}a$. The optimal asset allocation \mathcal{H}^* is feasible and minimizes total expected liquidation costs,

$$\mathcal{H}^* = \arg \min_{\mathcal{H}} \sum_i^N \mathbb{E}[h_i < 1] c, \quad (\text{P2})$$

subject to the feasibility constraint for asset allocation, $\mathcal{H} \times \mathbb{1}_{N \times 1} = \mathcal{H}^\top \times \mathbb{1}_{N \times 1} = \mathbb{1}_{N \times 1}$.

\mathcal{H} being a doubly stochastic matrix ensures that no assets are created or lost from asset pooling and that each firm holds one unit of assets. The following lemma characterizes the optimal asset allocation.

Lemma 3 If $\nexists i$ with $h_i^* = a_i$, then $h_i^* = \frac{1}{N} \sum_{j=1}^N a_j, \forall i \leq N$. If $\exists i$ with $h_i^* = a_i$ and $h_{i-1}^* \neq a_{i-1}$,

then $h_j^* = a_j, \forall j \geq i$ and $h_j^* = \frac{1}{i-1} \sum_{k=1}^{i-1} a_k, \forall j \leq i-1$.

Proof Let the number of firms that participate in risk-sharing be M . The total expected liquidation costs equal

$$\sum_{i=1}^M \Pr(h_i \leq 1) c = \sum_{i=1}^M \Phi \left(\frac{-\bar{z} - (1 - \sum_j H_{ij}) \nu_i - \sum_j H_{ij} \nu_j}{\sqrt{(1 - \sum_j H_{ij})^2 + \sum_j H_{ij}^2 \sigma}} \right) c. \quad (36)$$

Take the first order condition with respect to H_{ij} ,

$$\frac{\partial \sum_{i=1}^M \Pr(h_i \leq 1) c}{\partial H_{ij}} = \frac{\partial \Pr(h_i \leq 1) c}{\partial H_{ij}} + \frac{\partial \Pr(h_j \leq 1) c}{\partial H_{ji}}. \quad (37)$$

In particular, the derivative for firm i 's default probability with respect to H_{ij} is

$$\begin{aligned} \frac{\partial \Pr(h_i \leq 1) c}{\partial H_{ij}} &= \Phi' \left(\frac{-\bar{z} - H_{ii} \nu_i - \sum_j H_{ij} \nu_j}{\sqrt{H_{ii}^2 + \sum_j H_{ij}^2 \sigma}} \right) c \times \\ &\frac{(\nu_i - \nu_j) \sqrt{H_{ii}^2 + \sum_j H_{ij}^2 \sigma} + \left(-\bar{z} - H_{ii} \nu_i - \sum_j H_{ij} \nu_j \right) \sigma \left(H_{ii}^2 + \sum_j H_{ij}^2 \right)^{-\frac{1}{2}} (H_{ii} - H_{ij})}{H_{ii}^2 \sigma^2 + \sum_j H_{ij}^2 \sigma^2}. \end{aligned}$$

Similarly, write out the symmetric equation for firm j with respect to $H_{ji} = H_{ij}$ and plug into equation (37),

$$\frac{\partial \sum_{i=1}^M \Pr(h_i \leq 1)c}{\partial H_{ij}} \Big|_{H_{ii}=H_{ij}=\frac{1}{M}} = 0, \quad \forall i \neq j.$$

The first order conditions with respect to asset holdings equal zero when each element of H is evaluated at $\frac{1}{M}$, thus achieving the optimal allocation. $H_{ij} = \frac{1}{M}$ indicates full risk-sharing. It is worth noting that the only condition required for above results is that ε_i is independently distributed across firms. So the above result holds if we relabel Φ as a rather general distribution function. **Q.E.D.**

Lemma 3 states that if all firms diversify, they each hold the equally weighted asset $\sum_{j=1}^N a_j$; if there are firms not diversifying, then more distressed firms stay separate and liquid firms diversify holding the equally weighted assets composed of all firms diversifying. As such, the optimal asset holdings boil down to determining who should diversify. Recall from Lemma 1, the asset composition matrix H^* implied by the optimal network L^* also coincides with full risk-sharing among all connected firms. In this regard, under the iterative asset swap process, the optimal network H^* in (P1) achieves the best asset allocation matrix \mathcal{H}^* in (P2). Hence, the iterative feature of the asset swap itself does not deviate equilibrium from the optimal allocation.

A.2 Full Contingent Contracts

This section provides the technical results for subsection 3.4. I use an example of $N = 4$ and show that a complete set of contracts contingent on the entire network structure decentralizes the efficient network.

Proposition 6 *The efficient network is decentralized by a set of bilateral prices contingent on the entire network structure.*

Proof We prove the proposition for $N = 4$. It is equivalent to show that the bilateral prices decentralize $L^e = L^* = [4 - 1 - 2 - 3]$ in region $(\bar{z} > \bar{z}_1, \delta < \delta_1(\bar{z}))$, and $L^e = L^* = [1 - 2 - 3, 4]$ in region $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z}))$. We follow the same notation as in the proof of proposition 2. Different than in Proposition 2, the bilateral prices with contingency on faraway links are denoted as follows. (Here we only solve for those relevant for the pairwise stability and abstract from price contingency on L_{34} as agents has no incentive to form this link.)

$$\begin{aligned} & (p_{41} - p_{14})|_{L_{12}=L_{23}=0}, (p_{41} - p_{14})|_{L_{12}=\bar{l}, L_{23}=0}, (p_{41} - p_{14})|_{L_{12}=0, L_{23}=\bar{l}}, (p_{41} - p_{14})|_{L_{12}=L_{23}=\bar{l}}; \\ & (p_{21} - p_{12})|_{L_{14}=L_{23}=0}, (p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}}, (p_{21} - p_{12})|_{L_{14}=\bar{l}, L_{23}=0}, (p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}}; \\ & (p_{32} - p_{23})|_{L_{14}=L_{12}=0}, (p_{32} - p_{23})|_{L_{14}=0, L_{12}=\bar{l}}, (p_{32} - p_{23})|_{L_{14}=\bar{l}, L_{12}=0}, (p_{32} - p_{23})|_{L_{14}=L_{12}=\bar{l}}. \end{aligned}$$

Within each pair reservation prices are paid so $(p_{41} - p_{14})|_{L_{12}=L_{23}=0} = (p_{41} - p_{14})|_{L_{12}=0, L_{23}=\bar{l}} = V_1^a - V_4^a$, $(p_{21} - p_{12})|_{L_{14}=L_{23}=0} = V_1^a - V_2^a$, and $(p_{32} - p_{23})|_{L_{14}=L_{12}=0} = (p_{32} - p_{23})|_{L_{14}=\bar{l}, L_{12}=0} = V_2^a - V_3^a$.

(1) In region $(\bar{z} > \bar{z}_1, \delta < \delta_1(\bar{z}))$, $L^* = [4 - 1 - 2 - 3]$ and $\sum_1^4 \bar{V}_i^{4123} \geq \sum_1^3 \bar{V}_i^{123} + V_4^a$. In order to decentralize the full risk sharing network, prices satisfy

$$V_1^{4123} = \bar{V}_1^{4123} + \bar{l}(p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}} + (p_{41} - p_{14})|_{L_{12}=L_{23}=\bar{l}} \geq \max[V_1^a, V_1^{14}, V_1^{123}, V_1^{412}] \quad (38)$$

$$V_2^{4123} = \bar{V}_2^{4123} - \bar{l}(p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}} + (p_{32} - p_{23})|_{L_{14}=L_{12}=\bar{l}} \geq \max[V_2^{23}, V_2^a, V_2^{234}] \quad (39)$$

$$V_3^{4123} = \bar{V}_3^{4123} - (p_{32} - p_{23})|_{L_{14}=L_{12}=\bar{l}} \geq \max[V_3^a, V_3^{34}] \quad (40)$$

$$V_4^{4123} = \bar{V}_4^{4123} - (p_{41} - p_{14})|_{L_{12}=L_{23}=\bar{l}} \geq \max[V_4^a, V_4^{34}] \quad (41)$$

(40) and (41) binding gives $(p_{32} - p_{23})|_{L_{14}=L_{12}=\bar{l}}$ and $(p_{41} - p_{14})|_{L_{12}=L_{23}=\bar{l}}$. Plugging these two into the binding equation in (39) gives $(p_{21} - p_{12})|_{L_{14}=L_{23}=\bar{l}}$. The equilibrium replicates the optimal connection $L^e = L^* = [4 - 1 - 2 - 3]$.

(2) In region $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z}))$, $L^* = [1 - 2 - 3, 4]$ and $\sum_1^4 \bar{V}_i^{4123} < \sum_1^3 \bar{V}_i^{123} + V_4^a$. To decentralize $L^* = [4, 1 - 2 - 3]$, we require that firm2 transfer premium $\bar{l}(p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}}$ to prevent 1 from linking with 4,

$$V_2^{123} = \bar{V}_2^{123} - \bar{l}(p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}} + (p_{32} - p_{23})|_{L_{14}=0, L_{12}=\bar{l}} \geq V_2^{4123}, \quad (42)$$

$$V_3^{123} = \bar{V}_3^{123} - (p_{32} - p_{23})|_{L_{14}=0, L_{12}=\bar{l}} \geq V_3^{4123} \quad (43)$$

(42) and (43) binding gives $\bar{l}(p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}}$ and $(p_{32} - p_{23})|_{L_{14}=0, L_{12}=\bar{l}}$. The value of firm 1 becomes

$$V_1^{123} = \bar{V}_1^{123} + \bar{l}(p_{21} - p_{12})|_{L_{14}=0, L_{23}=\bar{l}} = V_1^{4123} + \sum_1^3 \bar{V}_i^{123} + V_4^a - \sum_1^4 \bar{V}_i^{4123}.$$

Hence, $V_1^{123} \geq V_1^{4123} \iff \sum_1^3 \bar{V}_i^{123} + V_4^a \geq \sum_1^4 \bar{V}_i^{4123}$ ($L^* = [1 - 2 - 3, 4]$), firm 1 disconnect L_{14} , i.e. the equilibrium switches from $[4 - 1 - 2 - 3]$ to $[1 - 2 - 3, 4]$.

Finally, we can confirm that $[4 - 1 - 2, 3]$ is not a potential deviation in either region for all possible $(p_{21} - p_{12})|_{L_{14}=\bar{l}, L_{23}=0}$ and $(p_{41} - p_{14})|_{L_{12}=\bar{l}, L_{23}=0}$ because $V_1^{4123} + V_2^{4123} + V_4^{4123} \geq V_1^{412} + V_2^{412} + V_4^{412}$ for $(\bar{z} > \bar{z}_1, \delta < \delta_1(\bar{z}))$, and $V_1^{123} + V_2^{123} + V_4^a \geq V_1^{412} + V_2^{412} + V_4^{412}$ for $(\bar{z} \in [\bar{z}_2, \bar{z}_1], \delta > \delta_1(\bar{z}))$.

When the length of chain increases, prices can be solved in a similar fashion. **Q.E.D.**

A.3 Extension with Government Bailout

This section provides the technical results for Section 5.2. I consider slight variations of the baseline model where the timing of the network formation does not coincide with the observation of distress. Under the set up in Section 5.2, if the regulators had optimally isolated the distressed N , the total liquidation cost is

$$C_{\text{iso-N}} = (N - 1) \Phi \left[\sqrt{N - 1} \left(-\bar{z} - \frac{1}{2}\delta \right) \right] c + \Phi \left[(k - 1) \bar{z} + \frac{N - 1}{2} \delta \right] c. \quad (44)$$

In the absence of the acquisition tax, all firms are connected and the liquidation costs are

$$C = \sum_{i=1}^N \Pr \left(\tilde{h}_i < 1 \right) c = N \Phi \left[\frac{k - N}{\sqrt{N}} \bar{z} \right] c. \quad (45)$$

When we enable the option of *ex post* government bailout as in 5.2.1, the costs equal liquidation plus bailout costs,

$$C_{GB} = \sum_{i=1}^N \Pr \left(\tilde{h}_i < 1 \right) c + B\sigma = N \Phi \left[\frac{(k - N)\bar{z} - B}{\sqrt{N}} \right] c + B\sigma. \quad (46)$$

Notice that $C = C_{GB}(B = 0)$. The gain from government bailout is $C - C_{GB}$. The next proposition shows that as long as the fixed liquidation cost c is large enough, a positive government bailout that at least matches the expected liquid value shortfall is *ex post* optimal.

Proposition 7 *If $c > \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$, $k > N$, the government bailout $B^*\sigma$ generates positive surplus, where*

$$B^* = (k - N)\bar{z} + \sqrt{N} \sqrt{-2 \log \left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c} \right]}. \quad (47)$$

Proof The optimal liquid value injection policy B^* minimizes total costs C_{GB} and thus satisfies the first order condition $\frac{\partial C_{GB}}{\partial B} = 0$, i.e. $N\Phi' \left[\frac{(k-N)\bar{z}-B}{\sqrt{N}} \right] c \left(-\frac{1}{\sqrt{N}} \right) + \sigma = 0$. This gives

$$\Phi' \left[\frac{(k-N)\bar{z}-B^*}{\sqrt{N}} \right] = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2} \left[\frac{(k-N)\bar{z}-B^*}{\sqrt{N}} \right]^2} = \frac{\sigma}{\sqrt{N}c}. \quad (48)$$

Solving for B^* gives (47). Given $e^{-\frac{1}{2} \left[\frac{(k-N)\bar{z}-B^*}{\sqrt{N}} \right]^2} \leq 1$, (48) implies $\frac{\sigma}{\sqrt{N}c} \leq \frac{1}{\sqrt{2\pi}}$. Hence $c \geq \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$, i.e. the liquidation cost needs to be large enough.

Further, in order that B^* archives the global minimum of $C_{GB}(B)$, we take the second derivative of B ,

$$\frac{\partial^2 C_{GB}}{\partial B^2} = \Phi'' \left[\frac{(k-N)\bar{z}-B^*}{\sqrt{N}} \right] c \geq 0, \quad \forall (k-N)\bar{z}-B^* \leq 0.$$

The second derivative is positive which ensures that B^* archives the global minimum of $C_{GB}(B)$, so the bailout surplus is positive, $C - C_{GB} = C_{GB}(B=0) - C_{GB}(B=B^*) > 0$. $B^* \geq (k-N)\bar{z}$ requires that B^* at least matches the expected liquid value short fall, $B^*\sigma > (k-N)\bar{z}\sigma$. The extra liquidity injection depends on the uncertainty and cost tradeoff. **Q.E.D.**

From equation (47), $B^*\sigma$ at least matches the expected liquid value shortfall, $B^*\sigma > (k-N)\bar{z}\sigma$. $c > \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$ ensures that B^* is non-zero. This requirement is easier to be satisfied when there are more counterparties to the distressed, and when uncertainty is lower. The extra liquidity injection, $\sqrt{N}\sigma\sqrt{-2\log\left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c}\right]}$, depends on the trade-off between cost and uncertainty. $\frac{\partial B^*}{\partial c} > 0$ implies that the bigger the liquidation cost is, the higher the optimal government bailout is; from $\frac{\partial B^*}{\partial \sigma} < 0$, optimal government bailout decreases with asset uncertainty.

If instead $0 \leq k \leq N$, the average distress after θ shock is positive. From equation (47), a positive government bailout requires that $c \geq \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} e^{\frac{(N-k)^2\bar{z}^2}{2N}} > \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$. Plugging equation (47) into (46), the total costs under optimal bailout policy B^* is

$$C_{GB}^* = (k-N)\bar{z}\sigma + N\Phi \left[-\sqrt{-2\log\left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c}\right]} \right] c + \sqrt{N}\sigma\sqrt{-2\log\left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c}\right]}. \quad (49)$$

Although C_{GB}^* improves upon C , it is important to compare C_{GB}^* with the cost when the acquisition link had been prevented *ex ante*.

Proposition 8 *There exists $\bar{c} > \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$, such that $C_{GB}^* > C_{isoN}$ for $c \in [\frac{\sqrt{2\pi}\sigma}{\sqrt{N}}, \bar{c}]$ and for all $\delta \geq 0$, where $c = \frac{\sigma B^*}{(N-1)\Phi[-\sqrt{N-1}\bar{z}] + \Phi[(k-1)\bar{z}] - N\Phi\left[\frac{(k-N)\bar{z}-B^*}{\sqrt{N}}\right]}$, and B^* is given by equation (47).*

Proof In this proof, I first show that C_{isoN} decreases monotonically with δ , hence it achieves the maximum at $C_{isoN}(\delta=0)$. Then I show that C_{GB}^* is a concave function: $C_{GB}^* > C_{isoN}(\delta=0)$ at the minimum value for cost $c = \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$, C_{GB}^* crosses the linear function $C_{isoN}(\delta=0)$ at \bar{c} . Accordingly, C_{GB}^* is greater than in the region $c \in [\frac{\sqrt{2\pi}\sigma}{\sqrt{N}}, \bar{c})$.

Step 1: $\frac{\partial C_{isoN}}{\partial \delta} < 0$, so C_{isoN} decreases with δ . Take the derivative of C_{isoN} with respect to δ ,

$$\frac{\partial C_{isoN}}{\partial \delta} = \frac{(N-1)c}{2} \left(\Phi' \left[(k-1)\bar{z} + \frac{N-1}{2}\delta \right] - \sqrt{N-1}\Phi' \left[\sqrt{N-1} \left(-\bar{z} - \frac{1}{2}\delta \right) \right] \right). \quad (50)$$

Notice that $(k-1)\bar{z} + \frac{N-1}{2}\delta > 0$, $\sqrt{N-1}(-\bar{z} - \frac{1}{2}\delta) < 0$, and we can also show that $(k-1)\bar{z} + \frac{N-1}{2}\delta > -\sqrt{N-1}(-\bar{z} - \frac{1}{2}\delta)$.⁴⁹ Accordingly, $\Phi'(x) = \frac{1}{\sqrt{2\pi}}e^{-\frac{x^2}{2}}$ implies that

$$\Phi' \left[(k-1)\bar{z} + \frac{N-1}{2}\delta \right] < \Phi' \left[\sqrt{N-1} \left(-\bar{z} - \frac{1}{2}\delta \right) \right] < \sqrt{N-1} \Phi' \left[\sqrt{N-1} \left(-\bar{z} - \frac{1}{2}\delta \right) \right].$$

Plugging into equation (50), we have $\frac{\partial C_{isoN}}{\partial \delta} < 0$. Evaluate C_{isoN} at $\delta = 0$, we obtain a linear function of c ,

$$C_{isoN}(\delta = 0) = (N-1)\Phi \left[-\sqrt{N-1}\bar{z} \right] c + \Phi \left[(k-1)\bar{z} \right] c.$$

Step 2: C_{GB}^* is a concave function. Denote $J = \sqrt{-2 \log \left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c} \right]} > 0$, then $\frac{\partial J}{\partial c} = \frac{1}{Jc}$, and from (48), $\Phi'(-J) = \frac{\sigma}{\sqrt{N}c}$. Now sub the expression of J into equation (49), we have $C_{GB}^* = N\Phi[-J]c + (k-N)\bar{z}\sigma + \sqrt{N}\sigma J$. Take the first derivative of c ,

$$\frac{\partial C_{GB}^*}{\partial c} = N\Phi[-J] + \frac{\sqrt{N}\sigma}{Jc} - \frac{N\Phi'[-J]}{J} = N\Phi[-J] = N\Phi \left[-\sqrt{-2 \log \left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c} \right]} \right].$$

Therefore, $\frac{\partial C_{GB}^*}{\partial c} > 0$. Since $\frac{\partial J}{\partial c} = \frac{1}{Jc} > 0$, $\frac{\partial C_{GB}^*}{\partial c^2} < 0$, i.e. $\frac{\partial^2 C_{GB}^*}{\partial c^2} < 0$. **Step 3:**

Establish $C_{GB}^* \left(c = \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} \right) > C_{isoN} \left(\delta = 0, c = \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} \right)$. Plugging in $c = \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$, we get

$$C_{GB}^* \left(c = \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} \right) = \frac{\sqrt{2\pi}\sigma}{2}\sqrt{N} + (k-N)\bar{z}\sigma,$$

$$C_{isoN} \left(\delta = 0, c = \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} \right) = (N-1)\Phi \left[-\sqrt{N-1}\bar{z} \right] \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} + \Phi \left[(k-1)\bar{z} \right] \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}.$$

Since $k > N$, $\Phi < 1$,

$$C_{isoN} \left(\delta = 0, c = \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} \right) < N \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} = \frac{\sqrt{2\pi}\sigma}{2}\sqrt{N} < C_{GB}^* \left(c = \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} \right).$$

Step 4: Solve for cross point \bar{c} . Equating $C_{GB}^* = C_{isoN}(\delta = 0)$ and solve for c gives \bar{c} .

To sum up, from Steps 1 - 4, we establish that $C_{GB}^* > C_{isoN}$, $\forall c \in \left[\frac{\sqrt{2\pi}\sigma}{2}, \bar{c} \right]$. Therefore, when liquidation cost is bounded by \bar{c} , C_{GB}^* is more costly than C_{isoN} . **Q.E.D.**

Next I consider the optimal policy when there are healthier institutions currently not connected with the distressed. Denote the existing firms $i = 1, \dots, N$ as group one. Now, consider group two of N other firms $i = N+1, \dots, 2N$ with the same liquid value structure, $\bar{z} > 0, \sigma > 0$. For simplicity, let the dispersion δ among these firms be zero, so *ex ante* an optimal full risk-sharing network is formed. Let the additional signal θ_i be $\theta_{N+1} = \hat{k}\bar{z}\sigma$ and $\theta_i = 0, \forall i = N+2, \dots, 2N$, so *ex post* the $N+1$ th firm gets a positive shock in the liquid value. The next corollary examines whether the *ex post* acquisition of heavily distressed N by the liquid $N+1$ can reduce total liquidation costs, and if not, whether subsidized acquisition is value increasing.

⁴⁹We take the difference of the squares, $\left((k-1)\bar{z} + \frac{N-1}{2}\delta \right)^2 - \left(\sqrt{N-1} \left(-\bar{z} - \frac{1}{2}\delta \right) \right)^2 = (k-1)^2\bar{z}^2 + \frac{(N-1)^2}{4}\delta^2 + (k-1)(N-1)\bar{z}\delta - (N-1)\bar{z}^2 - \frac{(N-1)}{4}\delta^2 - (N-1)\bar{z}\delta > (N-1)(N-2)\bar{z}^2 + \frac{(N-1)(N-2)}{4}\delta^2 + (N-2)(N-1)\bar{z}\delta = (N-2)(N-1)\left(-\bar{z} - \frac{1}{2}\delta\right)^2 > 0$.

Corollary 1 *With no subsidy, the liquid firm $N + 1$ acquires the heavily distressed N if and only if $\hat{k} \geq k - 2N$. Government subsidized acquisition is ex post optimal if $\hat{k} < k - 2N$ and $c > \frac{\sqrt{\pi}\sigma}{\sqrt{N}}$; the optimal subsidy to the acquirer firm $N + 1$ upon acquisition is $B_A^*\sigma$, where*

$$B_A^* = \left(k - \hat{k} - 2N\right) \bar{z} + \sqrt{2N} \sqrt{-2 \log \left[\frac{\sqrt{\pi}\sigma}{\sqrt{N}c} \right]}. \quad (51)$$

When there exist healthier institutions, ex post subsidized acquisition is always preferred to ex post government bailout.

Proof In this proof, I first analyze conditions for the acquisition link to be ex post optimal. Then I examine whether the acquisition link forms at equilibrium, and then move to conditions for the positive subsidy to be optimal. Finally, I conclude that subsidized acquisition is cheaper than government bailout.

Step 1: condition for the acquisition link to be ex post optimal. Without acquisition link, total liquidation costs of group one and group two are respectively

$$C_{g1} = N\Phi \left[\frac{-N + k}{\sqrt{N}} \bar{z} \right] c, \quad C_{g2} = N\Phi \left[\frac{-N - \hat{k}}{\sqrt{N}} \bar{z} \right] c. \quad (52)$$

With the acquisition link, the total liquidation costs of the two groups become

$$C_{\text{total}} = \sum_{i=1}^{2N} \Pr(\tilde{h}_i < 1) c = 2N\Phi \left[\frac{-2N - \hat{k} + k}{\sqrt{2N}} \bar{z} \right] c. \quad (53)$$

The acquisition link generates positive surplus if and only if $C_{g1} + C_{g2} > C_{\text{total}}$. Plugging in (52) and (53) and applying Lemma 2, we get

$$N\Phi \left[\frac{-N + k}{\sqrt{N}} \bar{z} \right] c + N\Phi \left[\frac{-N - \hat{k}}{\sqrt{N}} \bar{z} \right] c > 2N\Phi \left[\frac{-2N - \hat{k} + k}{\sqrt{2N}} \bar{z} \right] c \iff \hat{k} > k - 2N.$$

Step 2: condition for the acquisition link to be formed ex post at equilibrium. I show that as long as this acquisition is socially optimal, $C_{g1} + C_{g2} > C_{\text{total}}$, the acquisition link will form *ex post* at equilibrium. Since prices are already set between other banks, with only bilateral prices (p_N^{N+1}, p_{N+1}^N) to be contracted. Hence whether the acquisition link can form at equilibrium is equivalent to whether the bilateral surplus between N and $N + 1$ is positive. The value of firm N without the *ex post* acquisition link is⁵⁰

$$\hat{V}_N = 1 + \left(1 - \frac{N-1}{2}\delta - \frac{k}{N}\right) \bar{z}\sigma - \Phi \left[\frac{k-N}{\sqrt{N}} \bar{z} \right] c - \Phi \left(-\bar{z} + \frac{N-1}{2}\delta \right) c + \Phi \left(-\sqrt{N}\bar{z} \right) c.$$

Notice that when $k = 0$, $\hat{V}_N = V_N^a$, which matches the outside option of firm N . The value of firm $N + 1$ without the *ex post* acquisition link is

$$\hat{V}_{N+1} = 1 + \frac{\hat{k} + N}{N} \bar{z}\sigma - \Phi \left[\frac{-N - \hat{k}}{\sqrt{N}} \bar{z} \right] c.$$

⁵⁰ $\hat{V}_N = \mathbb{E}[\tilde{h}_N] - \Pr(\tilde{h}_N < 1) c + \frac{1}{2}p_N^1 - \frac{1}{2}p_1^N$, $p_N^1 = 1 + (\bar{z} - \frac{N-1}{2}\delta)\sigma - \Phi(-\bar{z} + \frac{N-1}{2}\delta)c$, $p_1^N = 1 + (\bar{z} + \frac{N-1}{2}\delta)\sigma + \Phi(-\bar{z} + \frac{N-1}{2}\delta)c - 2\Phi(-\sqrt{N}\bar{z})c$.

The bilateral surplus is

$$\Phi \left[\frac{-N - \hat{k}}{\sqrt{N}} \bar{z} \right] c + \Phi \left[\frac{k - N}{\sqrt{N}} \bar{z} \right] c > 2\Phi \left[\frac{-2N - \hat{k} + k}{\sqrt{2N}} \bar{z} \right] c \iff \hat{k} > k - 2N$$

which recovers precisely the condition for positive total acquisition surplus. This shows that if and only if $\hat{k} > k - 2N$, the acquisition link is efficient and forms in equilibrium after θ realizes.

Step 3: the positive acquisition subsidy is optimal if the liquidation cost is large enough. When $\hat{k} \leq k - 2N$, I next show that the positive acquisition subsidy is optimal if the liquidation cost is large enough. Let the positive government subsidy be $B_A\sigma$ given to the acquire $N + 1$. The total cost with subsidized acquisition becomes

$$C_{subA} = \sum_{i=1}^{2N} \Pr(\tilde{h} < 1) c + B_A\sigma = 2N\Phi \left[\frac{(k - \hat{k} - 2N) \bar{z} - B_A}{\sqrt{2N}} \right] c + B_A\sigma.$$

B_A^* satisfies the first order condition

$$\Phi' \left[\frac{(k - \hat{k} - 2N) \bar{z} - B_A^*}{\sqrt{2N}} \right] = \frac{\sigma}{\sqrt{2N}c}. \quad (54)$$

Solving for B_A^* gives (51), and we require that $c > \frac{\sqrt{\pi}\sigma}{\sqrt{N}}$ and $\hat{k} \leq k - 2N$.

Step 4: subsidized acquisition is preferred to government bailout. I show that the subsidized acquisition is less costly thus preferred to government bailout. Based on Proposition 7, for $c \in \left(\frac{\sqrt{\pi}\sigma}{\sqrt{N}}, \frac{\sqrt{2\pi}\sigma}{\sqrt{N}} \right)$, subsidized acquisition is the only feasible option. For $c > \frac{\sqrt{2\pi}\sigma}{\sqrt{N}}$, costs with government bailout for the two groups are

$$C_{GB}^* = N\Phi \left[-\sqrt{-2 \log \left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c} \right]} \right] c + (k - N)\bar{z}\sigma + \sqrt{N}\sigma \sqrt{-2 \log \left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c} \right]} + N\Phi \left[\frac{-N - \hat{k}}{\sqrt{N}} \bar{z} \right] c.$$

Costs with subsidized acquisition is

$$C_{subA}^* = (k - \hat{k} - 2N) \bar{z}\sigma + \sqrt{2N} \sqrt{-2 \log \left[\frac{\sqrt{\pi}\sigma}{\sqrt{N}c} \right]} \sigma + 2N\Phi \left[-\sqrt{-2 \log \left[\frac{\sqrt{\pi}\sigma}{\sqrt{N}c} \right]} \right] c.$$

Denote $J = \sqrt{-2 \log \left[\frac{\sqrt{2\pi}\sigma}{\sqrt{N}c} \right]} > 0$, $H = \frac{\hat{k} + N}{\sqrt{N}} \bar{z} > 0$, then

$$C_{GB}^* = \sqrt{N}\sigma J + N\Phi[-J]c + \sqrt{N}\sigma H + N\Phi[-H]c + (k - \hat{k} - 2N) \bar{z}\sigma.$$

From (48), $\Phi'(-J) = \frac{\sigma}{\sqrt{N}c}$. Hence, function $f(x) = \sqrt{N}\sigma x + N\Phi[-x]c$, satisfies $f'(J) = 0$, $f''(x) > 0, \forall x > 0$. This implies $C_{GB}^* > 2\sqrt{N}\sigma J + 2N\Phi[-J]c + (k - \hat{k} - 2N) \bar{z}\sigma > \sqrt{2N}\sigma J + 2N\Phi[-J]c + (k - \hat{k} - 2N) \bar{z}\sigma$.

In a similar approach, denote $G = \sqrt{-2 \log \left[\frac{\sqrt{\pi}\sigma}{\sqrt{N}c} \right]} > 0$, then $C_{subA}^* = \sqrt{2N}G\sigma + 2N\Phi[-G]c + (k - \hat{k} - 2N) \bar{z}\sigma$, and from (54), $\Phi'[-G] = \frac{\sigma}{\sqrt{2N}c}$. Function $f(x) = \sqrt{2N}\sigma x + 2N\Phi[-x]c$, $x > 0$, achieves global ($x > 0$) minimum at $x = G$. This implies that $C_{GB}^* > C_{subA}^*$. **Q.E.D.**

When the cardinality of the two groups differs, pushed acquisition could be *ex post* optimal. Denote N_1 (instead of N) the number of the group one firms including the heavily distressed $\theta_{N_1} = -k\bar{z}\sigma$. Consider N_2 other firms (group two), with the same $\bar{z} > 0$, $\sigma > 0$, but $\delta = 0$ for simplicity. *Ex ante* an optimal full risk-sharing network is formed among N_2 firms. The additional signal is $\theta_{N_1+1} = \hat{k}\bar{z}\sigma$, $\theta_i = 0$, $\forall i = N_1 + 2, \dots, N_1 + N_2$. Hence firm $i = N_1 + 1$ has the highest liquid value *ex post*. Suppose after $t = 1$ when links in each group are formed and prices are exchanged, the most liquid firm can acquire the heavily distressed.

Proposition 9 *The social surplus of the acquisition is positive when the liquidity shocks satisfy*

$$\hat{k} > \max \left[\frac{\sqrt{N_1 + N_2} - \sqrt{N_1}}{\sqrt{N_1 + N_2} - \sqrt{N_2}} (k - N_1) - N_2, k - N_1 - N_2 \right]. \quad (55)$$

Under (55),

- when $N_2 \geq N_1$ the bilateral surplus is positive;
- when $N_2 < N_1$ the bilateral surplus is negative when

$$2\Phi \left[\frac{k - \hat{k} - (N_1 + N_2)}{\sqrt{N_1 + N_2}} \bar{z} \right] c > \Phi \left[\frac{k - N_1}{\sqrt{N_1}} \bar{z} \right] c + \Phi \left[\frac{-\hat{k} - N_2}{\sqrt{N_2}} \bar{z} \right] c + \frac{(N_2 - N_1)(N_2 k + N_1 \hat{k})}{N_1 N_2 (N_1 + N_2)} \bar{z} \sigma. \quad (56)$$

Proof I first show that condition (55) implies positive social surplus from the acquisition link between the liquid $N_1 + 1$ and the distressed firm N_1 . Without acquisition link, total liquidation costs of group one and group two are respectively

$$C_{g1} = N_1 \Phi \left[\sqrt{N_1} \left(\frac{k}{N_1} - 1 \right) \bar{z} \right] c, \quad C_{g2} = N_2 \Phi \left[\sqrt{N_2} \left(-1 - \frac{\hat{k}}{N_2} \right) \bar{z} \right] c$$

With the acquisition link, the total liquidation costs of the two groups become

$$C_{\text{total}} = \sum_{i=1}^{N_1+N_2} \Pr(\tilde{h}_i < 1) c = (N_1 + N_2) \Phi \left[\sqrt{N_1 + N_2} \left(\frac{k - \hat{k}}{N_1 + N_2} - 1 \right) \bar{z} \right] c.$$

The acquisition link generates positive surplus if and only if $C_{g1} + C_{g2} > C_{\text{total}}$, i.e.

$$\frac{N_1}{N_1 + N_2} \Phi \left[\frac{k - N_1}{\sqrt{N_1}} \bar{z} \right] + \frac{N_2}{N_1 + N_2} \Phi \left[\frac{-\hat{k} - N_2}{\sqrt{N_2}} \bar{z} \right] > \Phi \left[\frac{k - \hat{k} - (N_1 + N_2)}{\sqrt{N_1 + N_2}} \bar{z} \right]. \quad (57)$$

Under (55), $\hat{k} > \max \left[\frac{\sqrt{N_1 + N_2} - \sqrt{N_1}}{\sqrt{N_1 + N_2} - \sqrt{N_2}} (k - N_1) - N_2, k - N_1 - N_2 \right]$. It follows

$$\begin{aligned} & (N_2 + \hat{k}) \left(\sqrt{N_1 + N_2} - \sqrt{N_2} \right) > (k - N_1) \left(\sqrt{N_1 + N_2} - \sqrt{N_1} \right) \iff \\ & \left(-N_1 \sqrt{N_1} + \sqrt{N_1} k \right) + \left(-\sqrt{N_2} N_2 - \sqrt{N_2} \hat{k} \right) > \sqrt{N_1 + N_2} k - \sqrt{N_1 + N_2} \hat{k} - \sqrt{N_1 + N_2} (N_1 + N_2) \iff \\ & \frac{N_1 \sqrt{N_1} \left(-1 + \frac{k}{N_1} \right) \bar{z}}{N_1 + N_2} + \frac{N_2 \sqrt{N_2} \left(-1 - \frac{\hat{k}}{N_2} \right) \bar{z}}{N_1 + N_2} > \frac{k - \hat{k} - (N_1 + N_2)}{\sqrt{N_1 + N_2}} \bar{z}. \end{aligned} \quad (58)$$

Given $\Phi(\cdot)$ is convex when $\frac{k - \hat{k} - (N_1 + N_2)}{\sqrt{N_1 + N_2}} \bar{z} < 0$, by definition

$$\frac{N_1}{N_1 + N_2} \Phi \left[\frac{k - N_1}{\sqrt{N_1}} \bar{z} \right] + \frac{N_2}{N_1 + N_2} \Phi \left[\frac{-\hat{k} - N_2}{\sqrt{N_2}} \bar{z} \right] \geq \Phi \left[\frac{N_1 \sqrt{N_1} \left(-1 + \frac{k}{N_1} \right) \bar{z}}{N_1 + N_2} + \frac{N_2 \sqrt{N_2} \left(-1 - \frac{\hat{k}}{N_2} \right) \bar{z}}{N_1 + N_2} \right].$$

Combining with equation (58), we establish (57).

Next I show that under (55), the bilateral acquisition surplus is positive when $N_2 \geq N_1$. Since prices are already set between other banks, there are only bilateral prices $(p_{N_1}^{N_1+1}, p_{N_1+1}^{N_1})$ to be contracted. Hence whether the acquisition link can form at equilibrium is equivalent to whether the bilateral surplus between N_1 and $N_1 + 1$ is positive. The value of firm N_1 without acquisition is

$$\hat{V}_{N_1} = 1 + \left(1 - \frac{N_1 - 1}{2}\delta - \frac{k}{N_1}\right) \bar{z}\sigma - \Phi\left[\frac{k - N_1}{\sqrt{N_1}}\bar{z}\right]c - \Phi\left(\frac{N_1 - 1}{2}\delta - \bar{z}\right)c + \Phi(-\sqrt{N_1}\bar{z})c.$$

Notice that when $k = 0$, $\hat{V}_{N_1} = V_{N_1}^a$, which matches the outside option of firm N_1 . The value of firm $N_1 + 1$ without the acquisition link is

$$\hat{V}_{N_1+1} = 1 + \left(1 + \frac{\hat{k}}{N_2}\right) \bar{z}\sigma - \Phi\left[\frac{-N_2 - \hat{k}}{\sqrt{N_2}}\bar{z}\right]c.$$

With the acquisition link, the value of firm N_1 , and firm $N_1 + 1$ are respectively

$$\begin{aligned} \hat{V}_{N_1}^A &= 1 + \left(1 - \frac{N_1 - 1}{2}\delta - \frac{k - \hat{k}}{N_1 + N_2}\right) \bar{z}\sigma - \Phi\left[\frac{k - \hat{k} - (N_1 + N_2)}{\sqrt{N_1 + N_2}}\bar{z}\right]c - \Phi\left(-\bar{z} + \frac{N_1 - 1}{2}\delta\right)c + \Phi(-\sqrt{N_1}\bar{z})c; \\ \hat{V}_{N_1+1}^A &= 1 + \left(1 - \frac{k - \hat{k}}{N_1 + N_2}\right) \bar{z}\sigma - \Phi\left[\frac{k - \hat{k} - (N_1 + N_2)}{\sqrt{N_1 + N_2}}\bar{z}\right]c. \end{aligned}$$

The bilateral surplus minus the total surplus is

$$\begin{aligned} &\frac{\hat{V}_{N_1}^A + \hat{V}_{N_1+1}^A - \hat{V}_{N_1} - \hat{V}_{N_1+1}}{2} - \frac{C_{g1} + C_{g2} - C_{\text{total}}}{N_1 + N_2} \\ &= \frac{1}{2} \left(\frac{k}{N_1} - \frac{\hat{k}}{N_2} - 2\frac{k - \hat{k}}{N_1 + N_2} \right) \bar{z}\sigma + \frac{N_2 - N_1}{2(N_1 + N_2)} \left(\Phi\left[\frac{k - N_1}{\sqrt{N_1}}\bar{z}\right] - \Phi\left[\frac{-\hat{k} - N_2}{\sqrt{N_2}}\bar{z}\right] \right) c \\ &= \frac{(N_2 - N_1)(N_2k + N_1\hat{k})}{2N_1N_2(N_1 + N_2)} \bar{z}\sigma + \frac{N_2 - N_1}{2(N_1 + N_2)} \left(\Phi\left[\frac{k - N_1}{\sqrt{N_1}}\bar{z}\right] - \Phi\left[\frac{-\hat{k} - N_2}{\sqrt{N_2}}\bar{z}\right] \right) c \\ &= \frac{N_2 - N_1}{2(N_1 + N_2)} \left[\frac{N_2k + N_1\hat{k}}{N_1N_2} \bar{z}\sigma + \left(\Phi\left[\frac{k - N_1}{\sqrt{N_1}}\bar{z}\right] - \Phi\left[\frac{-\hat{k} - N_2}{\sqrt{N_2}}\bar{z}\right] \right) c \right]. \end{aligned}$$

which is non-negative when $N_2 \geq N_1$. In other words, when $N_2 \geq N_1$ and $C_{g1} + C_{g2} - C_{\text{total}} > 0$,

$$\frac{\hat{V}_{N_1}^A + \hat{V}_{N_1+1}^A - \hat{V}_{N_1} - \hat{V}_{N_1+1}}{2} \geq \frac{C_{g1} + C_{g2} - C_{\text{total}}}{N_1 + N_2} > 0.$$

If $N_1 > N_2$, the average bilateral surplus is smaller than the average social surplus. Under condition (56), the bilateral surplus is negative. **Q.E.D.**

As a sufficient condition for a positive social surplus, (55) sets a lower bound for the positive liquidity shock \hat{k} . The relative cardinality of the two groups of firms is essential in determining the sign of the bilateral surplus. When $N_2 > N_1$, on average, the pair of $i = \{N_1, N_1 + 1\}$ gets bigger surplus than an average bank. When $N_1 = N_2$, we recover the case in subsection 5.2.2, so the sign of the bilateral surplus matches that of the social surplus. When $N_1 > N_2$, under condition (56), bilateral surplus can be negative even if social surplus is positive. (56) implies an upper bound for \hat{k} , hence is especially relevant when the potential acquirer does not have an abundant supply of liquidity.

B Additional Empirical Results

In this Appendix, I provide additional empirical results to supplement the findings in Section 6.

Table A.I presents supplementary univariate correlations to Table 3. I adopt alternative indicators for economic activity and systemic risk, including the *Recession Probability* from [Chauvet and Piger \(2008\)](#), the subcomponents of the Chicago Fed National Activity Index (CFNAI) on personal consumption and housing (C&H) and employment, unemployment, and hours (EU&H). Finally, following [Giglio, Kelly, and Pruitt \(2015\)](#), I take the systemic risk measures relating to liquidity and credit conditions in the financial market: the *Default Spread* (difference between 3-Month BAA bond yields and the Treasury) and the *Term Spread* (difference between 10-Year and 3-Month Treasury).

Table A.I. SUMMARY STATISTICS AND UNIVARIATE CORRELATIONS

	Mean	StDev	Sacf	Correlations w/ log Z-score	
				Mean	Dispersion
A. Economic activity and systemic risk					
Recession Probability	0.08	0.23	0.83	0.00	0.17
CFNAI: Personal Consumption and Housing	-0.03	0.13	0.93	-0.03	-0.78***
CFNAI: Employment, Unemployment, and Hours	-0.06	0.31	0.86	-0.03	-0.20*
Default Spread	4.19	1.54	0.93	-0.14	0.54***
Term Spread	1.87	1.11	0.91	-0.25**	0.37***
B. Lending and interbank lending					
Financial Business Leverage	29.40	5.59	0.94	-0.16	-0.71***
Security Broker-Dealers Leverage	41.11	17.94	0.73	0.51***	-0.18*
$\Delta\%$ Non-financial Corporate Liability	0.01	0.01	0.46	0.14	-0.22*
All Comm. Bank Credit over Assets	0.81	0.03	0.94	-0.13	-0.84***
Small Comm. Interbank Loan over Assets	0.02	0.01	0.87	0.10	-0.51***

Notes: This table supplements to Table 3 and reports the summary statistics for alternative measures of economic activity and systemic risk, lending and interbank lending, as well as their univariate correlation coefficients with the mean and dispersion of financials' log Z-scores. Group A series are taken from FRED. Group B series are constructed from the Fed's Z.1 and H.8 release. Data availability on bank holding companies restricts the analysis to 1986-2013. Sacf is the first-order sample autocorrelation coefficient. The last two columns report the correlation coefficients between the cross-sectional mean and dispersion of log Z-score and each series in groups A-B together with the significance levels. *, **, *** denote statistical significance at the 5%, 1%, and 0.1% level.

The alternative indicators for lending and interbank lending include the leverage of both financial business and the security broker-dealers discussed in [Adrian, Etula, and Muir \(2014\)](#), the growth rate of non-financial corporate liability, the credit and loans of all commercial banks over assets, and the interbank loans over assets of small and medium-sized commercial banks. The correlation coefficients show a clear pattern: the aggregate indicators correlate significantly with dispersion, whereas only the leverage of security broker-dealers comoves strongly with the mean.

Table A.II presents supplementary predictive regression results to Table 4. Using the same method as in Table 4, I run predictive regressions to forecast the alternative measures. The estimates strongly echo the findings from the correlation analysis. Both the significance level of the regression coefficients and the differences in R^2 s with and without dispersion in the regressors suggest the robustness of the predictive power of dispersion series.

The economic magnitude of the predictive power is also sizable. Take the forecasting of Recession Probability for instance. Holding the controls fixed, a one-standard-deviation increase in the *Dispersion* (=0.22) predicts a 0.095 ($= 0.22 \times 0.43$) increase in the *Recession Probability* in the next quarter, whereas a one-standard-deviation decrease in the *Mean* (=0.03) predicts a 0.046 ($= 0.03 \times 1.54$) raise in the future *Recession Probability*.

Table A.II. PREDICTIVE REGRESSIONS USING DISTRESS DISPERSION

Quarters	1	2	3	4	1	2	3	4
Forecasting	A. Recession Probability				B. CFNAI: CH			
Dispersion	0.43**	0.79**	1.07*	1.29*	-0.38***	-0.75***	-1.10***	-1.43***
Mean	-1.54**	-3.28**	-4.83**	-5.12*	0.27	0.70	1.23	1.76
R^2	40.98	43.91	45.95	42.37	70.18	72.88	74.29	75.30
R^2 w/o disp	33.95	37.23	39.95	36.96	53.71	56.23	57.85	59.39
Forecasting	C. Default Spread				D. Term Spread			
Dispersion	0.04***	0.08***	0.13***	0.18***	0.01*	0.02*	0.04*	0.06
Mean	0.00	-0.02	-0.08	-0.12	-0.02	-0.05	-0.13	-0.22
R^2	83.97	79.92	74.97	69.61	87.19	80.07	72.93	66.32
R^2 w/o disp	72.23	65.71	58.38	49.95	86.49	78.48	70.32	62.16
Forecasting	I. Bk Credit over Assets				K. Sml Bk Interbank L over Assets			
Dispersion	-0.09***	-0.18***	-0.28***	-0.37***	-0.01	-0.02	-0.04*	-0.05**
Mean	-0.02	0.07	0.18	0.27	0.06	0.10	0.11	0.09
R^2	80.41	82.41	83.95	85.16	48.13	54.09	56.03	56.46
R^2 w/o disp	64.37	65.53	65.98	65.79	45.00	49.57	49.55	47.33

Notes: This table summarizes the ability of distress dispersion to forecast future economic activity, systemic risk, failure rates, distressed acquisition rates, and bank lending behavior. In A-K, quarterly time series are regressed on the cross-sectional dispersion and mean of log Z-score controlling for the term spread, the leverage of financial business and security broker-dealers, and the growth rate of real non-financial corporate liability. Forecasting horizons range from one to four quarters and the data cover the years 1986-2013. The table reports the predictive regression coefficients on the dispersion and mean of log Z-score, the R^2 , as well as the R^2 when the regressions are run without the dispersion series. *, **, *** denote statistical significance (based on Newey-West standard errors) at the 5%, 1%, and 0.1% level.