Market Liquidity and Financial Fragility

Danilo L. B. Wegner

Australian Institute of Business

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Motivation

▶ Excess market liquidity, in the form of easy access to credit and the easiness of buying and selling assets, seems to precede financial crises
▶ Market liquidity is heavily influenced by government and central bank policies, e.g. monetary policy
▶ Through their actions, therefore, governments and central banks around the world affect the likelihood of crises
▶ 2007-2009 global financial crisis showed the need to design and implement macro-prudential policies, by definition focusing on measures of systemic risk
▶ As far as a measure of systemic risk is concerned, the topology of financial markets matters, making network analysis very suitable
▶ Question: how government and central bank policies (by affecting market liquidity) impact systemic risk (by leading to changes in financial networks)?
Financial Intermediaries’ Balance-Sheet (Shin, 2009)
Liquidity and Leverage (Adrian & Shin, 2008): HHold
Liquidity and Leverage (Adrian & Shin, 2008): CBanks
Liquidity and Leverage (Adrian & Shin, 2008): IBanks

**Lehman Brothers**

**Merrill Lynch**

**Morgan Stanley**

**Bear Stearns**

**Goldman Sachs**

**Citigroup Markets 98-04**
Liquidity and Interbank Lending

- Effective Federal Funds Rate, 2001:Q1=100
- Agency-and GSE-Backed Mortgage Pools; Total Mortgages; Asset, Level, 2001:Q1=100
- S&P/Case-Shiller 20-City Composite Home Price Index©, 2001-03=100
- Interbank Loans, All Commercial Banks, 2001-02-28=100
- Mortgage Debt Outstanding by Type of Holder: Major Financial Institutions: Depository Institutions, 2001:Q1=100

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Liquidity and Interbank Lending

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Liquidity and Interbank Lending

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Related Literature

▶ Financial crises:
  ▶ Diamond and Dybvig (JPE, 83); Shleifer and Vishny (JF, 92); Allen and Gale (EJ, 00), Abreu and Brunnermeier (ECTA, 03); Geanakoplos (NBER, 10); Brunnermeier and Pedersen (RFS, 09); Morris and Shin (AER, 98), He and Xiong (RFS, forth); Caballero and Krishnamurthy (JF, 08), Mendoza and Quadrini (JME, 10), Mendoza (AER, 10);

▶ Financial networks:
  ▶ Rochet and Tirole (JMCB, 96), Kyiotaki and Moore (97), Allen and Gale (JPE, 00), Freixas et al (JMCB, 00), Eisenberg and Noe (MS, 01), Lagunoff and Schreft (JET, 01), Cifuentes et al (JEEA, 05), Nier et al (JEDC, 07), Brusco and Castiglionesi (JF, 07), Caballero and Simsek (11), Zawadowski (11);

▶ Network formation:
  ▶ Leitner (JF, 05), Babus (09), Castiglionesi and Navarro (11), Cohen-Cole et al (11);

▶ Government intervention:
  ▶ Huang and Xu (EER, 99), Gorton and Huang (AER, 04), Schneider and Tornell (RES, 04), Corsetti et al (JME, 06), Morris and Shin (JIE, 06), Acharya and Yorulmazer (JFI, 07), Ennis and Keister (AER, 09), Diamond and Rajan (11), Farhi and Tirole (AER, forth).
Network Structures (Allen & Gale, 2000): Complete

![Diagram of a complete market structure](image)
Network Structures (Allen & Gale, 2000): Incomplete

Fig. 2.—Incomplete market structure
Network Structures (Allen & Gale, 2000): Disconnected

Fig. 3.—Disconnected incomplete market structure
Model

- 1-good ($), three-period economy, $t = 0, 1, 2$;
- Economy divided in $N$ regions, $N = \{1, \ldots, N\}$;
- Each region has a representative bank from $B^N = \{B^1, \ldots, B^N\}$
- Any bank has available two types of long-term, positive NPV projects:
  - A large project that pays $r_i^*$ at $t = 2$ and costs $2$ at $t = 0$;
  - A small project that pays $r_i$ at $t = 2$ and costs $1$ at $t = 0$.

Regions have continuums of depositors, each with $1$ and utility:

$$U^i(c_1, c_2) = \begin{cases} c_1, & \text{with probability } \omega_i, \\ c_2, & \text{with probability } 1 - \omega_i. \end{cases}$$
Banks’ Interaction Process

- At date 0, banks meet each other, randomly, in a pairwise fashion
- Assuming an even number $N$ of banks, there will be $N - 1$ rounds of interaction, so that, with four banks,

  Round 1: \((B^1 \leftrightarrow B^2, B^3 \leftrightarrow B^4)\)
  Round 2: \((B^1 \leftrightarrow B^3, B^2 \leftrightarrow B^4)\)
  Round 3: \((B^1 \leftrightarrow B^4, B^2 \leftrightarrow B^3)\)

- At each round of interaction, banks collect $1$ from depositors, receive $e_i$ as an equity endowment, and with that they decide whether to:
  
  \begin{enumerate}
  \item Invest in a small project;
  \item Borrow from the other bank to invest in a large project;
  \item Lend to the other bank.
  \end{enumerate}
Maturity Mismatch

- Banks partially finance long-term investments (projects or loans) with short-term funds (from early depositors)
- Banks are assumed to be cash-constrained at $t=1$, i.e., they are forced to sell - before maturity - a fraction of the investment in projects and loans in order to service early depositors
- Premature sell of assets at $t = 1$ comes at a fire-sale cost:
  1. One unit of payoff of a large project can be sold at $\rho^* < 1$;
  2. One unit of payoff of a small project can be sold at $\rho < 1$.
- Large projects are most costly to be prematurely liquidated:

  $$0 < \rho^* < \rho < 1.$$
Government Intervention

- Government reduces fire-sale costs by enhancing the market liquidity of projects and loans at $t = 1$
- Discount factors associated with the premature sell of assets are now:
  
  (i) Large projects: $\rho^* + \gamma^* (1 - \rho^*)$;
  (ii) For small projects, $\rho + \gamma (1 - \rho)$.

- No government intervention, $\gamma^* = \gamma = 0$: original fire-sale cost
- Full government intervention, $\gamma^* = \gamma = 1$: no fire-sale cost
- Too-big-to-fail policy: $\gamma^* > \gamma$
Effect of Government Intervention on Liquidity
Effect of Government Intervention on Liquidity

Small Project

Large Project
Effect of Government Intervention on Liquidity

Small Project

Large Project

Resale Price

0

t

Resale Price

0

t

Eect of Government Intervention on Liquidity
Effect of Government Intervention on Liquidity

Small Project

Resale Price

0 2 t

Large Project

Resale Price

0 2 t

Eect of Government Intervention on Liquidity
Effect of Government Intervention on Liquidity

**Small Project**

Resale Price

$r_i$  

0  2  $t$

**Large Project**

Resale Price

$r_i^*$

0  2  $t$
Effect of Government Intervention on Liquidity

**Introduction**

**Model**

**Illustration**

**Stress-Test**

**Remarks**

**Small Project**

Resale Price $r_i$

- $t=0$
- $t=1$
- $t=2$

**Large Project**

Resale Price $r_i^*$

- $t=0$
- $t=1$
- $t=2$
Effect of Government Intervention on Liquidity

Small Project

Large Project

Resale Price

$t_0$ $1$ $2$

$0$ $1$ $2$

Resale Price

$r_i$ $r_i \rho$

$r_i^*$ $r_i^* \rho^*$

$t$
Effect of Government Intervention on Liquidity

**Small Project**

- Resale Price
- $r_i$
- $r_i\rho$

**Large Project**

- Resale Price
- $r_i^*$
- $r_i^*\rho^*$

Resale Price at $t=1$

- $\lambda$
- $\lambda^*$
Effect of Government Intervention on Liquidity

Small Project

Resale Price

$\begin{align*}
& r_i \
& r_i \rho
\end{align*}$

$0 \quad 1 \quad 2 \quad t$

Resale Price at $t=1$

Factor: $\rho + \lambda (1 - \rho)$

Large Project

Resale Price

$\begin{align*}
& r_i^* \
& r_i^* \rho^*
\end{align*}$

$0 \quad 1 \quad 2 \quad t$

Resale Price at $t=1$

Factor: $\rho^* + \lambda^* (1 - \rho^*)$
Effect of Government Intervention on Liquidity

Small Project

Resale Price

\[ r_i \]

Factor: \( \rho + \lambda (1 - \rho) \)

Large Project

Resale Price

\[ r_i^* \]

Resale Price at \( t=1 \)

\[ r_i \rho \]

\[ r_i^* \rho^* \]

Factor: \( \rho^* + \lambda^* (1 - \rho^*) \)
Effect of Government Intervention on Liquidity

Small Project

Resale Price

\[ r_i \]
\[ r_i \rho \]

Resale Price at \( t=1 \)

\[ r_i \]
\[ r_i \rho \]

Factor: \( \rho + \lambda (1 - \rho) \)

Large Project

Resale Price

\[ r_i^* \]
\[ r_i^* \rho^* \]

Resale Price at \( t=1 \)

\[ r_i^* \]
\[ r_i^* \rho^* \]

Factor: \( \rho^* + \lambda^* (1 - \rho^*) \)
Effect of Government Intervention on Liquidity

Small Project

Resale Price

\[ r_i \]

\[ r_i \rho \]

0 1 2 \( t \)

Resale Price at \( t=1 \)

\[ r_i \]

\[ r_i \rho \]

0 1 \( \lambda \)

Factor: \( \rho + \lambda (1 - \rho) \)

Large Project

Resale Price

\[ r_i^* \]

\[ r_i^* \rho^* \]

0 1 2 \( t \)

Resale Price at \( t=1 \)

\[ r_i^* \]

\[ r_i^* \rho^* \]

0 1 \( \lambda^* \)

Factor: \( \rho^* + \lambda^* (1 - \rho^*) \)
Effect of Government Intervention on Liquidity

Small Project

Resale Price

Resale Price at $t=1$

Factor: $\rho + \lambda (1 - \rho)$

Large Project

Resale Price

Resale Price at $t=1$

Factor: $\rho^* + \lambda^* (1 - \rho^*)$
Timeline of Events

$\triangleright t = 0$:

1. Banks meet pairwise, randomly, deciding at each meeting:
   
   (i) Whether or not to form a link (extend or take a loan)
   (ii) How much to invest in the short-term asset
   (iii) How much of the long-term asset (project or loan) to sell in order to service early depositors

$\triangleright t = 1$:

1. Banks execute the selling strategy
2. Together with the investment in the short-term asset, proceeds are used to pay early depositors

$\triangleright t = 2$:

1. Payoffs from long-term assets (projects and loans) are realized, with the fraction not previously sold accruing to the banks
2. Banks pay late depositors and clear positions with other banks, consuming the remainings as profits
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**Network Formation Process**
Network Formation Process

Region i

Region j
Network Formation Process

Region i

\[ D^i_n \]

Region j

\[ D^j_n \]
Network Formation Process

Region i

Region j

Bank i

Bank j
Network Formation Process

Region i

\[ D_n^i \]

Region j

\[ D_n^j \]
Network Formation Process

Region i

Region j

Small Project i

Bank i

Bank j

Small Project j

Large Project i

Large Project j
Network Formation Process: Autarky

Region i

\{ 1 - \omega_i \}

Region j

\{ 1 - \omega_j \}

Small Project i

Bank i

Bank j

Small Project j

Large Project i

Large Project j
Network Formation Process: Autarky

Region i

Small Project i

Bank i

$1$

Large Project i

Region j

Small Project j

Bank j

$1$

Large Project j
Network Formation Process: Autarky

Region i

1 - \omega_i
\omega_i

Region j

1 - \omega_j
\omega_j

Small Project i

Bank i

Large Project i

Small Project j

Bank j

Large Project j
Network Formation Process: Autarky

Region i

Small Project i

Bank i

$1 \rightarrow r_i$

1 - $\omega_i$ $\omega_i$

Region j

Small Project j

Bank j

$1 \rightarrow r_j$

1 - $\omega_j$ $\omega_j$
Network Formation Process: Autarky

Region i

\[ 1 - \omega_i \]

\[ \omega_i \]

Region j

\[ 1 - \omega_j \]

\[ \omega_j \]

Bank i

\$1 \rightarrow r_i \rightarrow \text{Small Project i} \leftarrow \$1

Bank j

\$1 \rightarrow r_j \rightarrow \text{Small Project j} \leftarrow \$1

Large Project i

Large Project j
Network Formation Process: Autarky

Bank i

Bank j
Network Formation Process: j to i

Region i

Region j

Bank i

Bank j

Small Project i

Small Project j

Large Project i

Large Project j

Introduction

Model

Illustration

Stress-Test

Remarks
Network Formation Process: j to i

Region i

Small Project i

Bank i

Large Project i

Region j

Small Project j

Bank j

Large Project j

$1$
Network Formation Process: j to i

Region i

Region j

Bank i

Bank j

$1$

Small Project i

Large Project i

Small Project j

Large Project j

Illustration

Model

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Remarks
Network Formation Process: j to i

Region i

Region j

Bank i

Bank j

Small Project i

Small Project j

Large Project i

Large Project j

$1$

$1$

$1$

$2$
Network Formation Process: j to i

Region i

\{ 1 - \omega_i \}

Region j

\{ 1 - \omega_j \}

Bank i

Small Project i

Large Project i

Bank j

Small Project j

Large Project j

$1$

$r_i^*$

$2$

$1$

$1$
Network Formation Process: j to i

Region i

$1$

Small Project i

Bank i

Large Project i

Region j

$1$

Bank j

Large Project j

$1$

Small Project j

$\rho_i$

$\rho_j$

$1 - \omega_i$

$1 - \omega_j$

Introduction  
Model  
Illustration  
Stress-Test  
Remarks
Network Formation Process: j to i

Region i

Bank i

Small Project i

Large Project i

Region j

Bank j

Small Project j

Large Project j

1 - \omega_i

1 - \omega_j

r_j

r^*_i

\omega_i

\omega_j

$1

$1

$2

$1
Network Formation Process: j to i
Network Formation Process: i to j

Region i

Region j

Small Project i

Bank i

Bank j

Small Project j

Large Project i

Large Project j
Network Formation Process: i to j

Region i

Bank i

Small Project i

Large Project i

Region j

Bank j

Small Project j

Large Project j

$1$

$1$
Network Formation Process: i to j

Region i

Bank i

Large Project i

Small Project i

Region j

Bank j

Large Project j

Small Project j

Illustration

Model

Introduction

Remarks

Network Formation Process: i to j

Region i

Bank i

Large Project i

Small Project i

Region j

Bank j

Large Project j

Small Project j
Network Formation Process: i to j

- **Region i**: Small Project i, Bank i, Large Project i
- **Region j**: Small Project j, Bank j, Large Project j

Diagram:
- $1$ from Small Project i to Bank i
- $1$ from Bank i to Bank j
- $1$ from Bank j to Small Project j
- $2$ from Large Project i to Large Project j
Network Formation Process: i to j

Region i

Small Project i

Bank i

Large Project i

Region j

Small Project j

Bank j

Large Project j

$1$

$1$

$1$

$1$

$2$

$r_j^*$
Network Formation Process: i to j

Region i

Bank i

Region j

Bank j

Small Project i

Large Project i

Large Project j

Small Project j

$1$

$r_i$

$1 - \omega_i$

$1 - \omega_j$

$r^*_j$

$1$

$1$

$2$
Network Formation Process: i to j

Introduction

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Illustration

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Network Formation Process: i to j

Region i

Small Project i

Large Project i

Bank i

Bank j

Region j

Small Project j

Large Project j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j

Network Formation Process: i to j
Network Formation Process: i to j
Network Formation Process: Continuation

\[
\begin{align*}
\text{Region } i & \quad \{ \quad \text{Region } j \quad \}
\end{align*}
\]

\[
\begin{align*}
\text{Small Project } i & \quad \text{Large Project } i \\
\text{Bank } i & \quad r_i \\
\text{Small Project } j & \quad \text{Large Project } j \\
\text{Bank } j & \quad r_j
\end{align*}
\]

\[
\begin{align*}
1 - \omega_i & \quad \omega_i \\
1 - \omega_j & \quad \omega_j
\end{align*}
\]
Network Formation Process: Continuation

Network Diagram:
- Region i
  - Bank i
    - Small Project i
    - Large Project i
  - $1$ flow between Bank i and Small Project i
  - $r_i$ flow between Bank i and Large Project i
  - $r_i^*$ flow between Small Project i and Large Project i
- Region g
  - Bank g
  - Small Project g
  - Large Project g
  - $1$ flow between Bank g and Small Project g
  - $r_g$ flow between Bank g and Large Project g
  - $r_g^*$ flow between Small Project g and Large Project g
  - $2$ flow between Small Project g and Large Project g
Network Formation Process: Continuation
Network Formation Process: Continuation

\[ D_n^i = \omega_i (1 - \omega_i) D_n^y = \omega_y (1 - \omega_y) \]

\[ r_i \rightarrow \text{Bank } i \rightarrow \text{Large Project } i \]
\[ r_y \rightarrow \text{Bank } y \rightarrow \text{Large Project } y \]

\[ r_{i}^{*} \rightarrow \text{Small Project } i \rightarrow \text{Bank } i \]
\[ r_{y}^{*} \rightarrow \text{Small Project } y \rightarrow \text{Bank } y \]
Network Formation Process: Continuation

Introduction

Model

Illustration

Stress-Test

Remarks

Diagram:

- Region i
  - $D^i_n$
  - $\omega_i$
  - $1 - \omega_i$
  - $r_i$
  - $\omega_i$
  - $1 - \omega_i$
- Region o
  - $D^o_n$
  - $\omega_o$
  - $1 - \omega_o$
  - $r_o$
  - $\omega_o$
  - $1 - \omega_o$

Connections:

- Small Project i
  - $1$
  - $r_i$
  - $1$
  - $1$
  - $2$

- Bank i
  - $r^*_i$
  - $r_i$
  - $1$
  - $r_i$

- Bank o
  - $r^*_o$
  - $r_o$
  - $1$
  - $1$

- Large Project i
  - $1$

- Large Project o
  - $1$

- Small Project o
  - $1$

Financial Flows:

- $1$
- $2$
- $r^*_i$
- $r^*_o$
Characterization of the Financial System

Networks are characterized by the adjacency matrix,

\[ X = \begin{bmatrix}
0 & \chi_{12} & \cdots & \chi_{1N} \\
\chi_{21} & 0 & \cdots & \chi_{2N} \\
\vdots & \vdots & \ddots & \vdots \\
\chi_{N1} & \chi_{N2} & \cdots & 0
\end{bmatrix}, \]

and the parameters of the model,

\[ r^* = \begin{bmatrix}
r_1^* \\
r_2^* \\
\vdots \\
r_N^*
\end{bmatrix}, \quad r = \begin{bmatrix}
r_1 \\
r_2 \\
\vdots \\
r_N
\end{bmatrix}, \quad \omega = \begin{bmatrix}
\omega_1 \\
\omega_2 \\
\vdots \\
\omega_N
\end{bmatrix}, \quad e = \begin{bmatrix}
e_1 \\
e_2 \\
\vdots \\
e_N
\end{bmatrix}, \]

plus the fire-sale and government intervention parameters, \( \rho, \rho^* \) and \( \gamma \) and \( \gamma^* \), respectively.
Payoff Shocks

Large Project

Small Project

$r_i^*$

$-2$

$-1$
Payoff Shocks

Large Project

Small Project

\[ r_i^* \]

\[ \delta^* \]

\[ r_i \]

\[ \delta \]
**Payoff Shocks**

**Large Project**

\[ r_i^* (1 - \delta^*) \]

\[ t=0 \quad t=1 \quad t=2 \]

\[ -2 \]

**Small Project**

\[ r_i (1 - \delta) \]

\[ t=0 \quad t=1 \quad t=2 \]

\[ -1 \]
Measures of Fragility: Single Shocks

Consider a network with $N$ banks, and take an arbitrary bank $i$ facing shocks in its projects. The set

$$D^i := \{ j \mid \Delta^j > W^j \}$$

contains all those banks that become distressed after bank $i$ is hit by a shock.

The cardinality of this set, $|D^i|$, thus, gives the total number of failures following bank $i$'s shocks.

The index

$$f^i := |D^i|$$

gives, therefore, a measure of the relative fragility of the network to bank $i$, for a particular realization of shocks that it faces.

By doing the same for every bank $j \neq i$ in the network and combining all the results, for instance taking

$$f := \sum_{i \in N} f^i,$$

one has a measure of the overall fragility of the network relative to the individual failure of its members.
Example

Network with 6 banks, generated under $\rho^* = 0.05\rho$, $\gamma^* = 0.8$ and $\gamma = 0.3$, and its non-government counterpart, i.e., the one obtained in the same way but with $\gamma^* = \gamma = 0$. The other parameters used are given by:

<table>
<thead>
<tr>
<th>Bank</th>
<th>$r^*$</th>
<th>$r$</th>
<th>$\omega$</th>
<th>$e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank 1</td>
<td>3.23</td>
<td>1.19</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Bank 2</td>
<td>3.00</td>
<td>1.01</td>
<td>0.17</td>
<td>0.12</td>
</tr>
<tr>
<td>Bank 3</td>
<td>2.22</td>
<td>1.19</td>
<td>0.15</td>
<td>0.11</td>
</tr>
<tr>
<td>Bank 4</td>
<td>2.55</td>
<td>1.08</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Bank 5</td>
<td>2.97</td>
<td>1.00</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Bank 6</td>
<td>2.71</td>
<td>1.21</td>
<td>0.14</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Example (cont’d)

<table>
<thead>
<tr>
<th>Bank</th>
<th>LR</th>
<th>Links</th>
<th>Failures</th>
<th>Networth</th>
<th>Bank</th>
<th>LR</th>
<th>Links</th>
<th>Failures</th>
<th>Networth</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00</td>
<td>0.69</td>
<td>4.00</td>
<td>1152.00</td>
<td>4.08</td>
<td>6.00</td>
<td>0.82</td>
<td>3.00</td>
<td>1598.00</td>
<td>1.82</td>
</tr>
<tr>
<td>3.00</td>
<td>0.79</td>
<td>2.00</td>
<td>1138.00</td>
<td>1.86</td>
<td>5.00</td>
<td>0.68</td>
<td>3.00</td>
<td>1074.00</td>
<td>3.67</td>
</tr>
<tr>
<td>2.00</td>
<td>0.63</td>
<td>5.00</td>
<td>1108.00</td>
<td>6.04</td>
<td>2.00</td>
<td>0.62</td>
<td>4.00</td>
<td>745.00</td>
<td>5.32</td>
</tr>
<tr>
<td>1.00</td>
<td>0.67</td>
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Final Remarks

- Trade-off: networth and fragility
- Introducing measures of welfare and characterizing an efficient frontier of financial networks
- Can the model generate the type of financial networks most typically observed (core-periphery)?
- How to identify networks?