Financial networks and systemic fragility

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Motivations

- Financial crisis of 2007-2009: shocks can propagate through a variety of channels and cause large disruptions in the economic environment

- Battiston et al. (2016, Science) highlight that the literature is at its early stages in systemic risk estimation as existent models do not consider feedback mechanisms between economic agents

- No way to evaluate the feedback importance between the real and financial sectors → possible underestimation
Contributions

• Flexible framework that models the feedback effect between the real and financial sectors
• The feedback effect gives rise to a novel micro-level financial accelerator that amplifies shocks originating in financial or real sectors
• Multilayer financial networks to estimate systemic risk in a general form

• Application on a comprehensive and unique dataset on micro-level firm and bank data for Brazil → we show that the feedback effect is really important
Related literature

• Nature and causes of systemic risk (SR) in networks are studied either in the real or financial sectors, but not both endogenously → no space for feedback

• Financial sector (interbank) networks
  – Allen and Gale (2000, JPE): ↑ Denser networks ⇒ ↓ SR
  – Blume et al. (2013): ↑ Denser networks ⇒ ↑ SR
  – Acemoglu et al. (2015, AER): phase transition and SR = f (network, shock)
    • When shock is small: ↑ Denser networks ⇒ ↓ SR
    • When shock is large: ↑ Denser networks ⇒ ↑ SR

• Real sector (firm-firm) networks
  – Acemoglu et al. (2012, Econometrica): the role of interconnectedness in amplifying shocks in artificial real sector networks
Our model: feedback & financial accelerator

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- Thus, the increase in banks’ stress levels feedbacks to the real economy through a credit crunch, which exacerbates the initial shock on firms
- Closing the negative cycle, firms are further stressed due to the credit availability constraints imposed by banks, leading them into reduced levels of investment and consumption
- This negative effect on firms’ production levels causes a potential decrease in profit, which is then transmitted back to banks in the form of loan defaults
Our model

- **Vertices**: economic agents
- **Layers**: set of economic agents of the same nature
- **Edges**: potential vulnerabilities
  - **Bank to bank**: potential interbank loan defaults
  - **Firm to firm**: potential defaults in the trade network
  - **Bank to firm**: potential loan default in the real sector
  - **Firm to bank**: potential credit crunches
Dynamical system: definitions & states

- **Nonlinear dynamical system** → conditionally linear as long as no defaults occur
- Dynamical system’s state: **financial stress** → fraction of the loss absorbing capability that has been potentially compromised → similar to Battiston et al. (2012)
- **Gives a sense of continuum between insolvency and solvency**
Dynamical system: stress propagation rule

Bank $i$’s stress update rule:

$$h_i(t) = \min \left[ 1, h_i(t-1) + \sum_{j \in B} V_{ij}^{(bank-bank)} \Delta h_j(t-1) + \sum_{u \in F} V_{iu}^{(bank-firm)} \Delta f_u(t-1) \right]$$

Firm $k$’s stress update rule:

$$f_k(t) = \min \left[ 1, f_k(t-1) + \sum_{u \in F} V_{ku}^{(firm-firm)} \Delta f_u(t-1) + \sum_{j \in B} V_{kj}^{(bank-firm)} \Delta h_j(t-1) \right]$$
Definition of intra-layer vulnerability matrices

Interbank lending contagion channel

\[ V_{ij}^{(bank-bank)} \triangleq \frac{A_{ij}^{(bank-bank)}}{e_i} \]

- \( A_{ij}^{(bank-bank)} \): exposure of bank \( i \) to \( j \)
- \( e_i \): equity of bank \( i \)

Firm credit lines contagion channel

\[ V_{ku}^{(firm-firm)} \triangleq \frac{A_{ku}^{(firm-firm)}}{e_k} \]

- \( A_{ku}^{(firm-firm)} \): exposure of firm \( k \) to \( u \)
- \( e_k \): equity of firm \( k \)
Definition of inter-layer vulnerability matrices

\[ V_{iu}^{(bank\text{-}firm)} \triangleq \frac{A_{iu}^{(bank\text{-}firm)}}{e_i} \]

\[ V_{kj}^{(firm\text{-}bank)} \triangleq (1 - \rho_{kj}) \frac{A_{jk}^{(bank\text{-}firm)}}{e_k} \]

- \( \rho_{kj} \in [0,1] \): firm \( k \)'s ability to substitute bank \( j \) with another bank financer

- bank \( j \) is perfectly substitutable: \( V_{kj}^{(firm\text{-}bank)} = 0 \)
- bank \( j \) is not substitutable: \( V_{kj}^{(firm\text{-}bank)} \propto A_{jk}^{(bank\text{-}firm)} \)

“inability to substitute”
How to estimate bank substitutability?

- \( \rho_{kj} \in [0, 1] \): firm \( k \)'s ability to substitute bank \( j \) with another bank financer

\[
\rho_{kj} = [1 - \lambda_k] [1 - RL_{kj}]
\]

- \( \lambda_k \in [0, 1] \): firm \( k \)'s dependency on bank financing

\[
\lambda_k = \frac{\text{bank}}{\text{bank} + \text{bond} + \text{equity}}
\]

- \( RL_{kj} \in [0, 1] \): relationship lending between \( k \) and \( j \)

\[
RL_{kj} = \frac{\sum_t e^{-t} A_{jk}^{(\text{bank-firm})}(t)}{\sum_{i,t} e^{-t} A_{ik}^{(\text{bank-firm})}(t)}
\]
Definition of systemic risk

- **Intuition**: Initial shock is more harmful the more it stresses economic agents.
- **Systemic risk**: linear combine all the equilibrium stress levels weighted by corresponding importance of each economic agent.

\[
SR = SR^{(\text{financial})} + SR^{(\text{real})} = \sum_{i \in B} h_i^* v_i + \sum_{k \in F} f_k^* v_k - I_\varepsilon
\]

- \( h_i^*, f_k^* \): convergence stress levels
- \( I_\varepsilon \): initial shock
- \( v_j \): economic importance

System's total assets

Initial shock \( I_\varepsilon \)

Additional stress \( SR \)
Theoretical analysis

- System has two dynamical phases
  - **Transient phase**: defaults occur
  - **Persistent phase**: no defaults occur

- Persistent phase → contraction mapping → unique fixed point
Systemic risk: Brazilian financial and real sectors

- Unique supervisory data sets held by the Central Bank of Brazil

- Financial sector layer
  - Edges: only unsecured financial assets
  - Vertices: banking institutions

- Real sector layer
  - Edges: no edges (firm trade network: purchases on credit)
  - Vertices: firms that hold stocks on BM&Fbovespa

- Connection between financial and real sector layers
  - Edges: short-term loans that banks grant to firms → we use the Brazilian credit register
Systemic risk: common sectorial shock $\rightarrow$ 25% smallest sector

- Only additional stress is reported $\rightarrow$ we can easily identify the extent of the contagion and amplification components of systemic risk
- Average over years 2013 – 2015 $\rightarrow$ large persistence
Feedback importance: with & without it

Different profiles for different sectors

Systemic risk gap ranging from 15% to 25%

For a small shock!
Rank inconsistencies: feedback & no feedback versions

Inconsistencies arise because of heterogeneities in the feedback mechanism linking the real and financial sectors.

Systemic risk of the riskiest sector [% real sector total assets]

Food & Beverage

Tertiary

Metal extraction

Feedback curve

No feedback curve

Date: July/2015
Systemic risk: full sectorial defaults

- **Oil & gas** and metal extraction can withstand small shocks because of their relatively large equities.
- With full sectorial shocks, *albeit an extremely implausible assumption*, they would generate considerable risk to the economy.

**Systemic risk [% real sector total assets]**

- Oil and Gas: 18%
- Metal Extraction: 15%
- Food and Beverage: 12%
- Tertiary Sector: 9%
- Electric Power: 6%
- Construction: 4%
- Other: 3%
- Pulp and Paper: 3%
- Industrial Machineries: 2%
- Chemical: 2%
- Agriculture & Fisheries: 1%
- Technology: 0%
Battiston et al. (2012)’s original DebtRank \( \leq \) Bardoscia et al. (2015)’s differential DebtRank \( \leq \) Our model

- Adds vulnerability cycles
- Adds real sector + feedback

Graphs:
- Original DebtRank (bank-bank only)
- Differential DebtRank (bank-bank only)
- Feedback-based systemic risk (bank-bank & bank-firm)
Conclusions

- General model to assess systemic risk
  - Here, we only show two layers (real and financial sector layers)
  - The extensibility of the model is in the design of the vulnerability matrices

- Stress feedback between real and financial sectors is important in the Brazilian case
  - Regardless of whether the shock starts in the real or financial sector

- Our model may be useful for financial regulation and for financial stability monitoring tools
QUESTIONS & SUGGESTIONS

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