Financial networks over the business cycle

Alexandr Kopytov

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Motivation

- Years prior to financial crisis saw growing financial interconnectedness
  - Credit risk pooling (securitization), loan portfolio overlap, derivatives (CDS), interbank lending, etc.

- Financial architecture shapes systemic risk
  - ‘Robust-yet-fragile’ property: Risk sharing vs correlated failures
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  - ‘Robust-yet-fragile’ property: Risk sharing vs correlated failures

- This paper: a dynamic model with interlinked financial sector

1. How does systemic risk build up over time?

2. Why do systemic financial crises happen at the end of credit booms?
Interconnectedness is due to common portfolio holdings

- Asset commonality is a crucial source of systemic risk
  e.g., Borio (2003), Elsinger et al. (2006)

- Tractable, yet captures essential trade-off
  e.g., Allen et al. (2012), Cabrales et al. (2017)

Risk-sharing links are costly to form

Main novelty: time-varying and endogenous interconnectedness

Incentives to form links change over the credit cycle

Systemic risk is governed by evolving density of financial links
Framework

- Interconnectedness is due to common portfolio holdings
  - Asset commonality is a crucial source of systemic risk
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- **Finite** number of underlying sources of risks (asset classes/projects)
  - Risk sharing: individual default risk ↓; joint default probability ↑
  - Risk-sharing links are costly to form
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- Main novelty: **time-varying** and **endogenous** interconnectedness
  - Incentives to form links change over the credit cycle
  - Systemic risk is governed by evolving density of financial links
Main results

- Positive analysis: Systemic risk is built up during ‘good’ times
  - Systemic crises occur at the end of credit booms
  - Credit is abundant but real investment is not productive
  - Strong asset commonality due to active risk sharing

- Welfare analysis: Inefficiently high systemic risk
Literature

▶ Fragility of financial networks

_Difference: dynamic model of systemic risk and financial fragility_

▶ Macro models with financial frictions

_Difference: role of financial links for shock propagation and aggregate fluctuations_

▶ Interconnectedness and systemic risk: Empirics
I. Model
Model: Overview

- Closed economy, infinite horizon
- Two types of agents: households and banks
- Long-lived representative household
  - Owns all assets but relies on banks for real investment (no HH-banks frictions)
  - Makes intertemporal consumption/savings decision
- One-period banks
  - Raise funds from households, extend credit to real economy
The structure of the economy

Ex ante identical banks raise equity from HH. Investing banks receive access to risky projects. Noninvesting banks lend to investing ones. Inv. banks share risks by cross-investing/asset swaps. Project-specific shocks are realized; many banks are hit due to portfolio overlap. Interbank debt is repaid; costly defaults are possible. HH is repaid; HH makes intertemporal savings choice.
The structure of the economy

Ex ante identical banks raise equity from HH

Investing banks receive access to risky projects
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The structure of the economy

- **Time sequence**:
  - \( t \) to \( t + 1 \)

- **Ex ante identical banks** raise equity from HH

- **Investing banks** receive access to risky projects

- **Noninvesting banks** lend to investing ones

- Investing banks share risks by cross-investing or asset swaps

- Project-specific shocks are realized; many banks are hit due to portfolio overlap

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Financial networks over the business cycle 8 / 22
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Infected investing bank

Shocked investing bank

Household

Island Bank

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Financial networks over the business cycle 8 / 22
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- Island
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Investing banks receive risky projects.

Ex ante identical banks raise equity from HH.
Problem of investing banks

- Investing bank $i$ maximizes its expected earnings

$$\max_{\mu, \rho, \{\omega_{ij}\}_{j=1}^N} \frac{a_0}{1 - \mu} \times \left[ \frac{1}{N} \sum_{j=1}^N \int_x^{R - \rho \mu \omega_{ij}} (R - \omega_{ij}x - \rho \mu) d\Phi(x) - f \sum_{j \neq i} \omega_{ij} \right]$$

- Assets
- Expected net returns
- Linking costs
Problem of investing banks

▶ Investing bank $i$ maximizes its expected earnings

$$\max_{\mu, \rho, \{\omega_{ij}\}_{j=1}^N} \frac{a_0}{1 - \mu} \times \left[ \frac{1}{N} \sum_{j=1}^N \int_{x}^{\frac{R - \rho \mu}{\omega_{ij}}} (R - \omega_{ij}x - \rho \mu) d\Phi(x) - f \sum_{j \neq i} \omega_{ij} \right]$$

▶ $\rho$ makes noninvesting banks break even

$$\rho_s = \rho \frac{1}{N} \sum_{j=1}^N \Phi \left( \frac{R - \rho \mu}{\omega_{ij}} \right) + \frac{1}{\mu} \frac{1}{N} \sum_{j=1}^N \int_{\frac{R - \rho \mu}{\omega_{ij}}}^{\infty} (R - \omega_{ij}x - \theta) d\Phi(x)$$

- No default
- Default loss
- Default
Problem of investing banks

- Investing bank $i$ maximizes its expected earnings

$$\max_{\mu, \rho, \{\omega_{ij}\}_{j=1}^N} \frac{a_0}{1 - \mu} \times \left[ \frac{1}{N} \sum_{j=1}^{N} \int_{\omega_{ij}}^{R - \rho \mu} (R - \omega_{ij}x - \rho \mu) d\Phi(x) - f \sum_{j \neq i} \omega_{ij} \right]$$

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- Borrowing capacity: $\mu \leq \bar{\mu} \equiv \frac{M-1}{M}$, where each island has $M$ banks
  - Assumed to be binding in the theoretical analysis
Portfolio structure

**Proposition**

Portfolio \( \{\omega_{ij}\}_{i=1}^{N} \) of investing bank \( i \) has the following form:

<table>
<thead>
<tr>
<th>Bank ( i )</th>
<th>Project ( j &lt; i )</th>
<th>Project ( i )</th>
<th>Project ( k &gt; i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \omega_{ij} = \frac{1-\alpha}{N-1} )</td>
<td>( \omega_{ii} = \alpha &gt; \frac{1}{N} )</td>
<td>( \omega_{ik} = \frac{1-\alpha}{N-1} )</td>
<td></td>
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- All projects generate the same diversification benefit
- Projects \( j \neq i \) are costly to invest \( \Rightarrow \) portfolio is tilted toward project \( i \)
Portfolio structure

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</table>

- All projects generate the same diversification benefit
- Projects \(j \neq i\) are costly to invest \(\Rightarrow\) portfolio is tilted toward project \(i\)

Define financial interconnectedness as \(\text{IC} = \frac{1 - \alpha}{1 - 1/N} \in [0, 1]\)
Interconnectedness and systemic risk

- Systemic crisis: simultaneous defaults of all investing banks

\[ p_{syst}^d = 1 - \Phi \left( N \times \frac{R - \rho \mu}{IC} \right) \]
Interconnectedness and systemic risk

- Systemic crisis: simultaneous defaults of all investing banks

\[ p_{syst}^d = 1 - \Phi \left( N \times \frac{R - \rho \mu}{IC} \right) \]

- High when banks’ profit margin \( R - \rho \mu \) is narrow
Interconnectedness and systemic risk

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- High when banks' profit margin \( R - \rho \mu \) is narrow
- ...and interconnectedness is high
Interconnectedness and systemic risk

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- High when banks' profit margin \( R - \rho \mu \) is narrow
- ...and interconnectedness is high

Proposition

- Profit margin \( R - \rho \mu \) increases in projects' return \( R \); interconnectedness \( \text{IC} \) and probability of systemic crisis \( p_{syst}^d \) decrease in \( R \);

- \( R \) decreases in total amount of assets \( A \) and increases in aggregate productivity \( z \).
Household

- Representative household solves

\[
V(A, z, x) = \max_{C, K', L} \left[ \frac{1}{1 - \psi} \left( C - \frac{L^{1+\nu}}{1+\nu} \right)^{1-\psi} + \beta \mathbb{E} V(A', z', x') \right]
\]

s.t. \( A' = rA + wL - C + \chi \)

\[
\log z' = \rho_z \log z + \sigma_z \epsilon_z', \; \epsilon_z \sim \mathcal{N}(0, 1)
\]

- Return on assets \( r \) is

\[
r = R - \frac{1}{N} x - \frac{N^d(R, x)}{N} \theta - \frac{1}{A} \chi
\]

- \( N^d \) is the number of defaulted banks

- \( \chi \) is total risk-sharing costs
II. Numerical analysis
## Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Source/Target</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preferences</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IES</td>
<td>$1/\gamma = 0.2$</td>
<td>Standard</td>
</tr>
<tr>
<td>Frisch elasticity</td>
<td>$1/\nu = 1$</td>
<td>Standard</td>
</tr>
<tr>
<td>Time discounting</td>
<td>$\beta = 0.97$</td>
<td>Standard</td>
</tr>
<tr>
<td><strong>Production technology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital share</td>
<td>$\eta = 0.33$</td>
<td>Standard</td>
</tr>
<tr>
<td>Capital depreciation</td>
<td>$\delta = 0.087$</td>
<td>10% annually ($\times$ shocks)</td>
</tr>
<tr>
<td><strong>Aggregate shocks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Persistence</td>
<td>$\rho_z = 0.83$</td>
<td>US postwar data [Moments]</td>
</tr>
<tr>
<td>St.dev. of innovations</td>
<td>$\sigma_z = 0.019$</td>
<td>US postwar data</td>
</tr>
<tr>
<td><strong>Banking sector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of islands</td>
<td>$N = 10$</td>
<td>Source</td>
</tr>
<tr>
<td>Risk-sharing cost</td>
<td>$f = 0.005$</td>
<td>Craig and Ma (2018)</td>
</tr>
<tr>
<td>Default loss</td>
<td>$\theta = 0.1$</td>
<td>BGG (1999)</td>
</tr>
<tr>
<td>Storage technology</td>
<td>$\rho_s = 1.009$</td>
<td></td>
</tr>
<tr>
<td>Number of banks per island</td>
<td>$M = 670$</td>
<td></td>
</tr>
<tr>
<td><strong>Pareto project-specific shocks</strong>, $\Phi(x) = 1 - (x/\bar{x})^\gamma$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tail index</td>
<td>$\gamma = 3$</td>
<td>Gabax (2009)</td>
</tr>
<tr>
<td>Minimum value</td>
<td>$\bar{x} = 0.088$</td>
<td>Financial crises frequency</td>
</tr>
</tbody>
</table>
Typical systemic crisis

Aggregate productivity, $z$

[?? dev. from mean]

[Graph showing the trend of aggregate productivity over years]

Project-specific shock, $x$

[?? dev. from mean]

[Graph showing the trend of project-specific shock over years]

Total assets, $A$

[?? dev. from mean]

[Graph showing the trend of total assets over years]

Interconnectedness, $IC$

[?? dev. from mean]

[Graph showing the trend of interconnectedness over years]

Systemic crisis prob., $p_{syst}^d$

[??]

[Graph showing the trend of systemic crisis probability over years]

Profit margin, $R - \rho \mu$

[??]

[Graph showing the trend of profit margin over years]
Typical systemic crisis

- Aggregate productivity, $z$
  - [% dev. from mean]

- Project-specific shock, $x$
  - [% dev. from mean]

- Total assets, $A$
  - [% dev. from mean]

- Interconnectedness, $IC$
  - [% dev. from mean]

- Systemic crisis prob., $p_{\text{syst}}$
  - [%]

- Profit margin, $R - \rho \mu$
  - [%]

Keywords:
- Credit, productivity, lending distance
- Interconnectedness
- Housing and diversification
- Spreads
- Shocks and crises
Financial crises: Systemic vs nonsystemic

Aggregate productivity, $z$
[\% dev. from mean]

Project-specific shock, $x$
[\% dev. from mean]

Total assets, $A$
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Interconnectedness, $IC$
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Systemic crisis prob., $p_{syst}^d$
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Profit margin, $R - \rho \mu$
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[Images of graphs showing trends over time for each metric]
Financial crises: Statistics

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<td>All</td>
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<td>1.75</td>
<td>3.04</td>
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<td>Credit bust</td>
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<td>Output boom</td>
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<td>1.21</td>
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<td>Output bust</td>
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<td>−3.12</td>
</tr>
<tr>
<td>Frequency</td>
<td>4.2</td>
<td>1.7</td>
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All numbers are in %. Boom/bust is defined as an average 2 years growth of HP-filtered credit/output prior to/after crises. ***, **, * denote whether the value is statistically different from zero at 1%, 5% and 10% levels, respectively.
Financial crises: Statistics

- Systemic crises are preceded by large credit booms
  - The model matches the frequency of systemic crises (targeted)

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Financial crises: Statistics

- Systemic crises are preceded by large credit booms
  - The model matches the frequency of systemic crises (targeted)
- Credit booms are less pronounced prior to nonsystemic crises
  - The model matches the frequency of nonsystemic crises (not targeted)

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III. Welfare analysis
Inefficiencies

- Incomplete markets (interbank debt financing) and real default losses
- Pecuniary externality: agents do not internalize their impact on $R \Rightarrow$ overaccumulation of assets, too high systemic risk
Inefficiencies

- Incomplete markets (interbank debt financing) and real default losses

- Pecuniary externality: agents do not internalize their impact on $R \Rightarrow$ overaccumulation of assets, too high systemic risk

- (Constrained) planner takes this into account by reducing credit extension in booms

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<th>$A$</th>
<th>$C$</th>
<th>$L$</th>
<th>$Y$</th>
<th>$IC$</th>
<th>$p^d_{syst}$</th>
<th>$p^d_{nonsyst}$</th>
<th>$\kappa^{DE\to SB}$</th>
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<tr>
<td>$DE$</td>
<td>4.26</td>
<td>1.27</td>
<td>1.08</td>
<td>1.71</td>
<td>0.941</td>
<td>1.7%</td>
<td>2.5%</td>
<td></td>
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<tr>
<td>$SB$</td>
<td>4.00</td>
<td>1.25</td>
<td>1.06</td>
<td>1.65</td>
<td>0.928</td>
<td>1.1%</td>
<td>2.9%</td>
<td>0.05%</td>
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Welfare impacts of financial innovations

- Recent financial innovations (securitization) facilitated risk sharing
- A decline in risk-sharing cost $f$ leads to:
  - Lower expected default losses due to better risk sharing
  - Further increase in investment in the risky technology

![Graph showing welfare gain](image)

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IV. Concluding remarks
Conclusion

▶ A dynamic GE model of robust-yet-fragile financial systems
▶ Financial fragility endogenously changes over the credit cycle
  ▶ Systemic banking crises burst at the end of credit booms
▶ Decentralized eq’m: overconnected networks, too frequent crises
▶ Financial innovations are destabilizing: number of systemic crises ↑
  ▶ ...but welfare implications are generally ambiguous
Appendix
Credit and aggregate productivity

- Total factor productivity [% dev. from linear trend]
  - Trend is constructed starting from 1990

- Loans to nonfinancial private sector [% dev. from linear trend]
  - Trend is constructed starting from 1990

- TFP around financial crises: Gorton and Ordonez (2018)
- Credit around financial crises: Jorda, Schularick, and Taylor (2017)
Credit and aggregate productivity: UK

Total factor productivity
[\% dev. from linear trend]

Loans to nonfinancial private sector
[\% dev. from linear trend]

Source: FRED.
Trend is constructed starting from 1990

Trend is constructed starting from 1990
Credit and aggregate productivity: Full series

Total factor productivity

Loans to nonfinancial private sector

Source: Fernald (2014)

Source: Jorda, Schularick, and Taylor (2017)
Mortgages and geographic diversification

- Geographic diversification is used to mitigate risks by mortgage investors (Cotter, Gabriel, and Roll, 2014)
  - Freddie Mac’s 2007 annual report: “A key characteristic of our credit risk portfolio is diversification along a number of critical risk dimensions [such as] product mix, LTV ratios and geographic concentrations...”
  - Substantial pre-crisis decline in share of geographically concentrated mortgage lenders (Loutskina and Strahan, 2011)

- Geographic concentration is significantly negatively associated with proportion of RMBS deal rated AAA (Nadauld and Sherlund, 2009; Ashcraft, Goldsmith-Pinkham, and Vickery, 2010)
Financial innovation: Reduction in cost of link formation

Cost of link formation

Risk-sharing innovation

Credit

Interconnectedness

Systemic crisis probability

Individual bank’s default probability

$t_{\text{innovation}}$
Interconnectedness: Measures I

Securitization

Nonagency MBS + ABS
Assets

100 largest US BHC (FR Y-9C)
Interconnectedness: Measures II

Average banks' lending distance

Granja, Leuz, and Rajan (2019)
Interconnectedness: Measures III

Syndicated loan portfolio overlap

Interconnectedness: Measures IV

Noncore liabilities

Liabilities − Deposits

 Assets

Source: Barattieri et al. (2018), 100 largest US BHC (FR Y-9C)
Interconnectedness: Measures V

- PCA of banks’, hedge funds’, broker/dealers’, insurance firms’ returns

Source: Billio, Getmansky, Lo, and Pelizzon (2012)
Interconnectedness: Measures VI

- Average equity returns correlation across 12 major U.S. banks

Source: Huang, Zhou, and Zhu (2009)
Interconnectedness: Measures VII

- Procyclicality of $forward - \Delta CoVaR$

Source: Adrian and Brunnermeier (2016)
Interconnectedness: Measures VIII

- Volatility interconnectedness between major international banks

Source: Demirer, Diebold, Liu, and Yilmaz (2016)
Interconnectedness: Measures IX

- Country-level interbank flows network: fraction of all possible links established

Source: Minoiu and Reyes (2013)
Interconnectedness: Measures X

- International interbank syndicated loans

Source: Hale (2012)
Interconnectedness: Measures XI

- US syndicated loans: Loan share retained by the originating bank and total loan issuance

Source: Ivashina and Scharfstein (2010)
Securitization: Agency vs private

U.S. mortgage-backed securities issuance, 1985–2010

Source: Simkovic (2013)
Mortgage crisis: Regional pattern

Source: Bernanke (2008)

Figure 3: Change in Mortgage Delinquency by County
(4th quarter 2004 to 4th quarter 2007)

Source: TrenData from TransUnion, LLC

Source: Bernanke (2008)
Measure of systemic risk

- Systemic risk: tail comovement between individual institutions and the whole system
  - CoVaR measure of Adrian and Brunnermeier (2016)
    - $SR = \mathbb{P}[\text{All banks default}|\text{Bank } i \text{ defaults}]
    \[ SR = \frac{\left(\frac{1-\alpha}{N-1}\right)^\gamma}{\frac{1}{N} \alpha^\gamma + \frac{N-1}{N} \left(\frac{1-\alpha}{N-1}\right)^\gamma} \]
    - $\frac{\partial SR}{\partial \alpha} < 0$: higher systemic risk in densely connected systems
Comparative statics: Summary

- Regime 1: high projects’ return $R$, no investment in storage, $\mu = \bar{\mu}$
- Regime 2: low $R$, nonzero investment in storage, $\mu < \bar{\mu}$

Share of risky investment, $\frac{1-\bar{\mu}}{1-\mu}$

Interconnectedness, $IC$

Spread, $R - \rho \mu$

Systemic default prob., $p_{syst}^d$

Individual default prob., $p_{ind}^d$

Interbank rate, $\rho$
Interconnectedness and systemic risk: Derivation details

Denote profit margin $\xi = R - \rho \bar{\mu}$. Then bank’s problem can be written as

$$\max_{\rho,\alpha} \frac{a_0}{1 - \bar{\mu}} \left[ R - \rho_s \bar{\mu} - \theta g_1(\alpha, \xi) - \frac{1}{N} \mathbb{E}_x \tilde{x} - f(1 - \alpha) \right],$$

s.t. $\rho_s = \rho - \frac{1}{\bar{\mu}} \left( \theta g_1(\alpha, \xi) + g_2(\alpha, \xi) \right)$.

First order conditions imply

$$B(\alpha, \xi) = \frac{\partial g_1}{\partial \alpha} + \frac{\partial g_1}{\partial \alpha} \frac{\partial g_2}{\partial \xi} - \frac{\partial g_1}{\partial \xi} \frac{\partial g_2}{\partial \alpha} - \frac{f}{\theta} = 0.$$

Under sufficiently thin tailed project-specific shocks

$$\frac{\partial B}{\partial \alpha} > 0, \quad \frac{\partial B}{\partial \xi} < 0.$$

Hence, optimal $\alpha$ and $\xi$ move in the same direction.
Number of islands

- In the benchmark analysis we use $N = 10$
  - Results are largely unchanged if $N$ is increased (and $\bar{x}$ is recalibrated)
- Number of two-digit SIC industries (Cai et al., 2018)
- 10 largest BHCs account for 70% of total assets (FR Y-9C)
- 10 PCs explain $\approx 80\%$ of financial firms’ return variation (Billio et al., 2012)
Number of islands

- In the benchmark analysis we use $N = 10$
  - Results are largely unchanged if $N$ is increased (and $\bar{x}$ is recalibrated)
- Number of two-digit SIC industries (Cai et al., 2018)
- 10 largest BHCs account for 70% of total assets (FR Y-9C)
- 10 PCs explain $\approx 80\%$ of financial firms’ return variation (Billio et al., 2012)
- Main asset classes of BHCs:

<table>
<thead>
<tr>
<th>Weight</th>
<th>Weight</th>
</tr>
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<tbody>
<tr>
<td>Residential RE Loans</td>
<td>14.12%</td>
</tr>
<tr>
<td>C&amp;I Loans</td>
<td>9.69%</td>
</tr>
<tr>
<td>Repo</td>
<td>9.02%</td>
</tr>
<tr>
<td>Agency MBS</td>
<td>8.80%</td>
</tr>
<tr>
<td>Consumer Loans</td>
<td>8.36%</td>
</tr>
<tr>
<td>Cash</td>
<td>7.55%</td>
</tr>
<tr>
<td>Commercial RE Loans</td>
<td>6.55%</td>
</tr>
<tr>
<td>ABS and Other Debt Securities</td>
<td>6.46%</td>
</tr>
<tr>
<td>Residual Loans</td>
<td>4.62%</td>
</tr>
</tbody>
</table>

100 largest BHCs from FR Y-9C, 2001-2017
Macroeconomic moments

- Aggregate productivity: \( \log z' = \rho_z \log z + \sigma_z \epsilon_z', \epsilon_z' \sim N(0, 1) \)
  - \( \sigma_z \) and \( \rho_z \) are chosen to match persistence and st.dev. of Solow residuals

<table>
<thead>
<tr>
<th></th>
<th>Output</th>
<th>Hours</th>
<th>Consumption</th>
<th>Investment</th>
</tr>
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<tbody>
<tr>
<td>Data</td>
<td>1.98</td>
<td>1.70</td>
<td>0.74</td>
<td>5.06</td>
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<tr>
<td>Model</td>
<td>2.23</td>
<td>1.60</td>
<td>1.71</td>
<td>4.16</td>
</tr>
</tbody>
</table>

Standard deviations of macro variables: Model vs postwar US data (1950-2017). All series are HP-filtered with the smoothing parameter of \( \lambda = 6.25 \).

- \( x \) shocks and occasional financial crises generate excess kurtosis and negative skewness of output
  - Data: Skew(\( Y \)) = -0.57, Kurt(\( Y \)) = 3.52
  - Model (benchmark): Skew(\( Y \)) = -0.16, Kurt(\( Y \)) = 3.64
  - Model (no default losses): Skew(\( Y \)) = -0.02, Kurt(\( Y \)) = 3.14
Impulse response functions: Shock to $z$

- **Aggregate productivity, $z$**
- **Output, $Y$**
- **Labor, $L$**
- **Assets, $A$**
- **Interconnectedness, $IC$**
- **Systemic def. prob., $p_{syst}^d$ [%]**
Impulse response functions: Shock to $x$

Project-specific shock, $x$
- $x=x_1$, no systemic crisis
- $x=x_1+\epsilon$, systemic crisis

Output, $Y$

Labor, $L$

Assets, $A$

Interconnectedness, $IC$

Systemic def. prob., $p_{syst}^{d}$ [%]
Banks’ returns

Net interest margin for all U.S. banks [%]

Return on equity for all U.S. banks [%]

TED spread [%]

Source: FRED
Run-up of a systemic financial crisis:
- Banks become more alike ⇒ less likely to default in isolation
- Probability of some financial distress grows only marginally (≈CDX, top tranche)
Shocks leading to systemic crises

- **Aggregate productivity $z$:**
  - High in the run-up of credit booms
  - Low right prior to systemic crises

\[
\sigma = \frac{\sigma_z}{\sqrt{1 - \rho_z^2}}
\]

$t = 0$: systemic crisis
$t = -10$: ten periods before systemic crisis
Shocks leading to systemic crises

- **Aggregate productivity \( z \):**
  - High in the run-up of credit booms
  - Low right prior to systemic crises

\[ \sigma = \frac{\sigma_z}{\sqrt{1 - \rho_z^2}} \]

\( t = 0 \): systemic crisis
\( t = -10 \): ten periods before systemic crisis

- **Systemic crises burst in densely connected networks**
  - 88% occur when \( IC \geq \bar{IC} \)

Project-specific shock \( x \) at the moment of systemic crisis

\[ P[x \leq q_p\%] = p\% \]

\( IC < \bar{IC} \): below average connectedness
\( IC \geq \bar{IC} \): above average connectedness
Inspecting the mechanism: Interconnectedness and crises

- \( f \downarrow \Rightarrow IC \uparrow \) and \( A \uparrow \Rightarrow p_{syst}^d \uparrow , p_{nonsyst}^d \downarrow \)

![Graphs showing average interconnectedness, systemic crises frequency, and nonsystemic crises frequency over the business cycle.](image-url)
Inspecting the mechanism: Interconnectedness and crises

- $f \downarrow \Rightarrow IC \uparrow$ and $A \uparrow \Rightarrow p_{syst}^d \uparrow$, $p_{nonsyst}^d \downarrow$

- *Level effect*: same change in $f$ holding average $IC$ fixed

![Graphs showing the relationship between diversification cost, interconnectedness, and systemic/nonsystemic crises frequency.](image-url)
Inspecting the mechanism: Interconnectedness and crises

- $f \downarrow \Rightarrow IC \uparrow$ and $A \uparrow \Rightarrow p^d_{syst} \uparrow$, $p^d_{nonsyst} \downarrow$

- *Level* effect: same change in $f$ holding average $IC$ fixed

- *Time variation* effect: fixed $IC$ over the business cycle

**Average interconnectedness**
- $IC(f)$
- No level change
- No time variation

**Systemic crises freq.[%]**
- $p^d_{syst}(f)$
- No level change
- No time variation

**Nonsystemic crises freq.[%]**
- $p^d_{nonsyst}(f)$
- No level change
- No time variation
## Financial crises: Statistics

<table>
<thead>
<tr>
<th></th>
<th>Model</th>
<th>Data: RR</th>
<th>Data: JST</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>All</td>
<td>Systemic</td>
<td>All</td>
</tr>
<tr>
<td>Credit boom</td>
<td>1.75***</td>
<td>3.04***</td>
<td>1.36**</td>
</tr>
<tr>
<td>Credit bust</td>
<td>−3.27***</td>
<td>−5.95***</td>
<td>−1.96***</td>
</tr>
<tr>
<td>Output boom</td>
<td>1.00***</td>
<td>1.21***</td>
<td>1.34***</td>
</tr>
<tr>
<td>Output bust</td>
<td>−1.94***</td>
<td>−3.12***</td>
<td>−2.20***</td>
</tr>
<tr>
<td>Frequency</td>
<td>4.2</td>
<td>1.7</td>
<td>4.4</td>
</tr>
</tbody>
</table>

All numbers are in %. Boom/bust is defined as an average 2 years growth of HP-filtered credit/output prior to/after crises. 'JST' and 'RR' stand for Jorda, Schularick, and Taylor (2016) and Romer and Romer (2017), respectively. ***,**,* denote whether the value is statistically different from zero at 1%, 5% and 10% levels, respectively.
Romer and Romer (2017): Crises definition

- Financial distress in 24 OECD countries, 1967-2012
  - Consistent narrative source: OECD Economic Outlook

- *Nonsystemic crisis* should at most involve “...significant problems in the financial sector that are not so severe [to be] central to recent macroeconomic developments or to the economy’s prospects”

- *Systemic crisis*, at a minimum, should “...involve problems in the financial sector that are widespread and severe, central to the performance of the economy as a whole”
Systemic crises: Prediction

- Prediction of model-implied probability of systemic crisis

\[
\text{OLS: } \log p_{syst,t+1}^d
\]

\[
\begin{align*}
\log(z_t) & \quad -8.3 & . & . & -12.0 \\
\log(A_t) & \quad . & 4.4 & . & 4.3 \\
\log(IC_t) & \quad . & . & 19.2 & 4.4 \\
\end{align*}
\]

\[
R^2 \quad 7.4\% \quad 52.7\% \quad 72.0\% \quad 78.9\%
\]

Based on 1,000,000 simulations. All coefficients are significant at 1% level

- Early warning signals for systemic crises

\[
\text{Logit: } \mathbb{I}\{\text{systemic crisis}\}_{t+1}
\]

\[
\begin{align*}
R^2_{pseudo} & \quad 0.6\% & 4.2\% & 6.5\% & 6.8\% \\
\text{Type I error} & \quad 100\% & 85.9\% & 60.5\% & 69.7\% \\
\text{Type II error} & \quad 0\% & 5.2\% & 13.5\% & 10.0\% \\
\# \text{ of signals} & \quad 0 & 53,930 & 139,854 & 103,632 \\
\end{align*}
\]

Based on 1,000,000 simulations and 17,170 realizations of systemic crises. Threshold is chosen to have Type II error of 10% for specification \((z_t, A_t, IC_t)\)
Credit-to-output ratio

Credit-to-output ratio
[\% \text{ dev. from mean}]

Years

Systemic
Nonsystemic
Decentralized equilibrium: Recursive formulation

- The household solves

\[ V^{DE}(a, A, z, x) = \max_{c, l, a'} \frac{1}{1 - \psi} \left( c - \frac{l^{1 + \nu}}{1 + \nu} \right)^{1 - \psi} + \beta \mathbb{E} V^{DE}(a', A', z', x'), \]

s.t. \[ a' + c = r(A, z, x) a + w(A, z) l + \chi(\alpha(R(A, z))), \]

\[ r(A, z, x) = R(A, z) - \frac{1}{N} x - \frac{N^d(R(A, z), x)}{N} \theta - \frac{1}{A} \chi(\alpha(R(A, z))), \]

\[ R(A, z) = \eta z A^{\eta - 1} L(A, z)^{1 - \eta} + 1 - \delta, \]

\[ w(A, z) = (1 - \eta) z A^{\eta} L(A, z)^{-\eta}, \]

\[ A' = A'(A, z, x). \]

- \( N^d(R, x) \) and \( \alpha(R) \) solve interbank problem

- Labor market clears: \( l(A, A, z) = L(A, z) \)

- Goods market clears: \( C + A' = z A^{\eta} L^{1 - \eta} + A \left( 1 - \delta - \frac{1}{N} x - \frac{N^d}{N} \theta \right) \)

- Aggregate law of motion is consistent with individual choice: \( a'(A, A, z, x) = A'(A, z, x) \)
Constrained planner: Recursive formulation

- The planner makes saving decisions for the household and allows labor and interbank markets to operate like in the DE case.
- The planner internalizes that over-accumulation of assets leads to a fragile financial system. It also internalizes that linking costs are rebated to the household.

$$V^{SB}(A, z, x) = \max_{C, A'} \frac{1}{1 - \psi} \left( \frac{C - L(A, z)^{1+\nu}}{1 + \nu} \right)^{1-\psi} + \beta \mathbb{E} V^{SB}(A', z', x'),$$

s.t. $$A' + C = zA^{\eta} L(A, z)^{1-\eta} + A \left( 1 - \delta - \frac{1}{N} x - \frac{N^d(R(A, z), x)}{N} \theta \right).$$

- $N^d(R(A, z), x)$ solves interbank problem.
- $L(A, z)$ solves $L(A, z)\nu = (1 - \eta)zA^{\eta} L(A, z)^{-\eta}$.
- $R(A, z) = \eta zA^{\eta-1} L(A, z)^{1-\eta} + 1 - \delta$. 
In the first best, defaults are not costly ($\theta = 0$) and the economy reduces to a standard RBC model:

$$V_{FB}^F(A, z, x) = \max_{C, L, A'} \frac{1}{1 - \psi} \left( C - \frac{L^{1+\nu}}{1 + \nu} \right)^{1-\psi} + \beta \mathbb{E} V_{FB}^F(A', z', x'),$$

s.t. $A' + C = zA^n L^{1-n} + A \left( 1 - \delta - \frac{1}{N} x \right)$. 

<table>
<thead>
<tr>
<th></th>
<th>$K$</th>
<th>$C$</th>
<th>$L$</th>
<th>$Y$</th>
<th>$IC$</th>
<th>$p^d_{syst}$</th>
<th>$p^d_{nonsyst}$</th>
<th>$\kappa^{DE \rightarrow i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE</td>
<td>4.26</td>
<td>1.27</td>
<td>1.08</td>
<td>1.71</td>
<td>0.941</td>
<td>1.7%</td>
<td>2.5%</td>
<td>.</td>
</tr>
<tr>
<td>SB</td>
<td>4.00</td>
<td>1.25</td>
<td>1.06</td>
<td>1.65</td>
<td>0.928</td>
<td>1.1%</td>
<td>2.9%</td>
<td>0.05%</td>
</tr>
<tr>
<td>FB</td>
<td>4.67</td>
<td>1.34</td>
<td>1.12</td>
<td>2.81</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>0.78%</td>
</tr>
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</table>
Transitional dynamics: \( DE \rightarrow SB \)

\[
\Delta W = \sum_{t=0}^{\infty} W_t, \text{ where } W_t = \beta^t E_0 \left[ u(C_t^{SB}, L_t^{SB}) - u(C_t^{DE}, L_t^{DE}) \right]
\]

- Dissaving at the initial stages of transition \( \Rightarrow \) welfare gains
- (Discounted) welfare losses at a lower steady state later on
  - Fewer painful systemic crises in the new steady state
Cost of intertemporal inefficiencies

No rebate externality

Consider an economy where linking costs are *not* rebated to the hh

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>C</th>
<th>L</th>
<th>Y</th>
<th>IC</th>
<th>$p_{syst}^d$</th>
<th>$p_{nonsyst}^d$</th>
<th>$\kappa_{DE\rightarrow SB}$</th>
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<tr>
<td>DE</td>
<td>4.26</td>
<td>1.27</td>
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<td>0.928</td>
<td>1.1%</td>
<td>2.9%</td>
<td>0.05%</td>
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No rebate externality

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<td>3.80</td>
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<tr>
<td>C</td>
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<td>L</td>
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<td>Y</td>
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<td>IC</td>
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<td>0.913</td>
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<tr>
<td>$p_{syst}^d$</td>
<td>1.7%</td>
<td>0.9%</td>
</tr>
<tr>
<td>$p_{nonsyst}^d$</td>
<td>2.5%</td>
<td>3.1%</td>
</tr>
<tr>
<td>$\kappa_{DE\rightarrow SB}$</td>
<td>.</td>
<td>0.12%</td>
</tr>
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</table>

Rebate and oversaving externalities work against each other

$DE$ and $SB$ allocations get further from each other
Aligned risk preferences

- Benchmark case: risk-averse households, risk-neutral banks

- What if preferences are aligned?
  - No analytical results, more complicated numerical algorithm
  - Results are affected marginally

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>C</th>
<th>L</th>
<th>Y</th>
<th>IC</th>
<th>$p^d_{\text{syst}}$</th>
<th>$p^d_{\text{nonsyst}}$</th>
<th>$\kappa^{DE \rightarrow SB}$</th>
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<tbody>
<tr>
<td><strong>Benchmark case</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DE</td>
<td>4.26</td>
<td>1.27</td>
<td>1.08</td>
<td>1.71</td>
<td>0.941</td>
<td>1.7%</td>
<td>2.5%</td>
<td>.</td>
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<tr>
<td>SB</td>
<td>4.00</td>
<td>1.25</td>
<td>1.06</td>
<td>1.65</td>
<td>0.928</td>
<td>1.1%</td>
<td>2.9%</td>
<td>0.05%</td>
</tr>
<tr>
<td><strong>Aligned risk preferences</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$DE^{\text{aligned pref.}}$</td>
<td>4.27</td>
<td>1.27</td>
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<tr>
<td>$SB^{\text{aligned pref.}}$</td>
<td>3.99</td>
<td>1.24</td>
<td>1.06</td>
<td>1.65</td>
<td>0.924</td>
<td>1.1%</td>
<td>3.3%</td>
<td>0.05%</td>
</tr>
</tbody>
</table>
Optimal policy: Savings tax

- Policy to reach $SB$ allocation: state-contingent tax on savings $A'$

$$1 + \tau(A, z, x) = \beta \mathbb{E} \left[ \left( \frac{C_{SB}' - \frac{1}{1+\nu} L_{SB}'^{1+\nu}}{C_{SB} - \frac{1}{1+\nu} L_{SB}^{1+\nu}} \right)^{-\psi} \times r(A_{SB}', z', x') \right]$$

- Tax is positive on average (0.38%)
- Tax prevents large credit booms and speeds up post-crises recoveries
Flat tax on savings

- State-contingent tax might be challenging to implement
- Flat tax corrects the steady state but not business cycle fluctuations

<table>
<thead>
<tr>
<th></th>
<th>DE</th>
<th>SB</th>
<th>DE^{flat} (\tau)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>4.26</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>(IC)</td>
<td>0.941</td>
<td>0.928</td>
<td>0.925</td>
</tr>
<tr>
<td>(p^d_{syst})</td>
<td>1.7%</td>
<td>1.1%</td>
<td>1.2%</td>
</tr>
<tr>
<td>(p^d_{nonsyst})</td>
<td>2.5%</td>
<td>2.9%</td>
<td>2.9%</td>
</tr>
<tr>
<td>(\kappa^{DE\rightarrow i})</td>
<td>.</td>
<td>0.05%</td>
<td>0.03%</td>
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</tbody>
</table>
Financial innovations: Aligned risk preferences

- Benchmark case: risk-averse households, risk-neutral banks
- Systemic crises are more painful for hhs ⇒ too many connections?
  - Might be important for welfare impacts of financial innovations
- Aligned preferences: risk-sharing cost, not risk aversion, limits IC
  - Minor impact of preferences misalignment on the welfare analysis

![Graph showing welfare gain, \( \kappa^{DE \rightarrow DE^f} \)]

<table>
<thead>
<tr>
<th></th>
<th>DE</th>
<th>SB</th>
<th>DE(^{optimal\ f} )</th>
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</thead>
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<td>4.19</td>
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<tr>
<td>IC</td>
<td>0.938</td>
<td>0.924</td>
<td>0.921</td>
</tr>
<tr>
<td>( p_{syst} )</td>
<td>1.7%</td>
<td>1.1%</td>
<td>1.5%</td>
</tr>
<tr>
<td>( p_{nonsyst} )</td>
<td>3.0%</td>
<td>3.3%</td>
<td>3.9%</td>
</tr>
<tr>
<td>( \kappa^{DE \rightarrow i} )</td>
<td>.</td>
<td>0.05%</td>
<td>0.02%</td>
</tr>
</tbody>
</table>
Hedging: Interest rate derivatives

Interest rate hedging

Value weighted
Equal weighted

Interest rate derivatives held not for trading
Assets

Source: Rampini et al. (2017), 100 largest US BHC (FR Y-9C)
Asset accumulation policy: State-dependent fragility

- Point $O$: wide profit margin, low $IC \Rightarrow$ low $p_{syst}^d$
- Point $C$: narrow profit margin, high $IC \Rightarrow$ high $p_{syst}^d$
Asset accumulation policy: State-dependent fragility

- Point O: wide profit margin, low IC ⇒ low $p_{syst}^d$
- Point C: narrow profit margin, high IC ⇒ high $p_{syst}^d$
Credit, aggregate productivity, and lending distance

**Total factor productivity**

[% dev. from linear trend]

Source: Fernald (2014)

**Loans to nonfinancial private sector**

[% dev. from linear trend]

Source: Jorda, Schularick, and Taylor (2017)

**Average banks’ lending distance**

Source: Granja, Leuz, and Rajan (2019)