Modelling Contagion in Financial Networks

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Motivation

- The financial system has become increasingly **interconnected** and **complex**
- Supervision of individual financial institutions insufficient
  $\Rightarrow$ **Network structure** of interconnections matters
- Systemic risk takes various forms and is highly dynamic
  $\Rightarrow$ Better understanding needed to safeguard **financial stability**

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- This talk: **agent-based models** and **network theory** to address these questions

The interconnectedness of the Financial System Increased

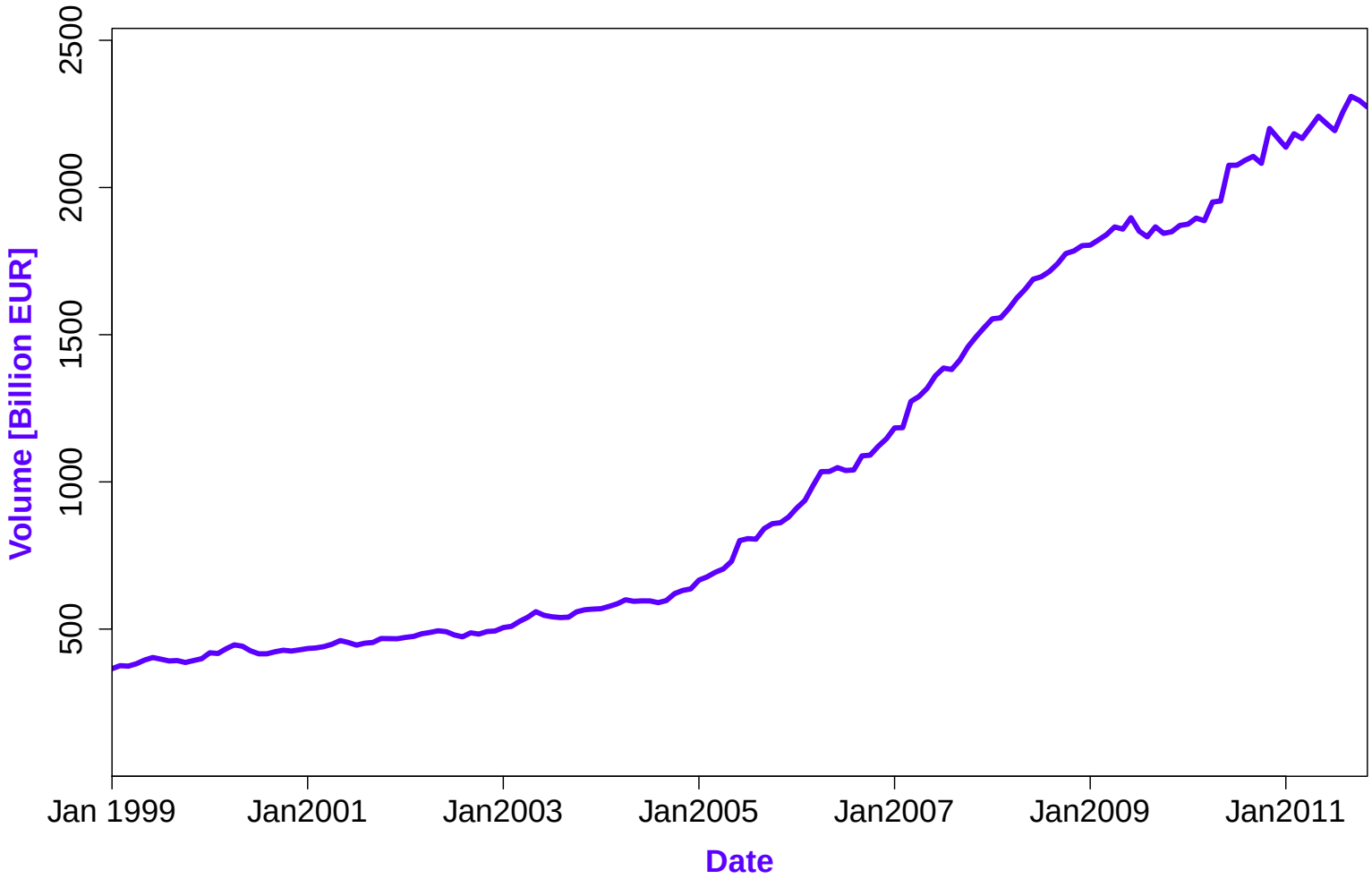

Figure: Deposits of euro area MFIs vs. other euro area MFIs, not seasonally adjusted.
Source: ECB

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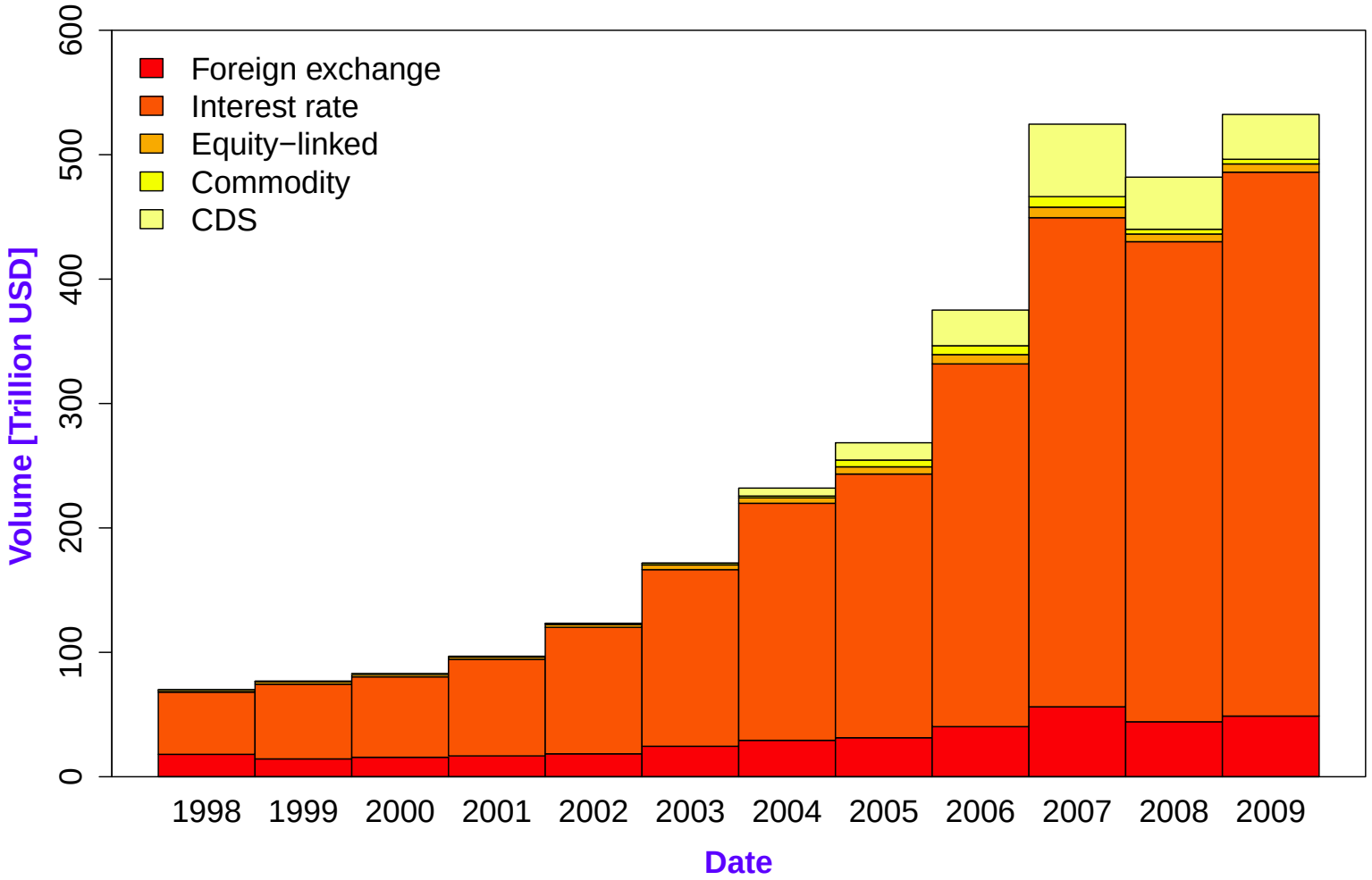

Figure: Global over-the-counter derivatives markets, notional amounts of contracts outstanding. Source: IMF

Indirect linkages amplify the risk of fire-sales

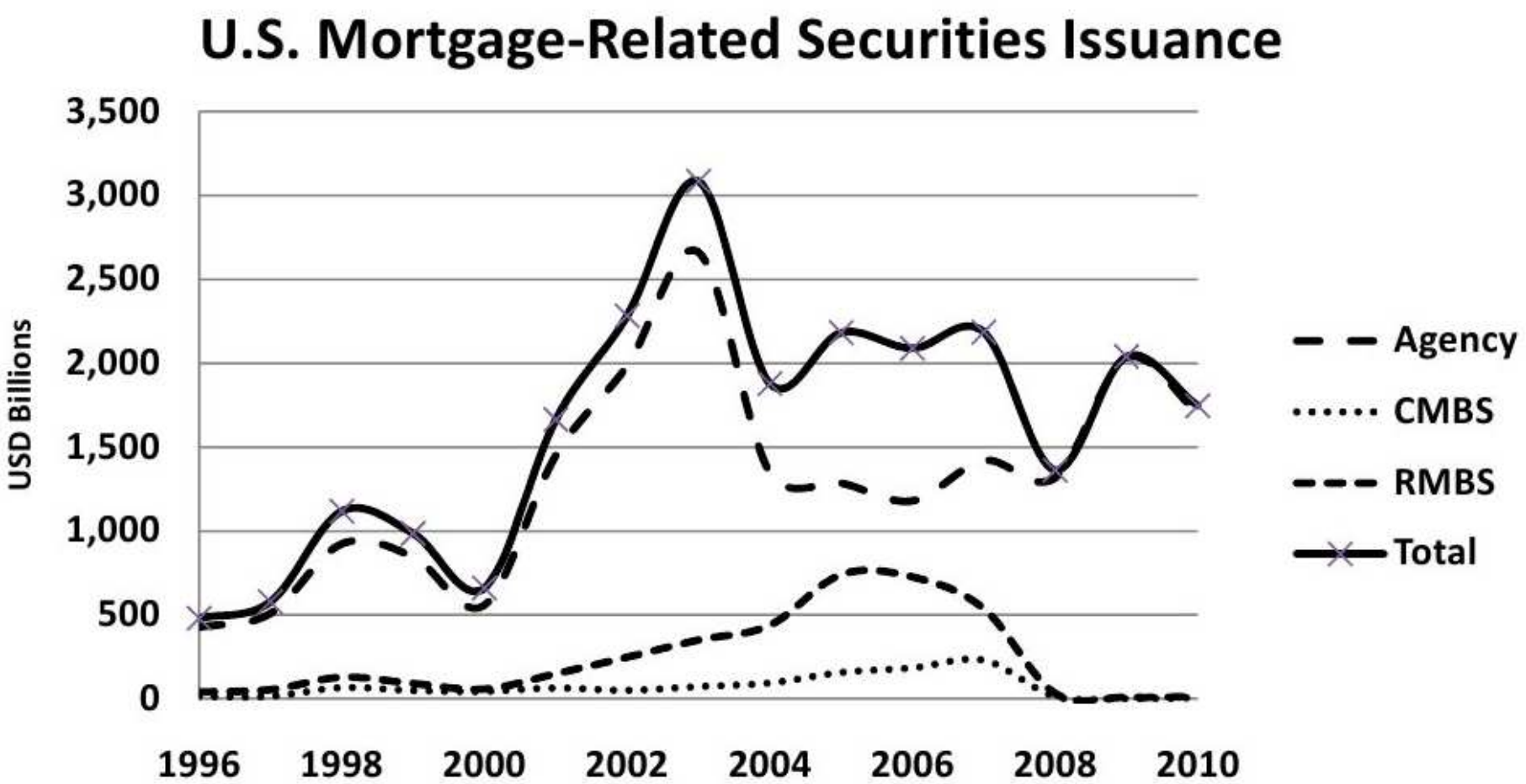

Figure: U.S. Mortgage-Related Securities Issuance. Source: Gorton and Metrick (2010)

Indirect linkages amplify the risk of fire-sales

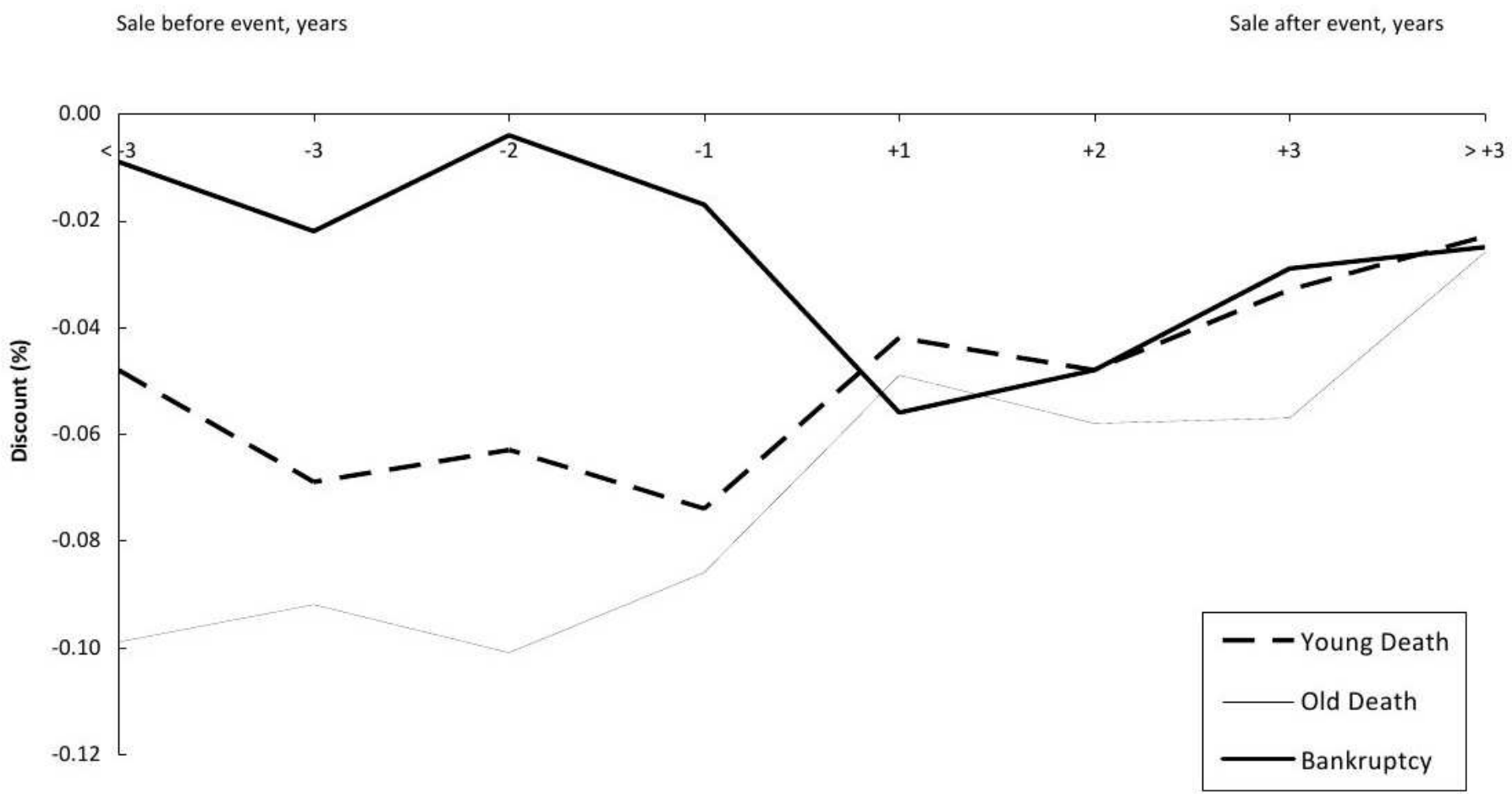

Figure: Forced Sales Discounts and Time Between Sale and Event. Source: Campbell, Giglio and Pathak (2012)

Indirect linkages amplify the risk of fire-sales

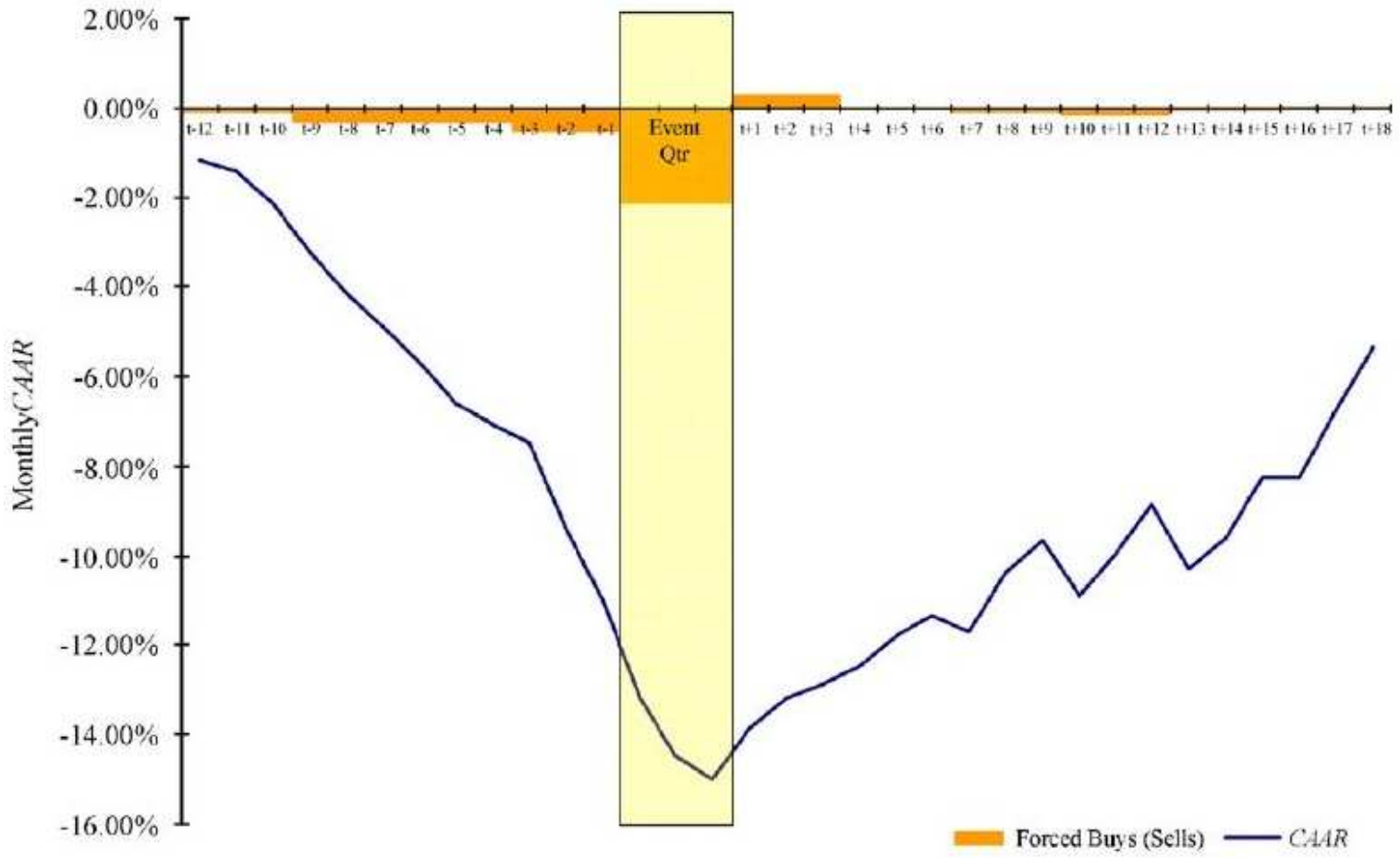

Figure: Cumulative average abnormal returns around mutual fund fire sales. Source: Coval and Stafford (2007)

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Do We Need Yet Another Paper?

Literature on Financial Networks

- Allen and Gale (2000), Freixas et al. (2000)
- Haldane and May (2011), Gai et al. (2011), Gai and Kapadia (2008)
- Becher et al. (2008), Gabrieli (2011), Chang et al. (2008), Brink and Georg (2011), Markose et al. (2010)

Literature on Fire-sales

- Shleifer and Vishny (1992): specialised asset holders are simultaneously in distress and sell to non-specialists
- Allen and Gale (1994): endogenous market participation

Literature on Multi-Agent Models:

- Iori et al. (2006), Nier et al. (2007)
- **However:** risk-free investments, no central bank, mechanistic agent behaviour, "fine-tuning"

What is Systemic Risk?

Definition by impact

- FSB definition: *"a risk of disruption to financial services that is (i) caused by an impairment of all or parts of the financial system and (ii) has the potential to have serious negative consequences for the real economy."*

Definition by cause

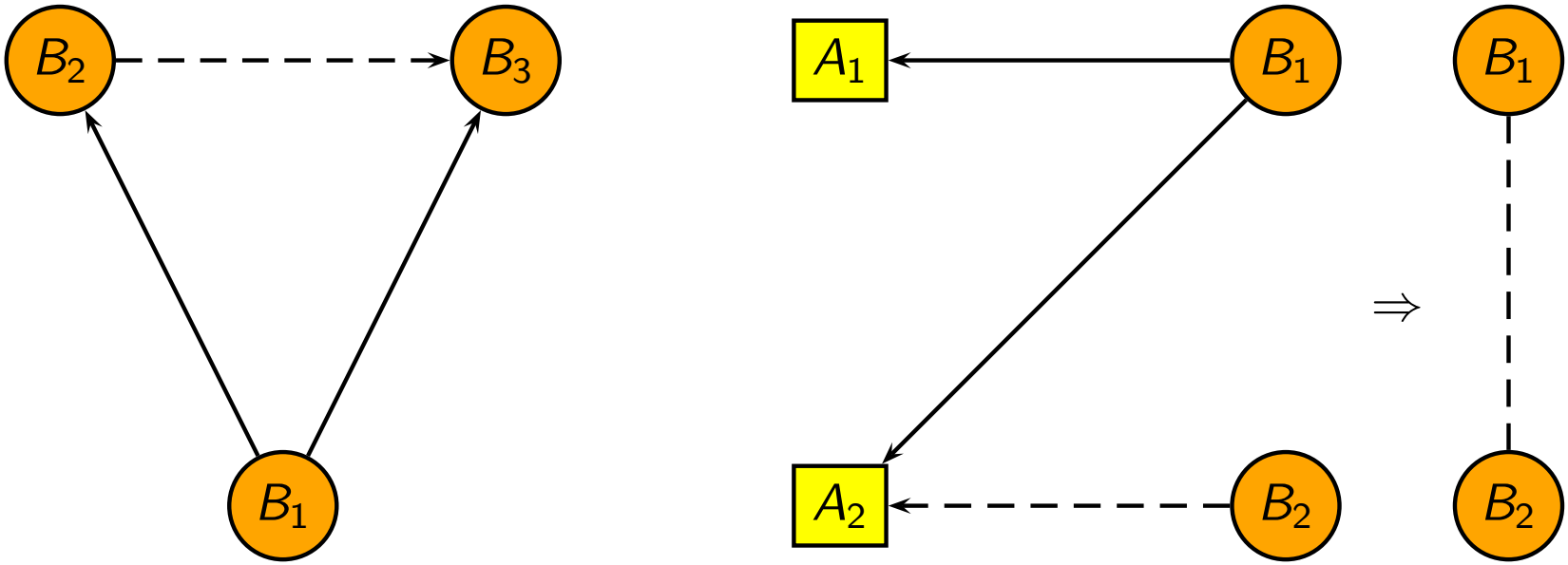


Figure: Left: direct connections (counterparty risk, contagion). Right: indirect connections (common shocks, fire-sales).

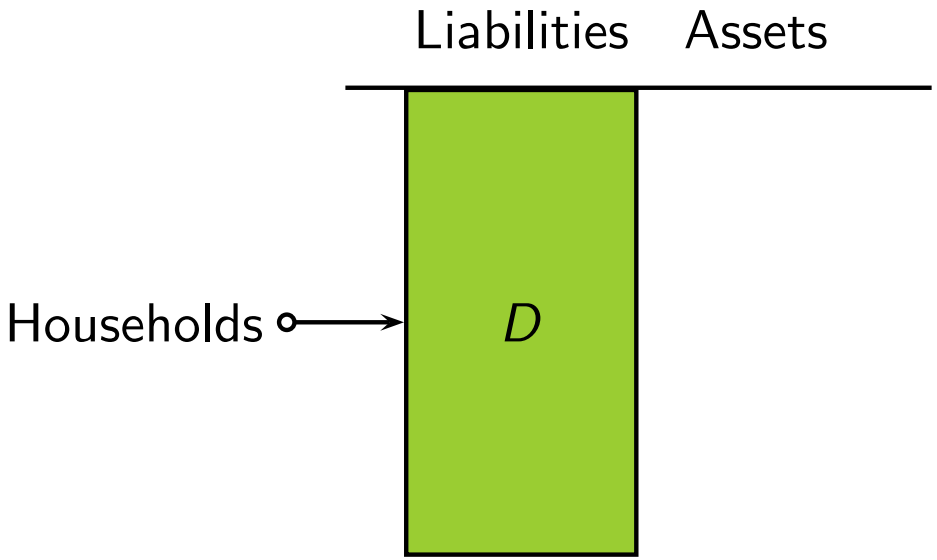
Focus of this Paper

- Complete dry-up of interbank markets in September 2008, central banks were forced to unprecedented non-standard measures
  $\Rightarrow$ **Q1: Can central banks stabilize interbank markets?**

- Systemic risk requires macroprudential oversight in addition to microprudential supervision
  $\Rightarrow$ **Q2: What are robust network structures?**

- Different forms of systemic risk can act differently on the financial system
  $\Rightarrow$ **Q3: What are the optimal policy responses?**

Microfoundations of Banks Determine Model



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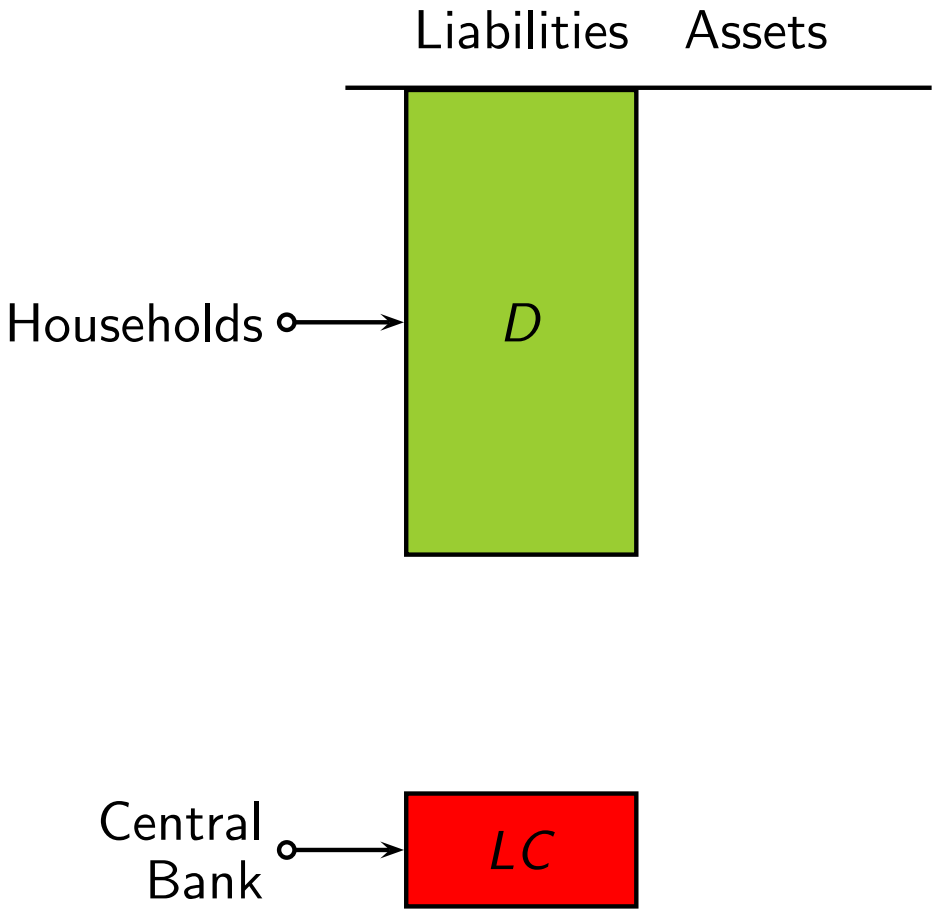

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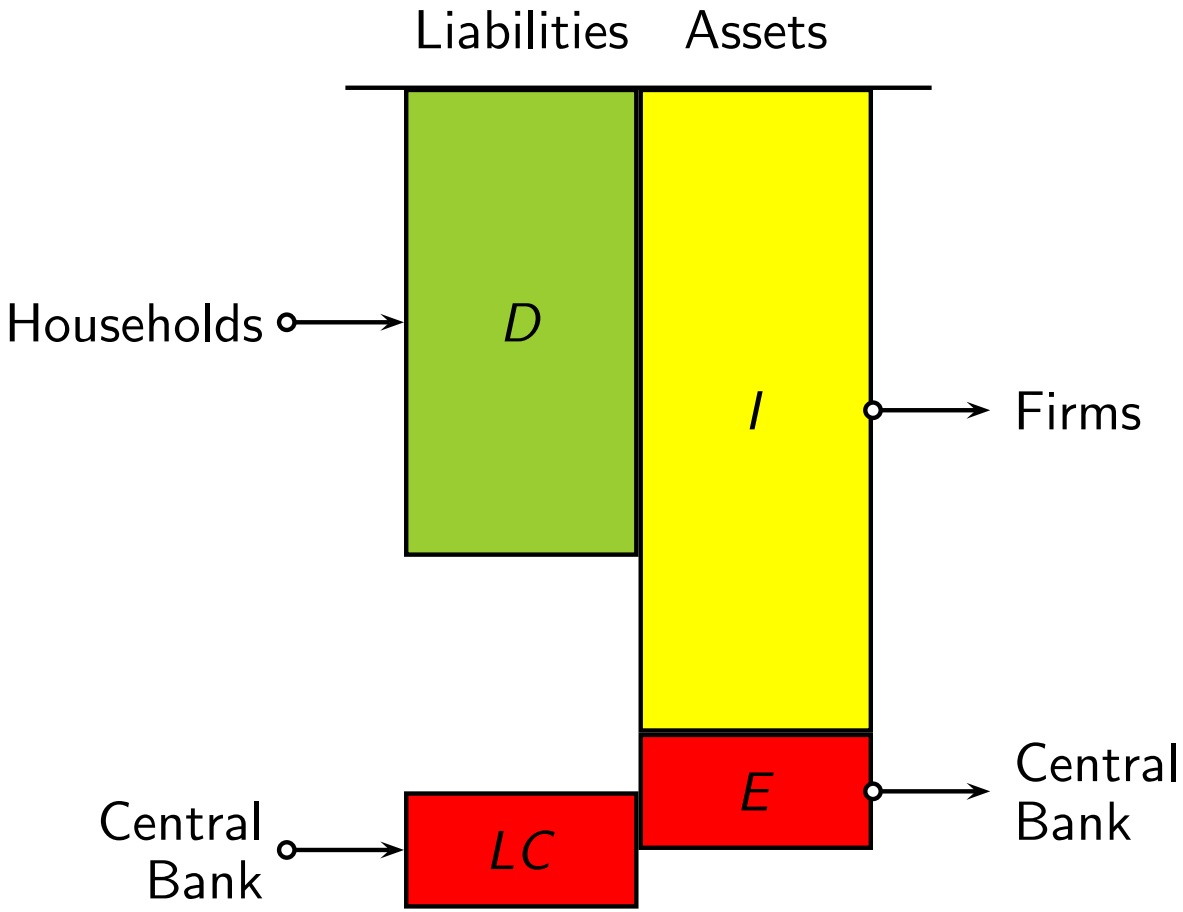

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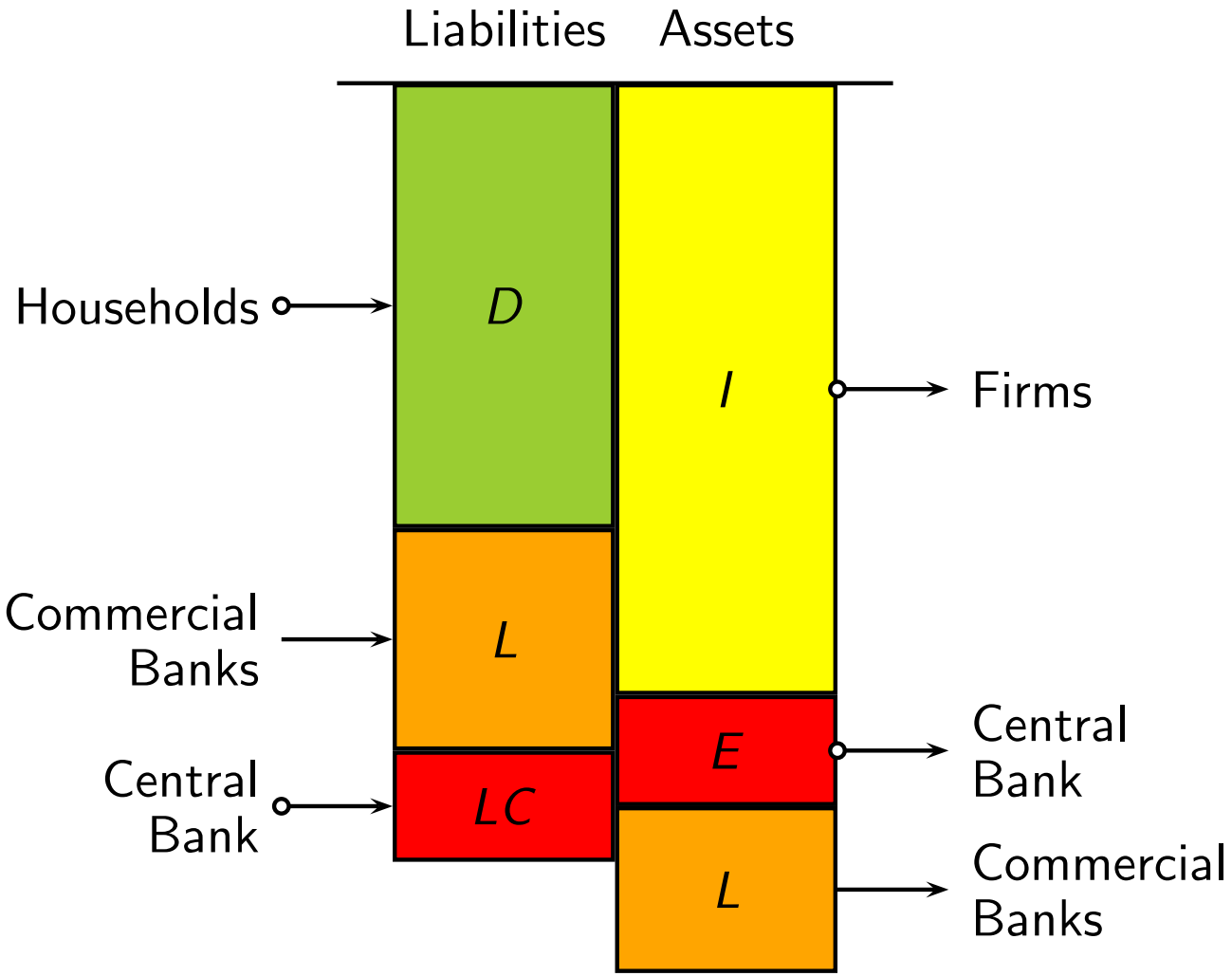

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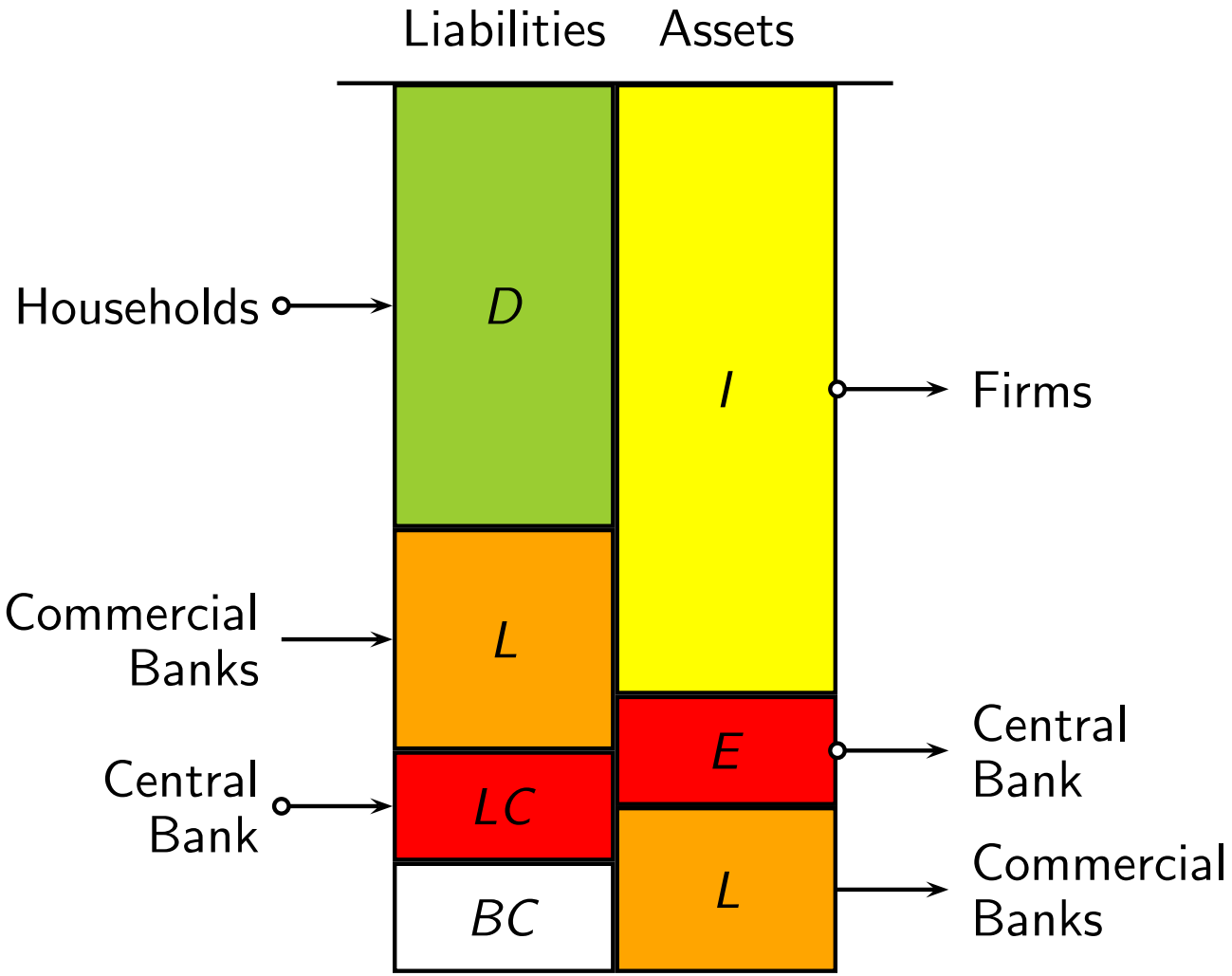

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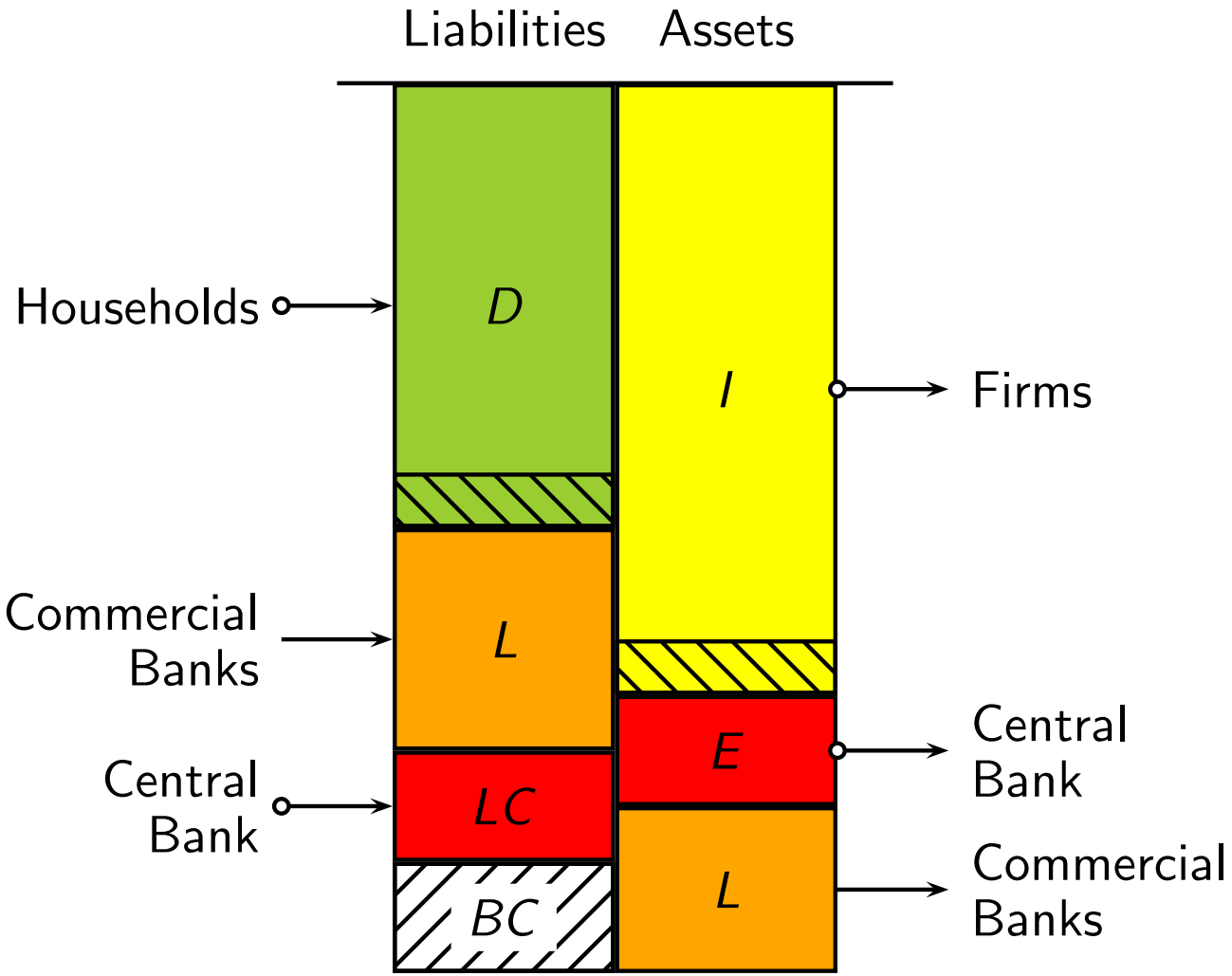


Agent Behaviour has to be Motivated

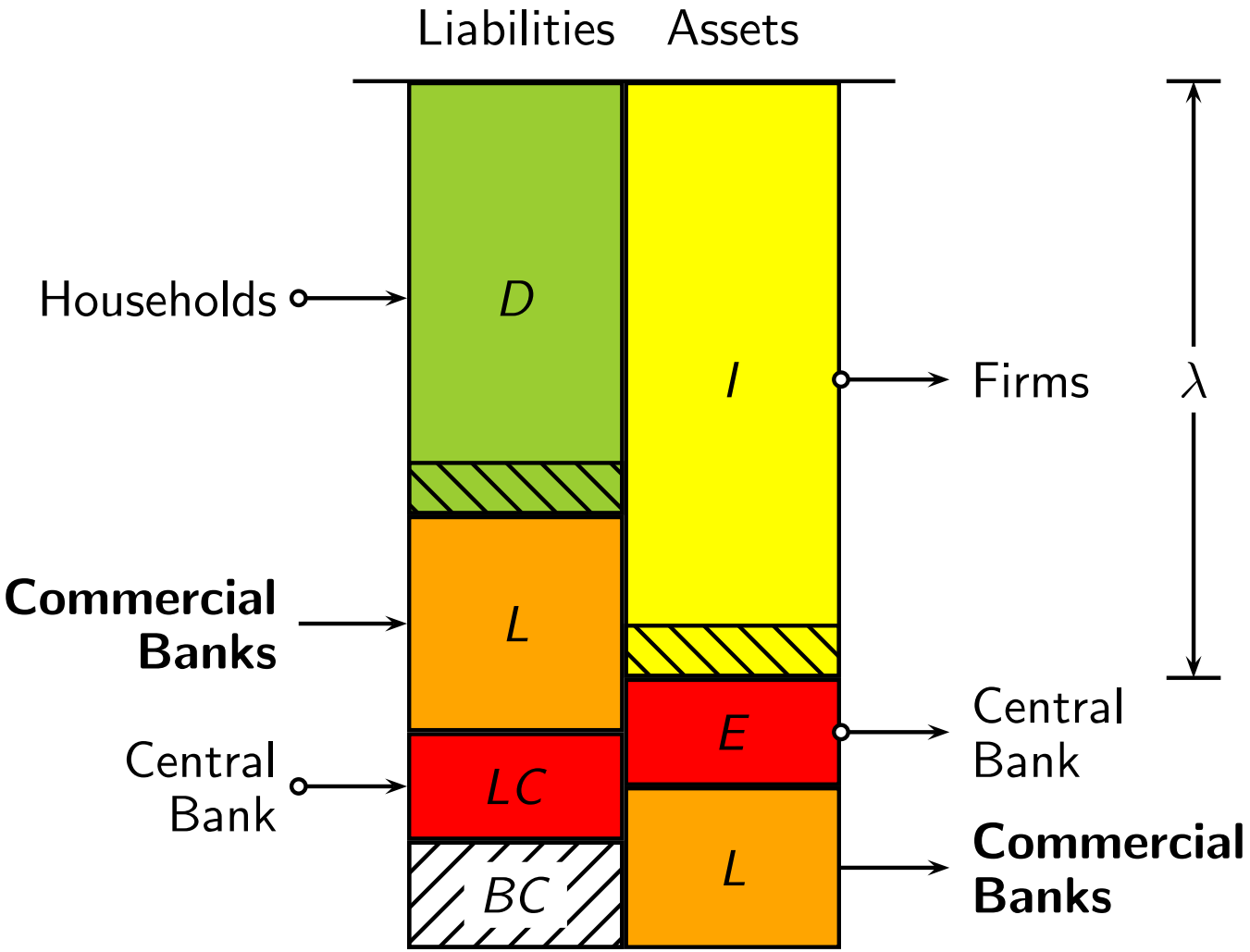
- Banks optimize their **portfolio structure and -volume** according to CRRA preferences

$$u = \frac{1}{1-\theta}\left(V(1+\lambda\mu - \frac{1}{2}\theta\lambda^2\sigma^2)\right)^{(1-\theta)}$$

where θ is risk-aversion parameter

- **Update algorithm** for $k = 1, \ldots, N$ banks and $t = 1, \ldots, \tau$ update steps:
  1. Obtain returns on investments, pay interest on deposits
  2. Deposit in- and out-flows, required reserves
  3. Settle interbank loans
  4. Determine new investment level
  5. Settle liquidity position
  6. Pay dividends

Microfoundations of Banks Determine Model



Interbank Loans Form a Network Structure

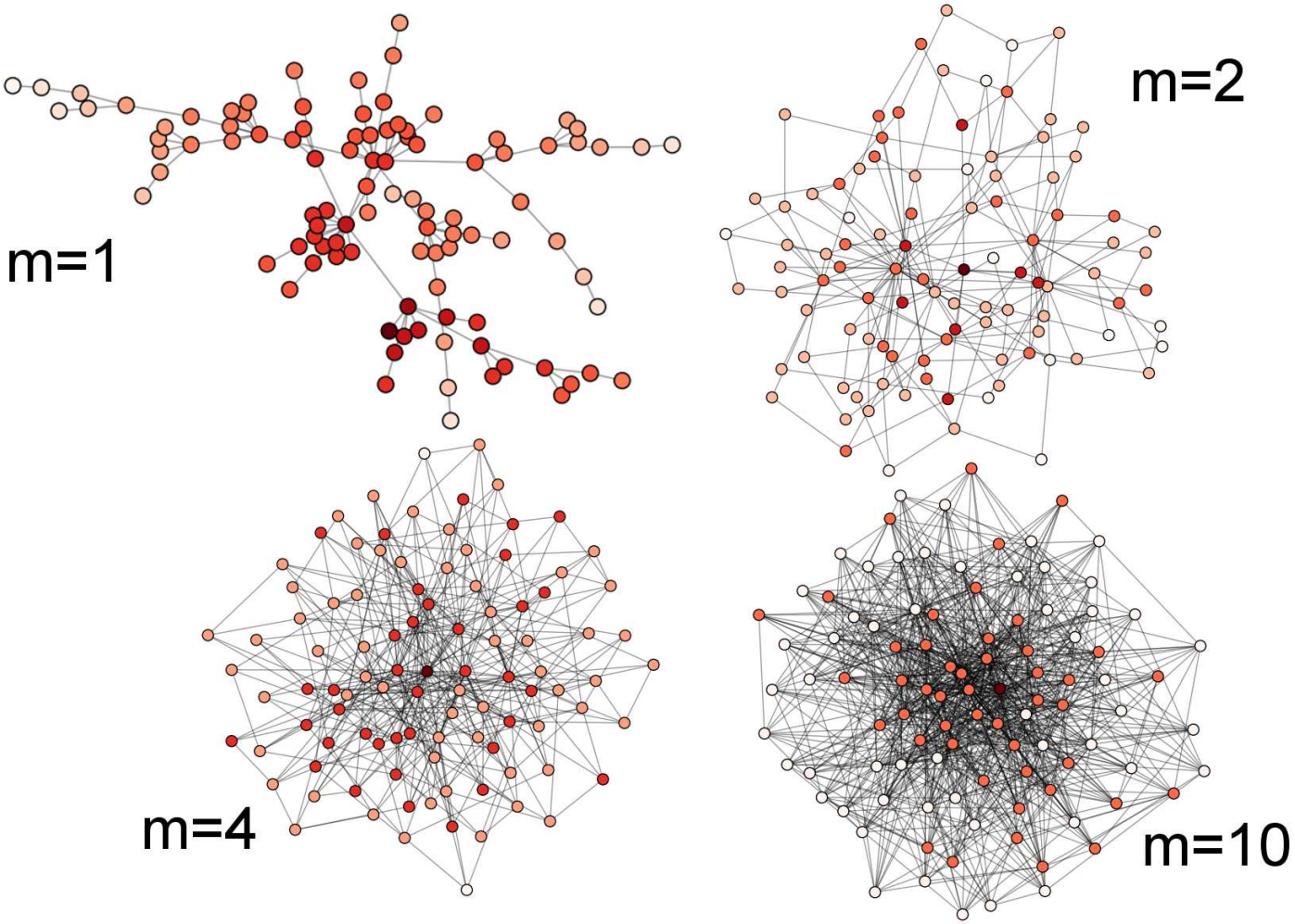


Figure: Different scale free networks

Model Parameters

Sektor	Parameter
Households	deposit fluctuations γ
Firms	credit success probability p_f, **realized credit return (ρ_f^+, ρ_f^-)**
Commercial banks	deposit interest rate r^d, dividend level β^k, expected credit success probability p_b, expected credit return (ρ_b^+,ρ_b^-), risk aversion parameter θ
Central bank	main refinancing rate r^b, minimum reserve requirement r, **quality of securities** α^k

Network parameters
number of banks N, **level of interbank connections** `connLevel`

Simulation parameters
number of update steps τ, number of simulations `numSimulations`

Central Bank Liquidity Stabilizes in the Short-Run...

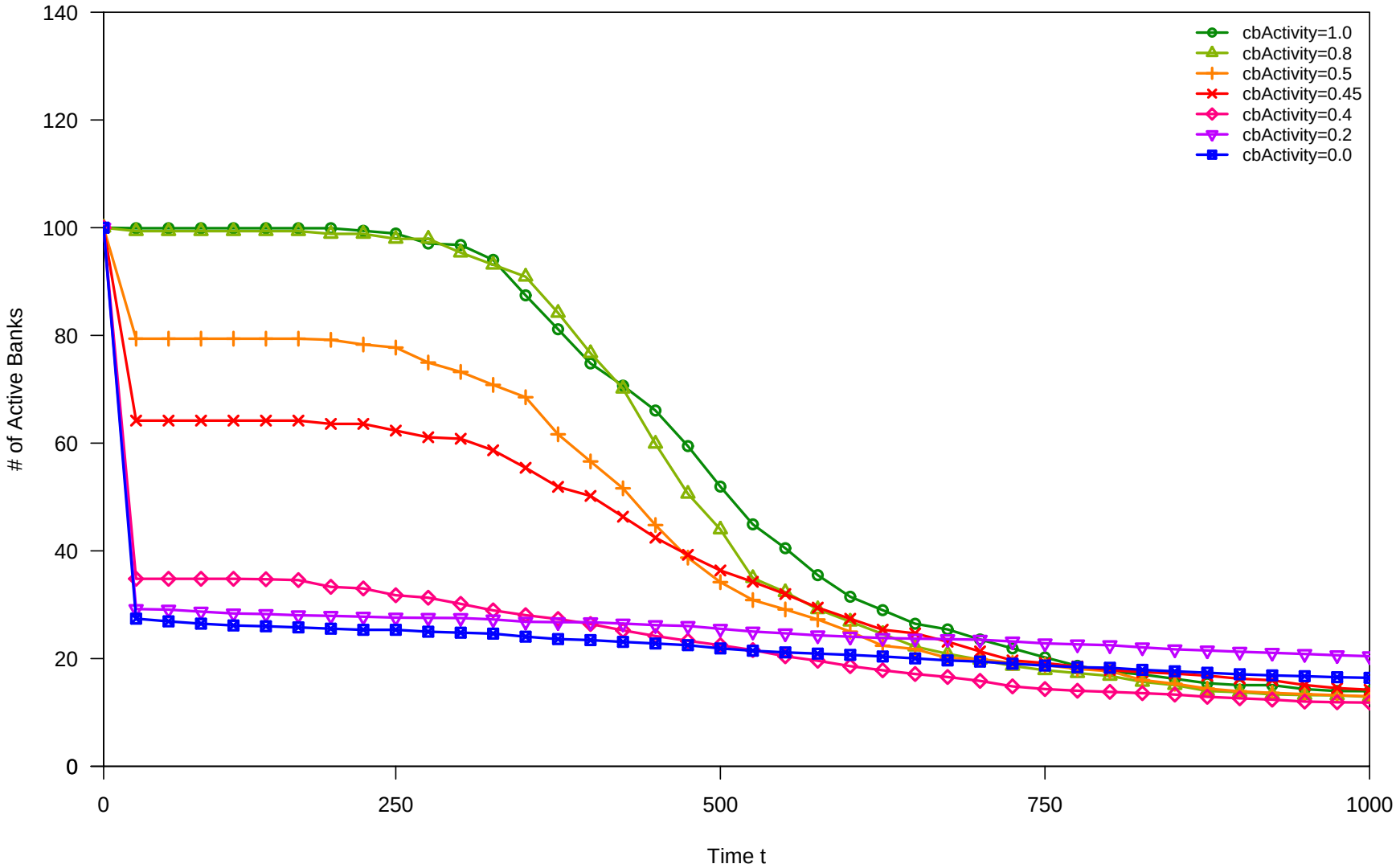


Figure: The effect of central bank activity α^k on financial stability in a crisis scenario ($\rho_f^+ = 0.09, \rho_f^- = -0.08$)

...but the Effect is Non-Monotonic

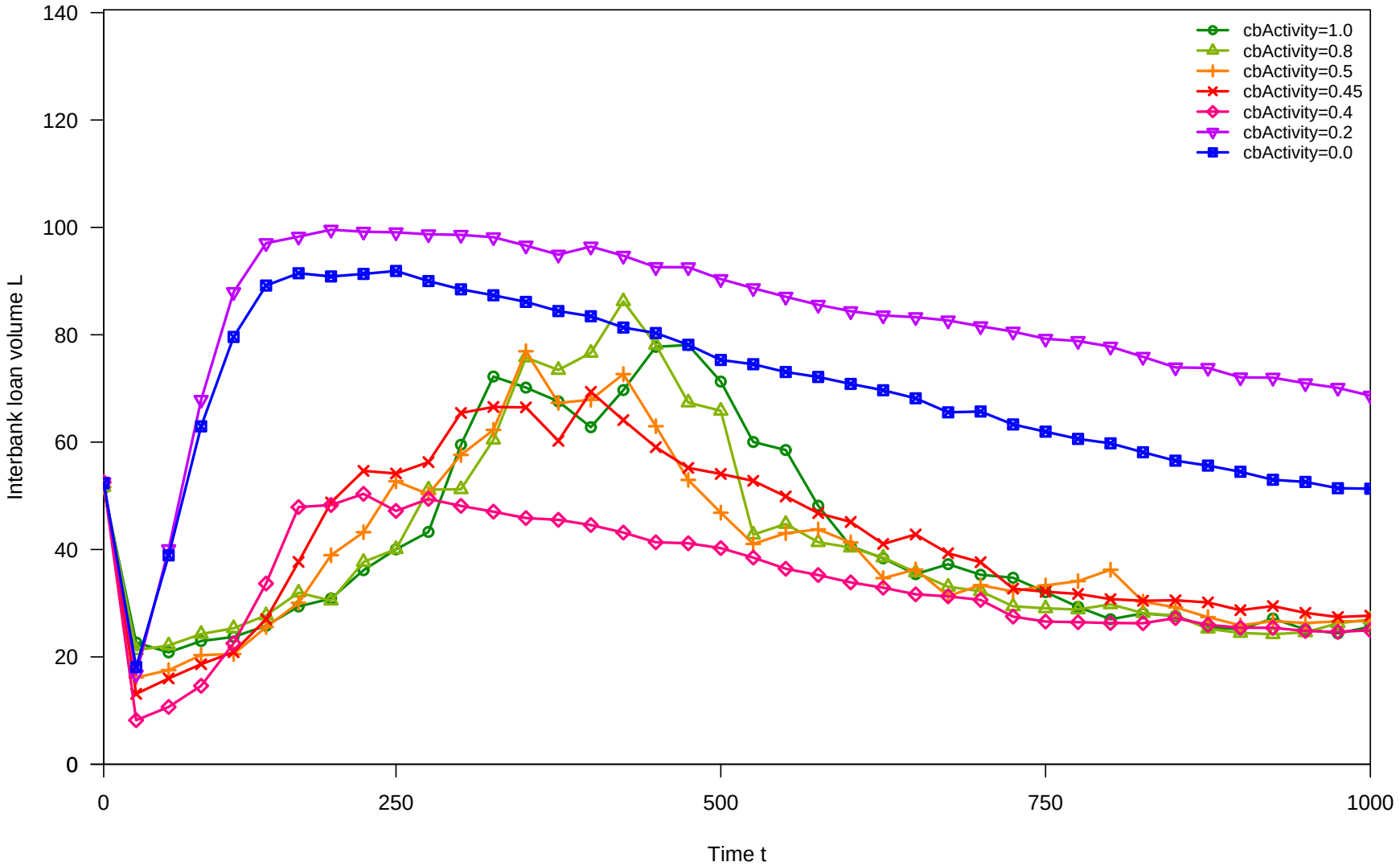


Figure: The effect of central bank activity α^k on interbank liquidity in a crisis scenario ($\rho_f^+ = 0.09, \rho_f^- = -0.08$)

Central Bank Liquidity Stabilizes in the Short-Run

Lesson 1:

- Central bank liquidity provision has **non-linear** effect on financial stability
  - $\Rightarrow$ Close threshold value, small changes have significant impact
  - $\Rightarrow$ Away from threshold value, even large changes can be ineffective
- Stabilizing effect in the **short-run** only
- Abundant central bank liquidity **crowds out** interbank liquidity

Some Network Structures are More Resilient Than Others

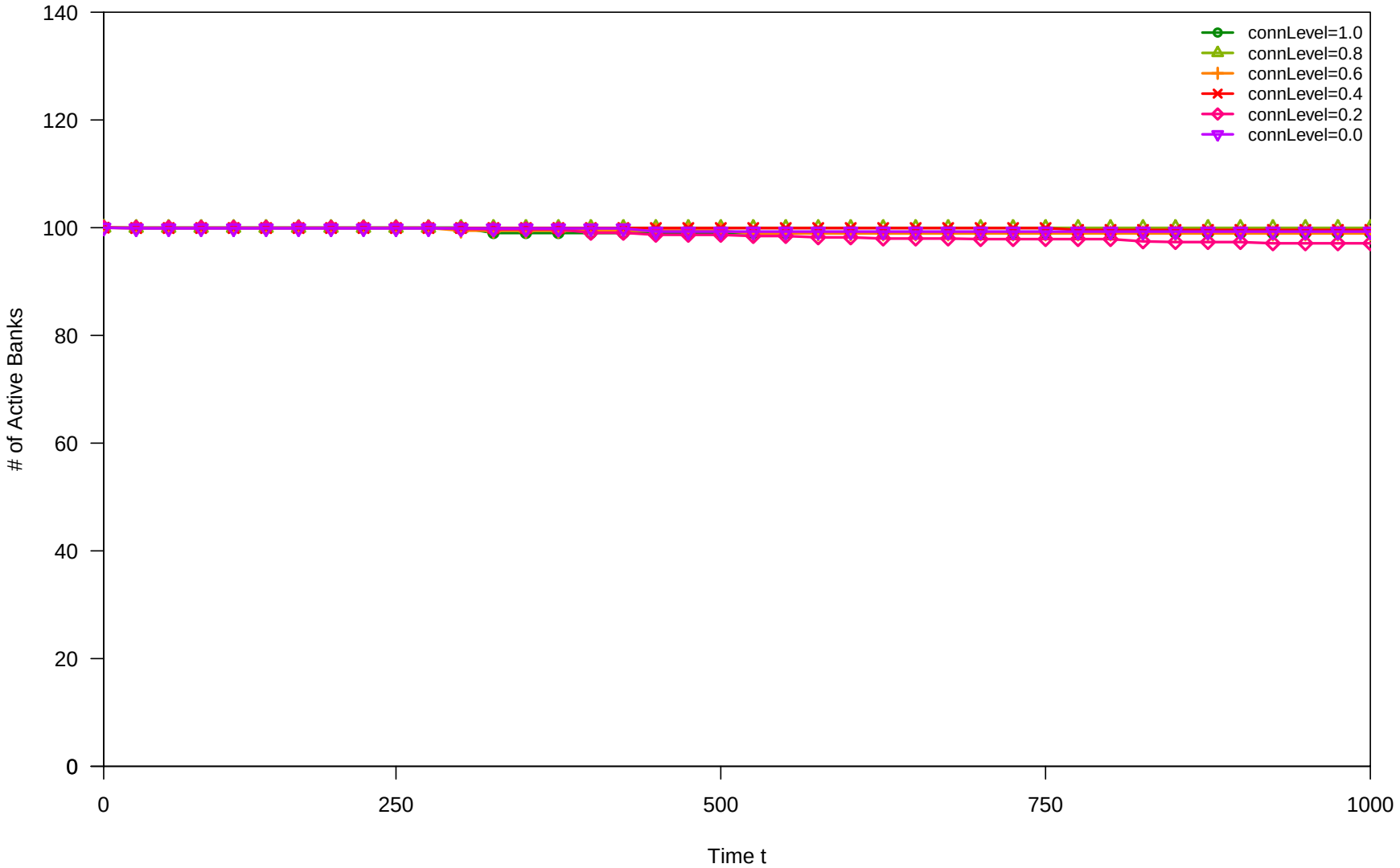


Figure: The impact of the network topology on financial stability in a normal scenario ($\rho_f^+ = 0.09, \rho_f^- = -0.05$) in a random network.

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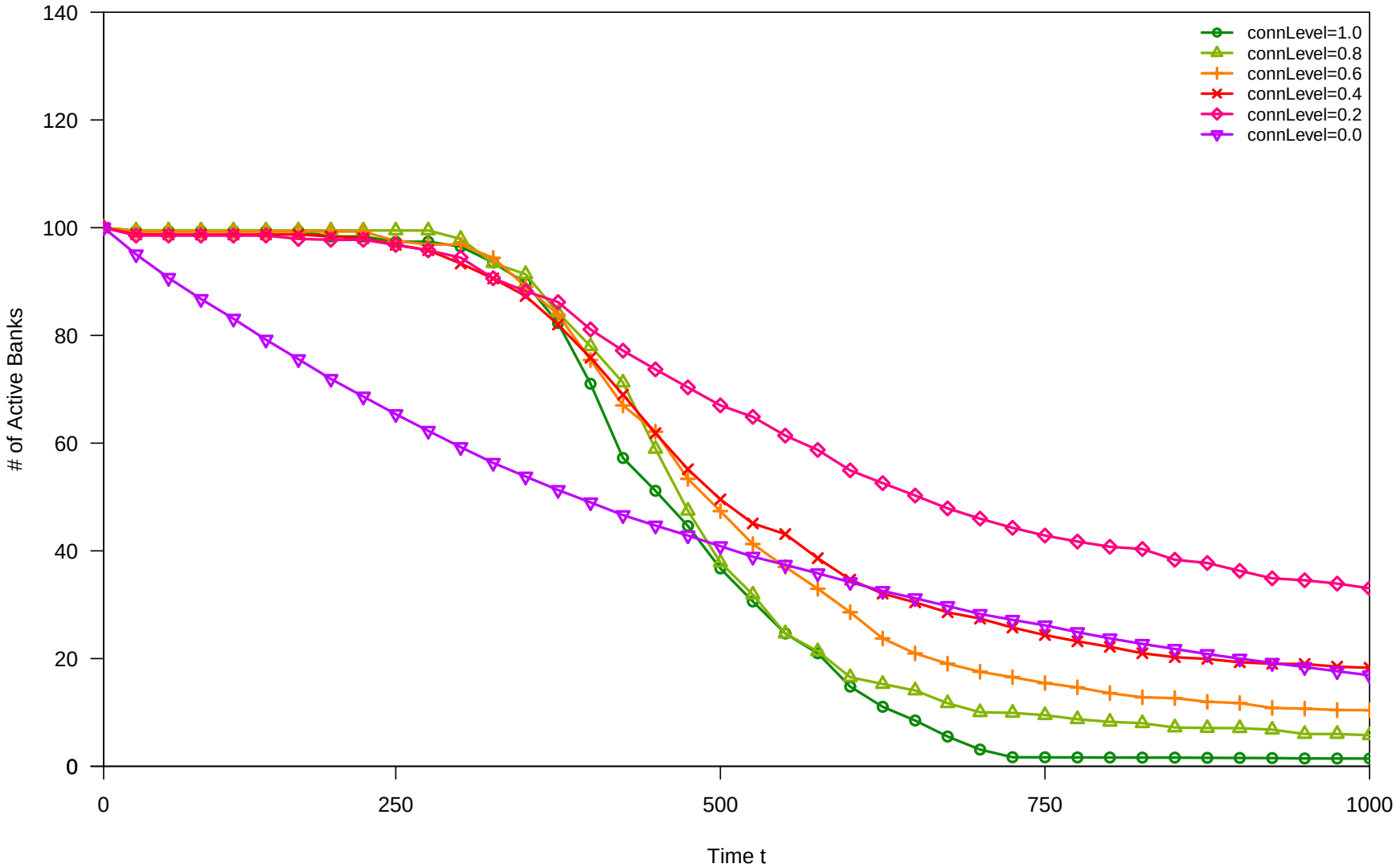

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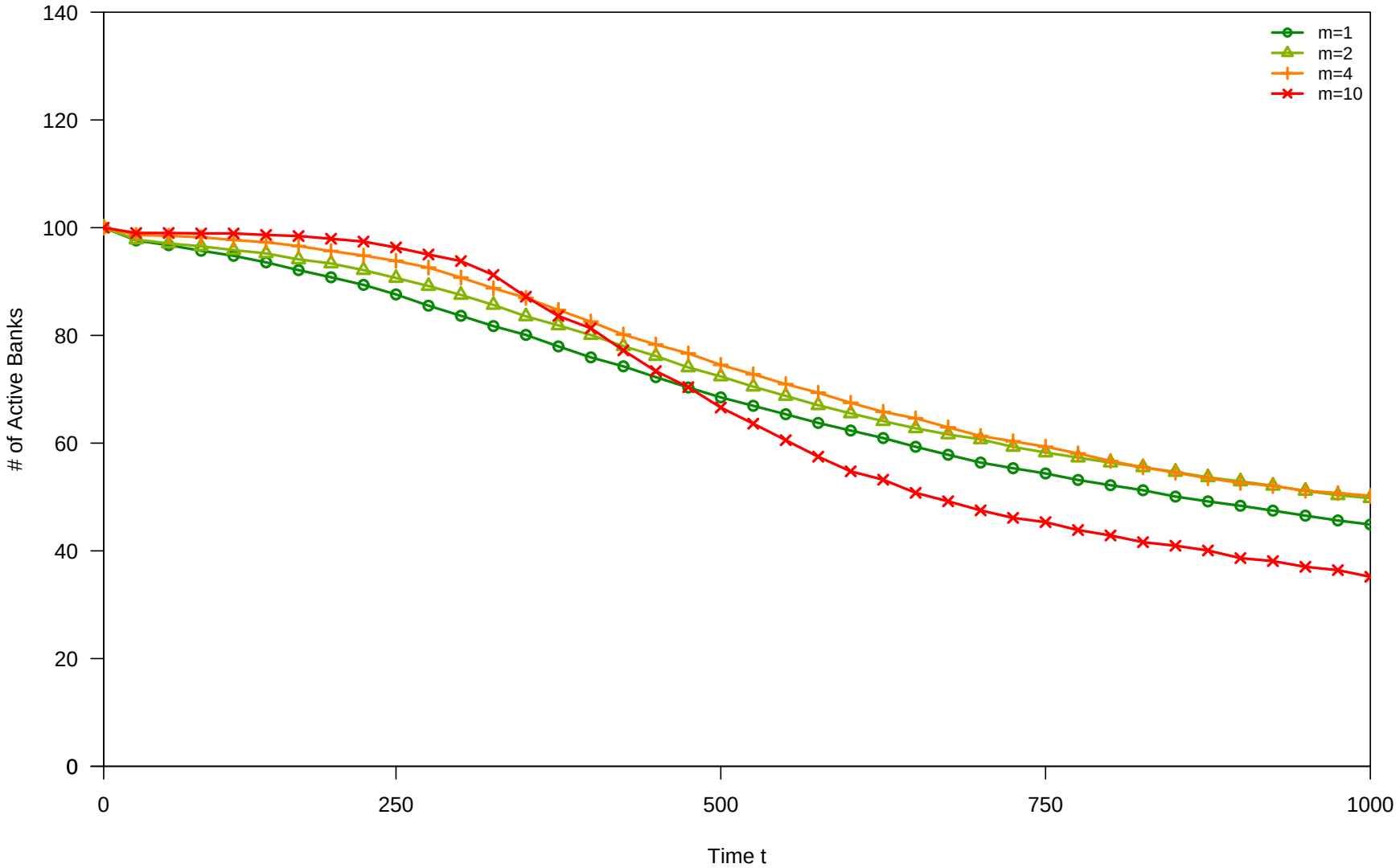

Figure: The impact of the network topology on financial stability in a crisis scenario ($\rho_f^+ = 0.09, \rho_f^- = -0.08$) in a BA network

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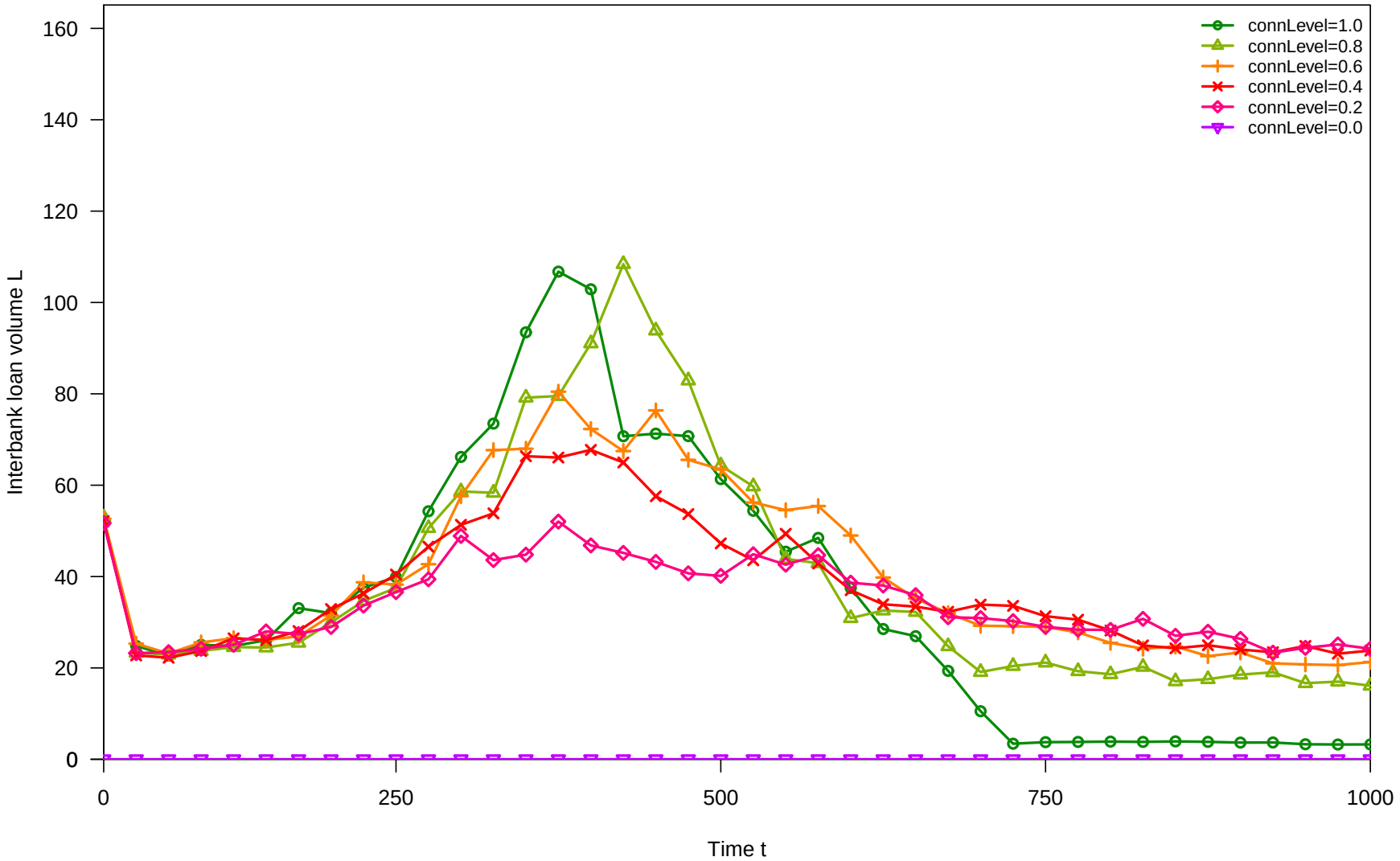


Figure: The impact of the network topology on interbank liquidity in a crisis scenario ($\rho_f^+ = 0.09, \rho_f^- = -0.08$) in a random network

Some Network Structures are More Resilient Than Others

Lesson 2:

- Network **structure matters** in crises
- Relationship between financial stability and interconnectedness in random networks is **non-monotonic**
- Scale-free networks tend to be **more stable** than random networks
- Interbank networks are **robust-yet-fragile**
  $\Rightarrow$ Size of endogenous fluctuations matter

Different Forms of Systemic Risk Require Different Answers

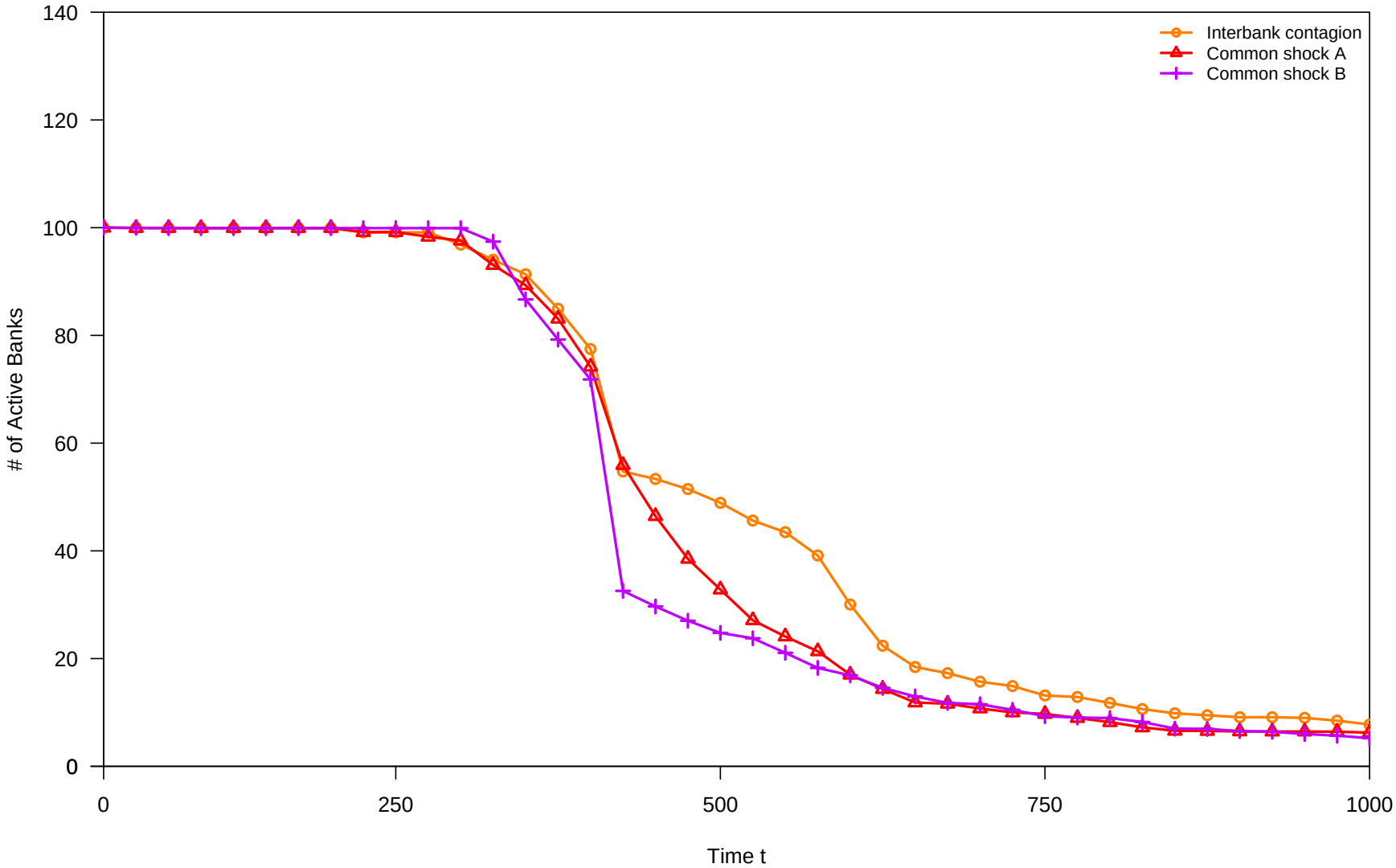
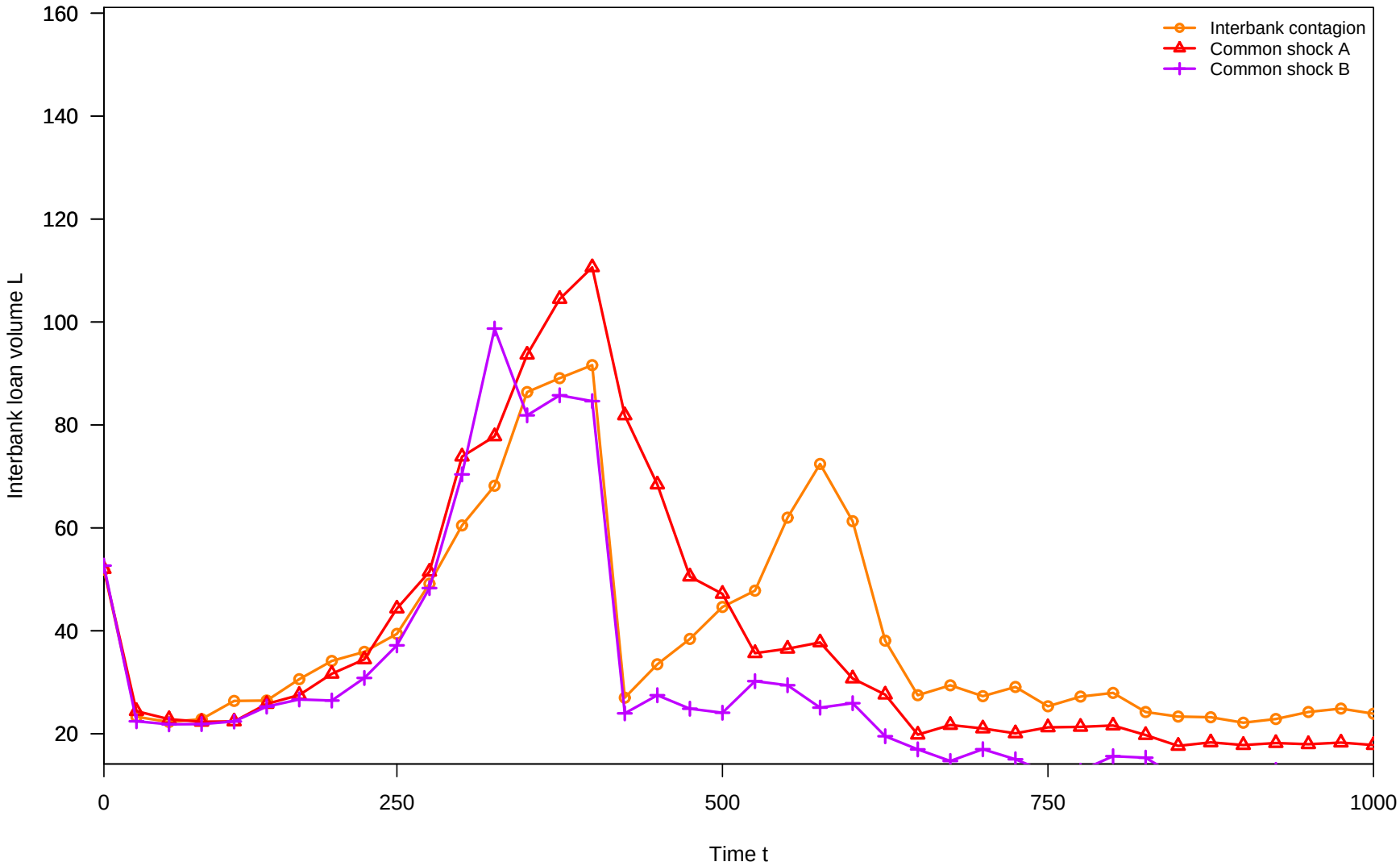


Figure: The impact of different forms of systemic risk on financial stability in a crisis scenario ($\rho_f^+ = 0.09, \rho_f^- = -0.08$) in a random network (`connLevel`=0.8)

Different Forms of Systemic Risk Require Different Answers



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Different Forms of Systemic Risk Require Different Answers

Lesson 3:

- Common shocks can pose greater threat to financial stability
- Contagion mainly reduces **liquidity** available in the system
- Common shock mainly reduces **banking capital** and increases (relative) size of endogenous fluctuations

  $\Rightarrow$ Different optimal responses, for different forms of systemic risk

  $\Rightarrow$ Implications for financial Regulation

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Thank you!

References

Francis Allen and Douglas Gale. Financial contagion. *Journal of Political Economy*, 108:1–33, 2000.

Christopher Becher, Stephen Millard, and Kimmo Soramäki. The network topology of chaps sterling. Bank of England working papers 355, Bank of England, 2008.

Nicola Brink and Co-Pierre Georg. Assessing systemic risk in the south african interbank market. Special Note in the Financial Stability Review April, South African Reserve Bank, 2011.

Eui Jung Chang, Eduardo José Araùjo Lima, Solange M. Guerra, and Benjamin M. Tabak. Measures of interbank market structure: An application to brazil. *Brazilian Review of Econometrics*, 28(2):163–189, 2008.

Silvia Gabrieli. The microstructure of the money market before and after the financial crisis: a network perspective. CEIS Research Paper 181, Tor Vergata University, CEIS, 2011.

Prasanna Gai and Sujit Kapadia. Contagion in financial networks. Discussion Paper 1231, Bank of England, 2008.

Prasanna Gai, Andrew Haldane, and Sujit Kapadia. Complexity, concentration and contagion. *Journal of Monetary Economics*, 58(4), 2011.

Andrew G. Haldane and Robert M. May. Systemic risk in banking ecosystems. *Nature*, 469: 351–355, 2011.

G. Iori, S. Jafarey, and F.G. Padilla. Systemic risk on the interbank market. *Journal of Economic Behavior & Organization*, 61(4):525–542, 2006.

Erland Nier, Jing Yang, Tanju Yorulmazer, and Amadeo Alentorn. Network models and financial stability. *Journal of Economic Dynamics and Control*, 31:2033–2060, 2007.