An Agent-based Model for Assessing Financial Vulnerabilities

Rick Bookstaber

Mark Paddrik

Office of Financial Research

Risk Management – Versions 1.0 to 3.0

OFR
OFFICE OF FINANCIAL RESEARCH

- **Version 1.0: Historical Data – VaR Models**
- **Version 2.0: Static Scenarios – Stress Tests**
- **Version 3.0: Dynamic Interaction – Agent-based Models**

The Problem to Solve: Fire Sale Dynamics

OFR
OFFICE OF FINANCIAL RESEARCH

Asset-based Fire Sale

- Asset (Price) Shock → Forced Sales → Shock to other Assets

  => Cascades + Contagion

Funding-based Fire Sale (Funding Run)

- Funding Shock → Forced Sales → Further Funding Reduction

  => Cascades + Contagion

Leverage- and Liquidity-driven

Asset-based Fire Sales ↔ Funding-based Fire Sales

What is an Agent-based Model

OFR
OFFICE OF FINANCIAL RESEARCH

Agents pursue their activities period by period

- Agents are heterogeneous
- Can use heuristics rather than optimize
- Observe and react to the changing environment
- Influence one another; interdependent with dynamic interaction

Example

Analysis of traffic flows

Bookstaber (2012), Using Agent-Based Models for Analyzing Threats to Financial Stability, OFR Working Paper No. 3.

Applications of the Agent-based Model

OFR
OFFICE OF FINANCIAL RESEARCH

Detect Vulnerabilities (Pre-Shock)

- What are the dynamic, knock-on effects

Weather Service (Post-Shock)

- Are we on the hurricane's path; how bad will it be

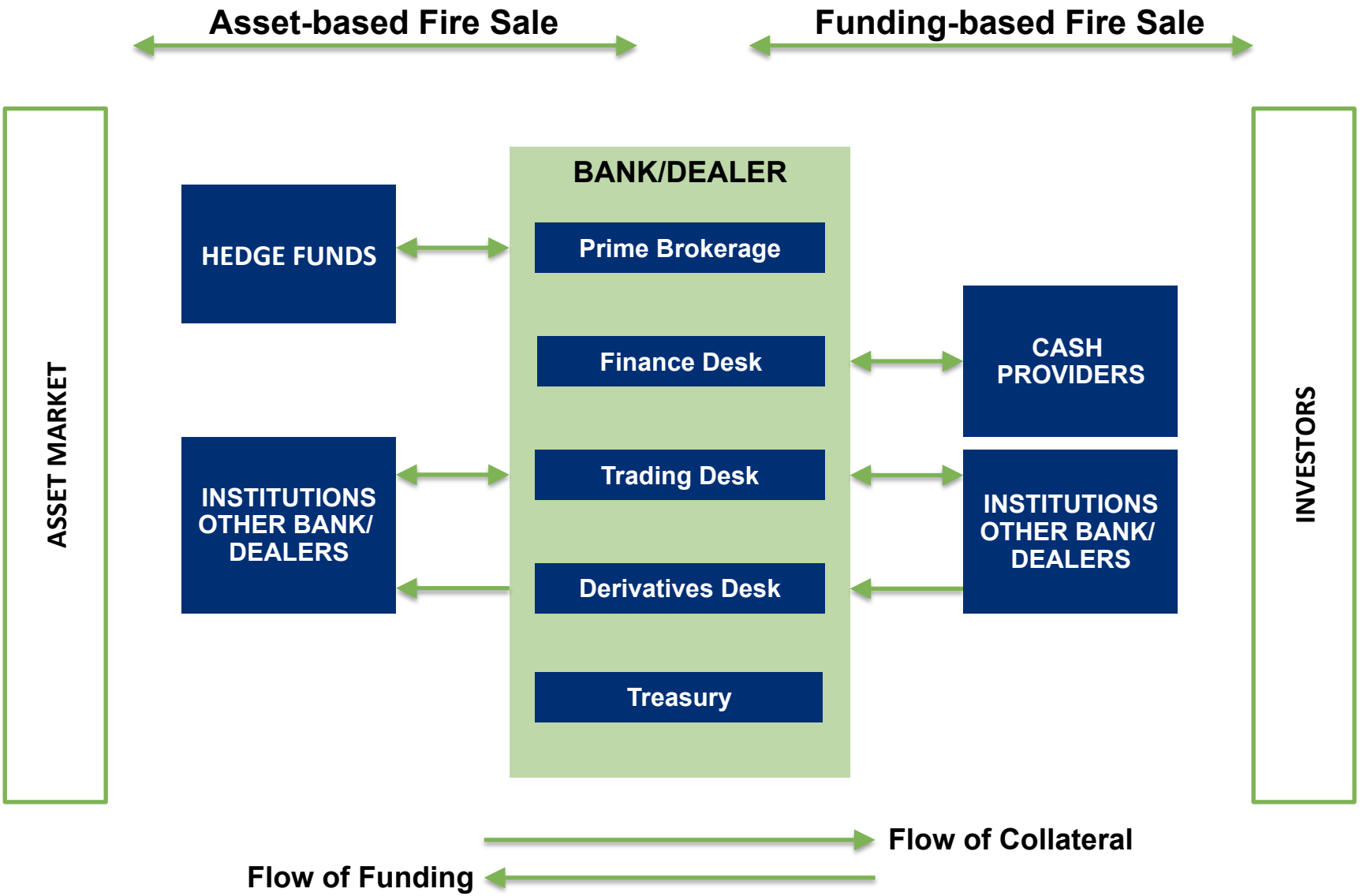
Policy Planning and Actions (Pre- and Post-Shock)

- Where do we put the emergency shut-off valves; which do we close
- When do we provide asset and funding liquidity

Data Needs

- How much can things be improved with better data

The Agents Caught Up in Fire Sales



The Agents of the Agent-based Model

OFR
OFFICE OF FINANCIAL RESEARCH

Cash Provider

- Supplies funding, sets haircuts based on market volatility, liquidity, borrower's credit risk

Hedge Fund (Asset Manager)

- Obtains funding and holds assets based on leverage target
- Can face investor redemptions
- Forced to sell if a margin call

Bank/Dealer

- Prime Broker – supplies funding, receives collateral
- Finance Desk – obtains secured funding via collateral
- Trading Unit – holds market exposure and market making; can have forced sales
- Derivatives – holds counterparty exposure;
- Treasury-- manages leverage, funding liquidity and unsecured funding

Prices

OFR
OFFICE OF FINANCIAL RESEARCH

Random movement day-to-day

- No price impact absent forced selling.

Event-driven selling

- The net quantity of shares of Hedge Fund and Bank/Dealers need to sell in response to an extraordinary event.

Market impact

- For event-driven selling, for each asset. Market impact can me modeled to increase with an increase of recent forced selling.

A Day in the Life of a Hedge Fund

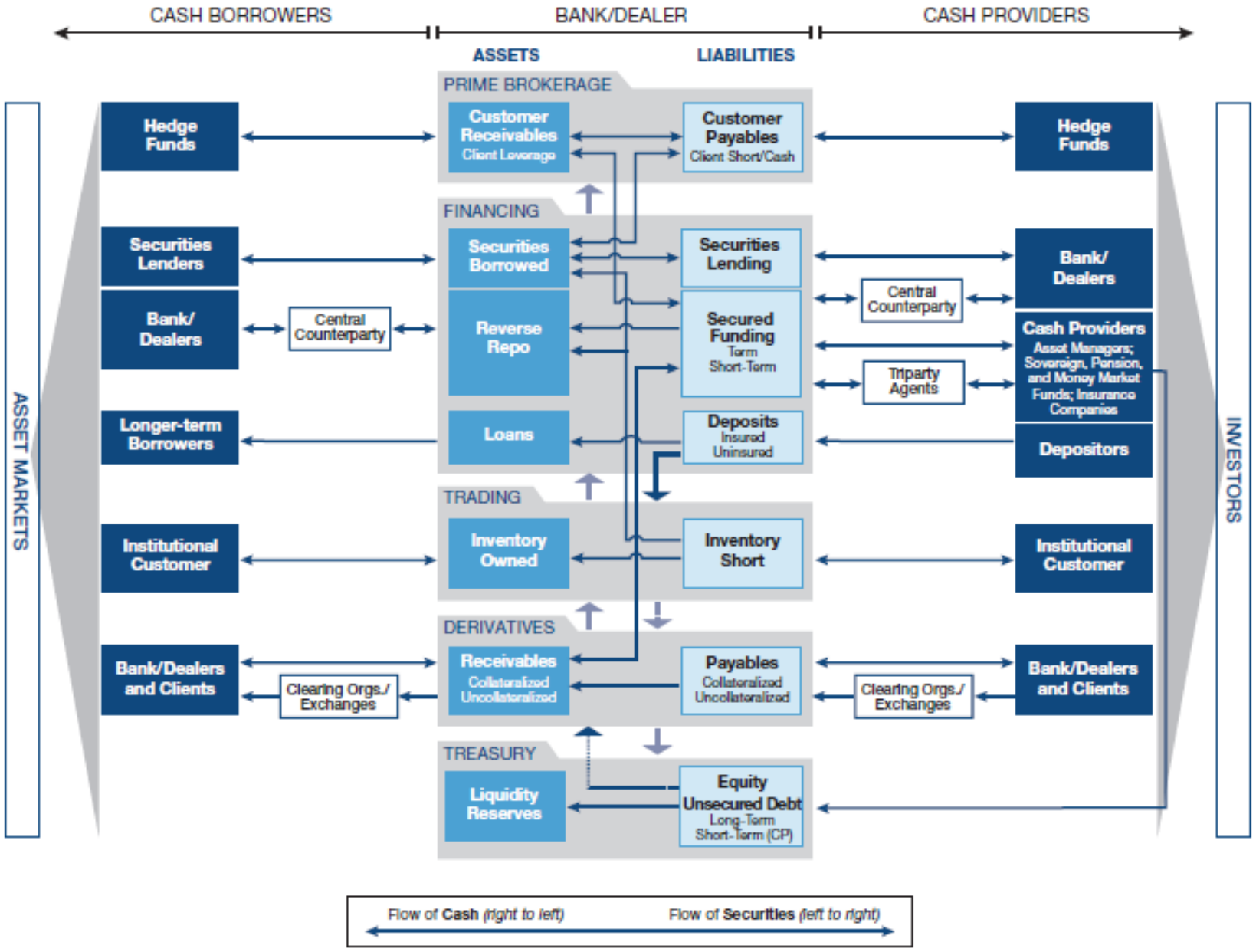
OFR
OFFICE OF FINANCIAL RESEARCH

Objective: Determine the quantity of assets to hold

1. Calculate value of portfolio using last observed price.
2. Compute leverage values given funding decisions conveyed by the Prime Broker.
3. Evaluate trading profit or loss from previous day.
4. Compute the value of capital, and the funding that is available.
5. Determine distance from leverage values given its current leverage.
6. Compute target asset level; dollar assets to own at its target leverage given its capital level and leverage values.
7. Determine the quantity of assets to buy or sell:
    1. Are sales forced by leverage constraints by funding
    2. Is trading to adjust to target.
8. Determine the funding needed going into the next period.

Flows Between the Agents: ABM Schematic

OFR
OFFICE OF FINANCIAL RESEARCH



How the Flows are Transformed

OFR
OFFICE OF FINANCIAL RESEARCH

Maturity transformation

- Short-term deposits to long-term loans.

Credit transformation

- Structured products with tranches of varying credit risk.
- Safe money into funding for risky hedge funds.

Collateral transformation

- Lower quality collateral to higher quality collateral.

Liquidity transformation

- Market making.
- Repackaging assets into liquid vehicles, such as ETFs.

Risk transformation

- Selling off part of the return distribution via derivatives.
- Tranches with varying risk characteristics.

Sources of Shocks

OFR
OFFICE OF FINANCIAL RESEARCH

A shock can arise from any type of agent

- Bank/Dealer: Credit Shock
- Cash Provider: Funding Shock
- Hedge Fund: Redemption Shock
- Asset Market: Price Shock

And shocks can occur sequentially

Price → Funding → Credit → Redemptions

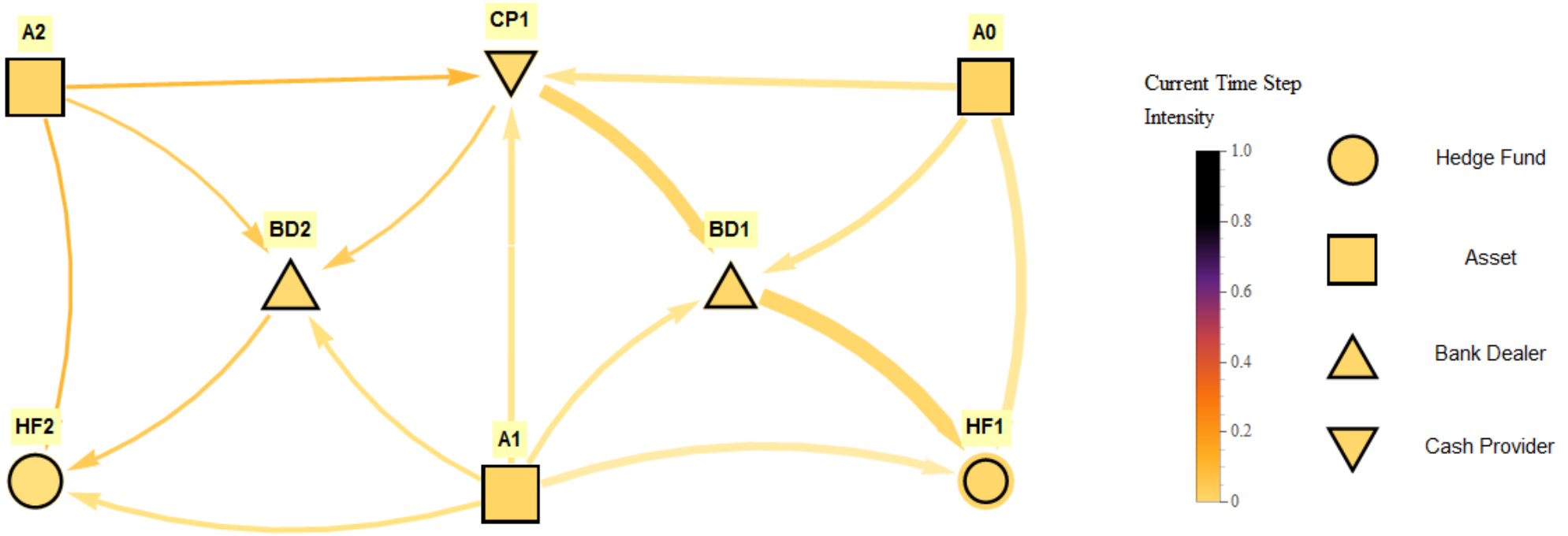
Demonstration of the Model

The model can have an arbitrary number of agents and markets.

In this demonstration there are:

- Three assets
- Two Hedge Funds
- Two Bank/Dealers
- One Cash Provider

Schematic for Looking at Network Dynamics

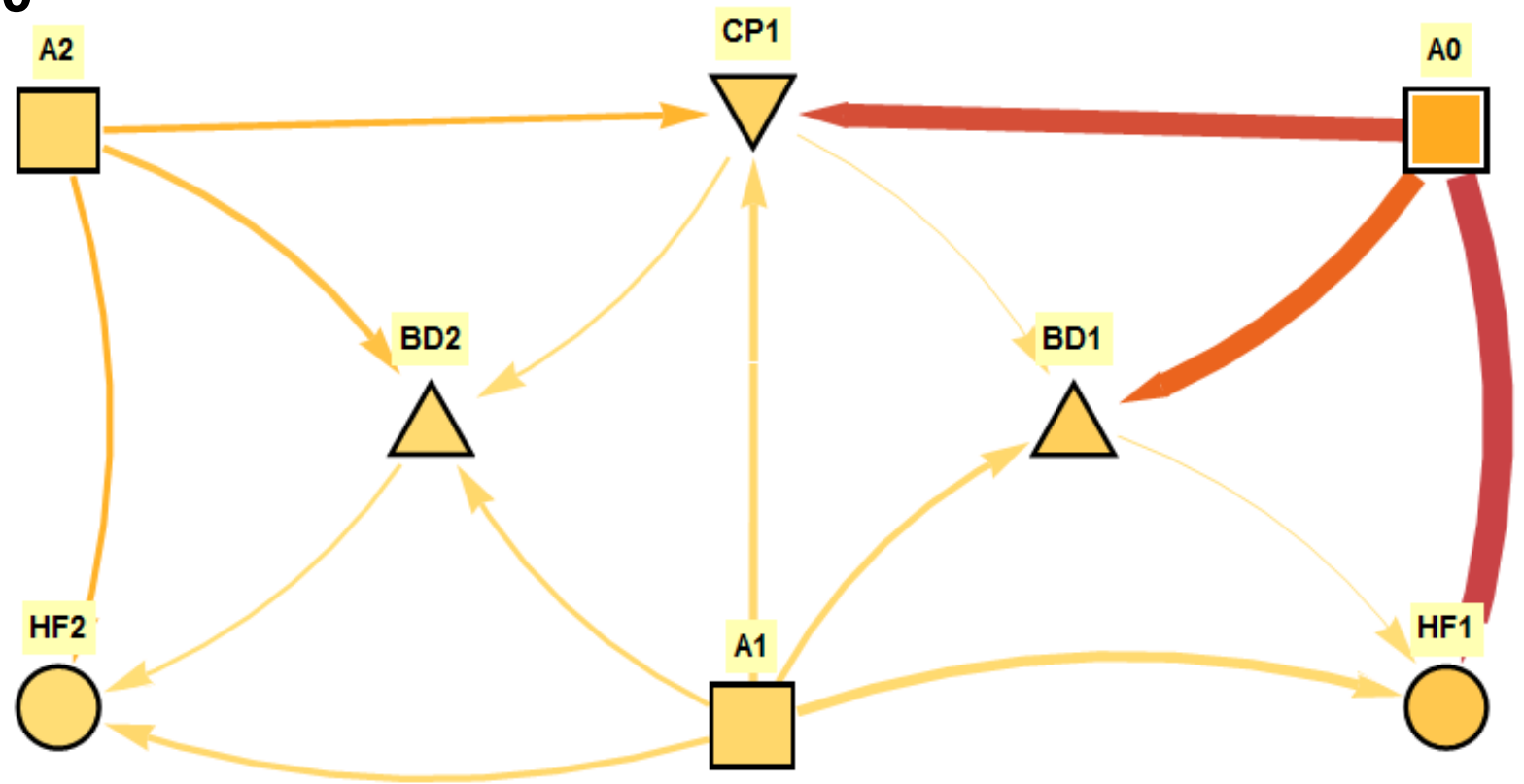


- Thickness of links shows cumulative effect.
- Color of links shows intensity of effect in the current period.
- Amount of node that is colored shows capital, funding, or price relative to initial value.

Example of Price Shock: Period 0

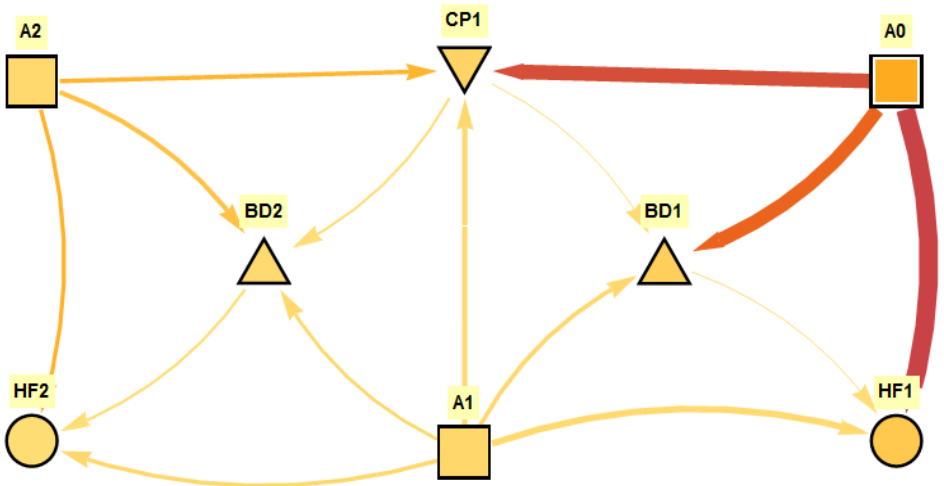
OFR
OFFICE OF FINANCIAL RESEARCH

Period 0

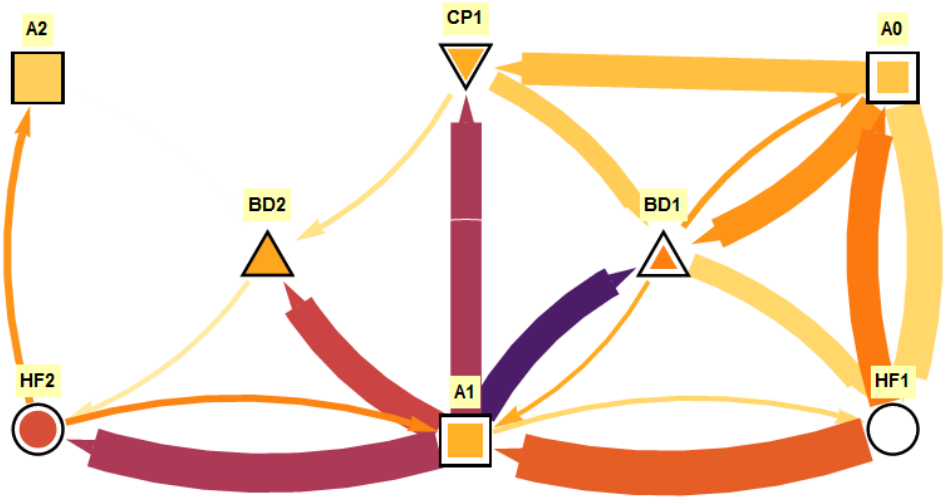


- A0 experiences a 15% price shock
- BD1 and HF1 hold A0 in their portfolio
- CP holds A0 as collateral

Example of Price Shock: Period 2



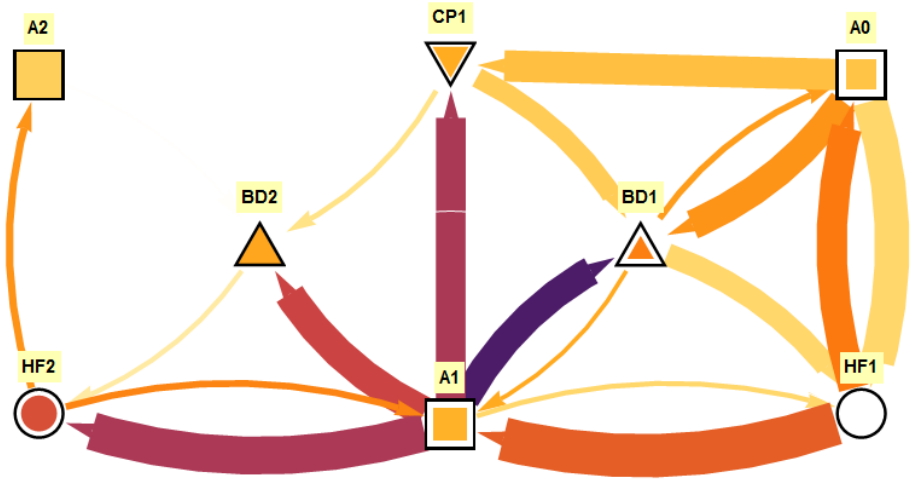
Period 0



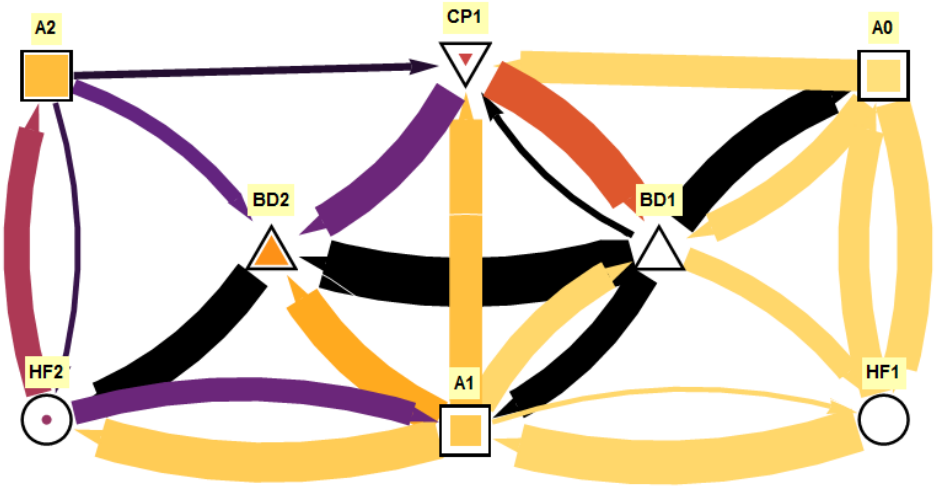
Period 2

- BD1 and HF1 decrease positions in both A0 and A1
- This affects other agents holding similar assets
- BD1 and HF1 try to meet collateral obligations
- BD1 seeks to maintain its credit worthiness

Example of Price Shock: Period 4



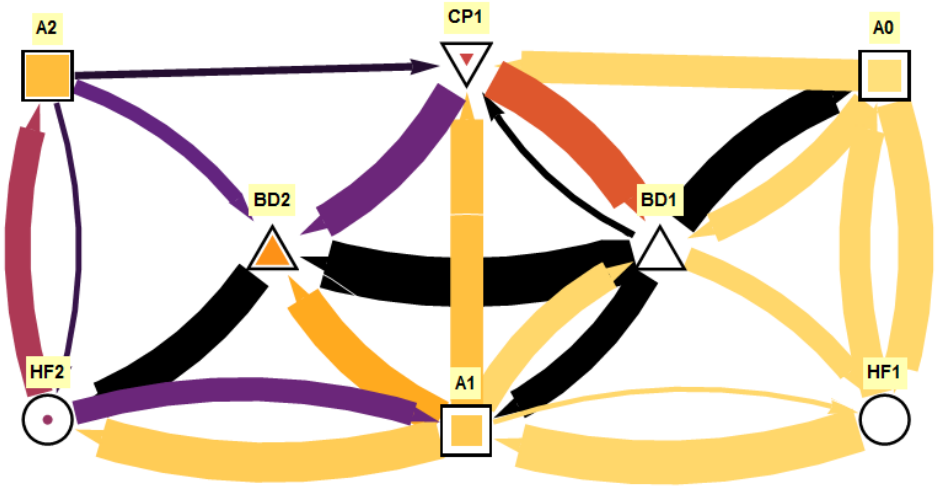
Period 2



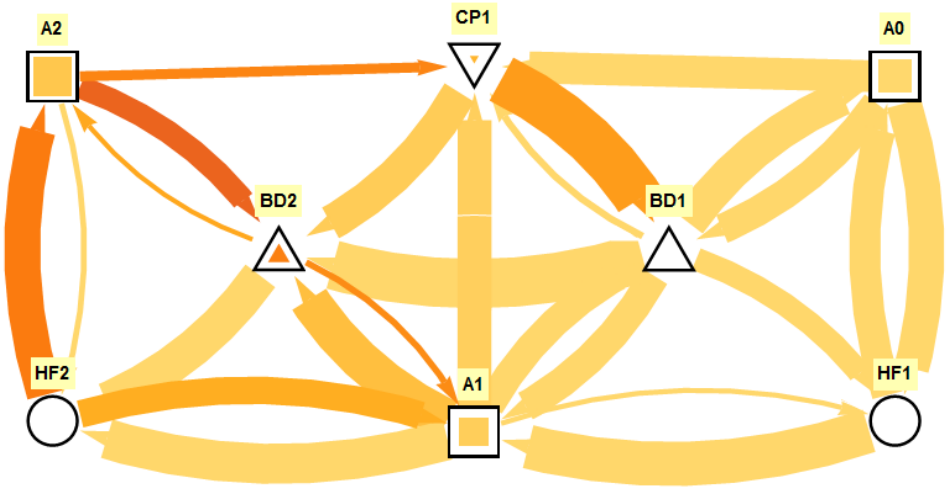
Period 4

- The fire sale and funding runs may lead to default
- This can spread the dynamic due to credit exposure from BD1 to BD2
- This can lead to difficulty in identifying the source of contagion

Example of Price Shock: Period 6



Period 4



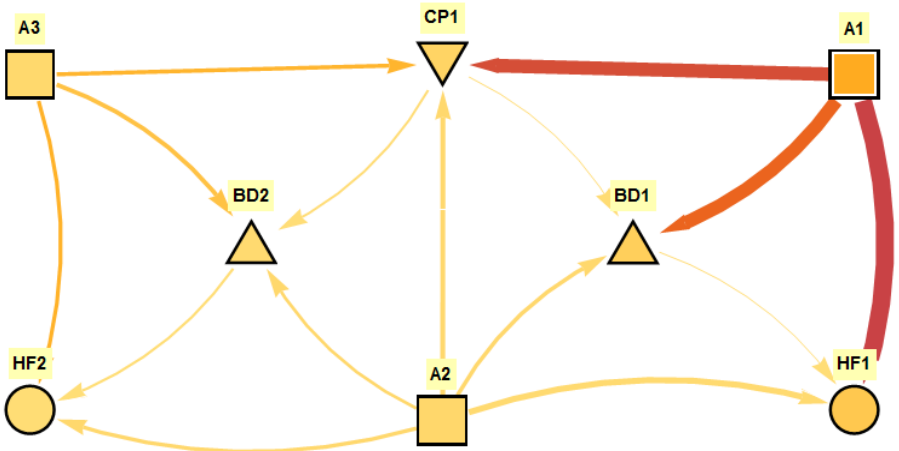
Period 6

- The fire sale reaches its end.
- In this run BD1, HF1, and HF2 have defaulted

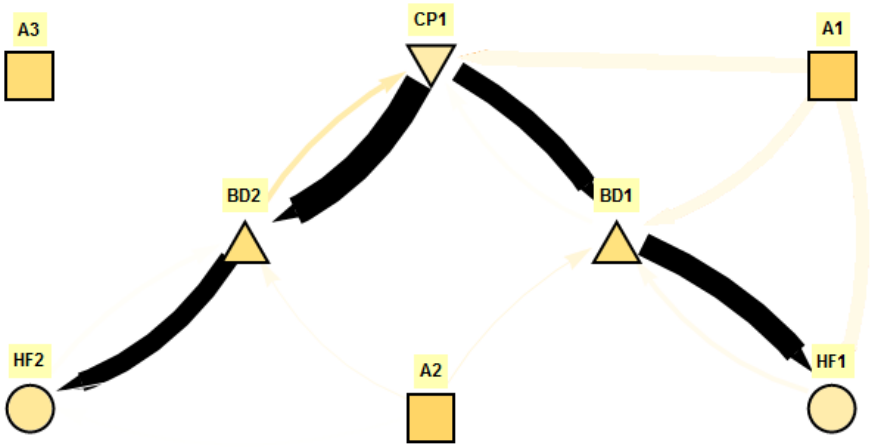
First Stages of Shocks by Type

OFR
OFFICE OF FINANCIAL RESEARCH

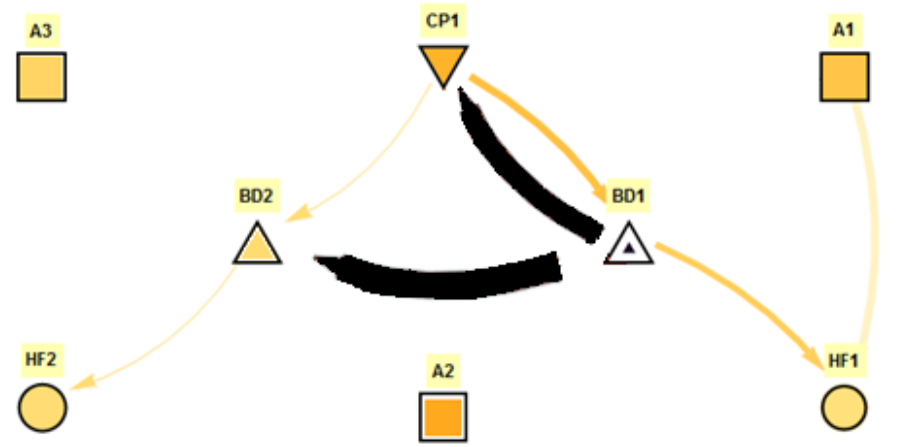
Price Shock



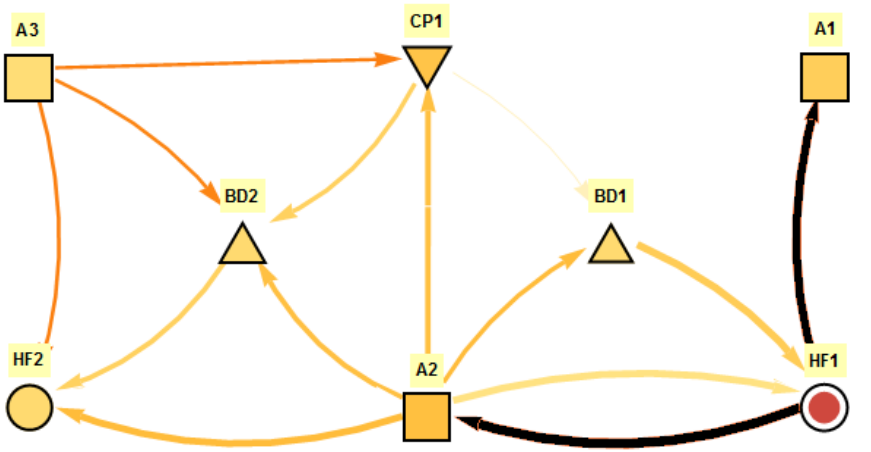
Funding Shock



Credit Shock



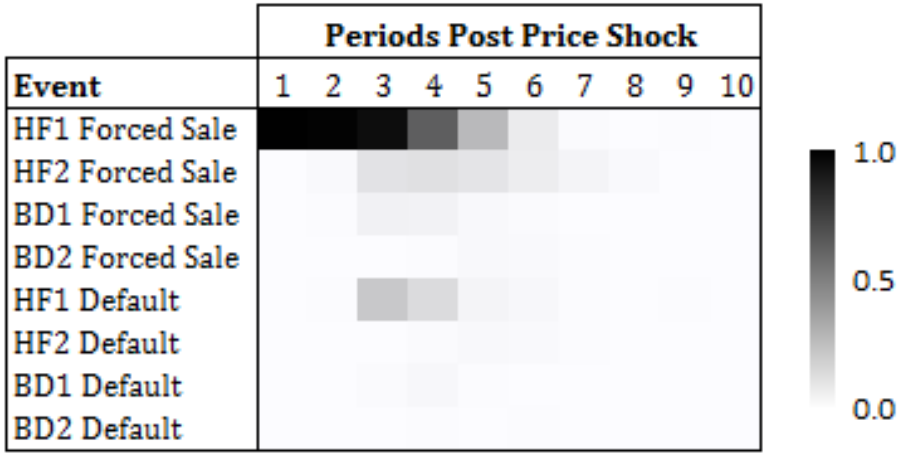
Redemption Shock



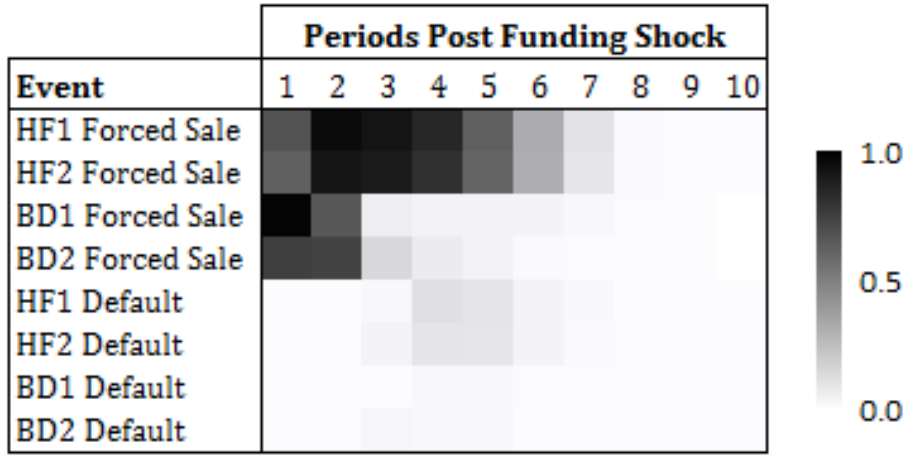
Heat Map View of Shocks

OFR
OFFICE OF FINANCIAL RESEARCH

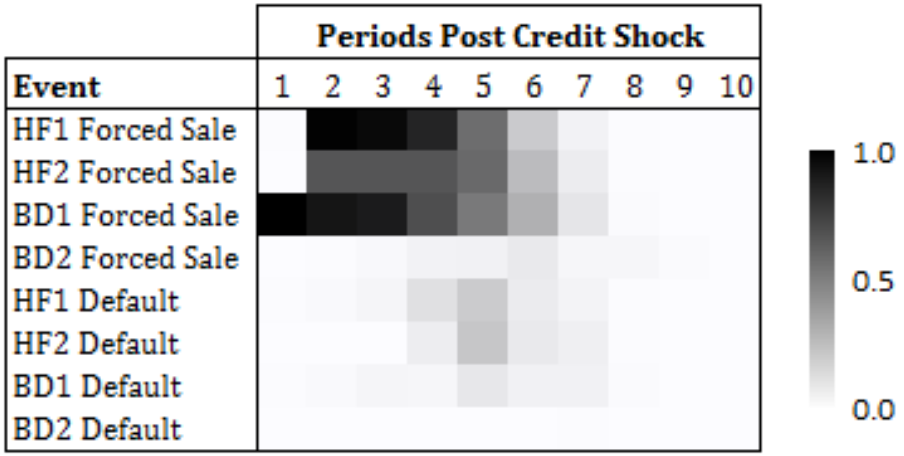
Price Shock



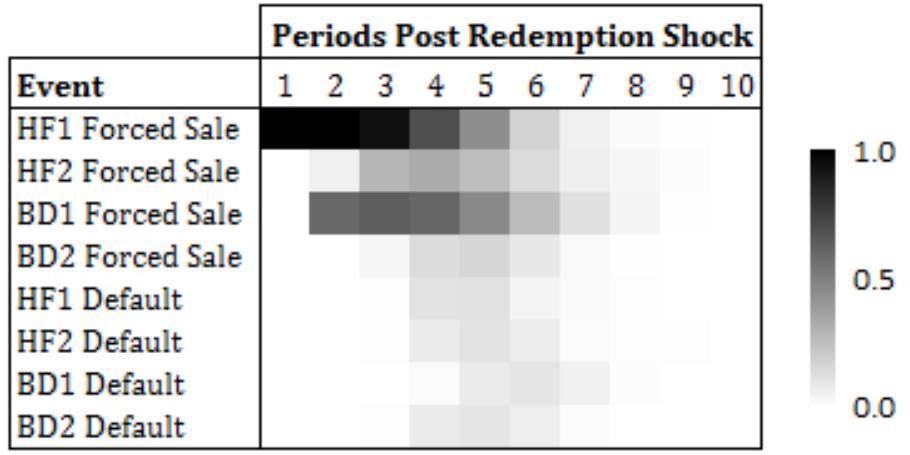
Funding Shock



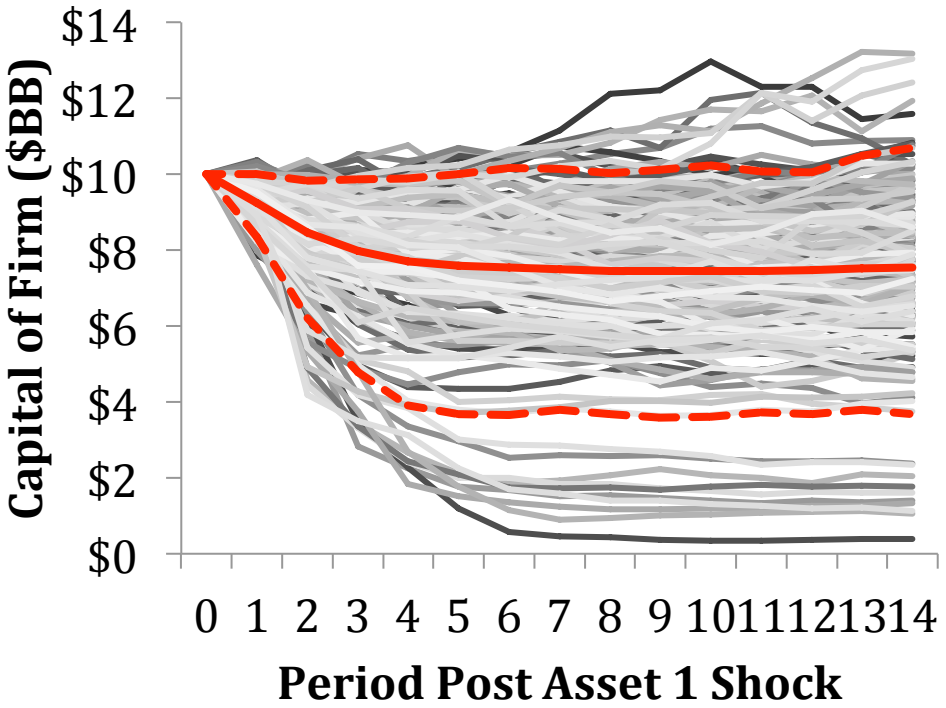
Credit Shock

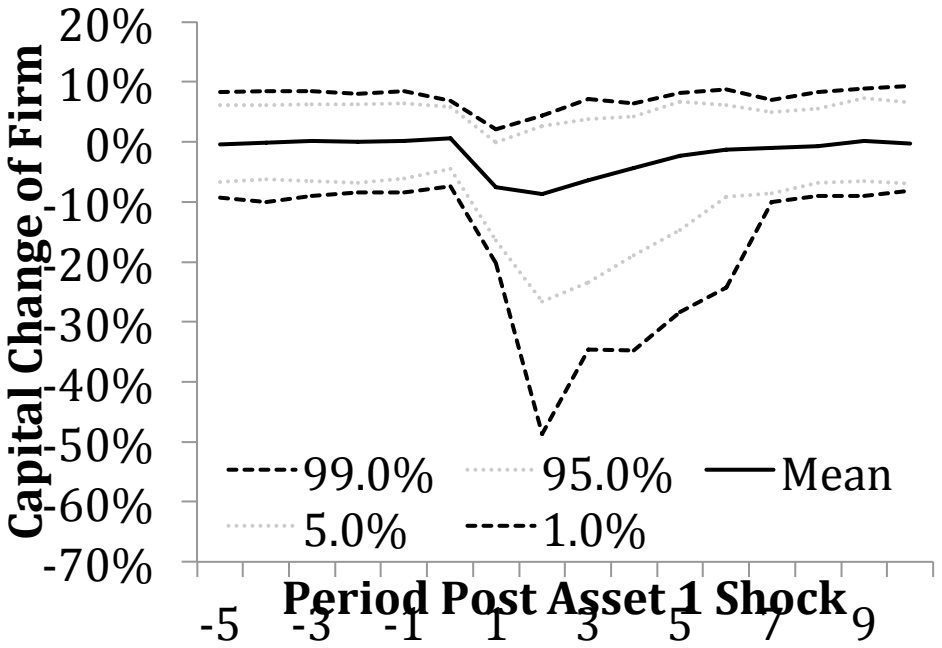


Redemption Shock



ABM-based VaR Envelope for a Hedge Fund Post-Shock





- The fire sale cascade leads to a downward skew for the capital post-shock.
- Red lines are the mean and 5%/95% envelope, 1000 runs of a 15% shock in Asset 1.

Testing the Agent-based Model

OFR
OFFICE OF FINANCIAL RESEARCH

Parameter Realism

- Do parameter values of real-world agents lead to real-world dynamics

Comparative Statics

- Do things move in the right direction, by the right amount, from a reasonable initial value
- Is there common sense consistency

Stylized Facts

- Do we see agents and markets behave in the right way

Back Testing

- Can we reproduce past events

Populating the Model with Data and Rules

OFR
OFFICE OF FINANCIAL RESEARCH

Data

- Exposures: dominant investment themes, credit
- Funding: sources, durability, leverage, collateral
- Prices: “big trade” liquidity
- Frequency: Exposures and funding build and change slowly
- Completeness: More is better; less can still work

Agents’ Rules

- Many actions during stress are pre-determined and non-proprietary