Risk Management Version 3.0: Agent-based Models and Crisis Dynamics

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Systemic Risk and the Financial Networks,
IPAM, March 26, 2015

Risk Management – Versions 1.0 to 3.0

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- **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

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Asset (Price) Shock or Funding Shock

→ Forced Sales *due to leverage*

→ Secondary decline and contagion to other assets *due to illiquidity*

⇒ Cascades + Contagion

Leverage- and Liquidity-driven:

Fire Sales ↔ Asset illiquidity

The Problem to Solve: Fire Sale Dynamics

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Asset (Price) Shock or Funding Shock

→ Forced Sales

→ Shock to other Assets

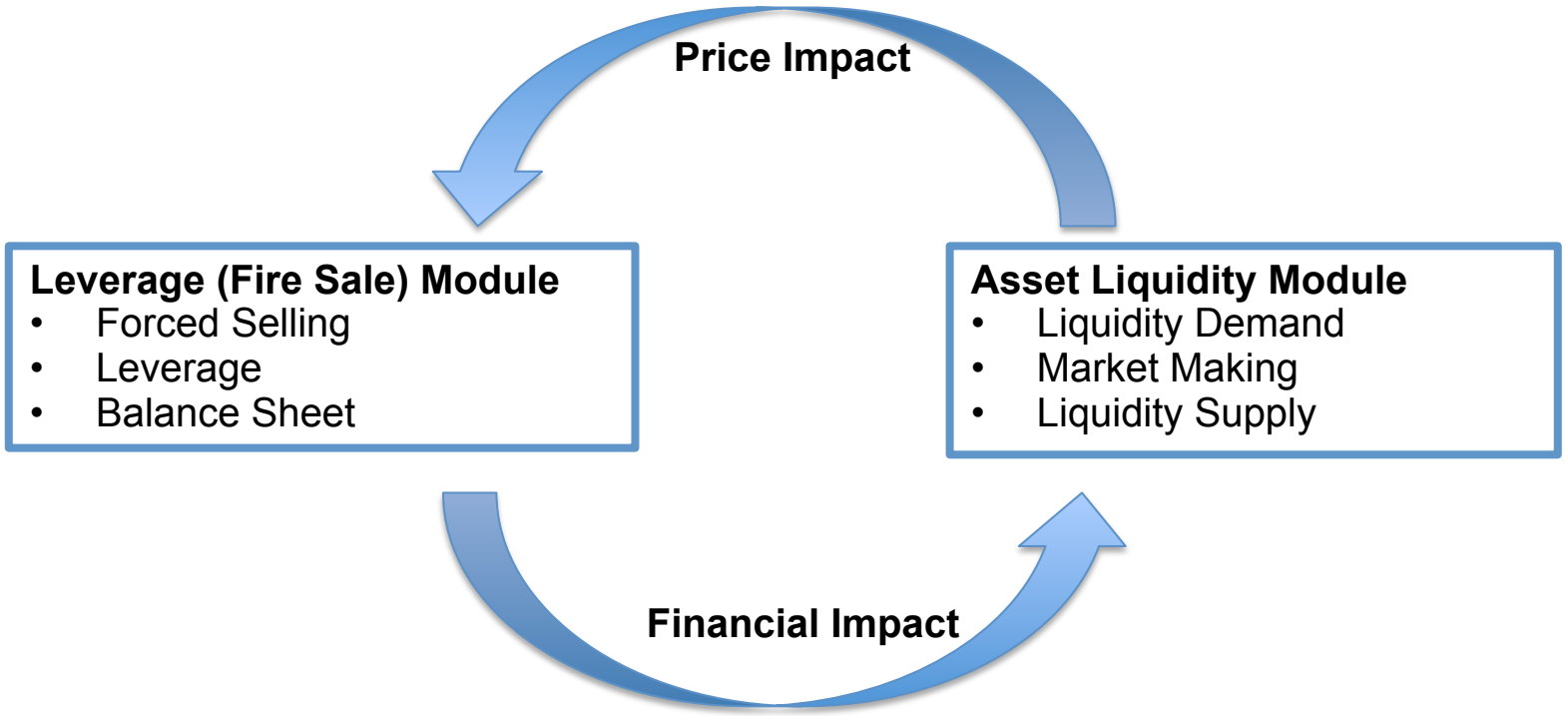
⇒ Cascades + Contagion

Leverage- and Liquidity-driven: Fire Sales ↔ Asset illiquidity

My Focus:

- Short-term
- Financial sector
- *Actual* financial sector (MS, Citi, etc.)
- Fixed income markets and instruments
- Crazy times

Leverage and Liquidity Modules



I. The Fire Sale (Leverage) Component

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A Network (Production Plant) View: Flows Between the Agents

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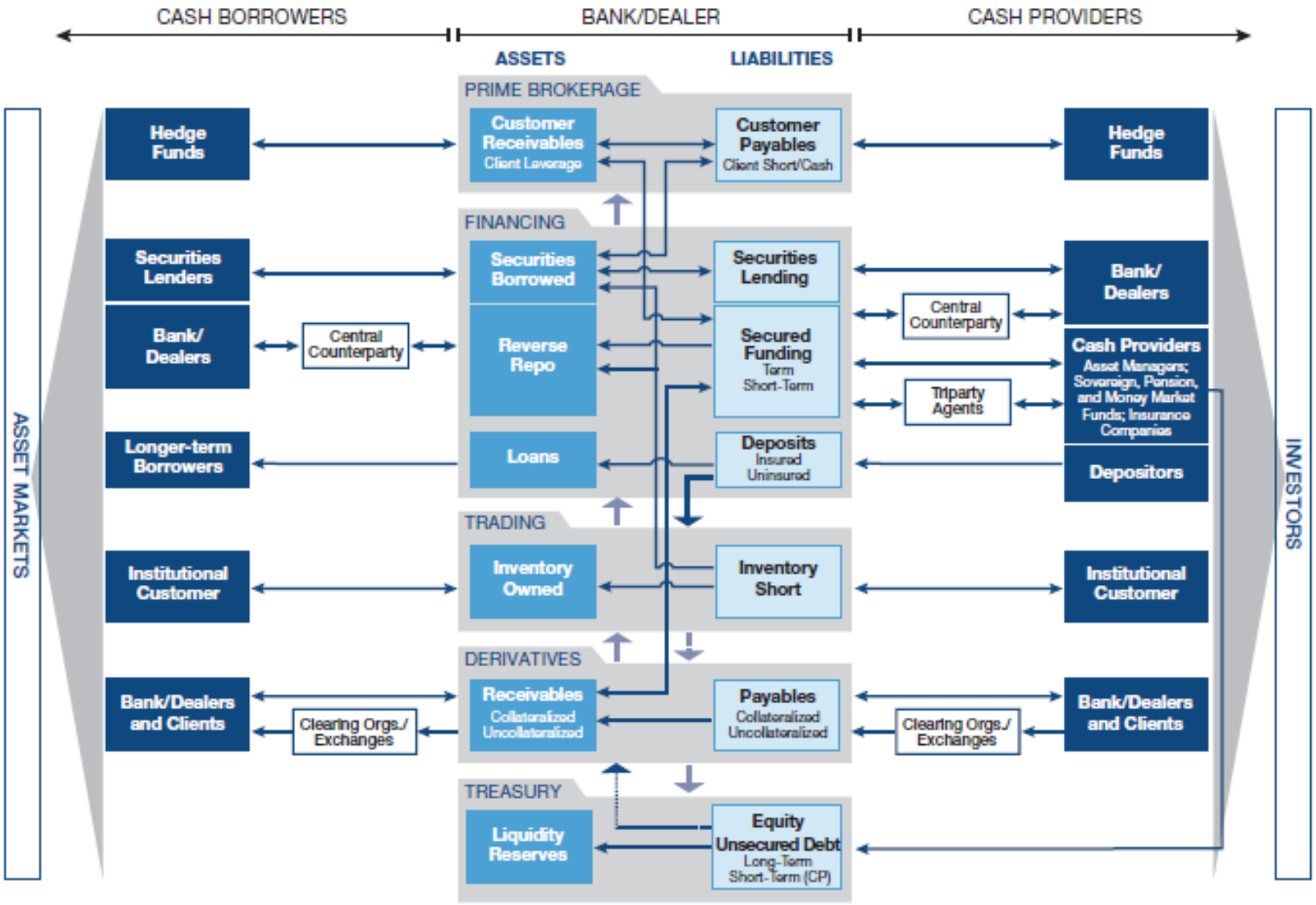

The Transformations of Flows Behind Stress Dynamics

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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

- Collateral upgrades.
- Collateral re-use.

Liquidity transformation

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

Risk transformation

- Molding return distributions via derivatives.
- Tranches with varying risk characteristics.

"A Map of Funding Durability and Risk", OFR Working Paper, May 1014.

A Tool for Version 3.0: Agent-based Models

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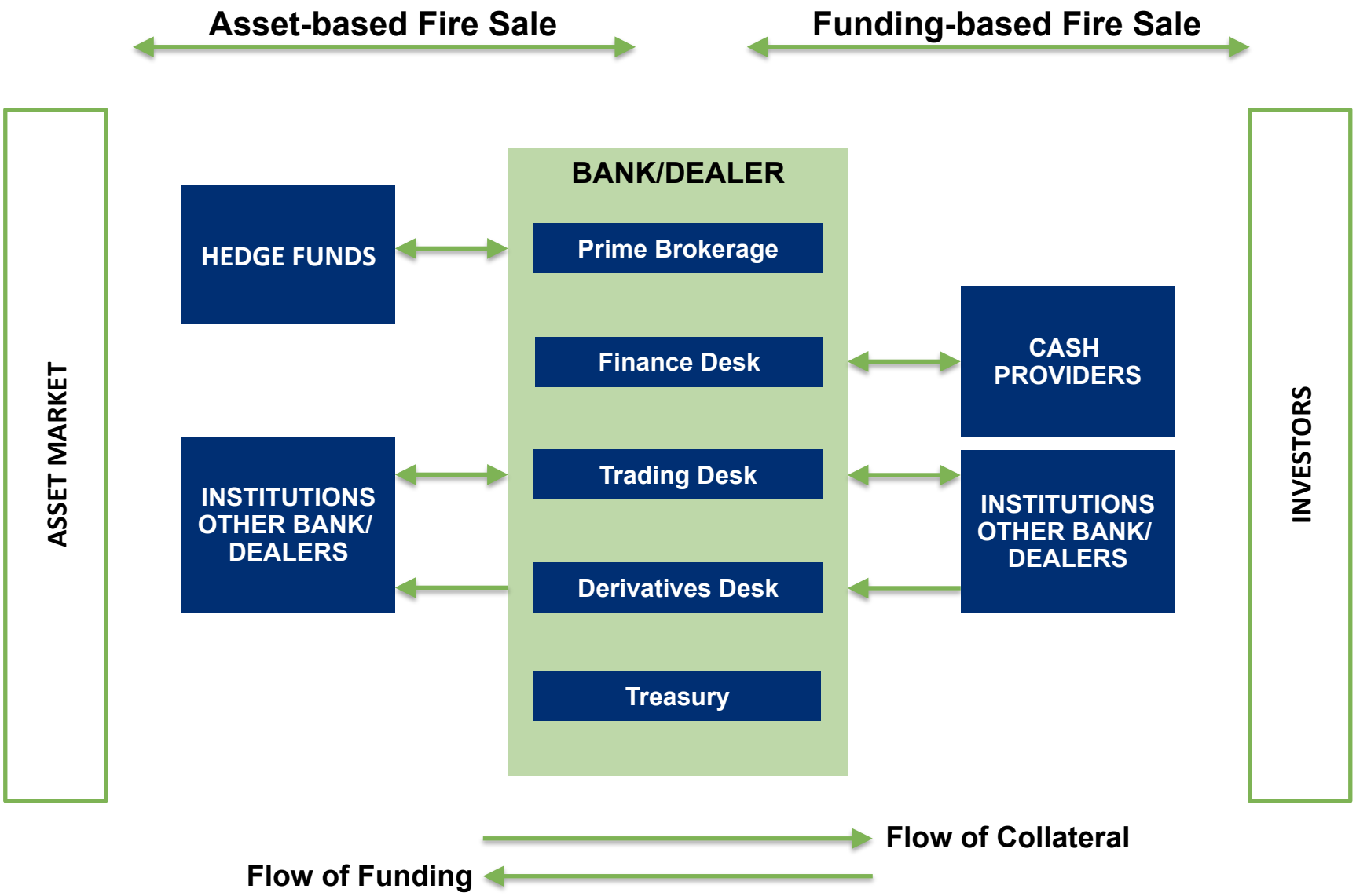
Agents pursue their activities period by period

- 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

Agents in the Fire Sale Model



Agent Behavior

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Cash Provider

- Haircuts, Collateral Value, Maximum Funding

Hedge Funds

- Target, Buffer, and Maximum Leverage, Liquidation Rule

Finance Desk

- Collateral; rules of Cash Provider and Treasurer

Treasurer

- Maximum Leverage; Target and Minimum Liquidity Ratio

Trading Unit

- Balance Sheet; Target, Buffer, and Maximum Leverage
- **Derivatives**
- Counterparty Risk; (market exposure is passed to the Trading Unit)

"An Agent-based Model for Financial Vulnerability", OFR Working Paper, July, 2014.

A Model Run

The model can have an any number of agents , markets, and iterations.

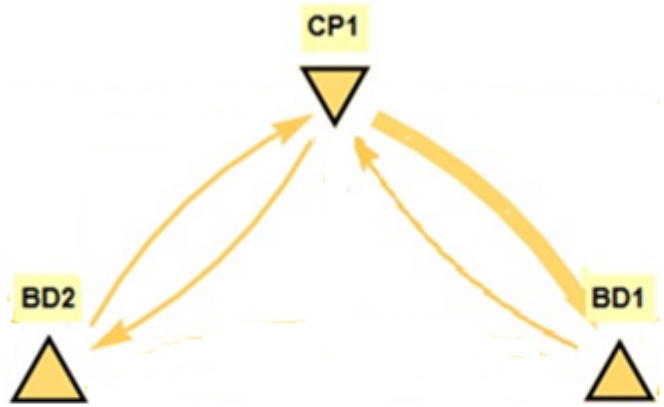
In this model parameterization we have:

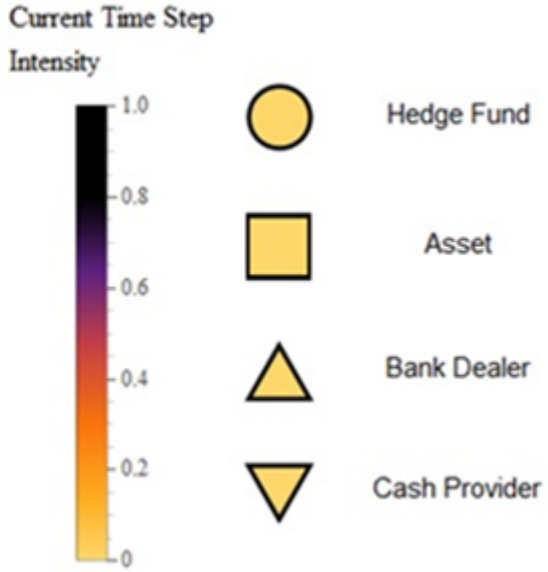
- Three Assets: A0, A1, A2
- Two Hedge Funds: HF1, HF2
- Two Bank/Dealers: BD1, BD2
- One Cash Provider: CP1

HF1, BD1 Portfolio: {A0, A1}
HF2, BD2 Portfolio: {A1, A2}

- Run over 1000 iterations

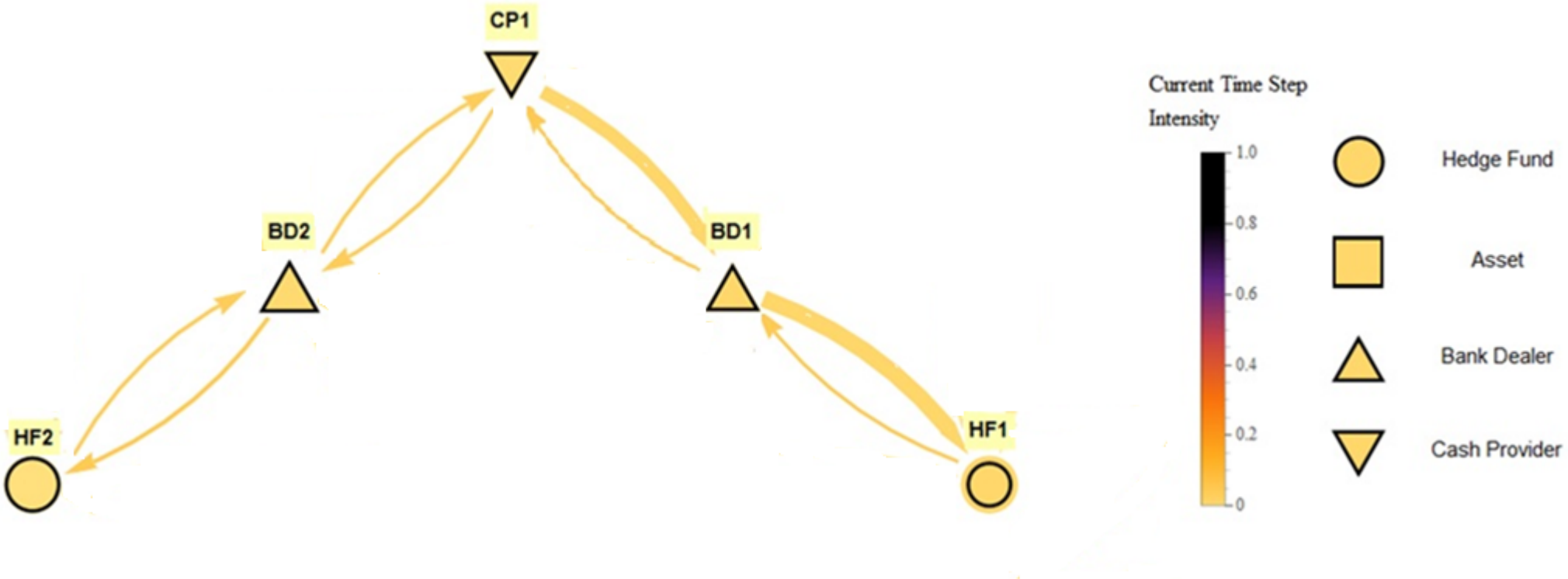
Schematic for Looking at the Network Dynamics





- 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.

Schematic for Looking at the Network Dynamics



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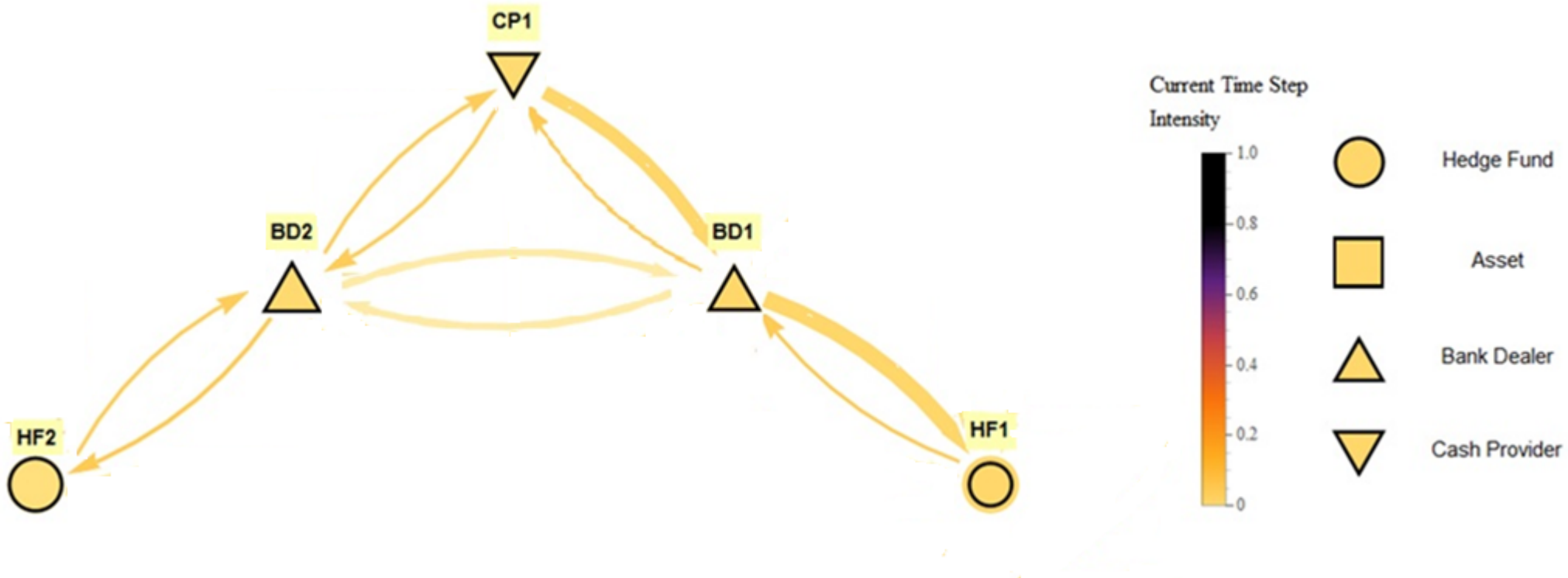

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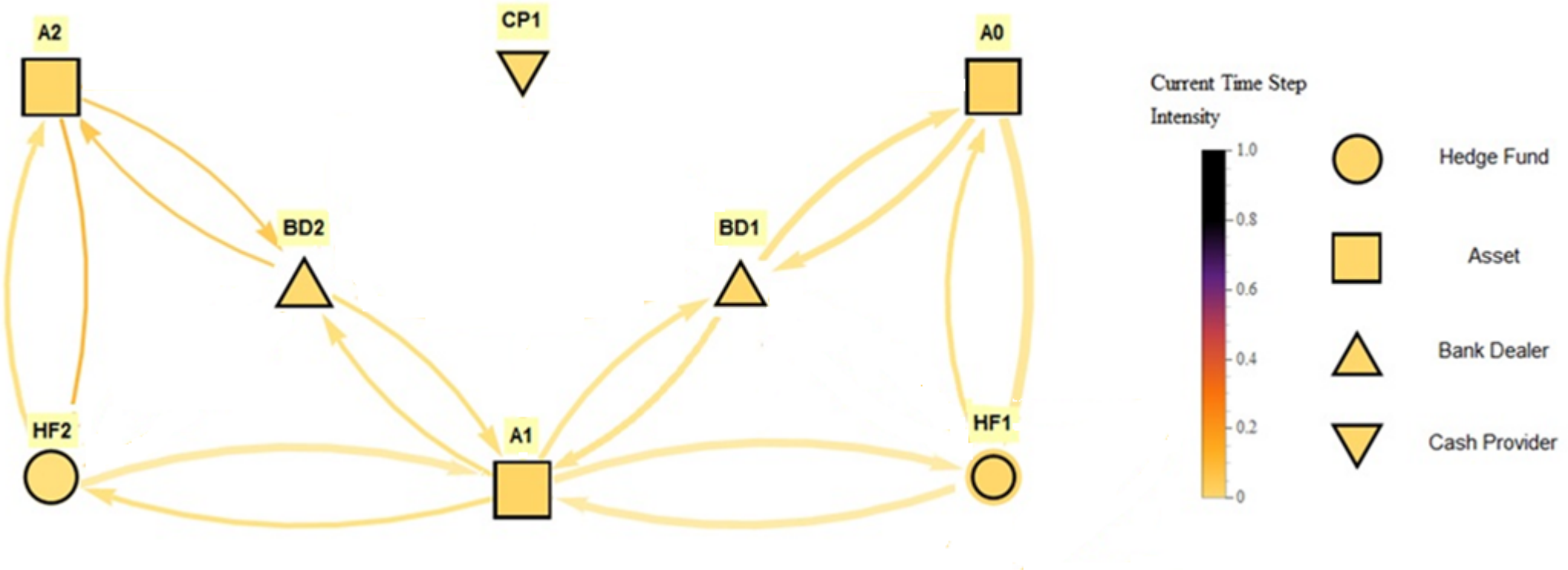

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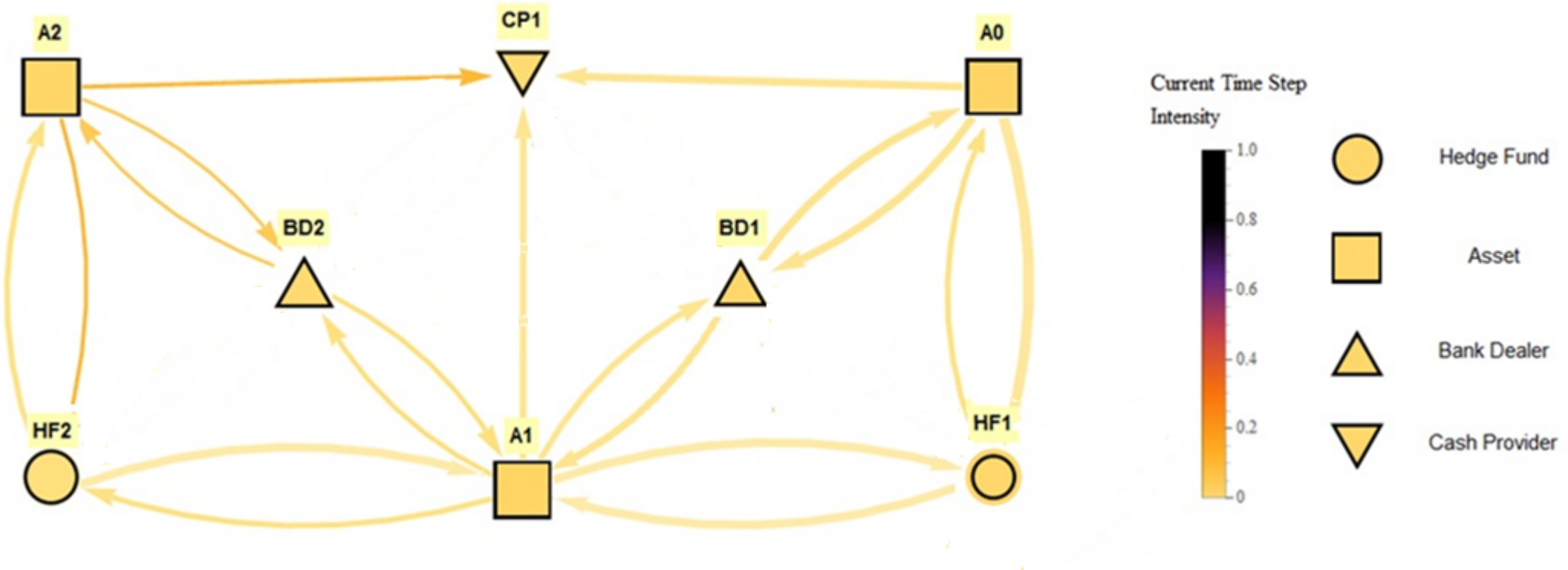

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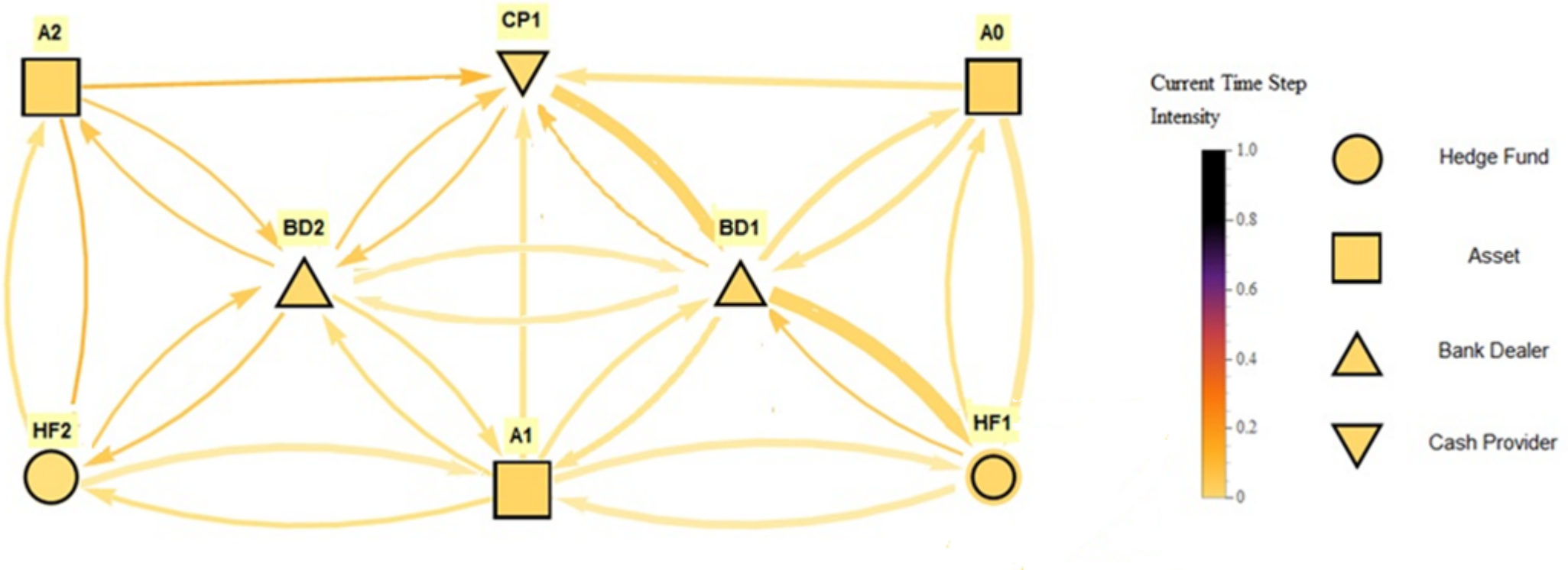

Period 0: The Static Stress – A 15% Price Shock to A0

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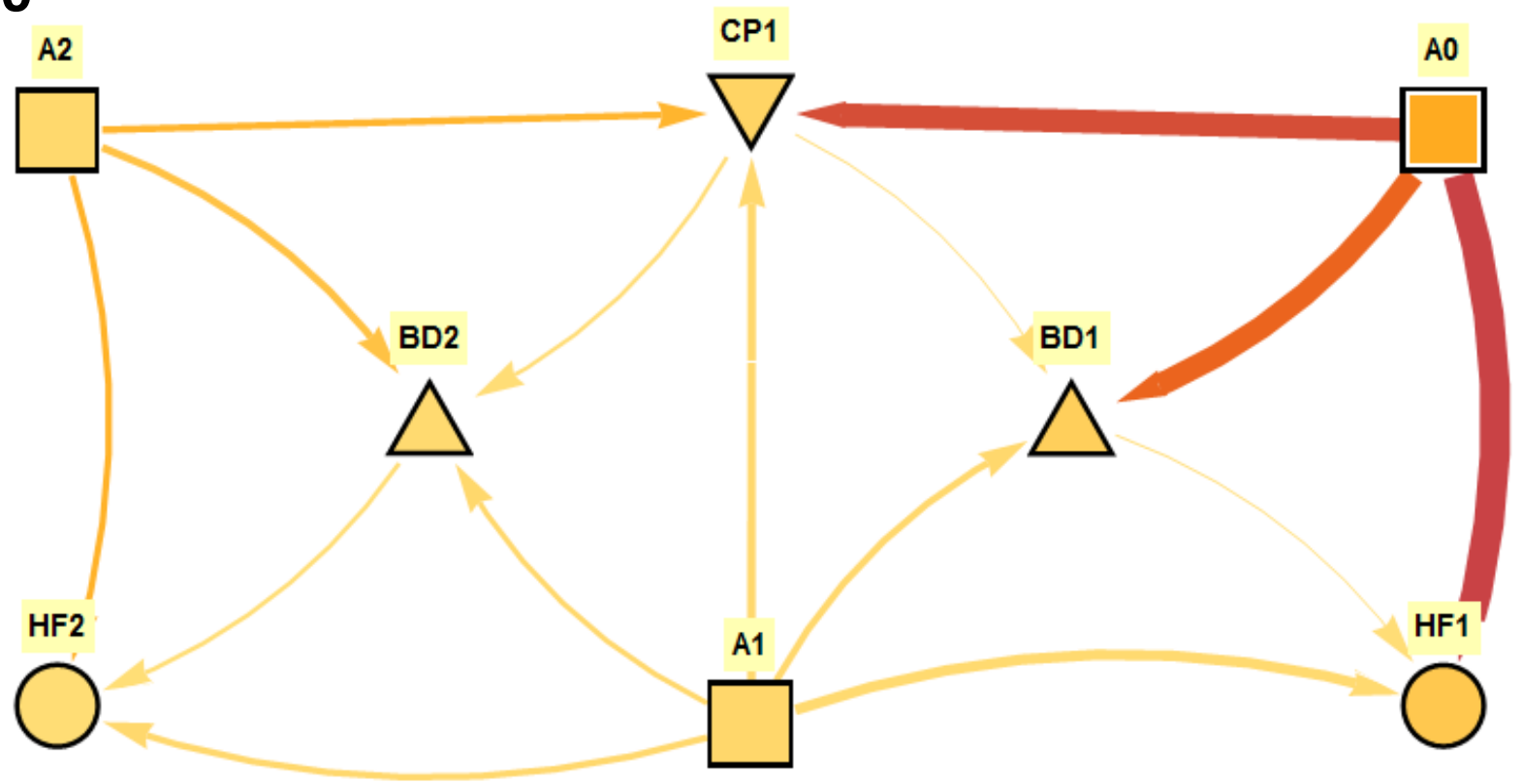
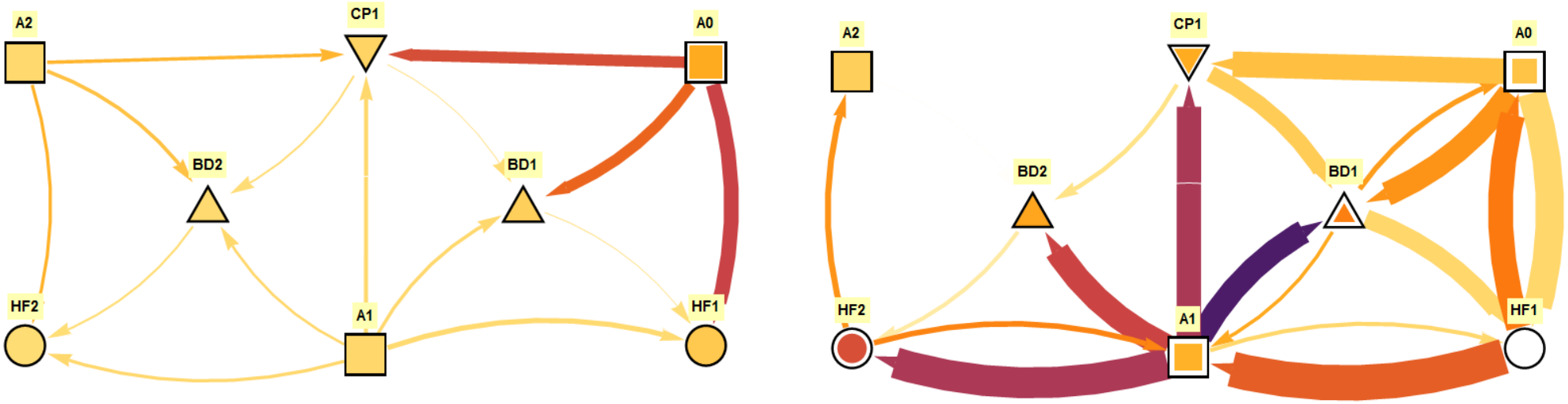
Period 0



- A0 experiences a 15% price shock – can have other types of shocks
- BD1 and HF1 hold A0 in their portfolio
- CP holds A0 as collateral
- The end of the story for the standard stress test

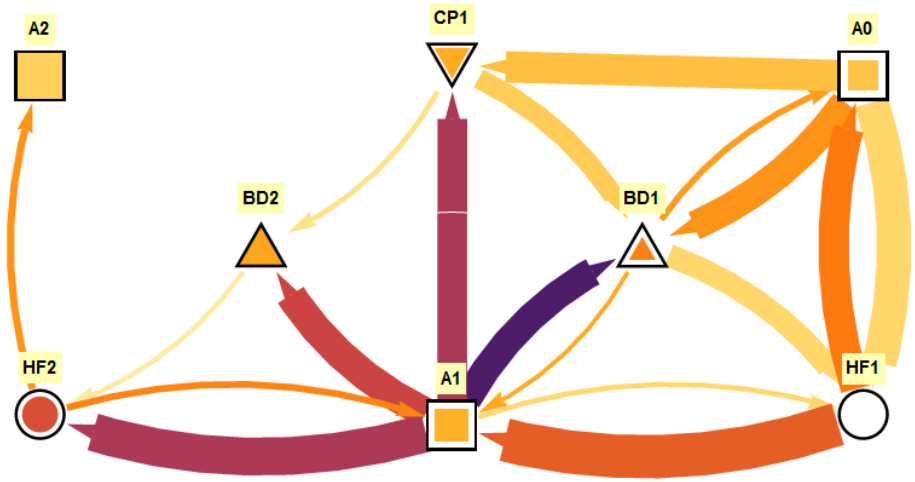
Period 2: Cascade in A0 and Contagion through A1

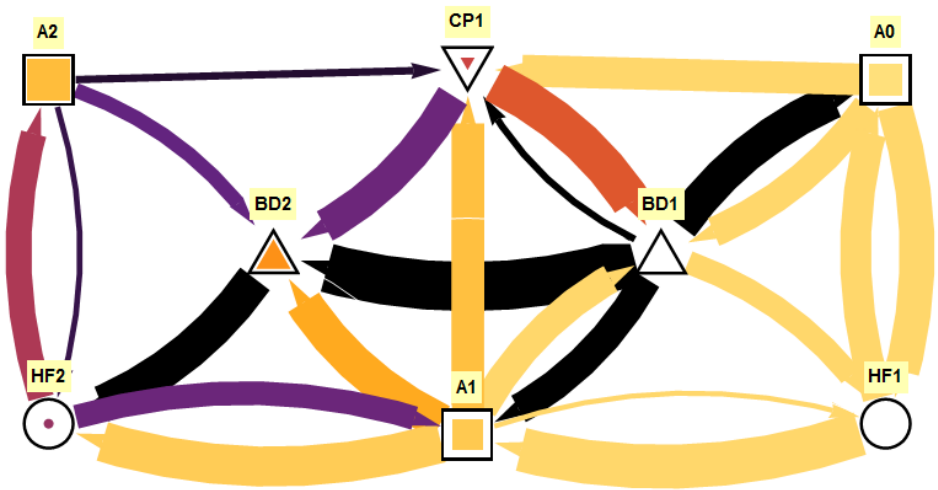


Period 0 → **Period 2**

- BD1 and HF1 decrease positions in both A0 and A1
- This creates a downward cycle for A0 and a drop in A1
- It also affects other agents holding A0 or A1
- CP1 reduces funding as its collateral value drops

Period 4: Credit and Funding Effects





Period 2 → **Period 4**

- The drop in prices ignites a funding-based fire sale through CP1
- The dynamic spreads due to credit exposure from BD1 to BD2
- This can lead to difficulty in identifying the source of contagion

Sources of Shock

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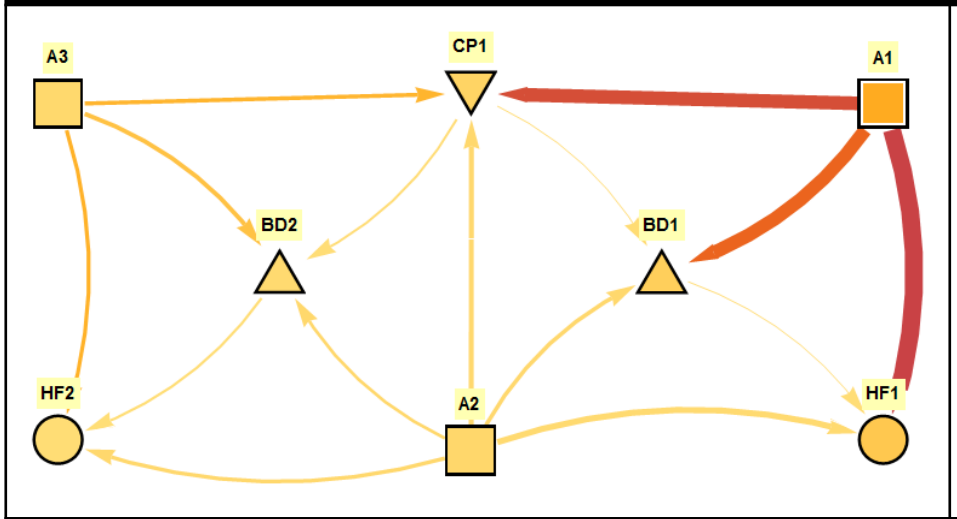
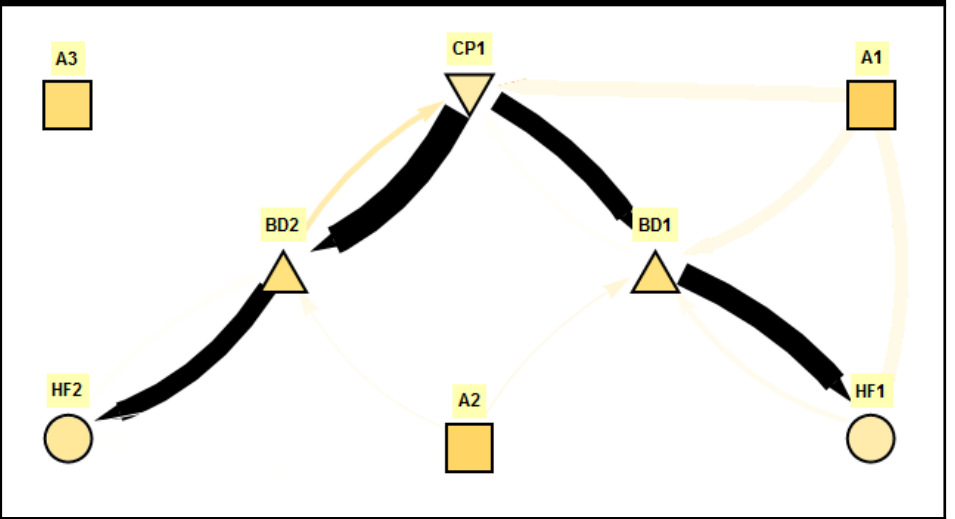
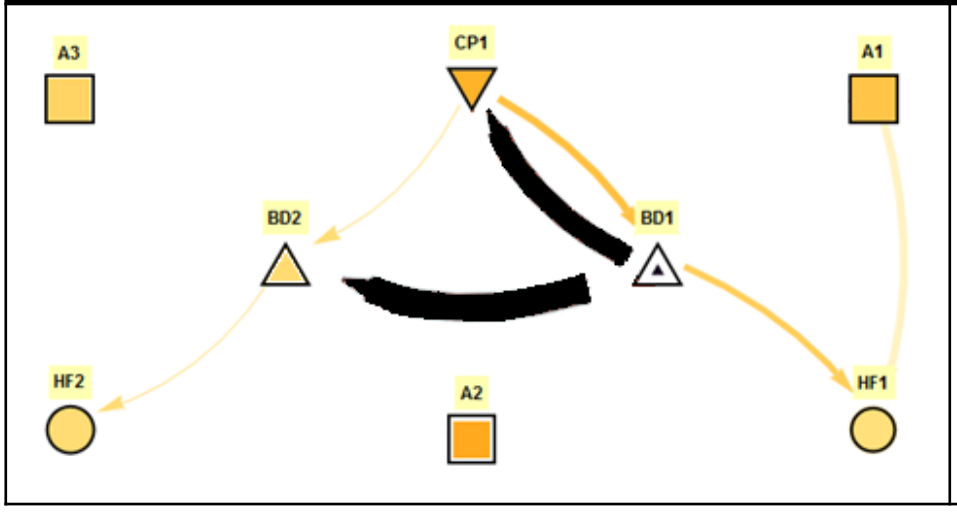
Asset Market: Price Shock



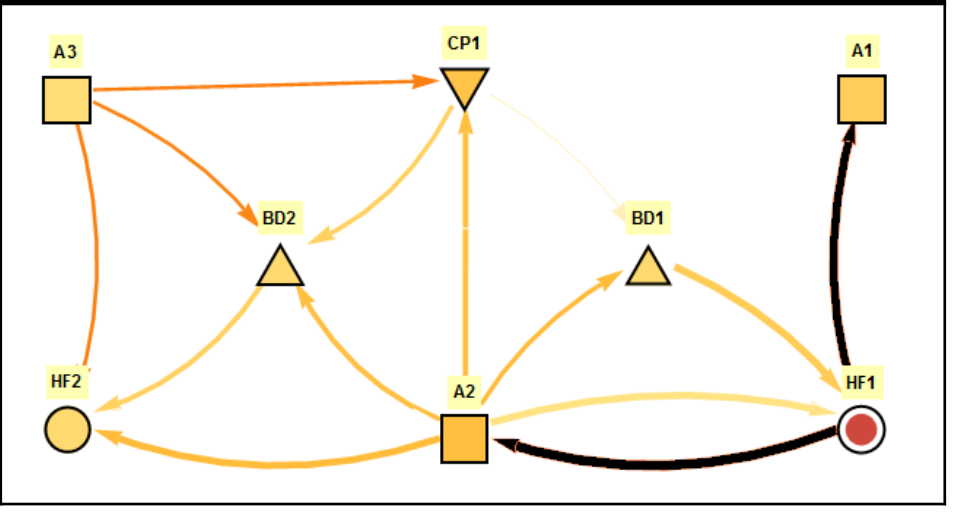
Cash Provider: Funding Shock



Bank/Dealer: Credit Shock



Hedge Fund: Redemption Shock



II. The Liquidity Component

The Rising Risk of Illiquidity

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For fire sales, both leverage and liquidity are critical. Leverage was central in the recent crisis. Now liquidity is of increasing concern, especially in the fixed income and credit markets.

- Bank-dealer market makers have less balance sheet and lower risk tolerance.
- The incentives for these market makers have diminished.

Estimating Liquidity During Market Dislocations

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Market impact and liquidity shocks are difficult to estimate.

- Limited value to measures of the day-to-day liquidity, such as bid-offer spreads and daily volumes.
- Limits of historical data on how markets behave during a crisis

Emergent Phenomena During Market Dislocations

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Financial crises are often characterized by sharp reductions, unusual behavior in liquidity, and emergent phenomena.

- A drop in prices can lead to more selling and less buying.
- A severe price drop can elicit less rather than more liquidity.
- The small cannot extrapolate to the large

Essentials of a Disruption-focused Liquidity Model

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- Capital declines for market makers.
- Inventory increases for market makers.
- Market makers begin to “bid to miss” and act as riskless principal (agent)
- Heterogeneity in the decision cycles disrupts supply versus demand
  - short cycle for liquidity demanders
  - long cycle for liquidity suppliers
- Participation declines for the liquidity suppliers.

Essentials of a Disruption-focused Liquidity Model

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Heterogeneous Decision Cycles, Portfolio Insurance and the Crash of '87

A Demon of Our Own Design, Chapter 2

- "The specialists at the NYSE tried to elicit more buyers by dropping the price, but there was a limit to how much more buying interest they could attract. No matter how much the price was dropped, the decision making by the equity investors took time; compared to the twitch-quick futures pit traders, they made portfolio adjustments only after longer consideration.
- "The root dynamic was what I call time disintermediation – Supply dried up because of the difference in time frames between the demanders and suppliers. By the time equity investors could have finally reacted to the prices and done some bargain hunting, the specialists moved prices so precipitously that these potential liquidity suppliers were scared away.
- "The key culprit was the different trading time frames between the demanders and the suppliers in the two markets [futures versus cash equities]. If the sellers could have waited longer for the liquidity they demanded, the buyers would have had time to react and the market would have cleared.

ABM and Version 3.0 on the Liquidity Side

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Liquidity Demander

- No discretion given to price.
- Places market orders.

Market Maker

- Short term liquidity provider.
- Places limit orders on both sides of the order book.
- Reduces willingness to take on inventory when approaching inventory limit.

Liquidity Supplier

- Arrives to the market infrequently.
- Places limit orders away from the bid/ask range.
- Provides liquidity based on price versus initial price.

"Market Liquidity and Heterogeneity in Investor Decision Cycles", OFR Working Paper, March, 2015.

Variables that Govern the Agents' Actions

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Order Arrival Rate

- New orders are placed by an agent based on a Poisson arrival process.

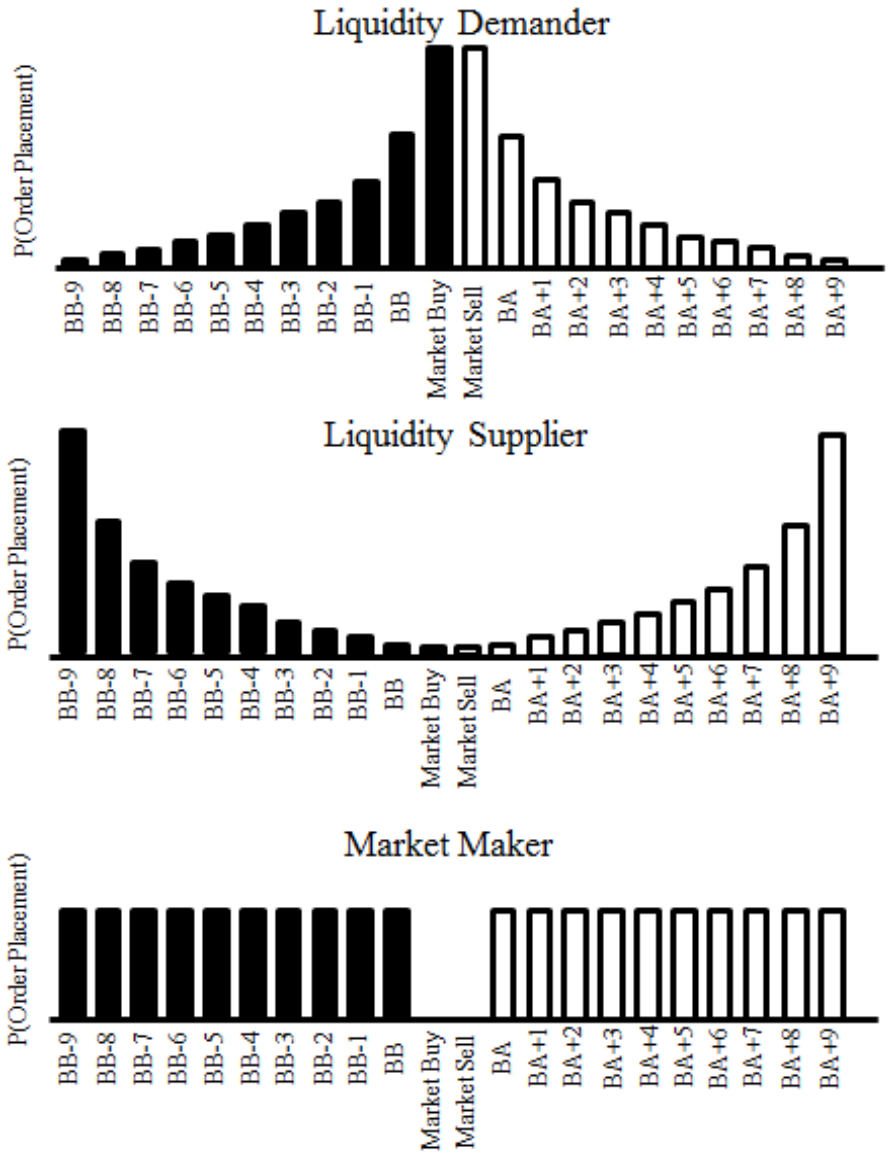
Order Size

- Liquidity Demander and Liquidity Supplier order size is inverse log normal.
- The Market Makers target a set order size.

Order Placement

- Distance from the bid/offer is randomly selected.
  - Inverse log-normal for Liquidity Demander
  - Log normal for Liquidity Supplier
  - Uniform for Market Maker
- Any old order is cancelled if a new order arrives.

Order Placement Distribution for the Agents



Order Placement Distribution for the Agents

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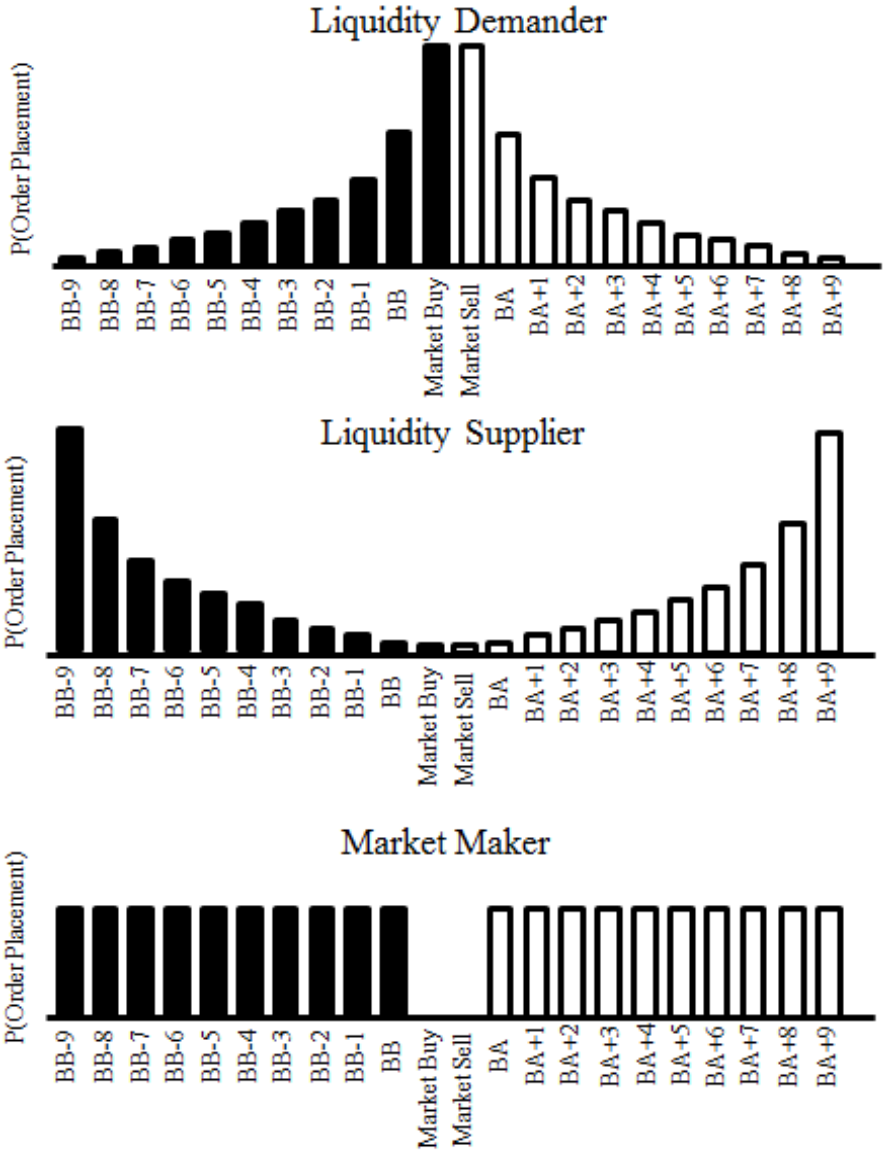
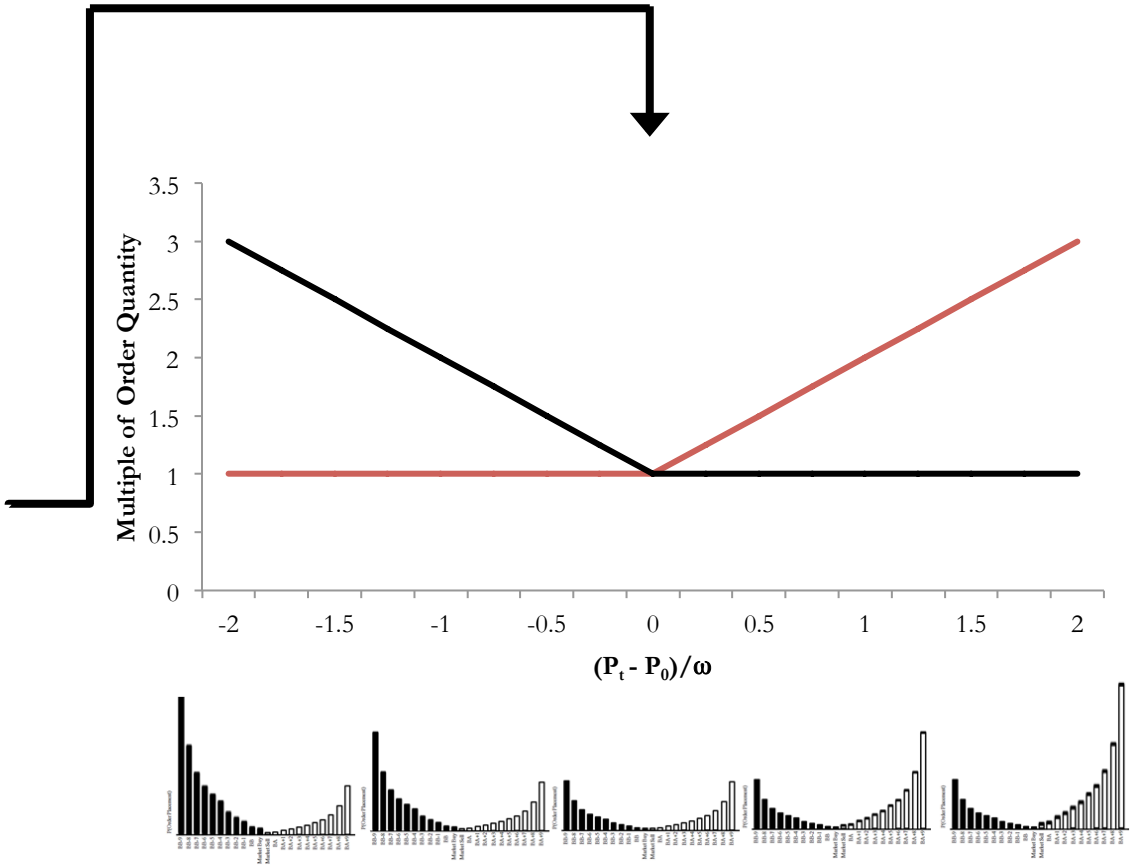
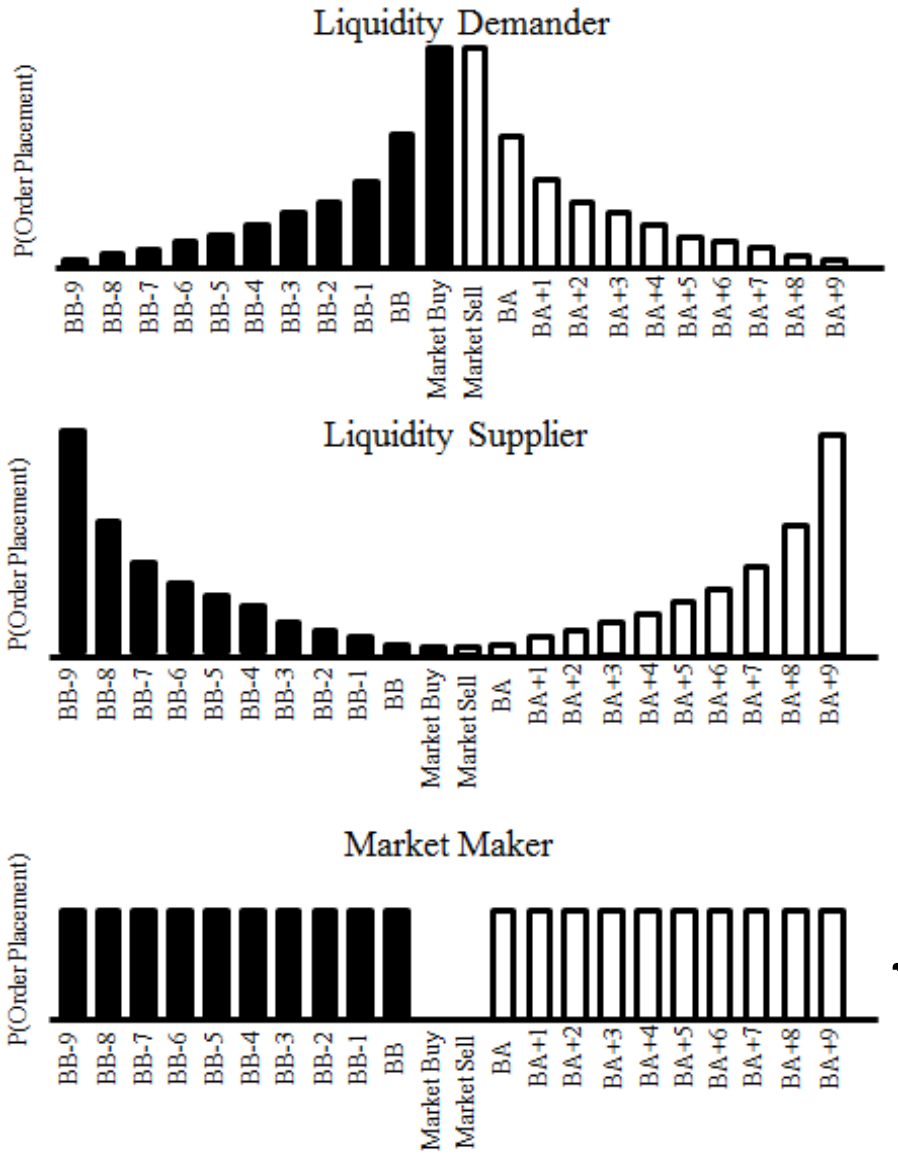
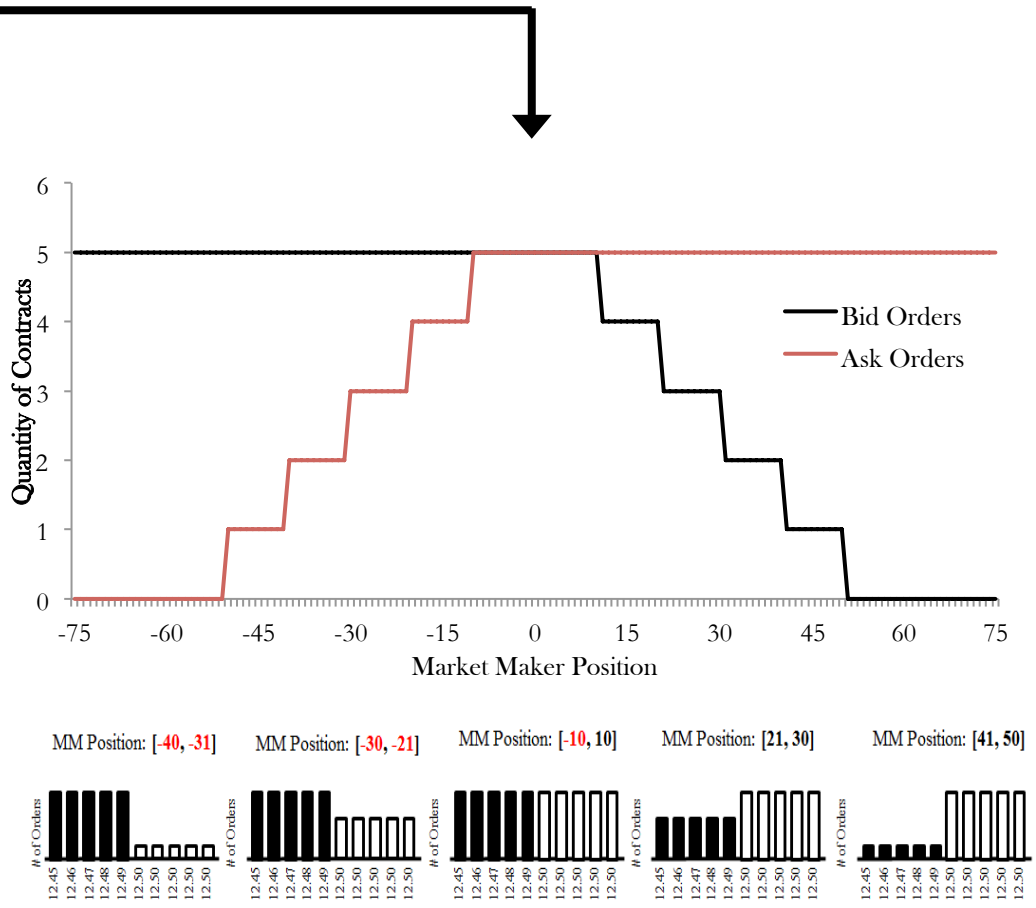




Order Placement Distribution for the Agents





Aggregation of Market Makers' Order Books

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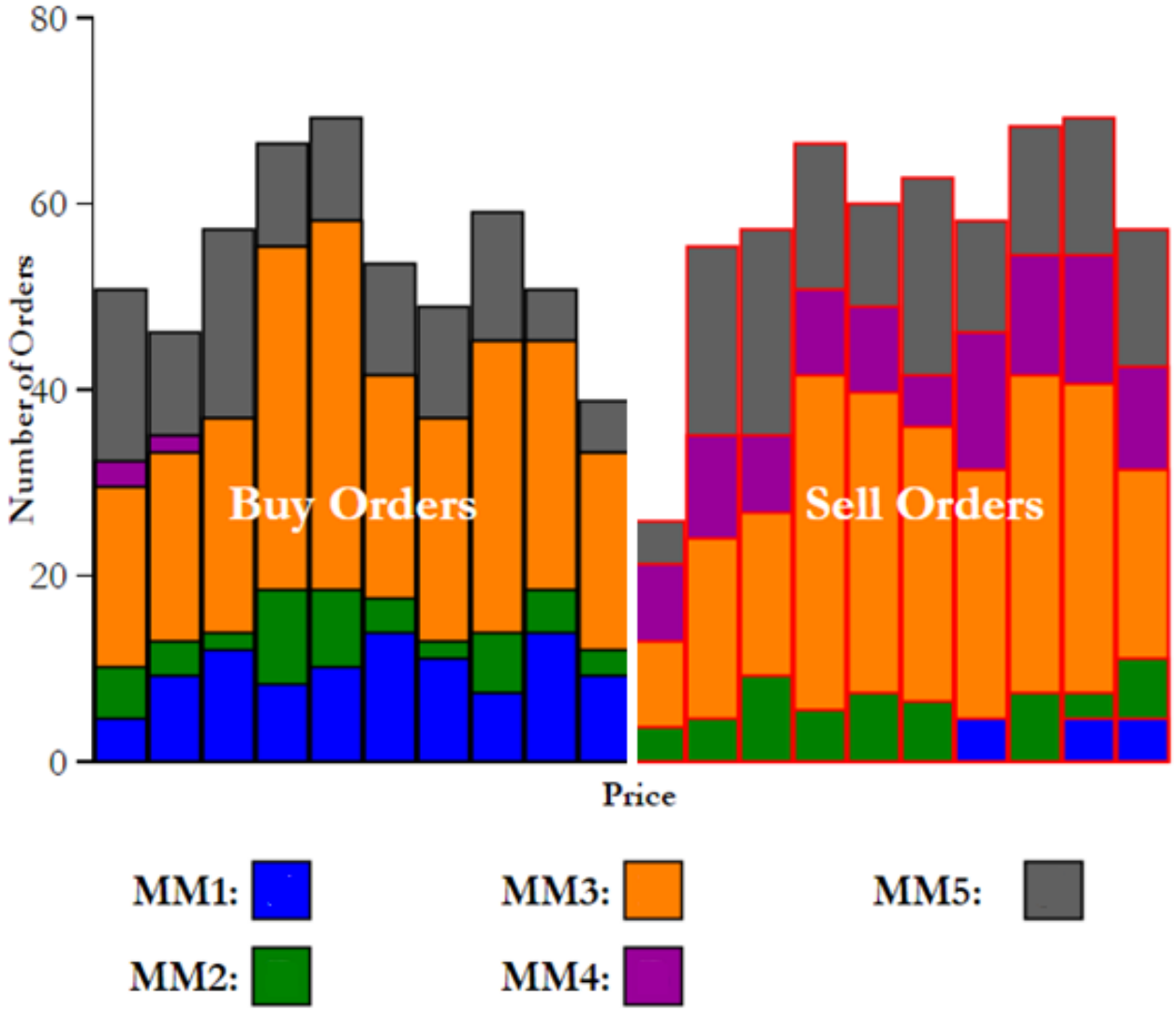

Order Book over Time

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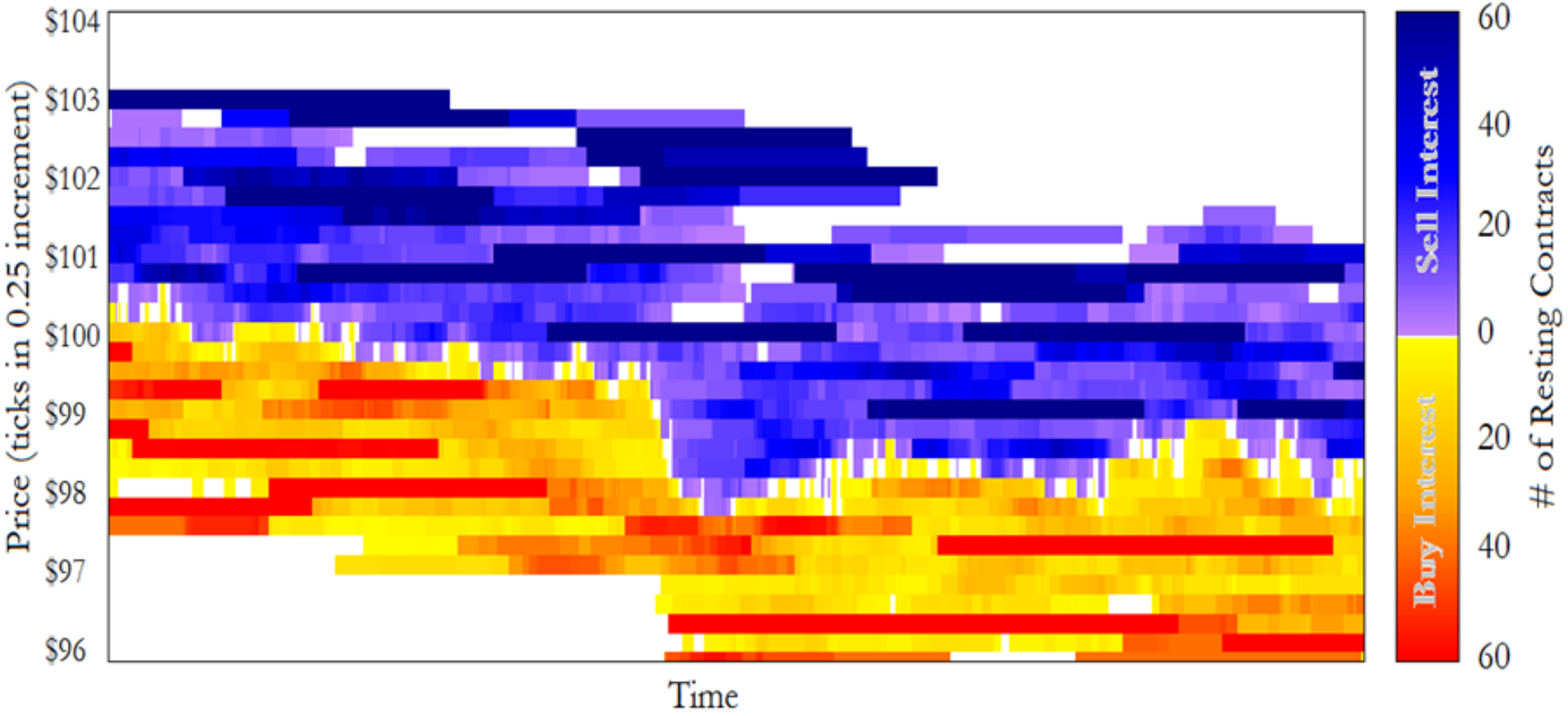

A vertical slice shows the order book for that time period. The darker the color, the larger the quantity bid or offered. The thicker the colored region, the deeper the order book on that side of the market.

Two Levels of Liquidity Supply

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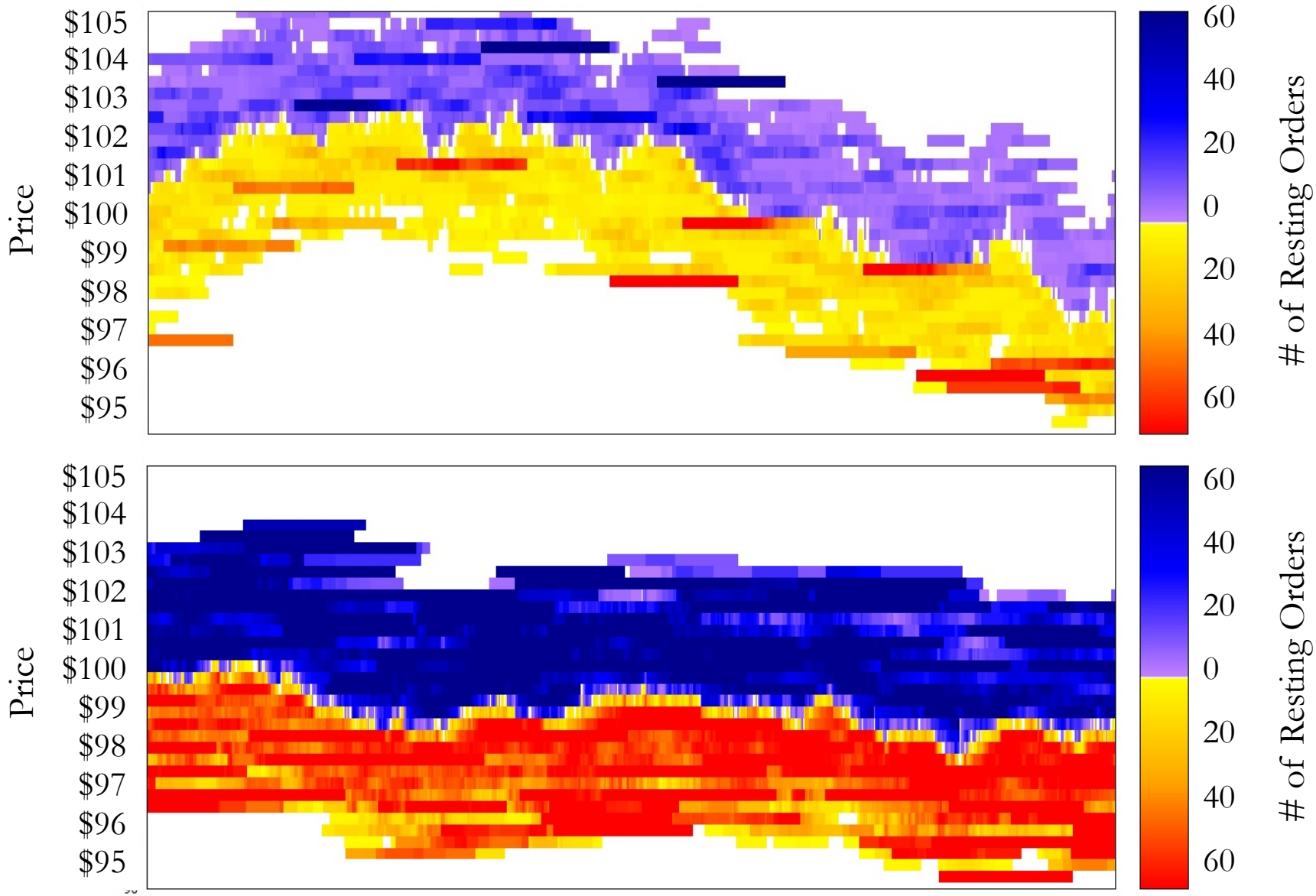

Agents' Actions: Normal Times

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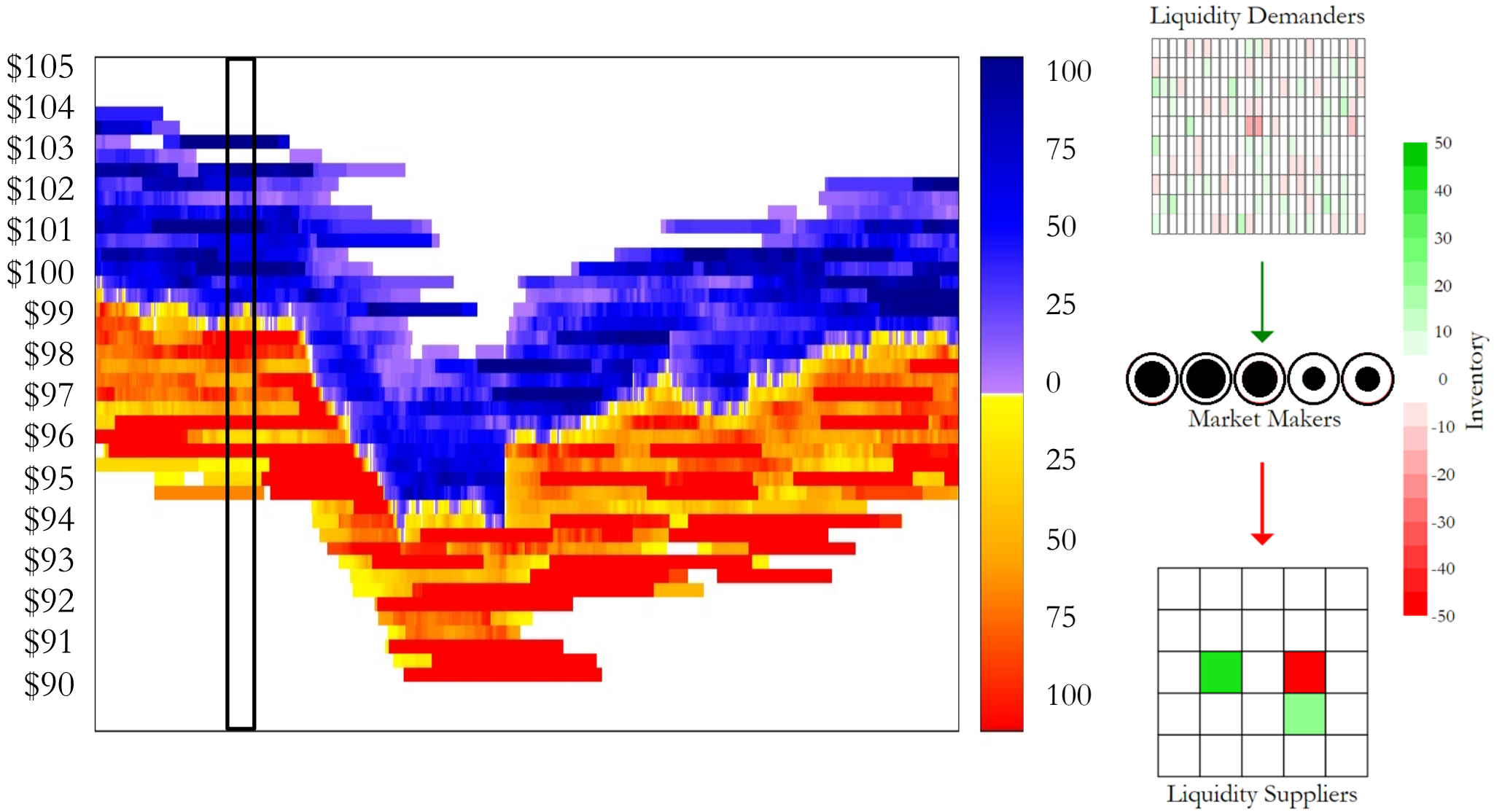

Agents' Actions: Start of Event

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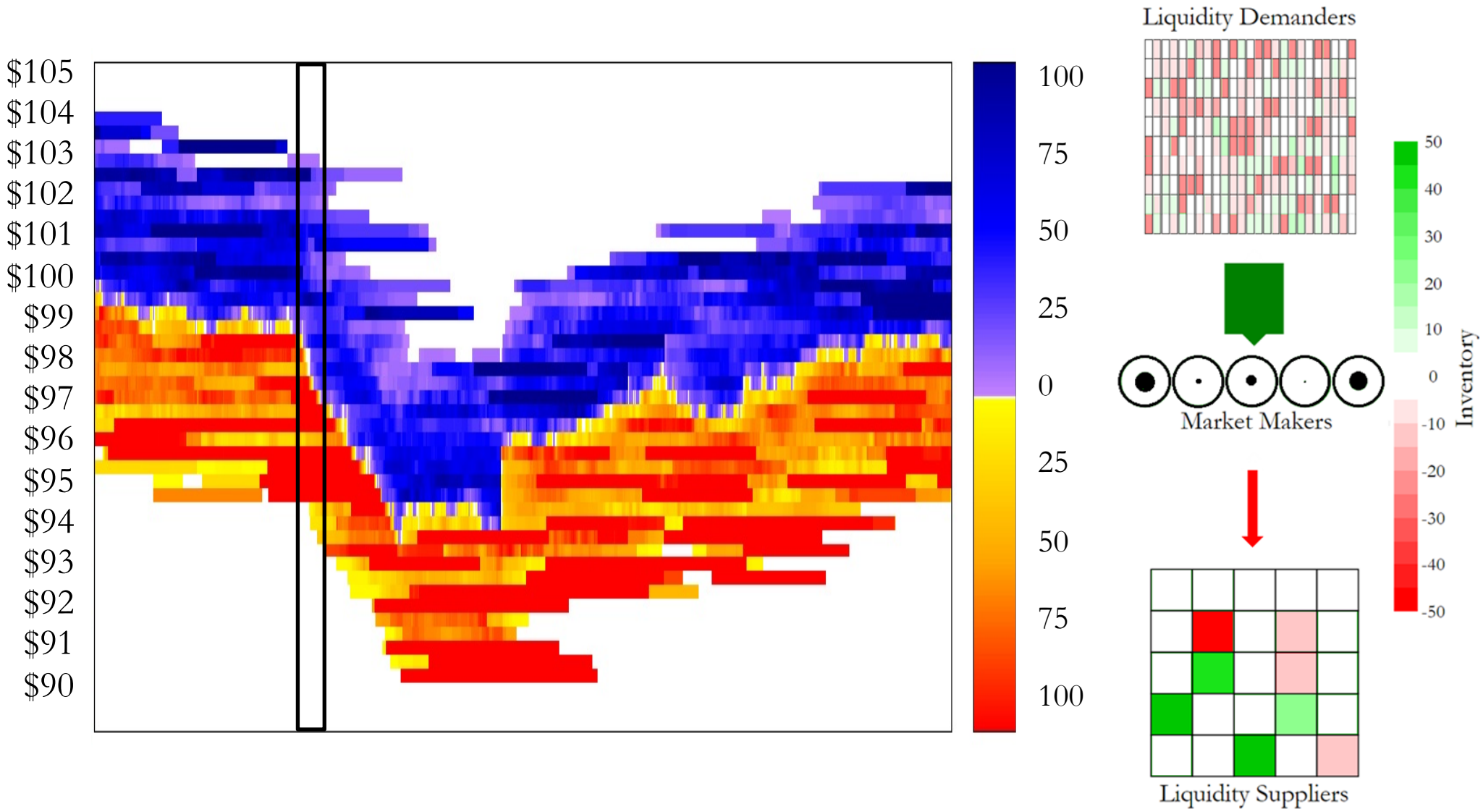

Agents' Actions : Capacity Declines

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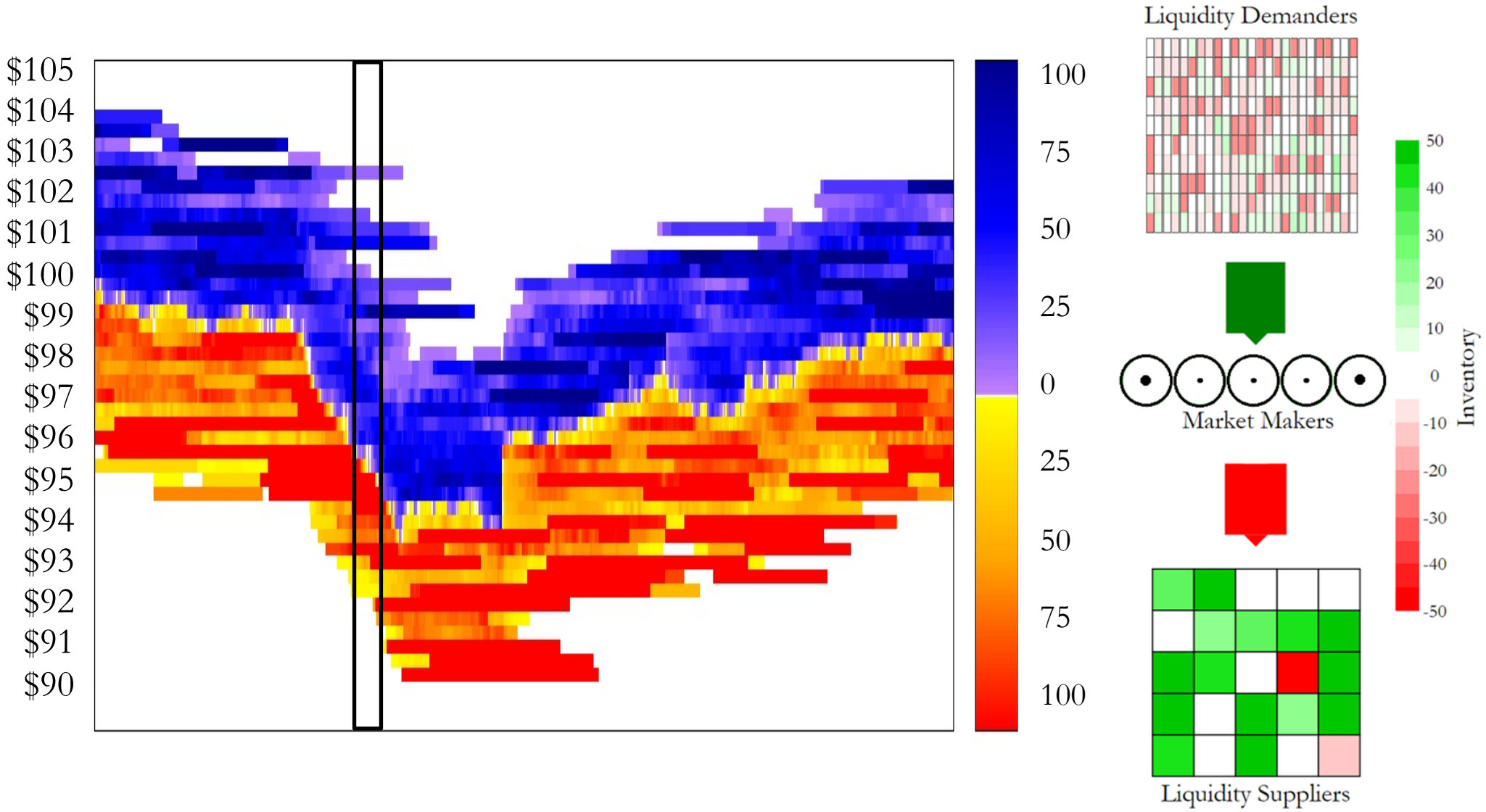
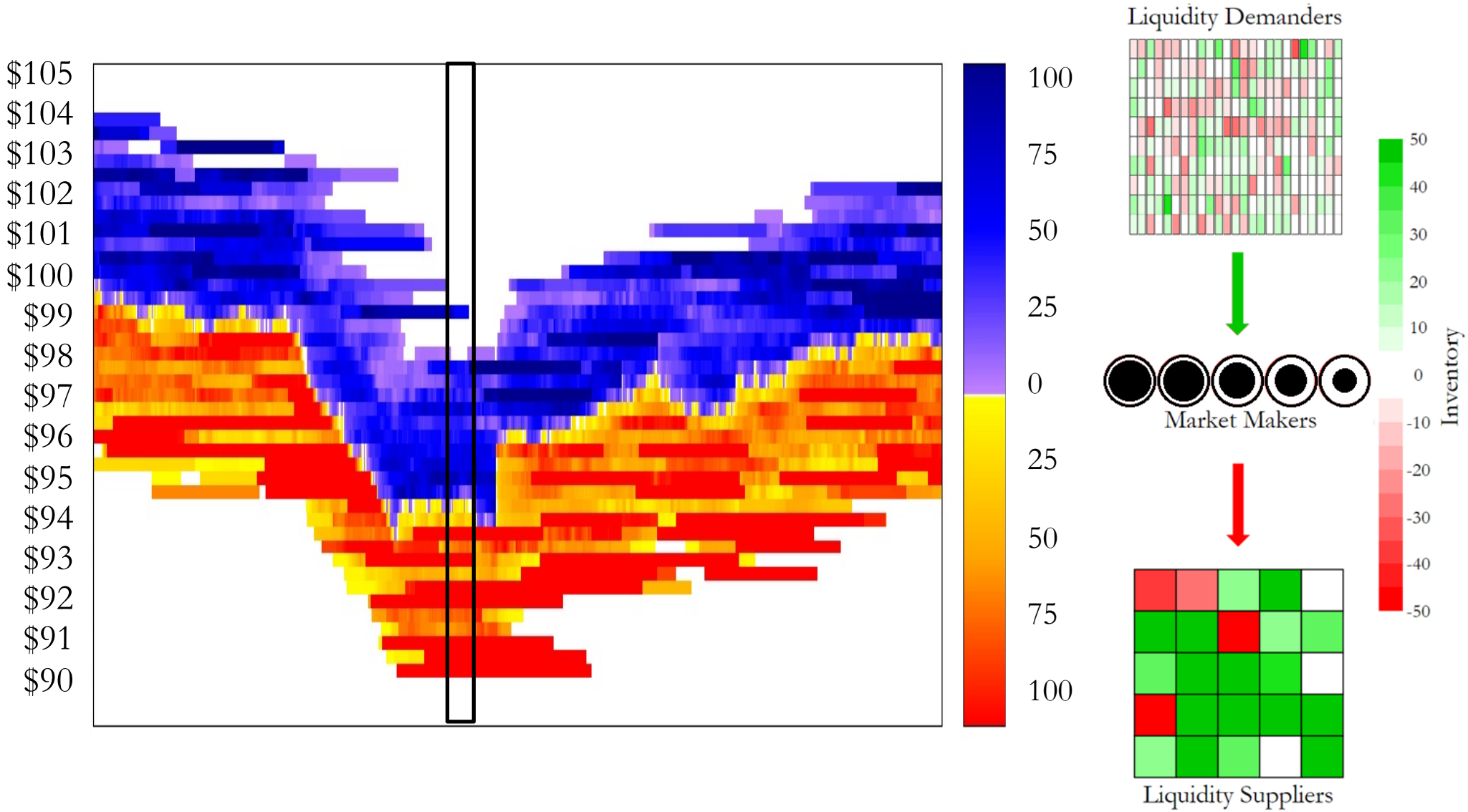
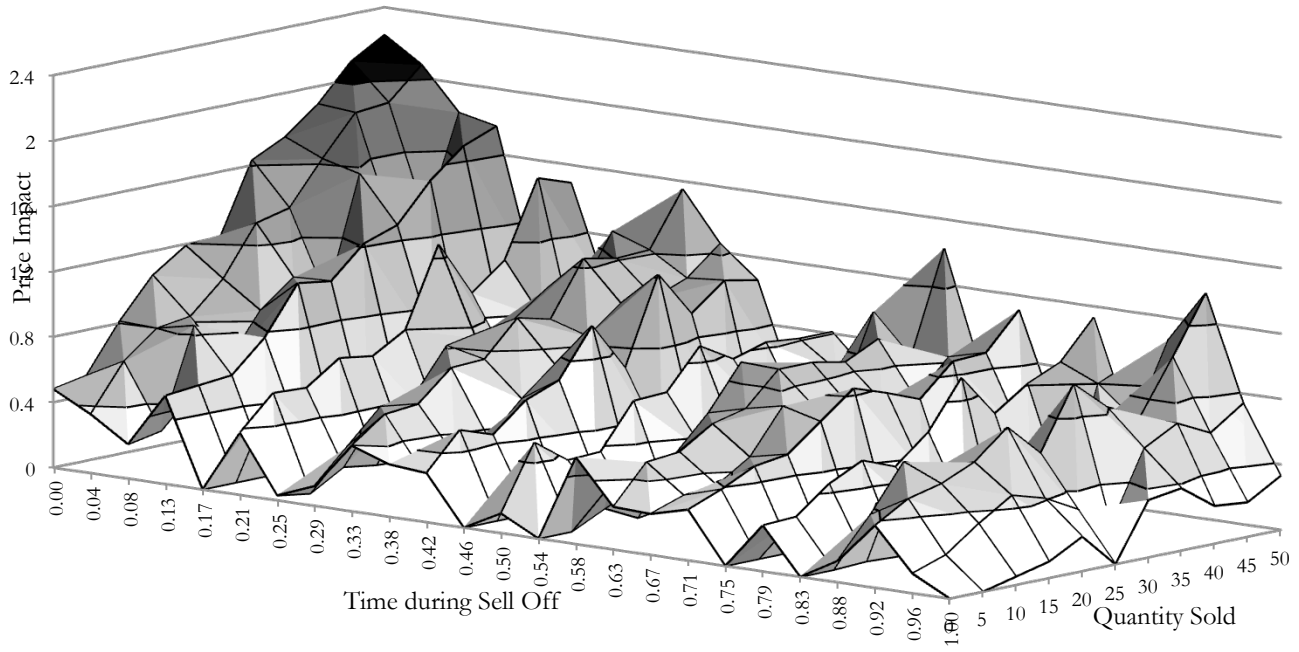


Agents' Actions: More Suppliers Enter

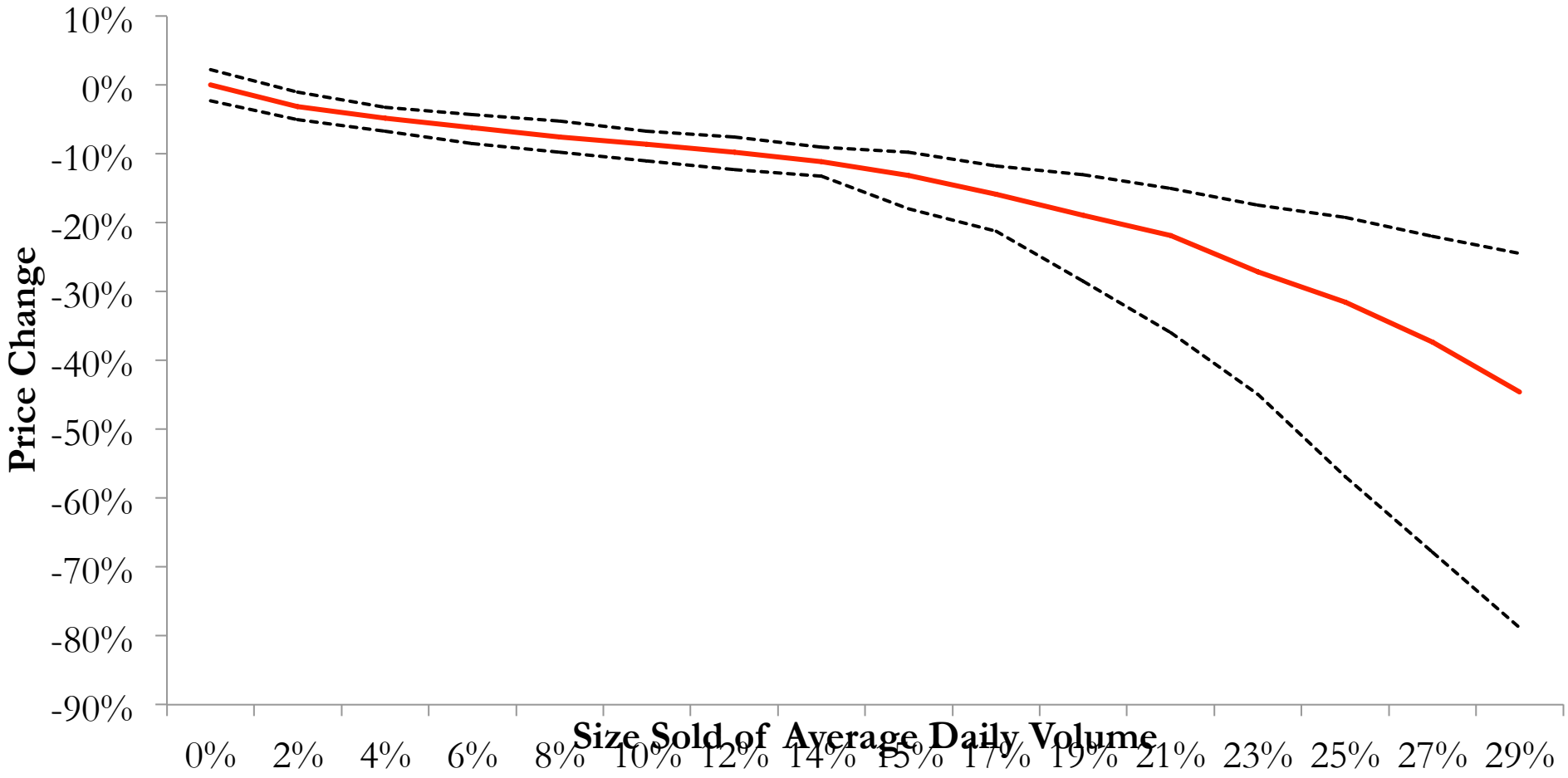


Market Impact versus Quantity and Time



- Shows the relationship between quantity sold and market impact over time during the liquidity event.
- It has several drops due to the arrival of large pockets of liquidity supply.
- Generally the market impact drops with time and increases with quantity.
- In practice the complexity is greater than illustrated here because the parameters vary over the course of the event, and the liquidation itself will have a feedback effect.

Market Impact: Change in Price vs Amount Sold



This chart shows the final price impact from a liquidation done in equal amounts for each of 1440 period, (representing 24 hours assuming one minute per period).

III. Conclusion

Using Stress Testing Version 3.0

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Storm Watch Weather Service

- Are you on the hurricane's path?
- How bad will it be?
- Will you become collateral damage

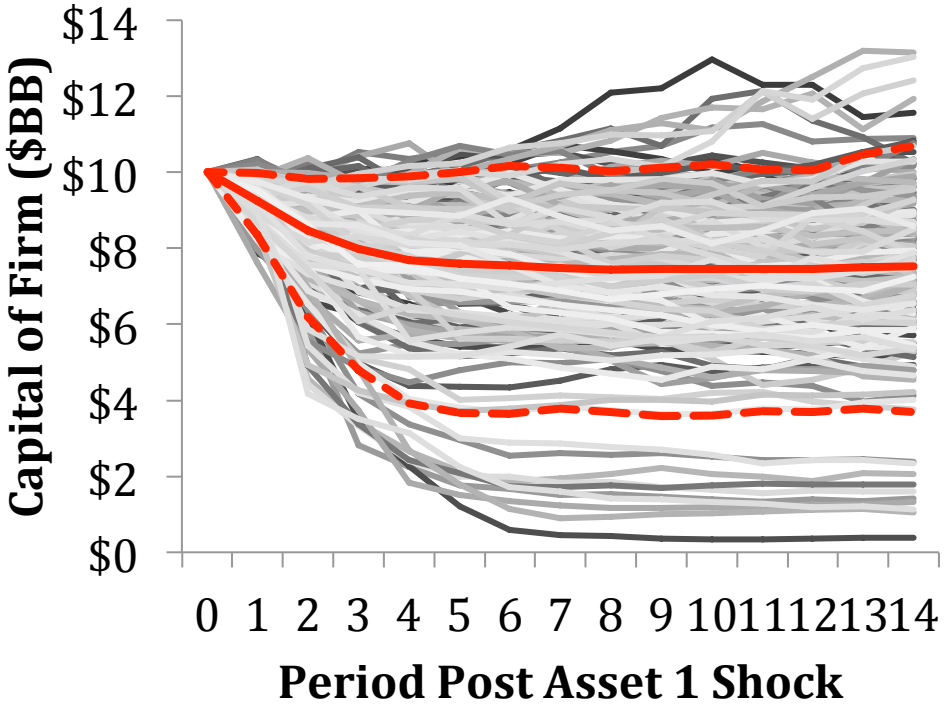
Salvaging VaR

- Crisis VaR and the VaR multiplier

Catching Falling Knives

- Being a liquidity supplier of last resort

Reworking Version 1.0



- 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.

Systemic Risk and Policy Setting

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Version 3.0: Dynamic Stress Testing

- What are the dynamic, knock-on effects

Policy Planning and Actions

- 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

Networks in Version 2.0 and 3.0

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The "Maps" as a Multi-layer Network

- Funding Map
- Collateral Map
- Assets Map

What agents facilitate movement from one layer to another

ABM as a Dynamical Networks

- Nodes provide transformations and to respond to the environment
- Changes in the size (and existence) of nodes
- Links vary in size of flows, and in their effect on the behavior of the transformations in the nodes

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Modeling Philosophy: Build Where the Light Is

Data Needs

- Frequency: Exposures and funding build and change slowly
- Completeness: More is better; less can still work

Data Types

- Exposures: dominant investment themes, credit
- Funding: sources, durability, leverage, collateral
- Inventory: capacity

Testing and Parameter Estimation

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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

How Can We Use a Version 3.0 Model

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The investment process involves storytelling

- Build a narrative.
- Build an improvable, consistent structure
- Test critical assumptions and variable
- Amass data in same way as for the investment decision process

End point: Do you buy the story?