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

- 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

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

Asset (Price) Shock or Funding Shock
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→ Shock to other Assets
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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

Leverage (Fire Sale) Module
- Forced Selling
- Leverage
- Balance Sheet

Asset Liquidity Module
- Liquidity Demand
- Market Making
- Liquidity Supply

Price Impact

Financial Impact
I. The Fire Sale (Leverage) Component
A Network (Production Plant) View: Flows Between the Agents
The Transformations of Flows Behind Stress Dynamics

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.

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

**Flow of Collateral**

**Asset-based Fire Sale**

- **HEDGE FUNDS**
- **INSTITUTIONS OTHER BANK/DEALERS**

**BANK/DEALER**

- Prime Brokerage
- Finance Desk
- Trading Desk
- Derivatives Desk
- Treasury

**Funding-based Fire Sale**

**CASH PROVIDERS**

**INSTITUTIONS OTHER BANK/DEALERS**

**INVESTORS**

**ASSET MARKET**

**Flow of Funding**
Agent Behavior

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)

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

- Run over 1000 iterations

HF1, BD1 Portfolio: \{A0, A1\}
HF2, BD2 Portfolio: \{A1, A2\}
• 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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• 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 0

- 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
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

Asset Market: Price Shock

Cash Provider: Funding Shock

Bank/Dealer: Credit Shock

Hedge Fund: Redemption Shock
II. The Liquidity Component
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.
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

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

- 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.
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

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.

Variables that Govern the Agents’ Actions

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

Liquidity Demander

Liquidity Supplier

Market Maker
Order Placement Distribution for the Agents

Liquidity Demander

Liquidity Supplier

Market Maker

\[ \text{Multiple of Order Quantity} = \frac{(P_t - P_0)}{\omega} \]
Order Placement Distribution for the Agents

Liquidity Demand

Liquidity Supply

Market Maker
Aggregation of Market Makers’ Order Books

![Chart showing the aggregation of market makers' order books. The chart displays the number of orders at different prices for MM1, MM2, MM3, MM4, and MM5. Buy orders are shown on the left, and sell orders are shown on the right.]
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
Agents’ Actions: Normal Times
Agents’ Actions: Start of Event
Agents’ Actions: Capacity Declines

![Graph showing agents' actions and capacity declines](image-url)
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.
This chart shows the final price impact from a liquidation done in equal amounts for each of 1440 periods (representing 24 hours assuming one minute per period).
III. Conclusion
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
• 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

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
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
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

**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
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?