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Nasdaq Modeling and Complex Systems Prediction: Games as Frames on Reality

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Thirty Years of Complexity
Stu-Fest 2019
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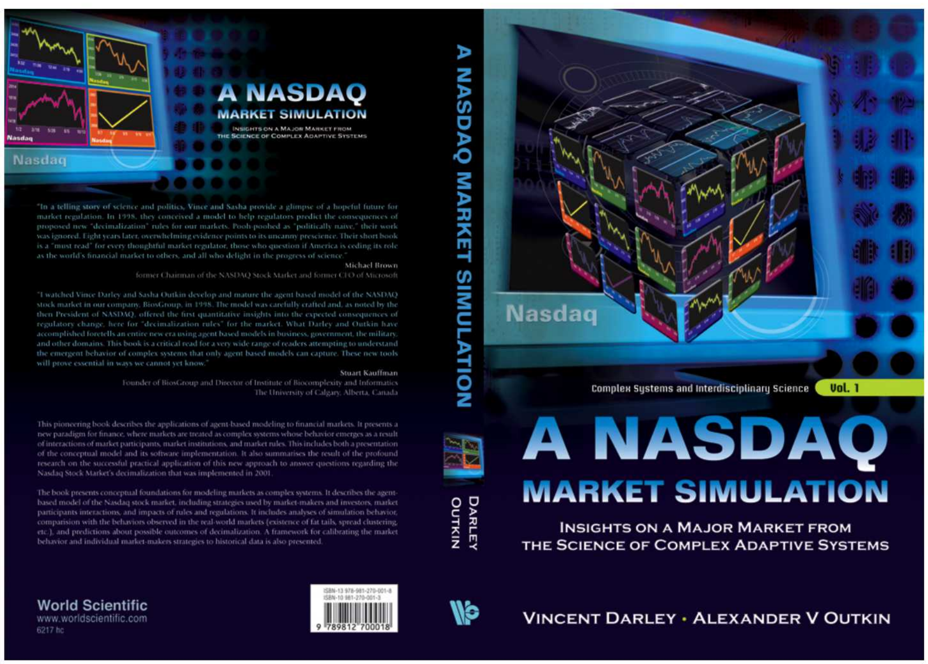
Predicting Effects of Decimalization

- Project goal: create a model and evaluate possible decimalization effects
- Project run approx. 1998-2001
- Tick size was officially reduced from a 1/16th to $.01 starting in March, 2001. Darley and Outkin (2007)



Approach and Results

- A single security, agent-based model
- Actual tick data, market rules,
- Inferred market maker strategies
  - Data, Nasdaq market makers
- Compare market behavior before and after decimalization
- We got a lot right about effects of decimalization:
  - Why? What can be used in other domains?

Summary of Findings

1. Decimalization (tick size reduction) will negatively impact the price discovery process.
2. Ambiguous investor wealth effects may be observed. (Investors' average wealth may actually decrease in the simulation, but the effect is not statistically significant).
3. Phase transitions will occur in the space of market-maker strategies.
4. Spread clustering may be more frequent with tick size reductions.
5. Parasitic strategies may become more effective as a result of tick size reductions.
6. Volume will increase, potentially ranging from 15% to 600%.

Why Agent-Based Modeling?

- Real-world systems are represented as collections of *autonomous decision-making entities, situated in appropriate environment and interaction structure*.
    - Agents execute context-appropriate behaviors (e.g. trade securities).
    - Agents are heterogeneous, as in reality.
    - Agents are not independent, but are affected by other agents and other factors.
- The dynamics of system *emerges* from agent interactions. Bottom up, rather than top down.

Simulation Basics

- Agents are trading in a single stock
- Investors have a price target which follows a Poisson process, random walk, *etc*.
- Investors:
  - Receive noisy information about this target
  - Decide whether to trade by
    - Comparing this target with available price
    - Incorporating market trends
    - Performing sophisticated technical trading, etc.
- Market makers:
  - Receive buy and sell orders
  - Must learn how to set their quotes profitably

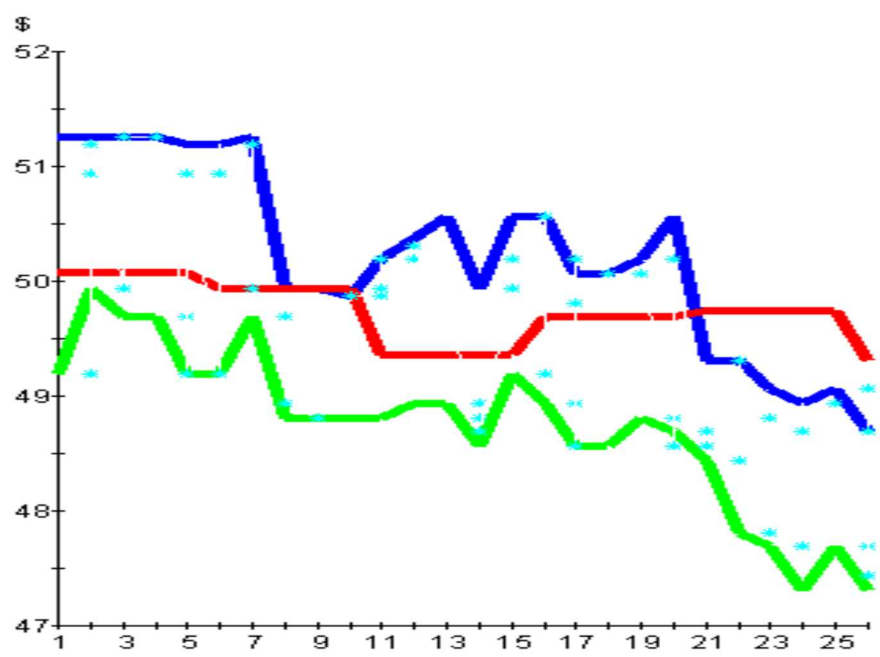
Agent Details

- Market makers
- Investors
- Market Agent Features:
  - Autonomous
  - Adaptive/handcrafted strategies
  - Various levels of sophistication/adaptability/ access to information

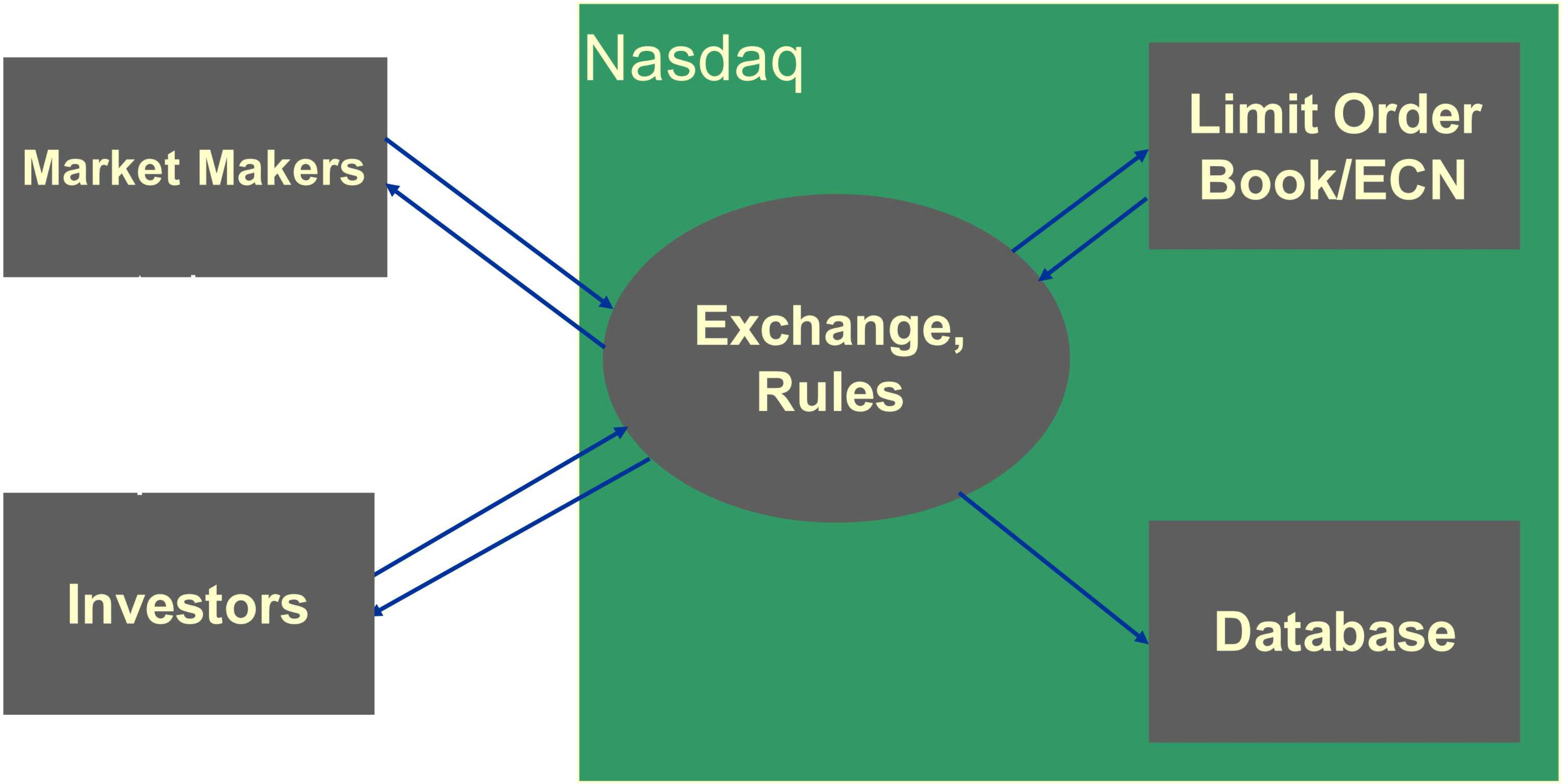
Investor – Market Maker Interaction and Parasitism

Parasitic strategy:

- Attempts to undercut the current bid/offer by a small increment (tick size)
- Is not a major source of liquidity for the market



Model Structure



Model Features

- Trading in:
  - Market orders
  - Limit orders
  - Negotiated orders
- Market rules/ parameters:
  - Order handling rules
  - Tick size, etc.
- Market agents’ modes of interaction:
  - Quote Montage
  - ECNs
  - Limit order books
  - Preferencing, etc.

Model Calibration

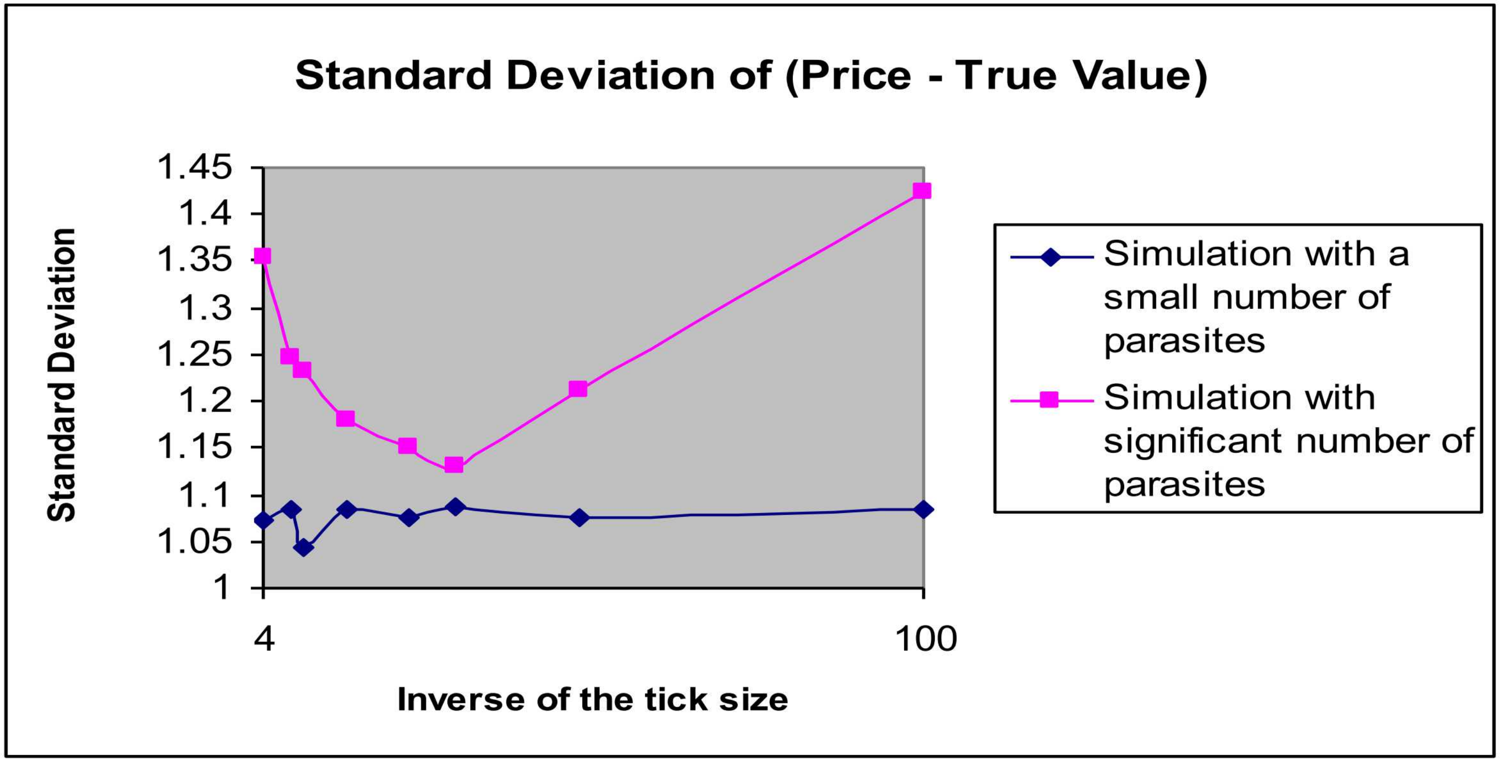
- Calibrated the model to
  - Individual strategies
  - Aggregate market parameters
- Simulated strategies are able to replicate the real-world ones (with precision up to 60-70%)
- Created self-calibrating software to use data as it comes in

Questions Investigated

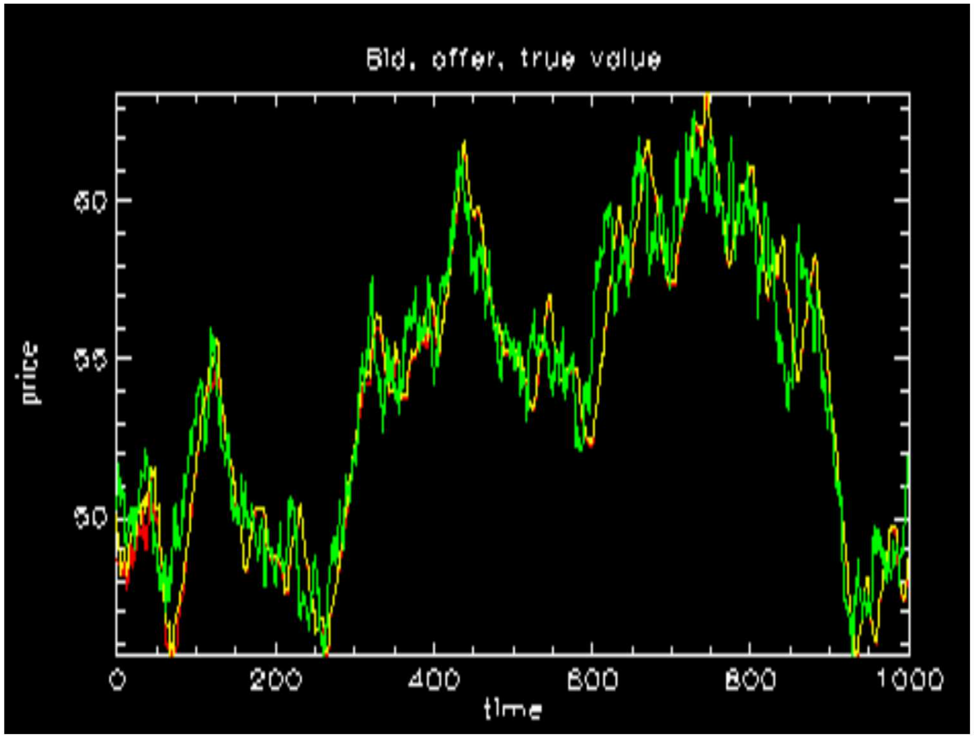
- Effects of tick-size changes and parasitism
- Aggregate market dynamics features:
  - Fat tails
  - Spread clustering
- "Phase-transitions" in market maker strategies
- Market maker learning and strategy adaptation

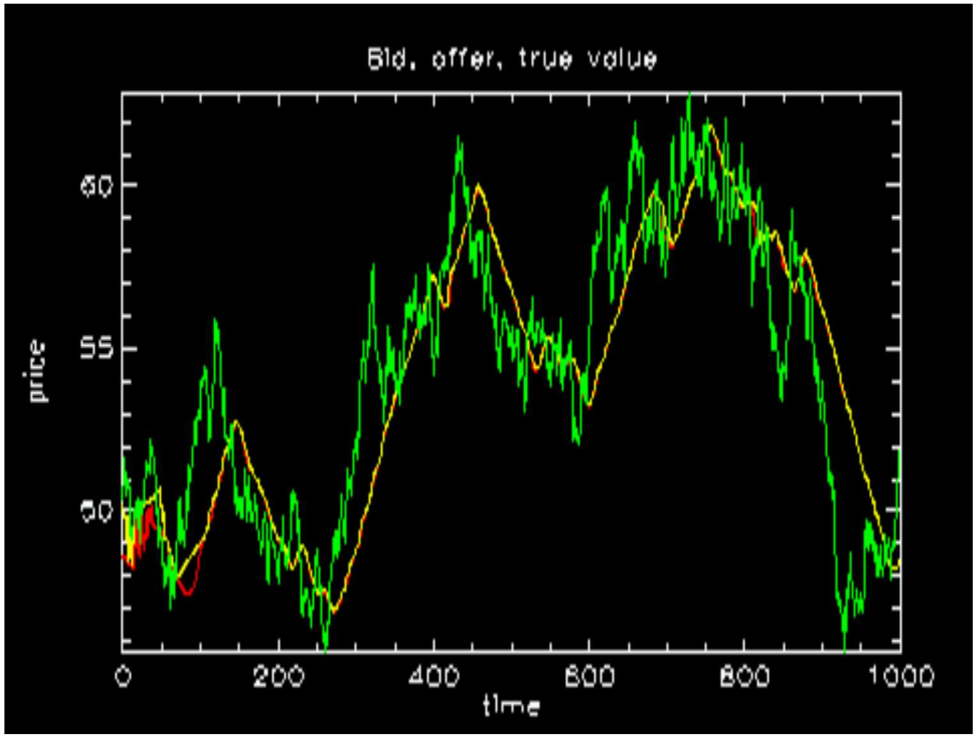
Tick size effects

As tick size is reduced, parasitic strategies increasingly impede price discovery / market's ability to generate useful information



Tick Size Effects, Many Parasites





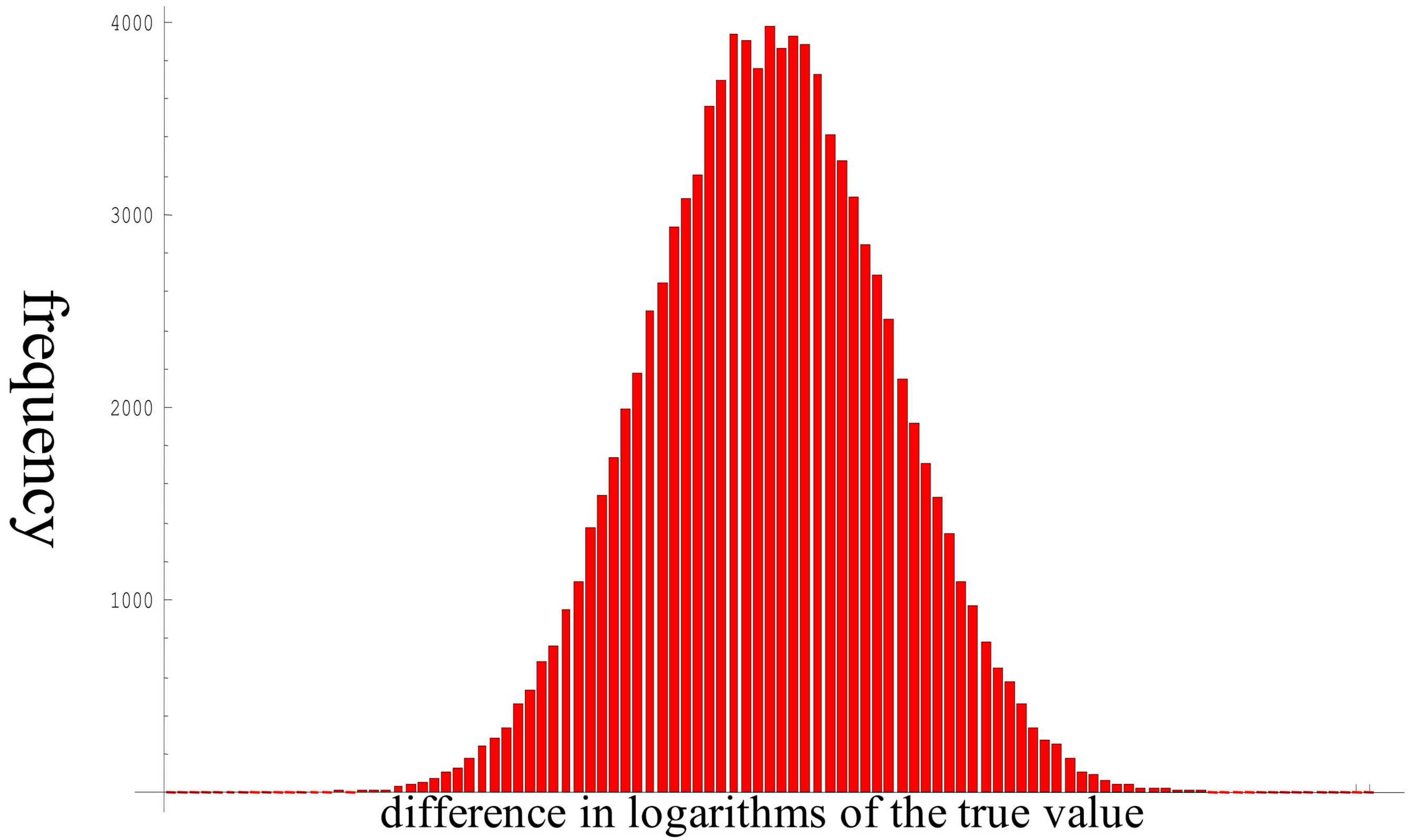
Tick size 1/16

Tick size 1/100

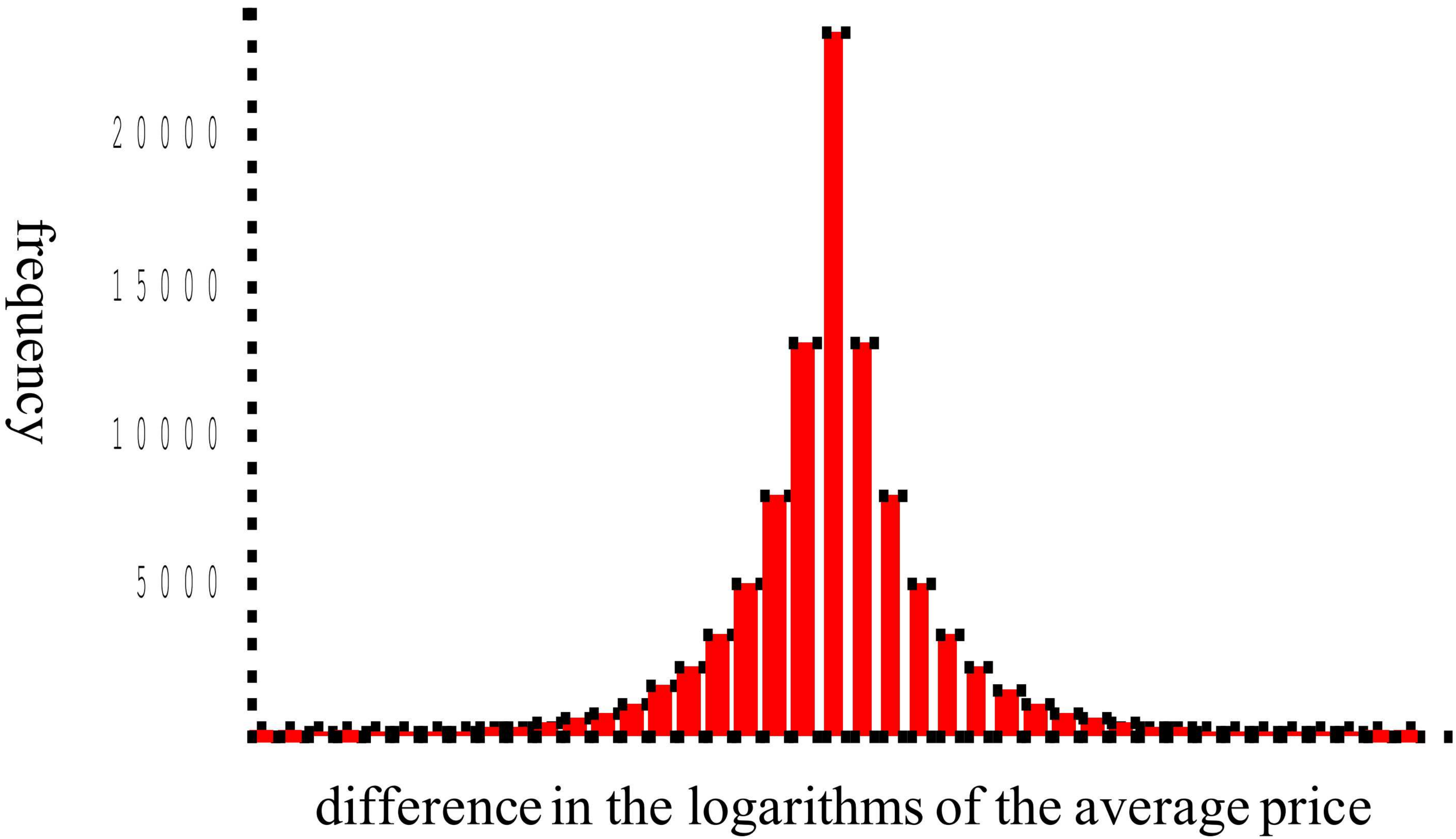
Fat Tails

- "Fat tails":
  - A large probability of extreme events by comparison with a Gaussian distribution
- Origins are uncertain
  - Herd effects, other?
- Our model generates fat tails with no herd effects

Original Gaussian Distribution

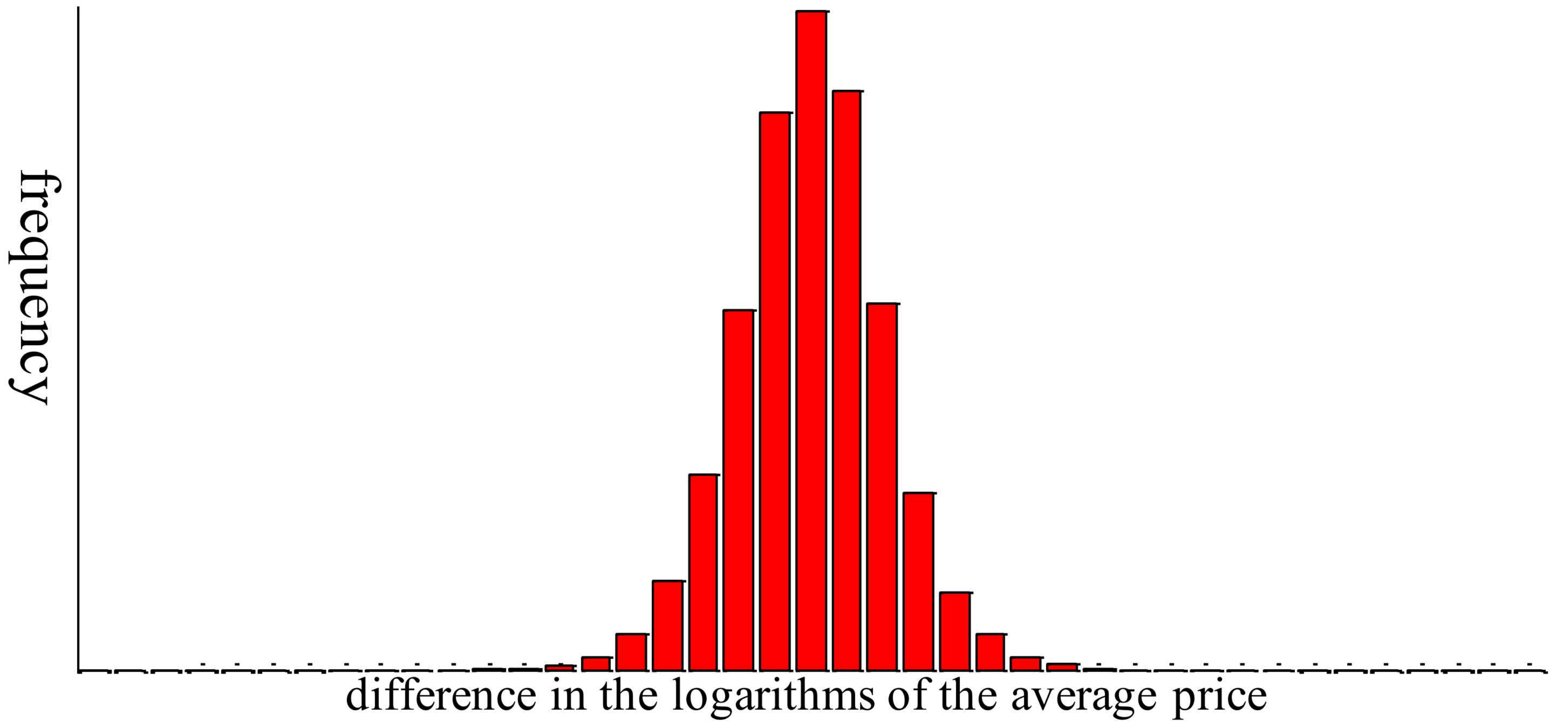


Fat Tails in Simulated Average Price Dynamics



Time Correlations and Fat Tails

The fat tails seem to disappear when the data points are taken far apart (50 periods here)



Why Fat Tails in the Simulation?

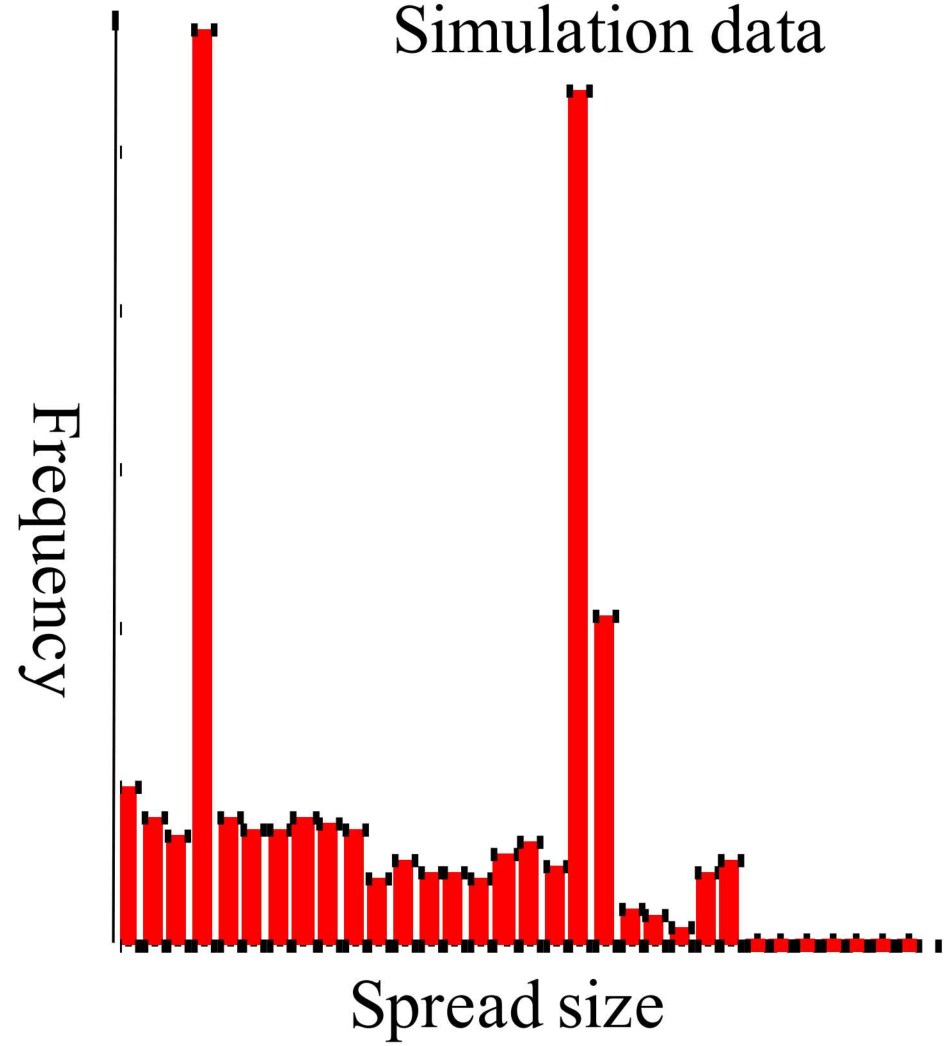
- Possible explanations:
    - Interaction and self-interaction through price
    - Existence of spread
    - Memory of traders, investors, etc.
- No explicit "herd" effects included

Spread Clustering

- Nasdaq dealers collusion accusations - Christie and Schulz (1994)
- SEC investigation into quoting behavior on Nasdaq (1996) and subsequent settlement
- Clustering in various financial markets - Hasbrouck (1998)

Spread Clustering

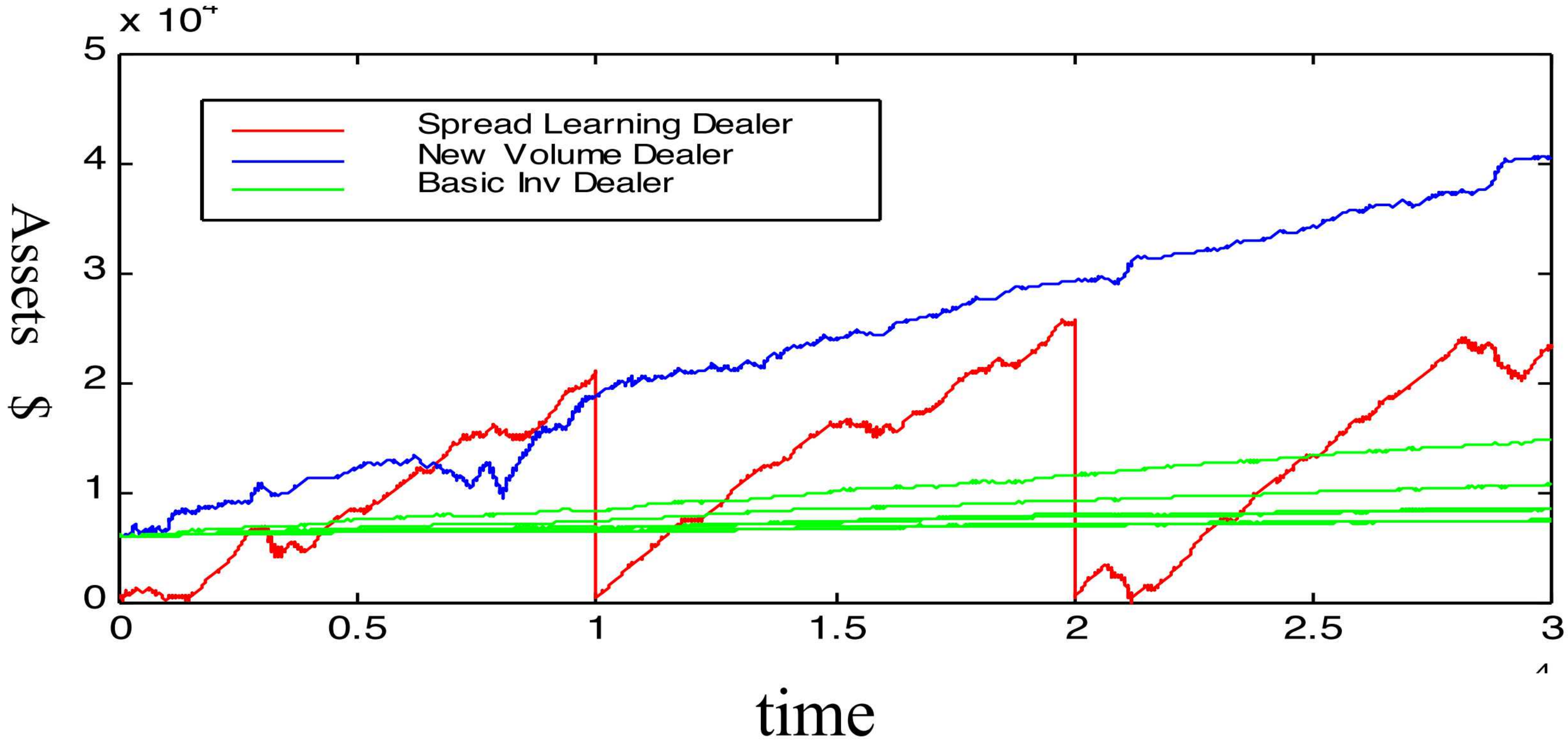
- Spread = difference between smallest offer and largest bid
- Spread clustering occurs when some spread values occur much more frequently than others



Importance of Spread Clustering

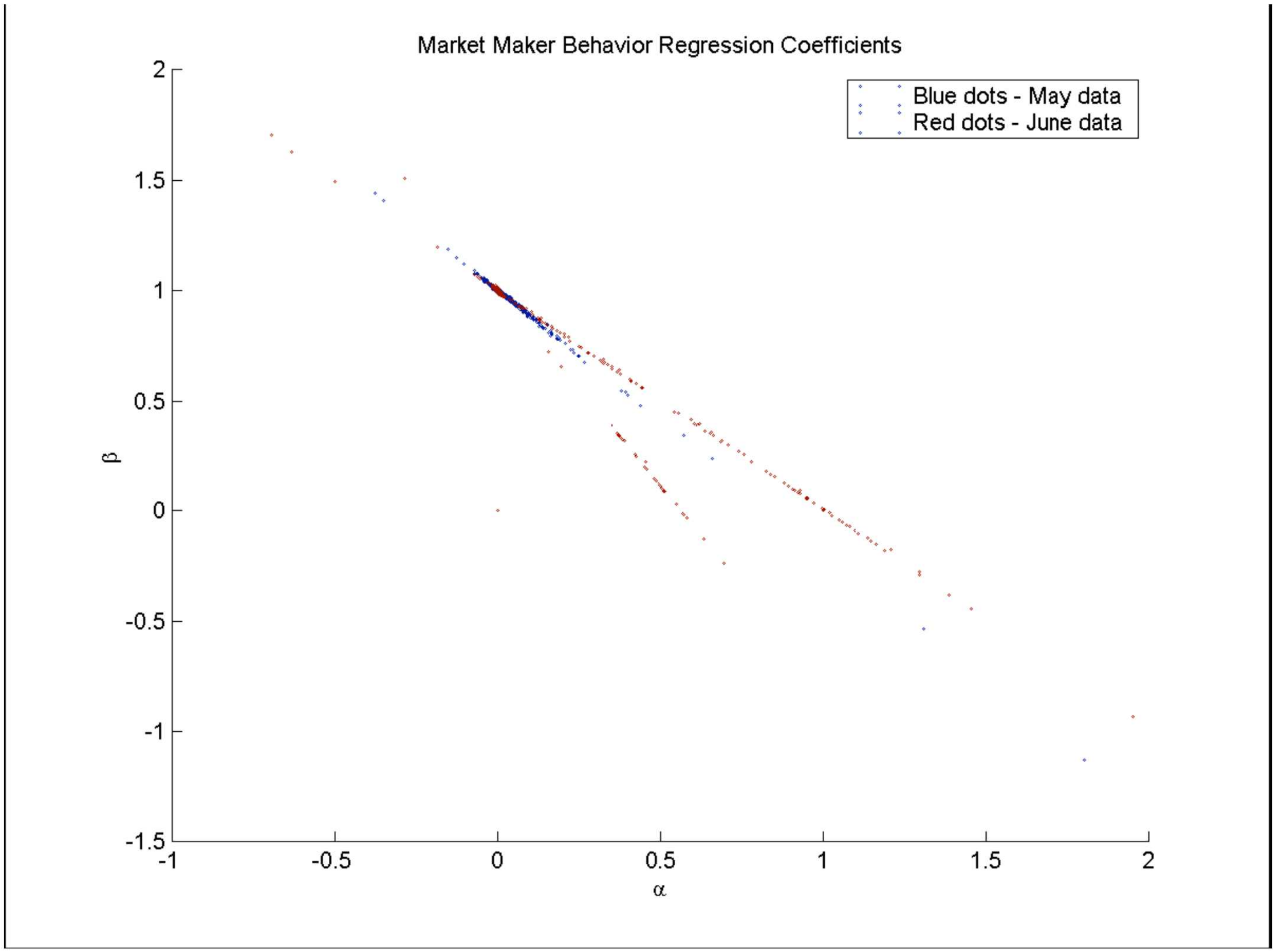
- Emergent property in the simulation: no collusion is present, yet the spread clustering occurs
- Real-world issue: Nasdaq, Forex

Learning in the Simulation



- Spread Learning market maker is the most profitable dealer on the market under many circumstances
- Known exceptions: high volatility, tough parasites

Phase Transitions



Model vs. What Happened

5 of the 6 likely outcomes actually occurred.

1. Decimalization (tick size reduction) will negatively impact the price discovery process.
2. Ambiguous investor wealth effects may be observed. (Investors' average wealth may actually decrease in the simulation, but the effect is not statistically significant).
3. Phase transitions will occur in the space of market-maker strategies.
4. Spread clustering may be more frequent with tick size reductions.
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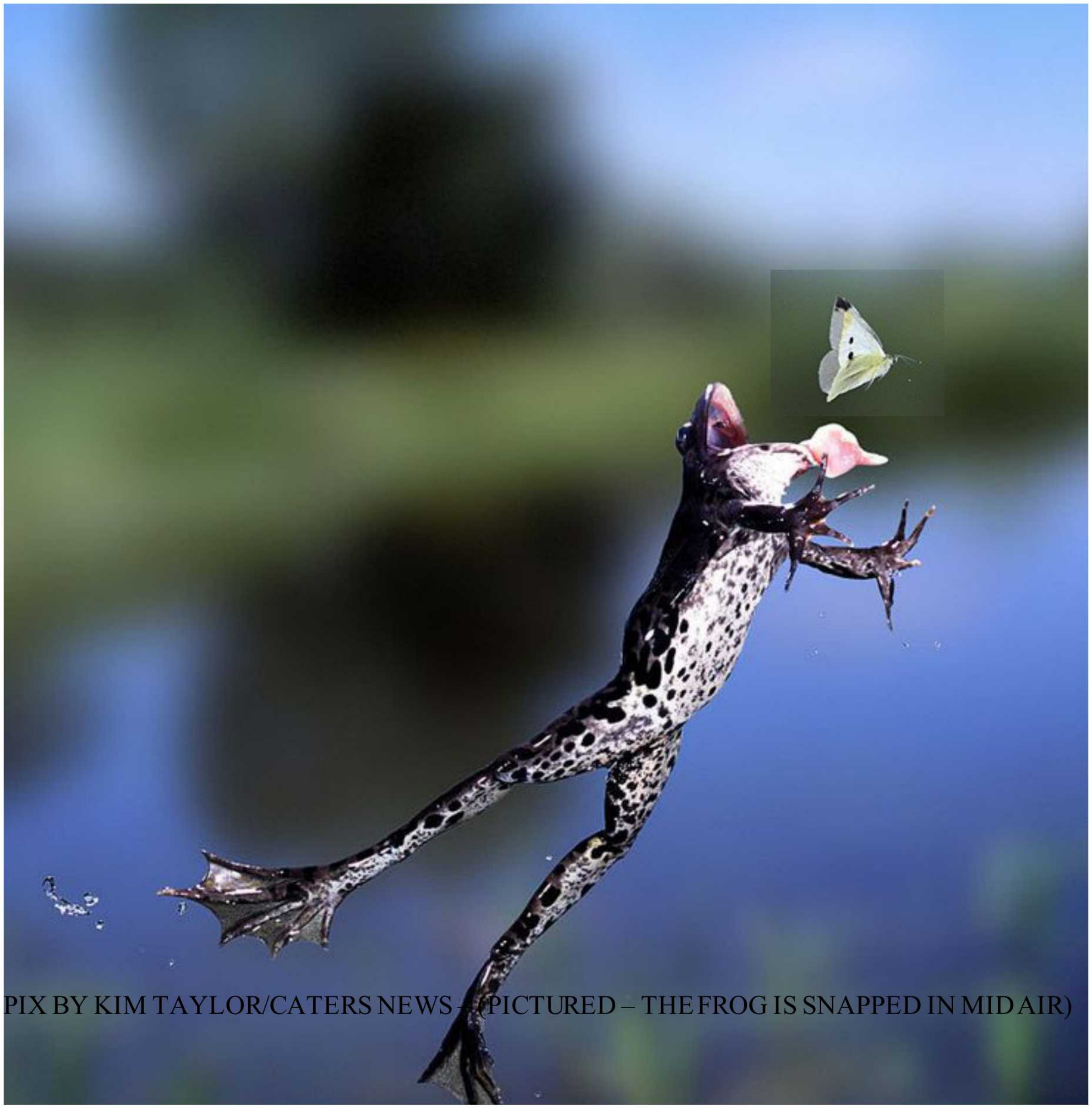
Art and Science in Prediction

- *What* to include in the game?
- *How* agents adapt after rule change?
- *How* to evaluate that game after rule change has predictive power?

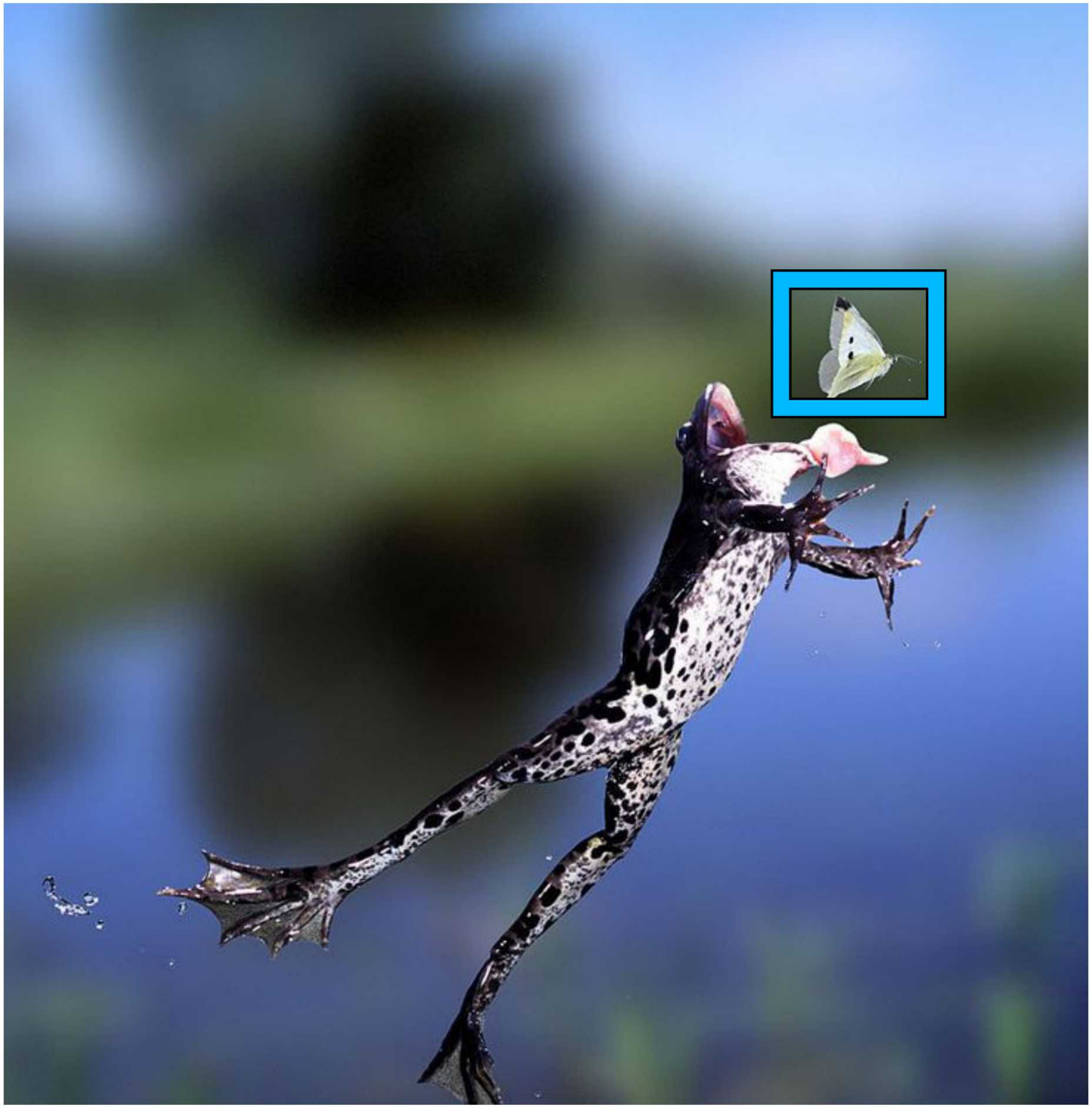
ABMs as Games as Frames

ABMs as Games as Frames

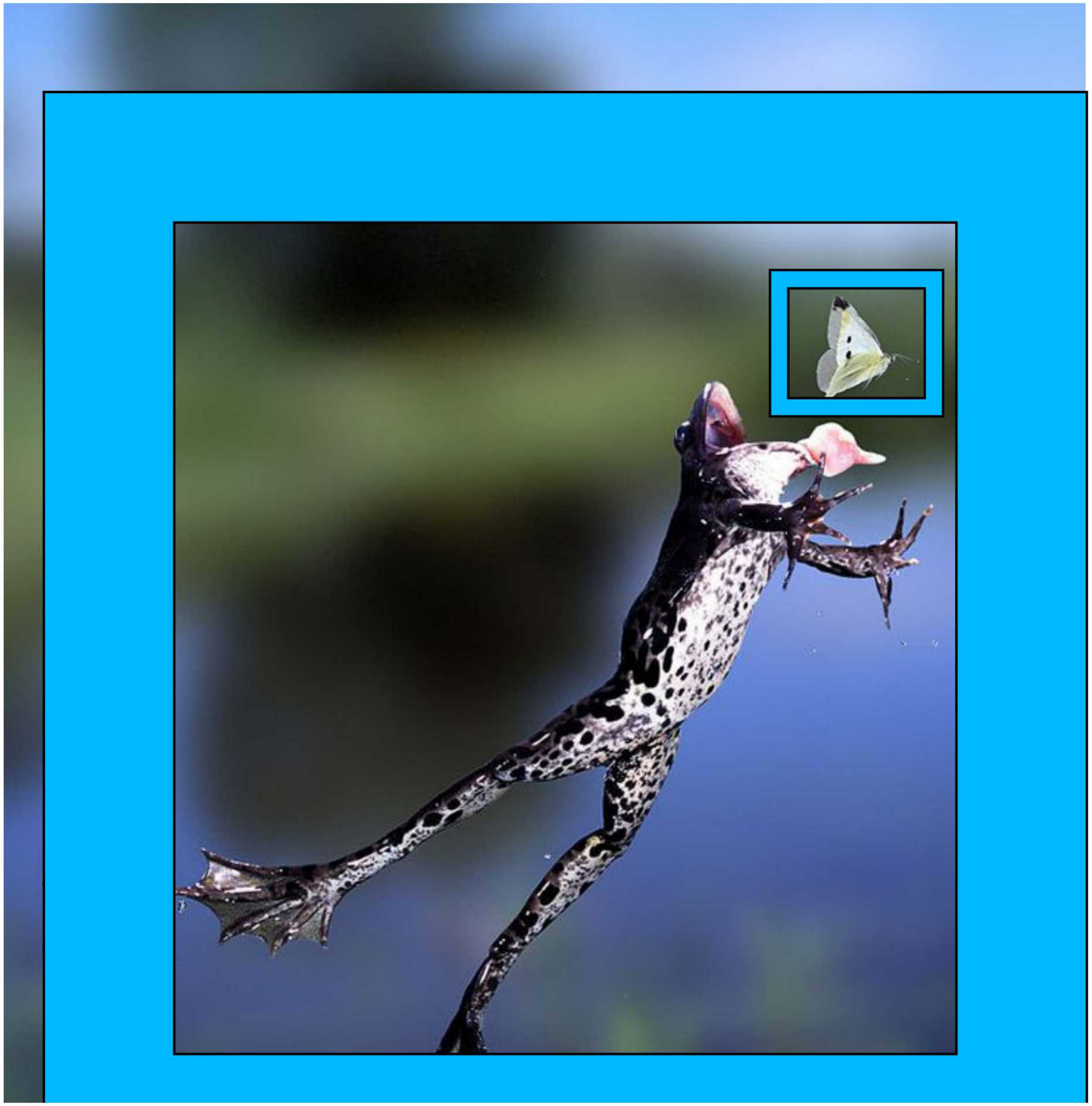


PIX BY KIM TAYLOR/CATERS NEWS – (PICTURED – THE FROG IS SNAPPED IN MID AIR)

ABMs as Games as Frames



ABMs as Games as Frames



Games as Frames on Reality and "Physical" Bounding Boxes

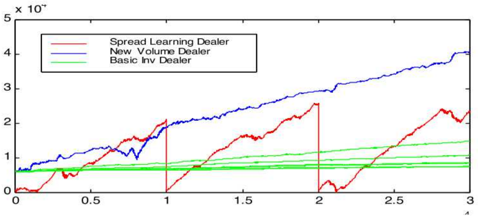
- Social interactions occur in open systems
  - A model will miss some interactions
- Game rules and participants objectives enforce partial closure
  - Game as a "physical" bounding box
  - Many strategies are possible but most are "bad"

What Happens After Change?

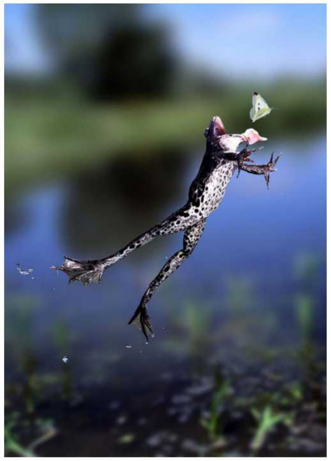
- New strategies may become available
- Payoffs to strategies may change
- Relative strategy dominance may change
- How agents may react:
  - Change strategy – e.g. play faster
  - Withdraw from the game
  - Play a new game – e.g. arbitrage across markets instead of Nasdaq only
- Will agents understand the implications from changes?
- Are multiple outcomes possible?
- Can all outcomes, games, and adjacent possible be enumerated?

Agents Against Prediction

- Decide not to play the new game
- Switch to a different game
- Change the unwritten game rules
- Challenge the game designer, e.g. regulatory capture
- Discover unforeseen strategies
- Become the game designers, e.g. alternative trading venues



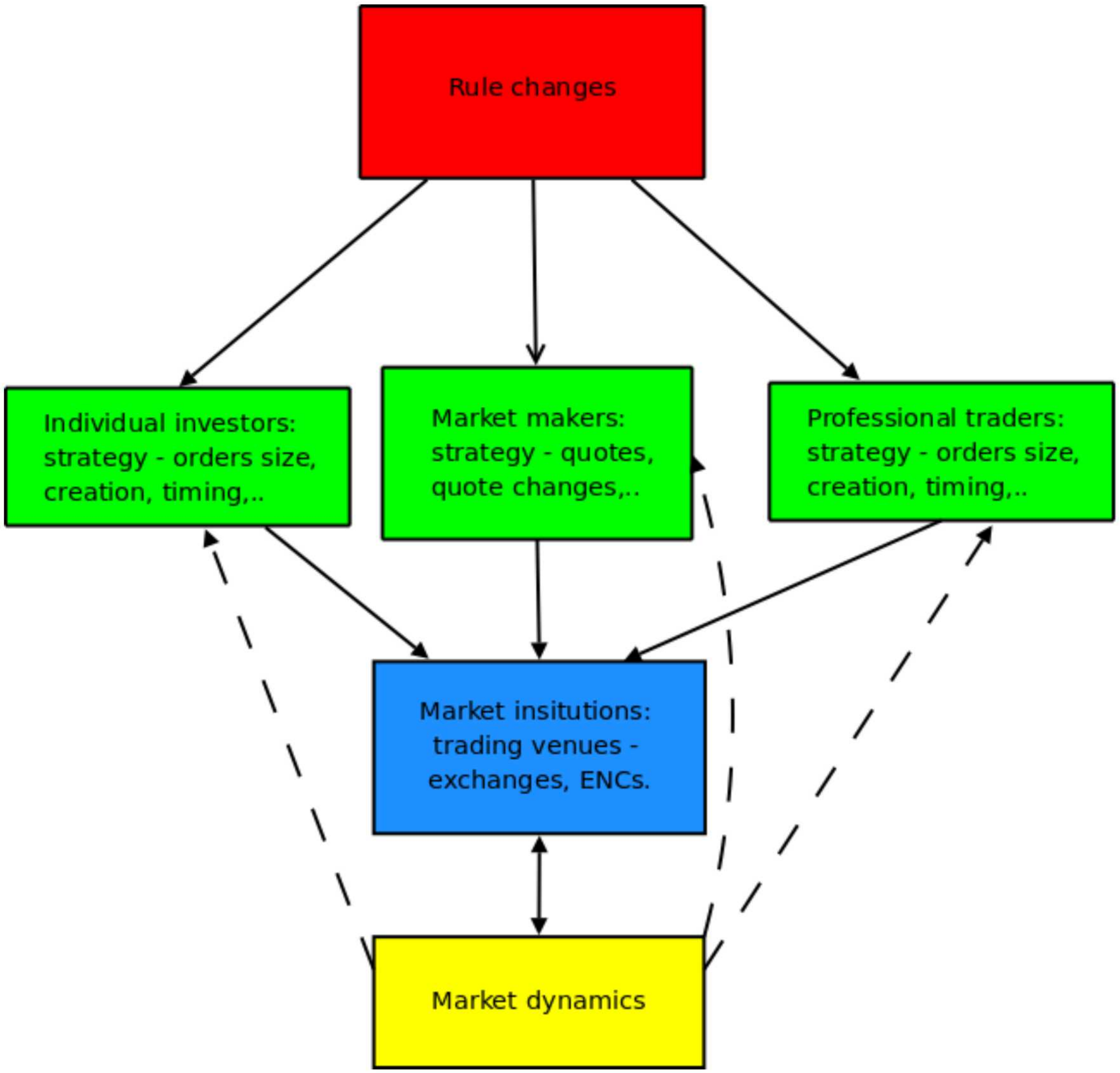
Change Prediction with ABMs and Games



- Select appropriate game frame
- Create minimal representative game
- Achieve reasonable replication of reality
- Investigate adaptations agents can make
- Find long-run tendencies in the new game
- Investigate if the game is still viable
- What we did in Nasdaq work:
  - Replicated individual market maker strategies
  - Replicated stylized features of market dynamics: fat tails, spread clustering
  - Created many new strategies
  - Confirmed sudden strategy change in previous tick size reduction
  - Confirmed that market makers are profitable after change

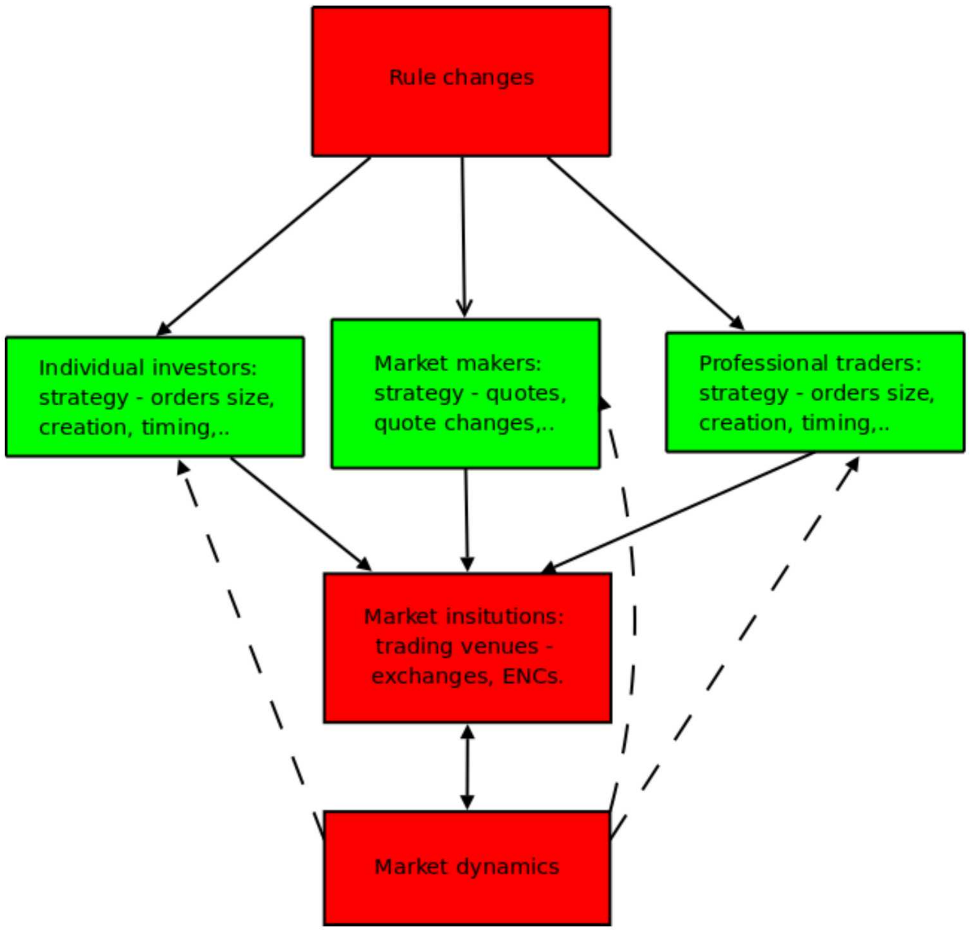
Appendix

Problem Architecture



Longer-Term Effects

- Not only the participants strategies change, but the market institutions change as the result.



ABMs and the World

- By definition, almost tautologically, the world is an agent-based system.
- The question is what predictive power such a representation has? For what kinds of problems?
- What are the theoretical reasons for agent-based representation to work?
- Crucial differences from existing approaches:
  - Modeling processes and mechanisms, rather than the outcomes and states.
  - Focus on emergent behaviors – potentially, counter intuitively, invalidating the initial model.

Advantages of ABMs

- ABMs and traditional statistical methods can produce the same results under same assumptions
- Models can be validated using historical data, but can be applied to *unique situations* that lack history
  - Allows combining both a hindsight and foresight perspective
- Agents can be programmed to *evolve* and *learn*. This permits the emergence of new, unanticipated behaviors and strategies
- A variety of what-if scenarios can be investigated

Games vs. ABMs

Analytical vs. simulation

Equilibrium vs. dynamics

Payoff function vs. explicitly modeled interactions

Homogeneous agents, normally best response vs. heterogeneous, heuristic, data-driven agents and strategies

Different levels of abstraction and applicability

Visualization

Shaver and Vovk (2001)

Some Relevant Publications

"A Nasdaq Market Simulation: Insights on a Major Market from the Science of Complex Adaptive Systems," with Vincent Darley. World Scientific Publishing. March 2007.

"FinSim: A Framework for Modeling Financial System Interdependencies," with Sam Flaim, Andy Seirp, and Julia Gavrilov in Ang Yang and Yin Shan (Eds.). *Applications of Complex Adaptive Systems*. IGI Global. February 2008.

"Neural Networks and Contagion," with Siegfried K. Berninghaus, and Hans Haller. *Revue d'économie industrielle*. 114/115, 205–224, 2006

"Cooperation and Local Interactions in the Prisoners' Dilemma Game". *Journal of Economic Behavior and Organization,* December 2003, v. 52/4 pp. 481-503.

"Sixteenths or Pennies? Observations from a Simulation of the Nasdaq Stock Market," with Vince Darley, Tony Plate and Frank Gao. Proceeding of *IEEE/IAFE/INFORMS 2000 Conference on Computational Intelligence for Financial Engineering (CIFEr)*. March 2000.