Dynamics of Investor Attention on the Social Web

Ph.D Defense

Presented by: Xian Li
Advisor: Dr. Jim Hendler

Tetherless World Constellation, Cognitive Science Department
Rensselaer Polytechnic Institute

November 25, 2013
Introduction

- The Problem
- Contributions Overview

Contribution I. Temporal Selectivity of Investor Attention

- Formalism of Cognitive Control Mechanisms
- Empirical Validation

Contribution II. Dynamical System of Collective Investor Attention

- Stylized Facts and Behavioral Regularity
- A Phenomenological Model

Contribution III. Investor Attention as the Social Tape

- Relevancy
- Reflexivity
- Robustness Check

Conclusion
CENTRAL QUESTION
How investors selectively allocate their limited attention under the current information environment?

MAJOR FINDINGS
Adaptive cognitive control, positive feedback, partial reflexivity
**Central Question**

How investors *selectively* allocate their limited attention under the current information environment?

**Major Findings**

Adaptive cognitive control, positive feedback, partial reflexivity
An Important Problem

How investors allocate their limited mental resource in investing?
An Important Cognitive Problem

How investors allocate their limited mental resource in investing?

- **Environment**
  - $M$ assets, each $i$ with attributes $\vec{Y}_i = \{\text{price, dividend, sector, ...}\}$
  - Information set $\mathcal{F}_t^{(i)}$

- **Subject**
  - Financial market participant: individual, retail, with goal, perception, preference
    - Goals: e.g. $\text{Max}\{\sum_{i \in \mathcal{A}} E[U(\hat{\omega}^{(i)})]\}$
    - Constraints: $|\mathcal{A}| < M$, $\mathcal{F}' \subset \mathcal{F}$, $\hat{\omega} \neq \omega$, ...

- **Cognitive Task**
  - **Attention**: Preferential processing for a selected aspect of sensory inputs
    - Directly impacts other tasks such as decision making, causal inference
An Important Cognitive Problem

How investors allocate their limited mental resource in investing?

- **Environment**
  - $M$ assets, each $i$ with attributes $\vec{Y}_i = \{\text{price, dividend, sector, ...}\}$
  - Information set $\mathcal{F}_t^{(i)}$

- **Subject**
  - Financial market participant: individual, retail, with *goal, perception, preference*
    - Goals: e.g. $\text{Max}\{\sum_{i \in \mathcal{A}} E[U(\hat{\omega}^{(i)})]\}$
    - Constraints: $|\mathcal{A}| < M$, $\mathcal{F}' \subset \mathcal{F}$, $\hat{\omega} \neq \omega$, ...

- **Cognitive Task**
  - **Attention**: Preferential processing for a selected aspect of sensory inputs
  - Directly impacts other tasks such as decision making, causal inference
An Important Cognitive Problem

How investors allocate their limited mental resource in investing?

- **Environment**
  - $M$ assets, each $i$ with attributes $\vec{Y}_i = \{\text{price, dividend, sector, ...} \}$
  - Information set $\mathcal{F}_t^{(i)}$

- **Subject**
  - Financial market participant: individual, retail, with *goal, perception, preference*
    - Goals: e.g. $\text{Max} \{ \sum_{i \in A} E[U(\hat{\omega}^{(i)})] \}$
    - Constraints: $|A| < M$, $\mathcal{F}' \subset \mathcal{F}$, $\hat{\omega} \neq \omega$, ...

- **Cognitive Task**
  - **Attention**: Preferential processing for a selected aspect of sensory inputs
  - Directly impacts other tasks such as decision making, causal inference
An Important Cognitive Problem

How investors allocate their limited mental resource in investing?

- Environment
  - $M$ assets, each $i$ with attributes $\vec{Y}_i = \{\text{price, dividend, sector, ... }\}$
  - Information set $\mathcal{F}_t^{(i)}$

- Subject
  - financial market participant: individual, retail, with goal, perception, preference
    - Goals: e.g. $\max\{\sum_{i \in A} E[U(\hat{\omega}^{(i)})]\}$
    - Constraints: $|A| < M$, $\mathcal{F}' \subset \mathcal{F}$, $\hat{\omega} \neq \omega$, ...

- Cognitive Task
  - **Attention**: Preferential processing for a selected aspect of sensory inputs
    - Directly Impacts other tasks such as decision making, causal inference
What We Know about Investors Attention

What does the Efficient Market Hypothesis (EMH) say?

**implicit assumptions:**

- investor attention is infinite, automatic, immediate
What We Know about Investors Attention

Empirical “anomalies”

- Important news or information is not reflected by prices until investors pay attention to it (Huberman, G. and Regev, T., 2001)
- Different consequences of investors attention, e.g. over-, under-reaction (Daniel, K., Hirshleifer, D., and Subrahmanyam, A., 1998)
How Investors Pay Attention

Existing theories:

- Anchoring bias (George, T. J. and Hwang, C.-Y., 2004)
- Categorical (Peng, L. and Xiong, W., 2006)
- All that glitters (Barber, B. M. and Odean, T., 2008)

Measurements:

- trading volumes, extreme returns (Barber, B. M. and Odean, T., 2008)
- media coverage, Google search (Da, Z., Engelberg, J., and Gao, P., 2011, Yuan, Y., 2011)
Motivation

Limitations:

1. Spatial attention allocation rather than a temporal perspective.
   - not only “the right stock”, but also “the right moment”

2. Handwaving on subjects and tasks
   - individual (non-investor) behavior from laboratory observations

3. Indirect proxies
   - news, trading volumes, extreme returns, etc.

New approaches explored in this dissertation:

1. The most up-to-date information environment for investors:
   - from newspaper, CNBC to WWW, social web

2. Direct observations with “big data”:
   - real-time laboratory of a large number of relevant subjects
Summary of Contributions

Methodologies:

1. Data-driven Cognitive Science
2. A novel and direct measure of investor attention, in the most up-to-date information environment for investors
3. An integrated view on a hierarchy of complex systems

Technical findings:

1. Modeled and evaluated **cognitive control** mechanisms of investor attention allocation
2. Characterized the **dynamical system** of collective investor attention
3. Quantified two-way **interactions** with financial market
Summary of Contributions

Contribution I. Cognitive control of investor attention

Contribution II. Dynamical system of collective investor attention

Contribution III. Reflexive relationship with the market
Remaining Work at Proposal

- **High priority**
  1. Quantify the role of social proof
  2. Develop formalism of the generative process of collective investor attention ✓
  3. Empirically quantify instantaneous collective endogeneity with estimated parameter ✓
  4. Evaluate roles of cognitive control in investor attention in related to overreaction ✓

- **Low priority**
  1. Analyze collective attention fluctuation in related to extreme behaviors ✓
  2. Investigate how investors attention relates to anchoring bias, such as 52-week high(low) ✓
  3. Perform backtest with long/short portfolios ✓
Contributions & Findings

1. Contribution I. Modeled and evaluated cognitive controls of investor attention in current information environment
   ▶ found adaptive, heterogeneity, interaction

2. Contribution II. Characterized collective behavioral regularities of attention allocation
   ▶ found clustering, multi-scaling, long-memory, feedback loops

3. Contribution III. Quantified reflexive relationships between investor attention and the environment
   ▶ found significant correlation and bi-directional causality, selectivity in information processing carves out an “attentional” market
Contribution I. Outline

• Developed formalisms of control mechanisms
• Empirical validation
• Quantify social contagion
### Summary: behavioral models and testable predictions:

<table>
<thead>
<tr>
<th>Origin</th>
<th>Allocation</th>
<th>Behavioral Profile</th>
<th>Predictions on pdf(τ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External stimuli</td>
<td>instant response</td>
<td>EMH</td>
<td>Exp $\lambda e^{-\lambda t}$</td>
</tr>
<tr>
<td></td>
<td>threshold</td>
<td>recognition</td>
<td>Gamma $\frac{t^{k-1}e^{-\lambda t}}{\Gamma(k)}$</td>
</tr>
<tr>
<td></td>
<td>memory</td>
<td>powerlaw forgetting</td>
<td>Weib $(\frac{t}{\tau_0})^{p-1}e^{-(\frac{t}{\tau_0})^p}$</td>
</tr>
<tr>
<td>Internal fluctuation</td>
<td>threshold</td>
<td>recognition</td>
<td>IG($\frac{m-X(0)}{\mu}$, $\frac{m-X(0)^2}{\sigma^2}$)</td>
</tr>
<tr>
<td></td>
<td>memory</td>
<td>historical weights</td>
<td>LN $\frac{1}{\sigma'\sqrt{2\pi}}t^{-1}e^{-\frac{[log(t)-\mu']^2}{2\sigma'^2}}$</td>
</tr>
</tbody>
</table>
Review: Empirical Validation

tweeting behavior on the social web

1. Real-time, direct measure
   ▶ appropriate subjects to proxy representative “investor”, attention tagged to assets
   ▶ each tweeting behavior \(\{T, i, j\}\) is considered as an explicit attention allocation.
   ▶ intertweet time as allocation durations \(\tau \equiv T(s + 1) - T(s)\)

2. Samples
   ▶ Subjects: 630 investors each with \(N_{i,j} \geq 100\)
   ▶ Sample period: 350 trading days
   ▶ Data points: 3.89 million observations
**Validation Results**

1. EMH is a highly non-realistic assumption of investor attention.
2. Both involuntary and voluntary origins are equally probably, memory and recognition controls appear in both.
3. Types of cognitive control depends on contexts, e.g. stock vs. indices, chartist vs. fundamentalists, novice vs. professionals.
New Results: Social Contagion

Quantify the role of “social proof” in attention allocation?

\[
ATT_{MarketHours} \sim (CROWD_{PreMarket}, JUMP_{OpenGap}, MCAP)^T
\]

- Significant, and larger than “all that glitters”
- Dependency on the environment? Increase with degrees of uncertainty

Table: Coefficients with Condition \(N \geq 1\), Ranked by Realized Volatility

<table>
<thead>
<tr>
<th>Quartiles</th>
<th>CROWD</th>
<th>JUMP</th>
<th>MCAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3631***</td>
<td>0.1384</td>
<td>0.1354</td>
</tr>
<tr>
<td>2</td>
<td>0.421***</td>
<td>0.0994</td>
<td>0.1207</td>
</tr>
<tr>
<td>3</td>
<td>0.4369***</td>
<td>0.111</td>
<td>0.0845</td>
</tr>
<tr>
<td>4</td>
<td>0.4785***</td>
<td>0.1458</td>
<td>0.0544</td>
</tr>
</tbody>
</table>

Note: *, **, *** denote 90%, 95%, and 99% confidence intervals respectively.
New Results: Social Contagion

Robustness check:

- use different measures of volatility, and high levels of cognitive demands $N > 1$

Table: Coefficients with Condition $N > 1$, Ranked by Absolute Returns

<table>
<thead>
<tr>
<th>Quartiles</th>
<th>CROWD</th>
<th>JUMP</th>
<th>MCAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3137***</td>
<td>0.1603</td>
<td>0.0085</td>
</tr>
<tr>
<td>2</td>
<td>0.3575***</td>
<td>0.1469</td>
<td>-0.0081</td>
</tr>
<tr>
<td>3</td>
<td>0.3924***</td>
<td>0.1285</td>
<td>-0.0169</td>
</tr>
<tr>
<td>4</td>
<td>0.4402***</td>
<td>0.1332</td>
<td>-0.0635</td>
</tr>
</tbody>
</table>
Summary of Contribution I.

**Contribution I.**
Investigated cognitive control mechanisms of temporal selective investor attention

1. Developed formalisms of temporal selective investor attention, and draw testable predictions
2. Empirically validated distinct control mechanisms of external stimuli and internal fluctuation along with recognition and memory effects
3. Demonstrated contextual utilization of cognitive controls and heterogeneity
4. Calibrated social proof in attention contagion
Contribution II. Central Questions

Emergent properties of collective investor attention from a big “social brain”

- What are implications from control mechanisms in previous section? More efficient/rational? less recognition bias?
- What are statistical laws that characterize collective investor attention?
- What are the underlying dynamics?
Contribution II. Outline

- Evaluated collective cognitive controls
- Calibrated memory effects
- Quantify scaling properties of fluctuation
- Calibrate multi-scaling in memory persistence
- Model the underlying process
Contribution II. Data and Measurements

Measurements

1. \( \tau_n \equiv t_{n+1} - t_n \) per asset during market hours

Sample

1. 350 trading days between May 17th 2011 and October 3rd 2012
2. 494 assets with more than 300 \( \tau \) observations

Table: Descriptive Statists of Intertweet Times

<table>
<thead>
<tr>
<th>Class</th>
<th>( N_{asset} )</th>
<th>( N_\tau )</th>
<th>Median ( &lt;\tau&gt; )</th>
<th>Mean ( &lt;\tau&gt; )</th>
<th>SD ( &lt;\tau&gt; )</th>
<th>CV ( \tau )</th>
<th>Kurtosis ( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETF</td>
<td>42</td>
<td>285955</td>
<td>1678</td>
<td>8750</td>
<td>9223</td>
<td>239</td>
<td>83</td>
</tr>
<tr>
<td>Future</td>
<td>16</td>
<td>141713</td>
<td>987</td>
<td>5606</td>
<td>5176</td>
<td>262</td>
<td>99</td>
</tr>
<tr>
<td>Forex</td>
<td>11</td>
<td>46860</td>
<td>1808</td>
<td>9500</td>
<td>8221</td>
<td>235</td>
<td>42</td>
</tr>
<tr>
<td>Index</td>
<td>8</td>
<td>52724</td>
<td>2007</td>
<td>7174</td>
<td>7873</td>
<td>188</td>
<td>50</td>
</tr>
<tr>
<td>Stock</td>
<td>417</td>
<td>975725</td>
<td>1528</td>
<td>23284</td>
<td>17704</td>
<td>355</td>
<td>77</td>
</tr>
</tbody>
</table>
Review: Collective Cognitive Control

- Poissonian assumed by EMH still not supported
- Recognition bias mitigated, memory-based control
- Short-term clustering behavior
- DFA (Detrended Fluctuation Analysis) shows long-range memory effect
New Results: Stylized Facts

**Extreme Fluctuations**

- Scale-invariant at both small ($\gamma_h$, left) and large ($\gamma_t$, right) timescales
- Scaling exponents are not uniform, rejecting universality but suggesting multiscaling
New Results: Stylized Facts

Temporal Correlation

Strengths of memory quantified by correlation exponents (\(\alpha\)):

- further supporting multi-scaling in the selectivity of collective attention

![Graph showing temporal correlation with frequency on the y-axis and \(\alpha\) on the x-axis, and another graph showing \(\alpha\) on the y-axis and \(\tau\) on the x-axis.](image)
New Results: a Phenomenological Model

Intensity of collective attention allocation:

\[ \lambda(t) = \mu(t) + \int_0^t \phi(t - s)dN(s) \]  

- Self-exciting, with memory kernel \( \phi(\tau) = \alpha \exp^{-\beta \tau} \).
- Capture both background intensity \( \mu(t) \) and endogenous feedbacks \( N(s) \).
- Corresponds to branching processes, with branching ratio \( n = \frac{\alpha}{\beta} \).
New Results: Empirical Validation

Data and Methods:

- Sample: asset-days with more than 300 tweets, every 30 minutes during trading hours, yielding 2,245 records
- Estimation methods: maximum likelihood estimation (MLE) of Hawke processes
- Goodness-of-fit: residual analysis

Results:

- Proposed memory kernel fits 97.24% (2,183 out 2,245) of observations.
- Significant endogeneity $n \geq 0.69$ for more than 75% of sample windows.
New Results: Empirical Implications

- Decomposition of exogenous ($\mu$) and endogenous dynamics ($n$)
- Potential usage of social attention in detecting asset price bubbles
Summary of Contribution II.

- Evaluated collective cognitive control, found recognition bias mitigated

- Characterized the dynamical system of collective investor attention, found statistical regularities
  1. scale-invariant fluctuations at small and large timescales
  2. short-term clustering, long-memory
  3. unlike other complex systems, multi-scaling instead of universality

- Modeled underlying dynamics
  1. represented exogenous and endogenous forces simultaneously
  2. explicitly quantified real-time feedbacks in collective attention
Contribution III. Reflexivity

Knowing

- investor attention could be driven by distinct cognitive controls
- collective investor attention has behavioral regularities with distinct nature

So what? Considering interactions with the environment

- Cognitive
  Which structures of the environment are perceived by investor attention?

- Manipulative
  What trading actions would be led to? How the environment will be affected?
Contribution III. Reflexivity

Knowing

- investor attention could be driven by distinct cognitive controls
- collective investor attention has behavioral regularities with distinct nature

So what? Considering **interactions** with the environment

- Cognitive
  Which structures of the environment are perceived by investor attention?
- Manipulative
  What trading actions would be led to? How the environment will be affected?
Contribution III. Reflexivity

Knowing

- investor attention could be driven by distinct cognitive controls
- collective investor attention has behavioral regularities with distinct nature

So what? Considering **interactions** with the environment

- Cognitive
  Which structures of the environment are perceived by investor attention?
- Manipulative
  What trading actions would be led to? How the environment will be affected?
Contribution III. Reflexivity

Knowing

- investor attention could be driven by distinct cognitive controls
- collective investor attention has behavioral regularities with distinct nature

So what? Considering **interactions** with the environment

- Cognitive
  Which structures of the environment are perceived by investor attention?
- Manipulative
  What trading actions would be led to? How the environment will be affected?
Contribution III. Outline

- Evaluated linear causality
- Characterize structures of the environment perceived by collective selectivity
- Quantify interactions with volatility
- Check robustness with known behavioral bias
Contribution III. Reflexive Relationship

Two systems calibrated as:

- Structures of the environment
  - volatility, $\sigma_h \equiv sd(R)$, Parkinson volatility $\sigma_p$
  - trading volume, $V \equiv \frac{\text{number of shares traded}}{\text{number of shares outstanding}}$
  - total return, $r \equiv \log(S_{tN}) - \log(S_1)$

- Investor attention
  - fluctuation $\gamma$
  - memory $\alpha$
  - counts $N$
Two-way Granger causality

- Integrated or separated?
  \[ \text{HYPOTHESIS a. } \beta_1 = \beta_2 = \ldots = \beta_p = 0 \]

- Time lag and predictive power.
  \[ \text{HYPOTHESIS b. } \beta_i = 0, \ i = 1, \ldots, p \text{ with } p \text{ up to 2} \]

**Table: Testing Results**

<table>
<thead>
<tr>
<th></th>
<th>Cognitive</th>
<th>Manipulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>Rejected, (\sim 2)</td>
<td>Partially rejected</td>
</tr>
<tr>
<td>Active</td>
<td>Rejected, (\sim 3)</td>
<td>Rejected, (\sim 3)</td>
</tr>
</tbody>
</table>
New Results: Collective Selectivity

The cross-section of attention turnover: an attentional market of stocks

- **Persistence**: “winners” (“losers”) tend to stay as “winners” (“losers”)
- **Jumps**: nontrivial “jump” across several deciles, i.e. extreme moves

**Figure**: Transition probabilities of tweets deciles from day to day
New Results: Collective Selectivity

Which structural properties are relevant?

- shown categorical structure of the environment (sector), and recognition (firm size) do not correspond to collective selectivity
- memory persistence and magnitudes highly correlated with volatility and trading volume
- significant relevance at various timescales

Table: Correlations between Scaling Exponents and Trading Variables

<table>
<thead>
<tr>
<th></th>
<th>$\sigma_1$</th>
<th>$\sigma_{22}$</th>
<th>$\sigma_{100}$</th>
<th>$&lt;R_1&gt;$</th>
<th>$&lt;R_{22}&gt;$</th>
<th>$&lt;R_{252}&gt;$</th>
<th>$V_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>0.19</td>
<td>0.17</td>
<td>0.18</td>
<td>0.15</td>
<td>0.19</td>
<td>0.17</td>
<td>0.26</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.17</td>
<td>0.15</td>
<td>0.16</td>
<td>0.14</td>
<td>0.17</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>0.27</td>
<td>0.26</td>
<td>0.27</td>
<td>0.25</td>
<td>0.28</td>
<td>0.23</td>
<td>0.19</td>
</tr>
<tr>
<td>$\gamma_h$</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.12</td>
<td>0.12</td>
<td>0.10</td>
<td>0.15</td>
</tr>
<tr>
<td>$\gamma_t$</td>
<td>-0.10</td>
<td>-0.09</td>
<td>-0.10</td>
<td>-0.07</td>
<td>-0.05</td>
<td>-0.07</td>
<td>0.11</td>
</tr>
</tbody>
</table>
New Results: Finer Fingerprints

Interactions with short-term volatility:

- significant *two-way* feedbacks
- “decoupled” within \( \sim 30 \) minutes
- more sustaining responses than forecast
- suggests behavioral explanations for “volatility clustering”
New Results: Finer Fingerprints

Volatility behaviors conditioning on presence or absence of investor attention:

- Both the level and relaxation of volatility shows distinct patterns (red vs. blue)
- Furthermore, stronger effect of elevated and prolonged volatility when investor attention is more persistent (bottom panel)
New Results: Finer Fingerprints

A closer look at volatility relaxation patterns for investor attention of distinct nature:

- Extremely slow (powerlaw) relaxation
- Different speeds of volatility dying-off depends on memory strength of collective investor attention
New Results: Robustness Check

The role of this “social tape” is not the same as known behavioral bias, e.g. anchoring on historical extremes:

- Event study: significant response to 52-week high/lows
- Return test: consistent profits from double-sorted portfolios
New Results: Robustness Check - Event Study

- Event days: prices move above(below) 52-week maxima(minima)
- Compare z-scores: five-day moving window

Investors do pay attention to “anchors”
- Asymmetric reaction to positive/negative events
New Results: Robustness Check - Return Test

Sort stocks based on closeness to 52-week (lows), as well as levels of investor attention

- consistent profit for stocks anchored on 52-week lows by differentiating investor attention
- largest effect for stocks far below 52-week lows

Table: 52-week Low Returns Conditional on Investor Attention

<table>
<thead>
<tr>
<th>$D_{low}$</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q 1</td>
<td>0.04</td>
<td>0.1*</td>
<td>0.1*</td>
<td>0.09</td>
<td>0.16***</td>
<td>0.12***</td>
</tr>
<tr>
<td>Q 2</td>
<td>0.02</td>
<td>0.05</td>
<td>0.09</td>
<td>0.09</td>
<td>0.1*</td>
<td>0.08**</td>
</tr>
<tr>
<td>Q 3</td>
<td>0.05*</td>
<td>0.08</td>
<td>0.08</td>
<td>0.09</td>
<td>0.12*</td>
<td>0.06*</td>
</tr>
<tr>
<td>Q 4</td>
<td>0.08*</td>
<td>0.09</td>
<td>0.11*</td>
<td>0.08</td>
<td>0.14**</td>
<td>0.06***</td>
</tr>
<tr>
<td>Q 5</td>
<td>0.16***</td>
<td>0.18**</td>
<td>0.2***</td>
<td>0.18**</td>
<td>0.21***</td>
<td>0.06**</td>
</tr>
</tbody>
</table>

Note: returns are in basis points. *, **, *** denote 90%, 95%, and 99% confidence intervals respectively
New Results: Robustness Check - Return Test

- limited effects for portfolios anchored on 52-week highs
- short-sale constraints may hinder “sell high”

### Table: 52-week High Returns Conditional on Investor Attention

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_{high}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q 1</td>
<td>0.23***</td>
<td>0.23***</td>
<td>0.23***</td>
<td>0.23***</td>
<td>0.33***</td>
<td>0.09***</td>
</tr>
<tr>
<td>Q 2</td>
<td>0.1*</td>
<td>0.1</td>
<td>0.13*</td>
<td>0.11*</td>
<td>0.14**</td>
<td>0.04**</td>
</tr>
<tr>
<td>Q 3</td>
<td>0.04</td>
<td>0.05</td>
<td>0.09</td>
<td>0.07</td>
<td>0.09</td>
<td>0.05*</td>
</tr>
<tr>
<td>Q 4</td>
<td>0.03</td>
<td>0.03</td>
<td>0.07</td>
<td>0.04</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Q 5</td>
<td>0.03</td>
<td>0.06*</td>
<td>0.08</td>
<td>0.08</td>
<td>0.09*</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Note: returns are in basis points. *, **, *** denote 90%, 95%, and 99% confidence intervals respectively
Summary of Contribution III.

Evaluated collective investor attention as a “social tape”:

- **Selectivity**
  - categorical and recognition matter less than volatility in collective selectivity

- **Linear causality:**
  - significant response to market movements, but only active attention strongly affect future movements

- **Feedbacks with short-term volatility:**
  - magnitudes and relaxation are different depending on the presence and nature of investor attention

- **Information content:**
  - different from “anchor bias”, and asymmetric in buy/sell
Concluding Remarks

1. Cognitive control mechanisms of temporal selective investor attention
   ▶ modeled adaptive cognitive controls and evaluated contextual utilization
   ▶ identified significant social contagion

2. Dynamical system of collective investor attention
   ▶ characterized scale-invariant fluctuations at both small and large timescales
   ▶ measured short-term clustering and long-memory
   ▶ modeled strong feedbacks with quantifiable endogeneity

3. Interactive social tape
   ▶ calibrated collective selectivity
   ▶ measured significant linear causality
   ▶ quantified effects on elevated and slow-relaxation in volatility
   ▶ performed robustness evaluation with known behavioral bias
Future Work

- Selective mechanisms along spatial dimension
- Combine with social properties of investor interactions along other dimensions
- Implications for asset pricing models
Acknowledgement

- Dr. Jim Hendler, Dr. Selmer Bringsjord, Dr. Deborah McGuinness, Dr. John Teall
- TWCers, Dr. Wayne Gray, Dr. Peter Kramer, Dr. Thomas Willemain, Dr. Steve Bratt, Dr. Keith Marzullo, Dr. Martha Pollack, and Dr. Bryant York
Contribution I. Formalisms of Control Mechanisms

- **Attention Potential**
  1. motivated by event-related potential (ERP), brain measures of cognitive processes
  2. ERPs correspond to selective attention \(^1\)
  3. at time \(t\), investor’s limited attention towards asset \(j\) measured by attention potential process \(X = \{X(t), t \geq 0\}\)

- **Temporal Allocation of Selective Attention**
  1. event time + response time
  2. recognition: an explicit allocation of attention would be observed when \(X_j(t)\) exceeds the threshold \(m\).
  3. memory availability

---

\(^1\) hillyard1998event.
Contribution I. Formalisms of Control Mechanisms

Origins:

- Involuntary (exogenous) external stimulus event which triggers a certain amount of abrupt brain activity potentials

\[ \Delta X_{exo}(t) = \gamma [N(t + \Delta t) - N(t)] \]  \hspace{1cm} (2)

where \( \{N(t), t \geq 0\} \) is the total number of events by time \( t \), corresponding to Poisson process of news arrivals in financial markets.
Contribution I. Formalisms of Control Mechanisms

Origins:

- Voluntary (endogenous)

ERP components have also been observed in the absence of external stimulations, but driven by the subject’s experience, goals and preferences, depending on the natures of the information processing tasks, e.g. expected asset price $E[S_i(t + \Delta t)]$ of asset $i$.

\[
\Delta X_{endo}(t) = \sum_{j=1}^{q} \epsilon_j
\]  

where $\epsilon_j$ is attention potential corresponding to utilities of returns $E[R_i(t + \Delta t)]$.

\[
dX_{endo}(t) = \mu dt + \sigma dW(t)
\]
Contribution I. Formalisms of Control Mechanisms

Candidate behavioral profiles of allocation time $\tau \equiv T_{n+1} - T_n$

- **instant response**
  Implicit assumption in the Efficient Market Hypothesis: infinite information processing capability, immediate response

- **threshold response**
  Human utilizes recognition thresholds for detecting presences in perception tasks

$$\tau_m = \min\{t; X(t) = m\} \quad (5)$$

where $m$ is activation threshold for attentional shift.

- **memory-mediated response**
  Both attention potential and memory availability determine attention allocation

$$\tau_\lambda = \frac{\tau_0(t)}{\lambda(X(t), t)} \quad (6)$$

where $\lambda(X(t), t)$ is conditional response rate based on memory availability of $X(t)$, e.g. “powerlaw” forgetting.
EMH is a highly non-realistic assumption of investor attention.

Both involuntary and voluntary origins are equally probably, memory and recognition controls appear in both.

Types of cognitive control depends on contexts, e.g. stock vs. indices, chartist vs. fundamentalists, novice vs. professionals.
Contribution I. Contextual Cognitive Controls

Control mechanisms towards assets of different nature

- Involuntary control for individual stocks while voluntary control for indices
Contribution I. Contextual Cognitive Controls

How do control mechanisms correspond to investing approach?

- Voluntary attention more utilized by technical traders
- Involuntary attention more practiced by fundamental investors
Contribution II. Review

Collective Cognitive Control
\{Involuntary, Voluntary\} \otimes \text{memory} > \{Involuntary, Voluntary\} \otimes \text{recognition} > \text{EMH}

1. Collective investor attention is still not as efficient as EMH highly non-Poissonian either.
2. Recognition bias mitigated!
3. Memory still in play
4. Both voluntary and involuntary control present at collective level
Contribution II. Collective Regularity

Short-term clustering.
- Conditional probability on original time series shows dependence (A).
- Contrast to shuffled records without interdependence (B).
Contribution II. Review

Long-range memory:

- detrended residuals are powerlaw-correlated ($\alpha = 0.5$ means no correlation)

- active attention has longer memory in general
Contribution II. New Findings

Table: Descriptive Statistics of Fitted Hawke Parameters

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>1st Qu.</th>
<th>Median</th>
<th>Mean</th>
<th>3rd Qu.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>0.00</td>
<td>0.07</td>
<td>0.14</td>
<td>0.24</td>
<td>0.26</td>
<td>14.95</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.09</td>
<td>0.17</td>
<td>0.21</td>
<td>0.24</td>
<td>0.27</td>
<td>1.69</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>4.252e-10</td>
<td>0.13</td>
<td>0.16</td>
<td>0.17</td>
<td>0.21</td>
<td>0.71</td>
</tr>
<tr>
<td>$n$</td>
<td>4.126e-10</td>
<td>0.69</td>
<td>0.78</td>
<td>0.74</td>
<td>0.85</td>
<td>0.99</td>
</tr>
</tbody>
</table>

- significant endogeneity $n \geq 0.69$ for more than 75% of sample windows.
- evidence of criticality $n \approx 1$, i.e. without exogenous ancestors
Contribution III. Review Reflexive Relationship

- Two way Granger causality
  1. Cross sectional panel with stock $j$, time $t_k$ at $\Delta t=30$ minutes interval, fixed effect
     \[ Y_t = \alpha + \sum_{i=0}^{p} \beta_i X_i + \sum_{i=1}^{q} \beta_i^L Y_i + \varepsilon_t \]  
  2. Lagged $Y$ was added as control variable
  3. Prewhiten to reduce serial correlation
  4. Remove intraday, weekday seasonality

- Integrated or separated?
  HYPOTHESIS a. $\beta_1 = \beta_2 = ... = \beta_p = 0$

- Time lag and predictive power.
  HYPOTHESIS b. $\beta_i = 0, i = 1, ..., p$ with $p$ up to 2
Contribution III. Review Results

Investor Attention as Cognitive Function

- **HYPOTHESIS a.** $\beta_1 = \beta_2 = \ldots = \beta_p = 0$.
  Rejected. Both active and passive investor attention is affected by recent volatility, trading volume and absolute return.

- **HYPOTHESIS b.** $\beta_i = 0$, $i = 1, \ldots, p$
  Rejected. All significant $\sim 2$ lags. Stronger effect for active cognitive control than passive ones.

<table>
<thead>
<tr>
<th>$X_p$</th>
<th>Passive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.11 *</td>
<td>0.14 *</td>
</tr>
<tr>
<td>-1</td>
<td>0.05 *</td>
<td>0.05 *</td>
</tr>
<tr>
<td>-2</td>
<td>0.02 *</td>
<td>0.02 *</td>
</tr>
<tr>
<td>-3</td>
<td>0.01</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$X_p$</th>
<th>Passive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.11 *</td>
<td>0.13 *</td>
</tr>
<tr>
<td>-1</td>
<td>0.05 *</td>
<td>0.07 *</td>
</tr>
<tr>
<td>-2</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>-3</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

**Table:** Independent Variable: $\sigma_h$

**Table:** Independent Variable: $\sigma_p$
**Investor Attention as Cognitive Function**

<table>
<thead>
<tr>
<th>$X_p$</th>
<th>Passive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.09 *</td>
<td>0.14 *</td>
</tr>
<tr>
<td>-1</td>
<td>0.07 *</td>
<td>0.11 *</td>
</tr>
<tr>
<td>-2</td>
<td>0.02 *</td>
<td>0.03 *</td>
</tr>
<tr>
<td>-3</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Table:** Independent Variable: $|R|$

<table>
<thead>
<tr>
<th>$X_p$</th>
<th>Passive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.15 *</td>
<td>0.2 *</td>
</tr>
<tr>
<td>-1</td>
<td>0.09 *</td>
<td>0.14 *</td>
</tr>
<tr>
<td>-2</td>
<td>0.04 *</td>
<td>0.07 *</td>
</tr>
<tr>
<td>-3</td>
<td>0.01</td>
<td>0.04 *</td>
</tr>
</tbody>
</table>

**Table:** Independent Variable: $V$
Contribution III. Results

Investor Attention as Manipulative Function

- HYPOTHESIS a. $\beta_1 = \beta_2 = \ldots = \beta_p = 0$.
  Partially rejected. Passive attention has no predictive power on returns.

|       | $\sigma$ | $V$ | $|r|$ |
|-------|----------|-----|------|
| Passive | $Y, \sim 2$ | $Y, \sim 0$ | N |
| Active  | $Y, \sim 3$ | $Y, \sim 1$ | $Y, \sim 3$ |

Table: Causality of Investor Attention on Market Variables
Contribution III. Results

Investor Attention as Manipulative Function

- **HYPOTHESIS b.** $\beta_i = 0, i = 1, ..., p$

  Rejected. Active investor attention has significant and stronger causal effect on volatility, absolute returns and volumes $\sim 3$ lags

<table>
<thead>
<tr>
<th>$X_p$</th>
<th>Passive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1 *</td>
<td>0.16 *</td>
</tr>
<tr>
<td>-1</td>
<td>0.06 *</td>
<td>0.07 *</td>
</tr>
<tr>
<td>-2</td>
<td>0.03 *</td>
<td>0.04 *</td>
</tr>
<tr>
<td>-3</td>
<td>0.01</td>
<td>0.03 *</td>
</tr>
</tbody>
</table>

**Table:** Dependent Variable: $\sigma_h$

<table>
<thead>
<tr>
<th>$X_p$</th>
<th>Passive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1 *</td>
<td>0.17 *</td>
</tr>
<tr>
<td>-1</td>
<td>0.02 *</td>
<td>0.06 *</td>
</tr>
<tr>
<td>-2</td>
<td>0.01</td>
<td>0.04 *</td>
</tr>
<tr>
<td>-3</td>
<td>0.01</td>
<td>0.02 *</td>
</tr>
</tbody>
</table>

**Table:** Dependent Variable: $|r|$