The Adaptive Markets Hypothesis: Financial Evolution at the Speed of Thought

Andrew W. Lo, MIT Sloan Alumni Webinar
July 11, 2017
“Lies my finance professor told me...”

1. DELIVERY OF MANUSCRIPT

You agree to deliver the complete manuscript ready for copyediting, including a preface, other front matter, and back matter, together with camera-ready copy for all illustrations, maps, charts, drawings, or other material (except index) to be included in the Work, not later than April 15, 2008, or a later date designated in writing by the Press (the “Delivery Date”), time of delivery being of the essence. The final manuscript submitted to the Press will consist of no more than 80,000 words in length (including text, notes, and bibliography), 20 illustrations, and 10 color plates, and we reserve the right to reject the manuscript if the manuscript exceeds this limit.
In a fashion analogous to Theorem 6.3.1, the behavior of $Q_n$ under long-range dependent alternatives may now be derived in several steps using Lemmas A.2, A.3, and Theorem 6.3.2.

**Theorem 6.3.3.** Let $\{c_t\}$ be a zero-mean stationary Gaussian stochastic process with autocovariance function $\gamma_k$ such that

$$\gamma_k \sim \begin{cases} \frac{\gamma_k}{2^H - 2} & \text{for } H \in (\frac{1}{2}, 1) \text{ or}, \\ -\frac{\gamma_k}{2^H - 2} & \text{for } H \in (0, \frac{1}{2}) \end{cases} \quad \text{as} \quad k \to \infty \quad (6.5.14)$$

where $1(k)$ is a slowly-varying function at infinity. Then as $n$ and $y$ increase without bound such that $(y/n) \to 0$, we have:

\[
\begin{align*}
(a) & \quad \max_{1 \leq k \leq n} \frac{1}{\sigma_n} \sum_{i=1}^{k} (X_i - \bar{X}_k) \Rightarrow \max_{0 \leq \tau \leq 1} W^n_H(\tau) \equiv M_H^n, \\
(b) & \quad \min_{1 \leq k \leq n} \frac{1}{\sigma_n} \sum_{i=1}^{k} (X_i - \bar{X}_k) \Rightarrow \min_{0 \leq \tau \leq 1} W^n_H(\tau) \equiv W^n_H, \\
(c) & \quad R_n = \frac{\hat{\alpha}(q) \sqrt{n}}{\sigma_n} \Rightarrow M_H^n - y_w^n \equiv \chi^2_1, \\
(d) & \quad \alpha_n = \frac{\hat{\alpha}(q) \sqrt{n}}{\sigma_n} \Rightarrow \begin{cases} \infty & \text{for } H \in (\frac{1}{2}, 1), \\ 0 & \text{for } H \in (0, \frac{1}{2}) \end{cases}, \\
(e) & \quad \frac{1}{\sqrt{n}} Q_n = \alpha_n R_n \Rightarrow \begin{cases} \infty & \text{for } H \in (\frac{1}{2}, 1), \\ 0 & \text{for } H \in (0, \frac{1}{2}) \end{cases},
\end{align*}
\]

where $\hat{\alpha}(q)$ is defined in (6.3.6), $\alpha_n$ is defined in Theorem 6.3.2, and $W^n_H(\tau) = W_H(\tau) - \tau W_H(1)$.

Theorem 6.3.3 shows that the modified rescaled range test is consistent against a class of long-range dependent stationary Gaussian alternatives. In the presence of positive strong dependence, the $R/S$ statistic diverges in probability to infinity; in the presence of negative strong dependence, it converges in probability to zero. In either case, the probability of rejecting the null hypothesis approaches unity for all stationary Gaussian stochastic processes satisfying (6.5.14), a broad set of alternatives that includes all fractionally-differenced Gaussian ARIMA($p, d, q$) models with $d \in (\frac{1}{2}, \frac{3}{2})$.

From (a) and (b) of Theorem 6.3.3 it is apparent that the normalized population rescaled, $R_n / \sqrt{n}$, converges to zero in probability. Therefore,

\[\text{Although it is tempting to call } W_H^n(\tau) \text{ a "fractional Brownian bridge," this is not the most natural definition despite the fact that it is "fitted down." See Jonaa (1993, Chapter 3.5) for a discussion.}\]
Markets are efficient. People behave irrationally.
Summary

- Traditional investment framework is flawed
- Not wrong, but incomplete
- Stability $\Rightarrow$ stable investment rules (EMH)
- Instability $\Rightarrow$ dynamic investment rules (AMH)
- The current environment is highly \textit{dynamic}
- We must adapt to changing market conditions
- “it’s the economy, stupid”
- AMH provides a framework for investing, risk management, financial regulation, and more
Personal Journey

- Efficient Markets
  - Rational Expectations
- Behavioral Finance
  - Psychology
- Behavioral Finance
  - Psychology
- Rational Expectations
- Adaptive Markets Hypothesis
- Cognitive Neurosciences
- Artificial Intelligence
  - Bounded Rationality
- Evolutionary Biology
  - Ecology
Rogers Commission
Rogers Commission

Rogers Commission Report Published June 9, 1986

O-Ring
The complexity of price discovery in an efficient market: the stock market reaction to the Challenger crash

Michael T. Maloney\textsuperscript{a,*}, J. Harold Mulherin\textsuperscript{b,1}

\textsuperscript{a}Department of Economics, Clemson University, Clemson, SC 29634, USA
\textsuperscript{b}Department of Economics, Claremont McKenna College, Claremont, CA 91711, USA

Received 15 November 2001; received in revised form 8 February 2002; accepted 12 July 2002
The Stock Market Reflected This Information Within **Minutes**

### Table 2: Intraday stock market behavior around the Challenger crash

<table>
<thead>
<tr>
<th>Time</th>
<th>Morton Thiokol</th>
<th>Lockheed</th>
<th>Martin Marietta</th>
<th>Rockwell International</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel A. Stock price movements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:30 a.m.</td>
<td>US$37.25</td>
<td>US$47.25</td>
<td>US$35.38</td>
<td>US$34.75</td>
</tr>
<tr>
<td>Noon</td>
<td><strong>Halt</strong></td>
<td>US$44.50</td>
<td>US$34.25</td>
<td>US$32.75</td>
</tr>
<tr>
<td>12:36 p.m.</td>
<td>US$25.00</td>
<td>US$45.00</td>
<td>US$32.50</td>
<td>US$34.13</td>
</tr>
<tr>
<td>1:00 p.m.</td>
<td>US$34.38</td>
<td>US$45.00</td>
<td>US$33.00</td>
<td>US$33.25</td>
</tr>
</tbody>
</table>

**Panel B. Stock returns**

<table>
<thead>
<tr>
<th>Time</th>
<th>Morton Thiokol</th>
<th>Lockheed</th>
<th>Martin Marietta</th>
<th>Rockwell International</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:30–Noon</td>
<td>Halt</td>
<td>−5.82%</td>
<td>−3.18%</td>
<td>−5.76%</td>
</tr>
<tr>
<td>Noon–12:36</td>
<td>−6.04%</td>
<td>1.12%</td>
<td>−5.11%</td>
<td>4.20%</td>
</tr>
<tr>
<td>12:36–1:00</td>
<td>−1.79%</td>
<td>0.00%</td>
<td>1.54%</td>
<td>−2.56%</td>
</tr>
</tbody>
</table>

This table reports the price movements and stock returns of the four major space-shuttle firms in the period immediately surrounding the 11:39 a.m. crash of the space shuttle Challenger on January 28, 1986. There is no reported price for Morton Thiokol at noon because of an NYSE trading halt in that stock from 11:52 a.m. to 12:44 p.m. The first post-crash trade in Morton Thiokol occurred at 12:36 p.m. on NASDAQ. Data are taken from the price sheets of Francis Emory Fitch.
Fig. 1. Intraday stock price movements following the challenger disaster.
The Wisdom of Crowds

\[ x_i = x + \epsilon_i \]

\[ \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \]

\[ = x + \frac{1}{n} \sum_{i=1}^{n} \epsilon_i \]

\[ \approx x \]

© 2017 by Andrew W. Lo  All Rights Reserved
The Challenge

- Rationality is not supported by the data
- Cognitive and behavioral biases
  - Loss aversion, anchoring, framing
  - Overconfidence
  - Overreaction
  - Herding
  - Mental accounting
  - Probability matching
  - etc.

© 2017 by Andrew W. Lo
All Rights Reserved
The Challenge

Crisis on Wall Street as Lehman Totters, Merrill Is Sold, AIG Seeks to Raise Cash

The Wall Street Journal

© 2017 by Andrew W. Lo
All Rights Reserved

Slide 16
The Madness of Mobs!
The Effects of Automobile Safety Regulation

Sam Peltzman

*University of Chicago*

Technological studies imply that annual highway deaths would be 20 percent greater without legally mandated installation of various safety devices on automobiles. However, this literature ignores offsetting effects of nonregulatory demand for safety and driver response to the devices. This article indicates that these offsets are virtually complete, so that regulation has not decreased highway deaths. Time-series (but not cross-section) data imply some saving of auto occupants’ lives at the expense of more pedestrian deaths and more nonfatal accidents, a pattern consistent with optimal driver response to regulation.

*Journal of Political Economy* 83(1975), 677–726.
Automobile Safety Regulation and the Incentive to Drive Recklessly: Evidence from NASCAR

Russell S. Sobel* and Todd M. Nesbit†

When safety regulation makes automobiles safer, drivers may drive more recklessly, partially or completely offsetting effects on the overall level of safety. Evidence of these offsetting effects has been hard to find, however, primarily because of the aggregate nature of accident data. In this paper we explore how changes in the safety of automobiles used in the National Association for Stock Car Auto Racing (NASCAR) has altered the incentive of drivers to drive recklessly. This unique data set allows more accurate and objective measurement of the necessary variables to test for these effects at a microlevel. Our results strongly support the presence of these offsetting behavioral effects.

Implications for the Current Ecosystem

Yahoo! Finance

S&P 500
2,426.18
+15.43 (+0.64%)

Dow 30
21,414.34
+94.30 (+0.44%)

Nasdaq
6,153.08
+63.61 (+1.04%)

Crude Oil
44.33
-1.19 (-2.61%

VOLATILITY S&P 500 (^VIX) 11.19 -1.35 (-10.77%) As of 4:14PM EDT Market closed.

Open 12.48
Close 11.19
Low 10.98
High 12.57
Vol 0.00
% Chg -55.88%

© 2017 by Andrew W. Lo
All Rights Reserved
Artificial vs. Natural Intelligence

- Expert systems vs. machine-learning techniques
- Expensive storage $\Rightarrow$ small data, complex code
- Cheap storage $\Rightarrow$ big data, simple code
- This is closer to natural intelligence!
Friend or Foe?
## Friend or Foe?

<table>
<thead>
<tr>
<th>Category</th>
<th>José</th>
<th>Julia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender and sex orientation (4)</td>
<td>GM</td>
<td>HF</td>
</tr>
<tr>
<td>Race/ethnicity (4)</td>
<td>Latino</td>
<td>White</td>
</tr>
<tr>
<td>Age (4)</td>
<td>Young Prof.</td>
<td>Mid. Age</td>
</tr>
<tr>
<td>Current home state (50)</td>
<td>CA</td>
<td>TX</td>
</tr>
<tr>
<td>Religious affiliation (4)</td>
<td>None</td>
<td>Christian</td>
</tr>
<tr>
<td>Political party (3)</td>
<td>Democrat</td>
<td>Republican</td>
</tr>
<tr>
<td>Economic status (3)</td>
<td>Mid. Class</td>
<td>Affluent</td>
</tr>
<tr>
<td>Education (3)</td>
<td>MBA</td>
<td>BA</td>
</tr>
</tbody>
</table>

### 345,600 Possible Types!

**But Beware of Learning With Sparse Data**
The Power of Narrative

Aron Lee Ralston, 4/26/03
A blond three-year-old boy in a red polo shirt comes running across a sunlit hardwood floor in what I somehow know is my future home. By the same intuitive perception, I know the boy is my own. I bend to scoop him into my left arm, using my handless right arm to balance him, and we laugh together as I swing him up to my shoulder... Then, with a shock, the vision blinks out. I’m back in the canyon, echoes of his joyful sounds resonating in my mind, creating a subconscious reassurance that somehow I will survive this entrapment. Despite having already come to accept that I will die where I stand before help arrives, now I believe I will live.

That belief, that boy, changes everything for me.

– Aron Lee Ralston (2005)
The Power of Narrative

We Need New Narratives In Finance!
The Adaptive Markets Hypothesis

- Investors, managers, regulators, policymakers are neither rational or irrational; they’re human
- They innovate, compete, adapt, reproduce, and evolve (within a generation, via heuristics)
- The environment is as important as their behavior in determining market dynamics
- Quantitative models can be useful in capturing these dynamics, but they, too, evolve
- Biology may be a better analogy than physics
Thank You!

For more on Adaptive Markets:

- [http://alo.mit.edu](http://alo.mit.edu) (website)
- @AndrewWLo (Twitter)