The Adaptive Markets Hypothesis

Market efficiency from an evolutionary perspective.

Andrew W. Lo

The 30th anniversary of *The Journal of Portfolio Management* is a milestone in the rich intellectual history of modern finance, firmly establishing the relevance of quantitative models and scientific inquiry in the practice of financial management. One of the most enduring ideas from this intellectual history is the Efficient Markets Hypothesis (EMH), a deceptively simple notion that has become a lightning rod for its disciples and the proponents of behavioral economics and finance.

In its purest form, the EMH obviates active portfolio management, calling into question the very motivation for portfolio research. It is only fitting that we revisit this groundbreaking idea after three very successful decades of this Journal.

In this article, I review the current state of the controversy surrounding the EMH and propose a new perspective that reconciles the two opposing schools of thought. The proposed reconciliation, which I call the *Adaptive Markets Hypothesis* (AMH), is based on an evolutionary approach to economic interactions, as well as some recent research in the cognitive neurosciences that has been transforming and revitalizing the intersection of psychology and economics.

Although some of these ideas have not yet been fully articulated within a rigorous quantitative framework, long time students of the EMH and seasoned practitioners will no doubt recognize immediately the possibilities generated by this new perspective. Only time will tell whether its potential will be fulfilled.

I begin with a brief review of the classic version of the EMH, and then summarize the most significant criticisms leveled against it by psychologists and behavioral economists. I argue that the sources of this controversy can

Andrew W. Lo is Harris & Harris Group Professor at the MIT Sloan School of Management, and chief scientific officer at AlphaSimplex Group, LLC, in Cambridge, MA.

be traced back to the very origins of modern neoclassical economics, and, by considering the sociology and cultural history of modern finance, we can develop a better understanding of how we arrived at the current crossroads for the EMH.

I then turn to the AMH, in which the dynamics of evolution—competition, mutation, reproduction, and natural selection—determine the efficiency of markets and the waxing and waning of financial institutions, investment products, and ultimately institutional and individual fortunes. I conclude by considering some implications of the AMH for portfolio management, and by outlining a research agenda for formalizing several aspects of the model.[1]

CLASSICAL EFFICIENT MARKETS HYPOTHESIS

We all know the joke about an economist strolling down the street with a companion. They come upon a $100 bill lying on the ground. As his companion reaches down to pick it up, the economist says, "Don't bother—if it were a genuine $100 bill, someone would have already picked it up."

This example of economic logic gone awry is a fairly accurate rendition of the Efficient Markets Hypothesis, one of the most contested propositions in all the social sciences. It is disarmingly simple to state; it has far-reaching consequences for academic theories and business practice; and yet is surprisingly resilient to empirical proof or refutation. Even after several decades of research and literally thousands of studies, many published in this Journal, economists have not yet reached a consensus about whether markets—particularly financial markets—are in fact efficient.

As with so many of the ideas of modern economics, the origins of the EMH can be traced back to Paul Samuelson [1965], whose contribution is neatly summarized by his title, "Proof that Properly Anticipated Prices Fluctuate Randomly." In an informationally efficient market, price changes must be unforecastable if they are properly anticipated, that is, if they fully incorporate the information and expectations of all market participants. Roberts [1967] and Fama [1970] operationalized this hypothesis—summarized in Fama's well-known description, "prices fully reflect all available information"—by placing structure on various information sets available to market participants.

This concept of informational efficiency has a Zen-like, counterintuitive flavor to it. The more efficient the market, the more random the sequence of price changes generated by such a market; and the most efficient market of all is a market in which price changes are completely random and unpredictable. This is not an accident of nature, but is in fact the direct result of many active market participants attempting to profit from their information.

Driven by profit opportunities, an army of investors pounce on even the smallest informational advantages at their disposal. In doing so, they incorporate their information into market prices and quickly eliminate the profit opportunities that first motivated their trades. If this occurs instantaneously, which it must in an idealized world of frictionless markets and costless trading, prices must always fully reflect all available information. Therefore, no profits can be garnered from information-based trading because such profits must have already been captured (the $100 bill on the ground). In mathematical terms, prices follow martingales.

A decade after Samuelson's [1965] landmark work, his framework was broadened to accommodate risk-averse investors, yielding a neoclassical version of the EMH where price changes, properly weighted by aggregate marginal utilities, must be unforecastable (see, for example, LeRoy [1973]; Rubinstein [1976]; and Lucas [1978]). In markets where, according to Lucas [1978], all investors have "rational expectations," prices do fully reflect all available information and marginal-utility weighted prices follow martingales.

The EMH has been extended in many other directions, to incorporate non-traded assets such as human capital, state-dependent preferences, heterogeneous investors, asymmetric information, and transaction costs. But the general thrust is the same: Individual investors form expectations rationally; markets aggregate information efficiently; and equilibrium prices incorporate all available information.

The current version of the EMH can be summarized compactly by the "three Ps of Total Investment Management": prices, probabilities, and preferences (see Lo [1999]). The three Ps have their origins in one of the most basic and central ideas of modern economics, the principle of supply and demand.

This principle states that the price of any commodity and the quantity traded are determined by the intersection of supply and demand curves, where the demand curve represents the schedule of quantities desired by consumers at various prices, and the supply curve represents the schedule of quantities producers are willing to supply at various prices. The intersection of these two curves determines an "equilibrium," a price-quantity pair that satisfies both consumers and producers simultaneously. Any other price-quantity pair may serve one group's interests, but not the other's.

Even in this simple description of a market, all the elements of modern finance are present. The demand curve is the aggregation of many individual consumers' desires, each derived from optimizing an individual's preferences, subject to a budget constraint that depends on prices and other factors (e.g., income, savings requirements, and borrowing costs). Similarly, the supply curve is the aggregation of many individual producers' outputs, each derived from optimizing an entrepreneur's preferences, subject to a resource constraint that also depends on prices and other factors (e.g., costs of materials, wages, and trade credit). And probabilities affect both consumers and producers as they formulate their consumption and production plans through time and in the face of uncertainty—uncertain income, uncertain costs, and uncertain business conditions.

It is the interactions among prices, preferences, and probabilities that give modern financial economics its richness and depth. Formal models of financial asset prices such as Leroy [1973], Merton [1973], Rubinstein [1976], Lucas [1978], and Breeden [1979] show precisely how the three Ps simultaneously determine a "general equilibrium" in which demand equals supply across *all* markets in an uncertain world where individuals and corporations act rationally to optimize their own welfare. The three Ps enter into any economic decision under uncertainty. It may be argued that they are fundamental to all forms of decision-making.

BEHAVIORAL CRITIQUES

The three Ps of Total Investment Management yield quite specific theoretical and empirical implications that have been tested over the years. The early tests focused primarily on whether prices of certain financial assets do fully reflect various types of information, and several tests have also considered the characteristics of probabilities implicit in asset prices (see, for example, Cootner [1964] and Lo [1997]). But the most enduring critiques of the EMH revolve around the preferences and behavior of market participants.

The standard approach to modeling preferences is to assert that investors optimize additive time-separable expected utility functions from certain parametric families, e.g., constant relative risk aversion. Psychologists and experimental economists have documented a number of departures from this paradigm, though, in the form of specific behavioral biases that are endemic in human decision-making under uncertainty, and several of these lead to undesirable outcomes for an individual's economic welfare. They include: overconfidence (Fischoff and Slovic [1980]; Barber and Odean [2001]; Gervais and Odean [2001]), overreaction (De Bondt and Thaler [1986]), loss aversion (Kahneman and Tversky [1979]; Shefrin and Statman [1985]; Odean [1998]), herding (Huberman and Regev [2001]), psychological accounting (Tversky and Kahneman [1981]), miscalibration of probabilities (Lichtenstein, Fischoff, and Phillips [1982]), hyperbolic discounting (Laibson [1997]), and regret (Bell [1982]; Clarke, Krase, and Statman [1994]). These critics of the EMH argue that investors are often if not always irrational, exhibiting predictable and financially ruinous behavior.

To see just how pervasive such behavioral biases can be, consider a slightly modified version of the experiment psychologists Kahneman and Tversky [1979] conducted 25 years ago. Suppose you are offered two investment opportunities, A and B. A yields a sure profit of $240,000, and B is a lottery ticket yielding $1 million with a 25% probability and $0 with 75% probability. If you had to choose between A and B, which would you prefer? Investment B has an expected value of $250,000, which is higher than A's payoff, but this may not be all that meaningful to you because you will receive either $1 million or zero. Clearly, there is no right or wrong choice here; it is simply a matter of personal preferences.

Faced with this choice, most subjects prefer A, the sure profit, to B, despite the fact that B offers a significant probability of winning considerably more. This behavior is often characterized as risk aversion for obvious reasons.

Now suppose you are faced with another two choices, C and D: C yields a sure loss of $750,000, and D is a lottery ticket yielding $0 with 25% probability and a loss of $1 million with 75% probability. Which would you prefer? This situation is not as absurd as it might seem at first glance; many financial decisions involve choosing between the lesser of two evils. In this case, most subjects choose D, despite the fact that D is more risky than C. When faced with two choices that both involve losses, individuals seem to be risk-seeking, not risk-averse as in the case of A versus B.

The fact that individuals tend to be risk-averse in the face of gains and risk-seeking in the face of losses can lead to some very poor financial decisions. To see why, observe that the combination of choices A plus D is equivalent to a single lottery ticket yielding $240,000 with 25% probability and –$760,000 with 75% probability, while the combination of choices B plus C is equivalent to a single lottery ticket yielding $250,000 with 25% probability and –$750,000 with 75% probability. The B plus C combination has the same probabilities of gains and losses, but the gain is $10,000 higher and the loss is $10,000 lower. In other words, B plus C is formally equivalent to A plus D plus a sure profit of $10,000. In light of this analysis, would you still prefer A plus D?

A common response to this example is that it is contrived, because the two pairs of investment opportunities are presented sequentially, not simultaneously. Yet in a typical global financial institution, the London office may be faced with choices A and B and the Tokyo office may be faced with choices C and D. Locally, it may seem as if there is no right or wrong answer—the choice between A and B or C and D seems to be simply a matter of personal risk preferences—but the globally consolidated financial statement for the entire institution will tell a very different story.

From that perspective, there *is* a right answer and a wrong answer, and the empirical and experimental evidence suggests most individuals tend to select the wrong answer. Therefore, according to the behavioralists, quantitative models of efficient markets—all predicated on rational choice—are likely to be wrong as well.

Grossman [1976] and Grossman and Stiglitz [1980] go even farther. They argue that perfectly informationally efficient markets are an *impossibility*, for if markets are perfectly efficient, there is no profit to gathering information, in which case there would be little reason to trade, and markets would eventually collapse.

Alternatively, the degree of market *inefficiency* determines the effort investors are willing to expend to gather and trade on information. Hence, a non-degenerate market equilibrium will arise only when there are sufficient profit opportunities, i.e., inefficiencies, to compensate investors for the costs of trading and information gathering. The profits earned by attentive investors may be viewed as economic rents that accrue to those willing to engage in such activities.

Who are the providers of these rents? Black [1986] gave us a provocative answer: "noise traders," individuals who trade on what they consider to be information that is, in fact, merely noise.

The supporters of the EMH have responded to these challenges by arguing that while behavioral biases and corresponding inefficiencies do arise from time to time, there is a limit to their prevalence and impact because of opposing forces dedicated to exploiting such opportunities. A simple example of such a limit is the so-called Dutch book, where irrational probability beliefs give rise to guaranteed profits for the savvy investor.

Consider, for example, an event E, defined as "the S&P 500 index drops by 5% or more next Monday," and suppose an individual has irrational beliefs as follows: There is a 50% probability that E will occur, and a 75% probability that E will *not* occur. This is clearly a violation of one of the basic axioms of probability theory—the probabilities of two mutually exclusive and exhaustive events must sum to one—but many experimental studies have documented such violations among an overwhelming majority of human subjects.

These inconsistent subjective probability beliefs imply that the individual would be willing to take both of the following bets B_1 and B_2:

$$B_1 = \begin{cases} \$1 & \text{if } E \\ -\$1 & \text{otherwise} \end{cases}$$

$$B_2 = \begin{cases} \$1 & \text{if } E^c \\ -\$3 & \text{otherwise} \end{cases} \quad (1)$$

where E^c denotes the event "not E."

Now suppose we take the opposite side of both bets, placing \$50 on B_1 and \$25 on B_2. If E occurs, we lose \$50 on B_1 but gain \$75 on B_2, yielding a profit of \$25. If E^c occurs, we gain \$50 on B_1 and lose \$25 on B_2, also yielding a profit of \$25. Regardless of the outcome, we have secured a profit of \$25, an arbitrage that comes at the expense of the individual with inconsistent probability beliefs.

Such beliefs are not sustainable, and market forces—namely, arbitrageurs such as hedge funds and proprietary trading groups—will take advantage of these opportunities until they no longer exist, that is, until the odds are in line with the axioms of probability theory.[2]

Therefore, proponents of the classical EMH argue that there are limits to the degree and persistence of behavioral biases such as inconsistent probability beliefs, as well as substantial incentives for those who can identify and exploit such occurrences. While all of us are subject to certain behavioral biases from time to time, according to EMH supporters market forces will always act to bring prices back to rational levels, implying that the impact of irrational behavior on financial markets is generally negligible and, therefore, irrelevant.

But this last conclusion relies on the assumption that market forces are powerful enough to overcome any type of behavioral bias, or, equivalently, that irrational beliefs are not so pervasive as to overwhelm the capacity of arbitrage capital dedicated to taking advantage of them. This is an empirical issue that cannot be settled theoretically, but must be tested through careful measurement and statistical analysis.

One piece of anecdotal evidence is provided by the collapse of fixed-income relative-value hedge funds in 1998 such as Long-Term Capital Management (LTCM). The default by Russia on its government debt in August 1998 triggered a global flight to quality, widening credit spreads to record levels and causing massive dislocation in fixed-income and credit markets.

During that period, bonds with virtually identical cash flows and supposedly little credit risk traded at dramatically different prices, implying extraordinary profit opportunities to those who could afford to maintain spread positions by purchasing the cheaper bonds and shorting the richer bonds, yielding a positive carry at the outset. If held to maturity, these spread positions would have generated payments and obligations that offset each other exactly, hence they were structured as near-arbitrages—just like the Dutch book example above.

But as credit spreads widened, the gap between the long and the short side increased because illiquid bonds became cheaper and liquid bonds became more expensive, causing brokers and other creditors to require holders of these spread positions to either post additional margin or liquidate a portion of their positions to restore their margin levels. These margin calls caused many hedge funds to start unwinding some of their spread positions, causing spreads to widen further, which led to more margin calls, more unwinding, and so on. This created a cascade effect that ended with the collapse of LTCM and several other notable hedge funds.

In retrospect, even the most ardent critics of LTCM and other fixed-income relative-value investors now acknowledge that their spread positions were quite rational, and that their downfall was largely due to an industrywide underappreciation of the commonality of their positions and the degree of leverage applied across the many hedge funds, investment banks, and proprietary trading groups engaged in these types of spread trades. This suggests that the forces of irrationality—investors flocking to safety and liquidity in the aftermath of the Russian default in August 1998—were stronger, at least for several months, than the forces of rationality.

This example, and many similar anecdotes of speculative bubbles, panics, manias, and market crashes—a classic reference is Kindleberger [1989]—have cast reasonable doubt on the hypothesis that an aggregate rationality will always be imposed by market forces.

So what does this imply for the EMH?

THE SOCIOLOGY OF MARKET EFFICIENCY

To see how a reconciliation between the EMH and its behavioral critics might come about, it is useful to digress to consider the potential origins of this controversy. Although there are no doubt many factors contributing to this debate, one of the most compelling explanations involves key differences in the cultural and sociological aspects of economics and psychology, which are surprisingly deep even though both fields are concerned with human behavior.

Consider, first, some of the defining characteristics of psychology (from the perspective of an economist):

- Psychology is based primarily on observation and experimentation.
- Field experiments are common.
- Empirical analysis leads to new theories.
- There are multiple theories of behavior.
- Mutual consistency among theories is not critical.

Contrast these with the comparable characteristics of economics:

- Economics is based primarily on theory and abstraction.
- Field experiments are not common.
- Theories lead to empirical analysis.
- There are few theories of behavior.
- Mutual consistency is highly prized.

Although there are of course exceptions to these generalizations, they do capture much of the spirit of the two disciplines.[3] For example, while psychologists certainly do propose abstract theories of human behavior from time to time, the vast majority of academic psychologists conduct experiments. Although experimental economics has made important inroads into the mainstream of economics and finance, the top journals still publish only a small fraction of experimental papers; the majority is more traditional theoretical and empirical studies.

And although new theories of economic behavior have been proposed from time to time, most graduate programs in economics and finance teach only one such theory: expected utility theory and rational expectations, and its corresponding extensions, e.g., portfolio optimization, the capital asset pricing model, and dynamic general equilibrium asset pricing models. It is only recently that departures from this theory are not rejected out of hand. Less than a decade ago, manuscripts describing models of financial markets with arbitrage opportunities were routinely rejected at the top economics and finance journals, in some cases without even a review.

The fact that economics is still dominated by a single model is a testament to the remarkable achievements of one person: Paul A. Samuelson. In 1947, Samuelson published his Ph.D. thesis titled *Foundations of Economic Analysis*, which might have seemed somewhat arrogant were it not for the fact that it did, indeed, become the foundations of modern economic analysis. Much of the economic literature of the time was based on somewhat informal discourse and diagrammatic exposition. Samuelson, however, developed a formal mathematical framework for economic analysis that could be applied to a number of seemingly unrelated contexts. His opening paragraph makes this intention explicit:

> *The existence of analogies between central features of various theories implies the existence of a general theory which underlies the particular theories and unifies them with respect to those central features.* This fundamental principle of generalization by abstraction was enunciated by the eminent American mathematician E.H. Moore more than thirty years ago. It is the purpose of the pages that follow to work out its implications for theoretical and applied economics [1947, p.3; italics in the original].

Samuelson then proceeded to build the infrastructure of what is now called microeconomics, which is taught as the first graduate-level course in every Ph.D. program in economics today, and along the way, made major contributions to welfare economics, general equilibrium theory, comparative static analysis, and business cycle theory.

If there is a single theme to Samuelson's thesis, it is the systematic application of scientific principles to economic analysis, much like the approach of modern physics. This was no coincidence. In Samuelson's account of the intellectual origins of his dissertation, he acknowledges:

> Perhaps most relevant of all for the genesis of *Foundations*, Edwin Bidwell Wilson (1879–1964) was at Harvard. Wilson was the great Willard Gibbs's last (and, essentially only) protégé at Yale. He was a mathematician, a mathematical physicist, a mathematical statistician, a mathematical economist, a poly-

> math who had done first-class work in many fields of the natural and social sciences. I was perhaps his only disciple… I was vaccinated early to understand that economics and physics could share the same formal mathematical theorems (Euler's theorem on homogeneous functions, Weierstrass's theorems on constrained maxima, Jacobi determinant identities underlying Le Chatelier reactions, etc.), while still not resting on the same empirical foundations and certainties [1998, p. 1,376].

In a footnote to his statement regarding the general principle of comparative static analysis, Samuelson adds:

> It may be pointed out that this is essentially the method of thermodynamics, which can be regarded as a purely deductive science based upon certain postulates (notably the First and Second Laws of Thermodynamics). [1947, p. 21].

And much of the economics and finance literature since *Foundations* has followed Samuelson's lead in attempting to deduce implications from certain postulates such as utility maximization, the absence of arbitrage, or the equalization of supply and demand. In fact, the most recent milestone in economics—rational expectations—is founded on a single postulate, around which an entire literature has developed.

This cultural bias in economics, also known as "physics envy," is, I claim, largely responsible for the controversy between EMH supporters and critics. The supporters point to the power of theoretical arguments such as expected utility theory, the principle of no arbitrage, and general equilibrium theory, while the latter point to experimental evidence to the contrary.

A case in point is the Random Walk Hypothesis, which was taken to be synonymous with the EMH prior to Leroy [1973], Rubinstein [1976], and Lucas [1978], and even several years afterward. A number of well-known empirical studies had long since established the fact that markets were weak-form efficient in Roberts's [1967] terminology, implying that past prices could not be used to forecast future price changes.[4]

And although some of these studies did find evidence against the random walk, e.g., Cowles and Jones [1937], they were largely dismissed as statistical anomalies, or not economically meaningful after accounting for transaction costs, e.g., Cowles [1960]. For example, after conducting an extensive empirical analysis of runs of U.S. stock returns from 1956 to 1962, Fama [1965, p. 80] concluded that: "there is no evidence of important dependence from either an investment or a statistical point of view."

It was in this milieu that Lo and MacKinlay [1988] reexamined the Random Walk Hypothesis, rejecting it for weekly U.S. stock returns indexes from 1962 to 1985. The surprising element of their analysis was not only that the rejections were based on fairly well-known properties of returns—ratios of variances of different holding periods—but also the strong reaction that their results provoked among some of their senior colleagues (see Lo and MacKinlay [1999, Chapter 1] for further details).

Moreover, Lo and MacKinlay [1999] observed that after the publication of their article they discovered several other studies that also rejected the Random Walk Hypothesis, and that the departures from the random walk uncovered by Larson [1960], Alexander [1961], Cootner [1962], Osborne [1962], Steiger [1964], Niederhoffer and Osborne [1966], and Schwartz and Whitcomb [1977], to name just a few examples, were largely ignored by the academic finance community.

Lo and MacKinlay provide an explanation:

> With the benefit of hindsight and a more thorough review of the literature, we have come to the conclusion that the apparent inconsistency between the broad support for the Random Walk Hypothesis and our empirical findings is largely due to the common misconception that the Random Walk Hypothesis is equivalent to the Efficient Markets Hypothesis, and the near religious devotion of economists to the latter (see Chapter 1). Once we saw that we, and our colleagues, had been trained to study the data through the filtered lenses of classical market efficiency, it became clear that the problem lay not with our empirical analysis, but with the economic implications that others incorrectly attributed to our results—unbounded profit opportunities, irrational investors, and the like [1999, p. 14].

The legendary trader and squash player Victor Niederhoffer pointed to similar forces at work in creating this apparent cultural bias in favor of the Random Walk Hypothesis in an incident that took place while he was a finance PhD student at the University of Chicago in the 1960s (Niederhoffer [1997, p. 270]):

> This theory and the attitude of its adherents found classic expression in one incident I personally observed that deserves memorialization. A team of four of the most respected graduate students in finance had joined forces with two professors, now considered venerable enough to have won or to have been considered for a Nobel prize, but at that time feisty as Hades and insecure as a kid on his first date. This elite group was studying the possible impact of volume on stock price movements, a subject I had researched. As I was coming down the steps from the library on the third floor of Haskell Hall, the main business building, I could see this Group of Six gathered together on a

> stairway landing, examining some computer output. Their voices wafted up to me, echoing off the stone walls of the building. One of the students was pointing to some output while querying the professors, "Well, what if we really do find something? We'll be up the creek. It won't be consistent with the random walk model." The younger professor replied, "Don't worry, we'll cross that bridge in the unlikely event we come to it."
>
> I could hardly believe my ears—here were six scientists openly hoping to find no departures from ignorance. I couldn't hold my tongue, and blurted out, "I sure am glad you are all keeping an open mind about your research." I could hardly refrain from grinning as I walked past them. I heard muttered imprecations in response.

To Samuelson's credit, he was well aware of the limitations of a purely deductive approach even as he wrote the *Foundations*, and in his introduction he offered warning:

> Only the smallest fraction of economic writings, theoretical and applied, has been concerned with the derivation of *operationally meaningful* theorems. In part at least this has been the result of the bad methodological preconceptions that economic laws deduced from *a priori* assumptions possessed rigor and validity independently of any empirical human behavior. But only a very few economists have gone so far as this. The majority would have been glad to enunciate meaningful theorems if any had occurred to them. In fact, the literature abounds with false generalization.
>
> We do not have to dig deep to find examples. Literally hundreds of learned papers have been written on the subject of utility. Take a little bad psychology, add a dash of bad philosophy and ethics, and liberal quantities of bad logic, and any economist can prove that the demand curve for a commodity is negatively inclined [1947, p. 3, italics in the original].

This remarkable passage seems as germane today as it was over 50 years ago when it was first written. One interpretation is that a purely deductive approach may not always be appropriate for economic analysis. As impressive as the achievements of modern physics are, physical systems are inherently simpler than economic systems; hence deduction based on a few fundamental postulates is likely to be more successful in the former than in the latter. Conservation laws, symmetry, and the isotropic nature of space are powerful ideas in physics that simply do not have exact counterparts in economics.

Alternatively, imagine the impact on the explanatory power of physical theories if relations like $F = ma$ were to vary with the business cycle, Federal Reserve policy, or changes in the U.S. tax code. Economic systems involve human interactions, which almost by definition are more complex than interactions of inanimate objects governed by fixed and known laws of motion. Because human behavior is heuristic, adaptive, and not completely predictable—at least not nearly to the same extent as physical phenomena—modeling the joint behavior of many individuals is far more challenging than modeling just one individual. Indeed, the behavior of even a single individual can be baffling at times, as we all know.

ADAPTIVE MARKETS: THE NEW SYNTHESIS

The sociological backdrop of the EMH debate suggests that an alternative to the traditional deductive approach of neoclassic economics might be necessary. One particularly promising direction is the application of evolutionary principles to financial markets as suggested by Farmer and Lo [1999] and Farmer [2002]. This approach is heavily influenced by recent advances in the emerging discipline of "evolutionary psychology," which builds on the seminal research of E.O. Wilson [1975] in applying the principles of competition, reproduction, and natural selection to social interactions, yielding surprisingly compelling explanations for certain kinds of human behavior such as altruism, fairness, kin selection, language, mate selection, religion, morality, ethics, and abstract thought (see, for example, Barkow, Cosmides, and Tooby [1992]; Pinker [1993, 1997]; Crawford and Krebs [1998]; Buss [1999]; and Gigerenzer [2000]).

"Sociobiology" is the rubric Wilson [1975] gave to these powerful ideas, which generated a considerable degree of controversy in their own right, and the same principles can be applied to economic and financial contexts. In doing so, we can fully reconcile the EMH with all its behavioral alternatives, leading to a new synthesis: the Adaptive Markets Hypothesis.

Students of the history of economic thought will recall that Thomas Malthus used biological arguments—the fact that populations increase at geometric rates while natural resources increase at only arithmetic rates—to arrive at rather dire economic consequences, and that both Darwin and Wallace were influenced by these arguments (see Hirshleifer [1977] for further details). Also, Joseph Schumpeter's [1937] views of business cycles, entrepreneurs, and capitalism have an unmistakable evolutionary flavor to them; in fact, his notions of creative destruction and bursts of entrepreneurial activity are similar in spirit to natural selection and Eldredge and Gould's [1972] notion of "punctuated equilibrium."

More recently, economists and biologists have begun to explore these connections in several veins: direct extensions of sociobiology to economics (Becker [1976]; Hirshleifer [1977]; Tullock [1979]; evolutionary game theory (Maynard Smith [1982]; Weibull [1995]); evolutionary economics (Nelson and Winter [1982]; Andersen [1994]; Englund [1994]; Luo [1999]); and economics as a complex system (Anderson, Arrow, and Pines [1988]). Hodgson [1995] provides additional examples of studies at the intersection of economics and biology, and publications like the *Journal of Evolutionary Economics* and the *Electronic Journal of Evolutionary Modeling and Economic Dynamics* now provide a home for this burgeoning literature.

Evolutionary concepts have also appeared in a number of financial contexts. Luo [1995, 1998, 2001, 2003] explores the implications of natural selection for futures markets, and Hirshleifer and Luo [2001] consider the long-run prospects of overconfident traders in a competitive securities market. The literature on agent-based modeling pioneered by Arthur et al. [1997] that simulates interactions among software agents programmed with simple heuristics, relies heavily on evolutionary dynamics.

And at least two prominent practitioners have proposed Darwinian alternatives to the EMH. In a chapter titled "The Ecology of Markets," Niederhoffer [1997, Ch. 15] likens financial markets to an ecosystem with dealers as "herbivores," speculators as "carnivores," and floor traders and distressed investors as "decomposers." And Bernstein [1998] makes a compelling case for active management by pointing out that the notion of equilibrium, which is central to the EMH, is rarely realized in practice and that market dynamics are better explained by evolutionary processes.

Clearly the time is now ripe for an evolutionary alternative to market efficiency.

To that end, we begin, as Samuelson [1947] did, with the theory of the individual consumer. Contrary to the neoclassic postulate that individuals maximize expected utility and have rational expectations, an evolutionary perspective makes considerably more modest claims, viewing individuals as organisms that have been honed, through generations of natural selection, to maximize the survival of their genetic material (see, for example, Dawkins [1976]).

While such a reductionist approach might degenerate into useless generalities, e.g., the molecular biology of economic behavior, there are valuable insights to be gained from a broader biological perspective. Specifically, this perspective implies that behavior is not necessarily intrinsic and exogenous, but evolves by natural selection and depends on the particular environment through which selection occurs. That is, natural selection operates not only upon genetic material, but also upon social and cultural norms in *Homo sapiens*, hence Wilson's term, "sociobiology."

To operationalize this perspective within an economic context, consider the idea of *bounded rationality* first espoused by Nobel Prize winning economist Herbert Simon. Simon [1955] suggests that individuals are hardly capable of the kind of optimization that neoclassic economics calls for in the standard theory of consumer choice. Instead, he argues that because optimization is costly and humans are naturally limited in their computational abilities, they engage in something he calls "satisficing," an alternative to optimization in which individuals make choices that are merely satisfactory, not necessarily optimal. In other words, individuals are bounded in their degree of rationality, which is in sharp contrast to the current orthodoxy—rational expectations—where individuals have unbounded rationality (the term *hyperrational expectations* might be more descriptive).

Unfortunately, although this idea garnered a Nobel Prize for Simon, it had relatively little impact on the economics profession at the time. Apart from the sociological factors discussed above, Simon's framework was commonly dismissed because of one specific criticism: What determines the point at which an individual stops optimizing and reaches a satisfactory solution? If such a point is determined by the usual cost/benefit calculation underlying much of microeconomics (i.e., optimize until the marginal benefits of the optimum equal the marginal cost of getting there), this assumes the optimal solution is known, which would eliminate the need for satisficing. As a result, the idea of bounded rationality fell by the wayside, and rational expectations has become the *de facto* standard for modeling economic behavior under uncertainty.[5]

An evolutionary perspective provides the missing ingredient in Simon's framework. The proper response to the question of how individuals determine the point at which their optimizing behavior is satisfactory is this: Such points are determined not analytically, but through trial and error and, of course, natural selection. Individuals make choices based on past experience and their best guess as to what might be optimal, and they learn by receiving positive or negative reinforcement from the outcomes. If they receive no such reinforcement, they do not learn. In this fashion, individuals develop heuristics to solve various economic challenges, and as long as those challenges remain stable, the heuristics will eventually adapt to yield approximately optimal solutions to them.

If, on the other hand, the environment changes, it should come as no surprise that the heuristics of the old environment are not necessarily well suited to the new. In such cases, we observe "behavioral biases"—actions that are apparently ill advised in the context in which we observe them. But rather than labeling such behavior irrational, we should recognize that suboptimal behavior is not unlikely when we take heuristics out of their evolutionary context. A more accurate term for such behavior might be "maladaptive." The flopping of a fish on dry land may seem strange and unproductive, but underwater, the same motions are capable of propelling the fish away from its predators.

By coupling Simon's notion of bounded rationality and satisficing with evolutionary dynamics, many other aspects of economic behavior can also be derived. Competition, cooperation, market-making behavior, general equilibrium, and disequilibrium dynamics are all adaptations designed to address certain environmental challenges for the human species, and by viewing them through the lens of evolutionary biology, we can better understand the apparent contradictions between the EMH and the presence and persistence of behavioral biases.

Specifically, the Adaptive Markets Hypothesis can be viewed as a new version of the EMH, derived from evolutionary principles. Prices reflect as much information as dictated by the combination of environmental conditions and the number and nature of "species" in the economy or, to use a more appropriate biological term, the *ecology*.

By *species*, I mean distinct groups of market participants, each behaving in a common manner. For example, pension funds may be considered one species; retail investors another; market makers a third; and hedge fund managers a fourth.

If multiple species (or the members of a single highly populous species) are competing for rather scarce resources within a single market, that market is likely to be highly efficient, e.g., the market for 10-year U.S. Treasury notes, where most relevant information is incorporated into prices within minutes. If, on the other hand, a small number of species are competing for rather abundant resources in a given market, that market will be less efficient, e.g., the market for oil paintings from the Italian Renaissance. Market efficiency cannot be evaluated in a vacuum, but is highly context-dependent and dynamic, just as insect populations advance and decline as a function of the seasons, the number of predators and prey they face, and their abilities to adapt to an ever-changing environment.

The profit opportunities in any given market are akin to the amount of food and water in a particular local ecology—the more resources present, the less fierce the competition. As competition increases, either because of dwindling food supplies or an increase in the animal population, resources are depleted, which in turn causes a population decline, eventually reducing the level of competition and starting the cycle again. In some cases cycles converge to corner solutions; i.e., certain species become extinct, food sources are permanently exhausted, or environmental conditions shift dramatically. By viewing economic profits as the ultimate food source on which market participants depend for their survival, the dynamics of market interactions and financial innovation can be readily derived.

Under the AMH, behavioral biases abound. The origins of such biases are heuristics that are adapted to non-financial contexts, and their impact is determined by the size of the population with such biases versus the size of competing populations with more effective heuristics.

During the fall of 1998, the desire for liquidity and safety by a certain population of investors overwhelmed the population of hedge funds attempting to arbitrage such preferences, causing those arbitrage relations to break down. In the years prior to August 1998, however, fixed-income relative-value traders profited handsomely from these activities, presumably at the expense of individuals with seemingly irrational preferences (in fact, such preferences were shaped by a certain set of evolutionary forces, and might have been quite rational in other contexts).

Therefore, under the AMH, investment strategies undergo cycles of profitability and loss in response to changing business conditions, the number of competitors entering and exiting the industry, and the type and magnitude of profit opportunities available. As opportunities shift, so too will the affected populations. For example, after 1998, the number of fixed-income relative-value hedge funds declined dramatically—because of outright failures, investor redemptions, and fewer startups in this sector—but many have reappeared in recent years as the performance of this type of investment strategy has improved.

Even fear and greed—the two most common culprits in the downfall of rational thinking, according to most behavioralists—are the product of evolutionary forces, adaptive traits that enhance the probability of survival. Recent research in the cognitive neurosciences and economics suggests an important link between rationality in decision-making and emotion (Grossberg and Gutowski [1987]; Damasio [1994]; Elster [1998]; Lo [1999]; Loewenstein [2000]; Peters and Slovic [2000]; and Lo and Repin [2002]), implying that the two are not antithetical, but in fact complementary.

For example, contrary to the common belief that emotions have no place in rational financial decision-making processes, Lo and Repin [2002] present preliminary evidence that physiological variables associated with the autonomic nervous system are highly correlated with market events even for highly experienced professional securities traders. They argue that emotional responses are a significant factor in the real-time processing of financial risks, and that an important component of a professional trader's skills lies in his or her ability to channel emotion, consciously or unconsciously, in specific ways during certain market conditions.

This argument often surprises economists because of the ostensible link between emotion and behavioral biases, but a more sophisticated view of the role of emotions in human cognition shows that they are central to rationality (see, for example, Damasio [1994] and Rolls [1990, 1994, 1999]). In particular, emotions are the basis for a reward and punishment system that facilitates the selection of advantageous behavior, providing a numeraire for animals to engage in a "cost-benefit analysis" of the various actions open to them (Rolls [1999, Chapter 10.3]). From an evolutionary perspective, emotion is a powerful adaptation that dramatically improves how efficiently animals learn from their environments and their pasts.[6]

These evolutionary underpinnings are more than simple speculation in the context of financial market participants. The extraordinary degree of competitiveness of global financial markets and the outsize rewards that accrue to the "fittest" traders suggest that Darwinian selection—"survival of the richest," to be precise—is at work in determining the typical profile of the successful trader. After all, unsuccessful traders are eventually eliminated from the population after suffering a certain level of losses.

The AMH is still under development, and certainly requires much more research to render it "operationally meaningful" in Samuelson's sense. Even at this early stage, though, it seems clear that an evolutionary framework is able to reconcile many of the apparent contradictions between efficient markets and behavioral exceptions. The former may be viewed as the steady-state limit of a population with constant environmental conditions, and the latter involves specific adaptations of certain groups that may or may not persist, depending on the particular evolutionary paths that the economy experiences.

More specific implications may be derived through a combination of deductive and inductive inferences—for example, theoretical analysis of evolutionary dynamics, empirical analysis of evolutionary forces in financial markets, and experimental analysis of decision-making at the individual and group level—and are currently under investigation.

PRACTICAL IMPLICATIONS

Despite the rather abstract and qualitative nature of the AMH presented above, a number of surprisingly concrete implications can be derived.

The first implication is that, to the extent that there is a relation between risk and reward, it is unlikely to be stable over time. Such a relation is determined by the relative sizes and preferences of various populations in the market ecology, as well as institutional aspects such as the regulatory environment and tax laws. As these factors shift over time, any risk/reward relation is likely to be affected.

A corollary of this implication is that the equity risk premium is also time-varying and path-dependent. This is not so revolutionary an idea as it might first appear—even in the context of a rational expectations equilibrium model, if risk preferences change over time, then the equity risk premium must vary too.

The incremental insight of the AMH is that aggregate risk preferences are not universal constants, but are shaped by the forces of natural selection. For example, until recently, U.S. markets were populated by a significant group of investors who have never experienced a genuine bear market—this fact has undoubtedly shaped the aggregate risk preferences of the U.S. economy, just as the experience of the last four years, since the bursting of the technology bubble has affected the risk preferences of the current population of investors. In this context, natural selection determines who participates in market interactions; those investors who experienced substantial losses in the technology bubble are more likely to have exited the market, leaving a different population of investors today than four years ago.

Through the forces of natural selection, history matters. Irrespective of whether prices fully reflect all available information, the particular path that market prices have taken over the past few years influences current aggregate risk preferences.

Among the three Ps of Total Investment Management, *preferences* is clearly the most fundamental and least understood. Several large bodies of research have developed around these issues—in economics and finance, psychology, operations research (also called decision sciences) and, more recently, brain and cognitive sciences—and many new insights are likely to flow from synthesizing these different strands of research into a more complete understanding of how individuals make decisions. Simon's [1982] seminal contributions to this literature are still remarkably timely and their implications have yet to be fully explored.[7]

A second implication is that, contrary to the classical EMH, arbitrage opportunities do arise from time to time in the AMH. As Grossman and Stiglitz [1980] observe, without such opportunities, there will be no incentive to gather information, and the price discovery aspect of financial markets will collapse.

From an evolutionary perspective, the very existence of active liquid financial markets implies that profit opportunities must be present. As they are exploited, they disappear. But new opportunities are also constantly being created as certain species die out, as others are born, and as institutions and business conditions change.

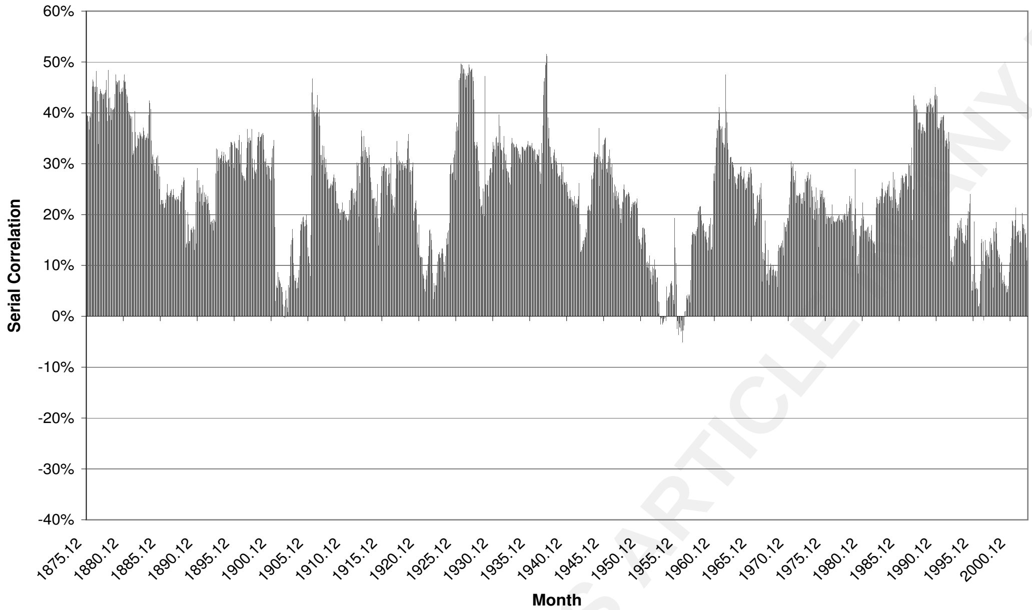
Rather than the inexorable trend toward higher efficiency predicted by the EMH, the AMH implies considerably more complex market dynamics, with cycles as well as trends, and panics, manias, bubbles, crashes, and other phenomena that are routinely witnessed in natural market ecologies. These dynamics provide the motivation for active management as Bernstein [1998] suggests, and give rise to Niederhoffer's [1997] "carnivores" and "decomposers."

A third implication is that investment strategies will also wax and wane, performing well in certain environments and performing poorly in other environments. Contrary to the classical EMH in which arbitrage opportunities are competed away, eventually eliminating the profitability of the strategy designed to exploit the arbitrage, the AMH implies that such strategies may decline for a time, and then return to profitability when environmental conditions become more conducive to such trades.

An obvious example is risk arbitrage, which has been unprofitable for several years because of the decline in investment banking activity since 2001. As M&A activity begins

EXHIBIT

Rolling 60-Month First-Order Autocorrelation Coefficient $\hat{\rho}_1$ of Monthly S&P Composite Returns— January 1987–April 2003



Data source: Robert J. Shiller, available at http://www.econ.yale.edu/~shiller/.

to pick up again, however, risk arbitrage will start to regain its popularity among both investors and portfolio managers, as it has just this year.

A more striking example can be found by computing the rolling first-order autocorrelation $\hat{\rho}_1$ of monthly returns of the S&P composite index from January 1871 through April 2003 (see the Exhibit). As a measure of market efficiency, $\hat{\rho}_1$ might be expected to take on larger values during the early part of the sample and become progressively smaller during recent years as the U.S. equity market becomes more efficient. (Recall that the random walk hypothesis implies that returns are serially uncorrelated, hence $\hat{\rho}_1$ should be 0 in theory).

It is apparent from the Exhibit, however, that the degree of efficiency—as measured by the first-order autocorrelation—varies through time in a cyclical fashion, and there are periods in the 1950s when the market is more efficient than in the early 1990s.

Such cycles are not ruled out by the EMH in theory, but in practice none of its empirical implementations has incorporated these dynamics, assuming instead that the world is stationary and markets are perpetually in equilibrium. This widening gulf between the stationary EMH and obvious shifts in market conditions no doubt contributed to Bernstein's [2003] recent critique of the policy portfolio in strategic asset allocation models and his controversial proposal to reconsider the case for tactical asset allocation.

A fourth implication is that innovation is the key to survival. The classic EMH suggests that certain levels of expected returns can be achieved simply by bearing a sufficient degree of risk. The AMH implies that because the risk/reward relation varies through time, a better way to achieve a consistent level of expected returns is to adapt to changing market conditions. By evolving a multiplicity of capabilities that are suited to a variety of environmental conditions, investment managers are less likely to become extinct as a result of rapid changes in business conditions. Consider the current theory of the demise of the dinosaurs, and ask where the next financial killer asteroid might come from (see Alvarez [1997]).

Finally, the AMH has a clear implication for all financial market participants. Survival is the only objective that matters. While profit maximization, utility maximization, and general equilibrium are certainly relevant aspects of market ecology, the organizing principle in determining the evolution of markets and financial technology is simply *survival*.

There are many other practical insights and potential breakthroughs that can be derived from the AMH as we shift our mode of thinking in financial economics from the physical to the biological sciences. Although evolutionary ideas are not yet part of the financial mainstream, my hope is that they will become more commonplace as they demonstrate their worth—ideas are also subject to survival of the fittest.

No one has illustrated this principle so well as Harry

Markowitz, the father of modern portfolio theory and a Nobel laureate in economics in 1990. In describing his experience as a Ph.D. student on the eve of his graduation, he wrote in his Nobel address:

> When I defended my dissertation as a student in the Economics Department of the University of Chicago, Professor Milton Friedman argued that portfolio theory was not Economics, and that they could not award me a Ph.D. degree in Economics for a dissertation which was not Economics. I assume that he was only half serious, since they did award me the degree without long debate. As to the merits of his arguments, at this point I am quite willing to concede: at the time I defended my dissertation, portfolio theory was not part of Economics. But now it is [1991, p. 476].

Perhaps over the next 30 years, *The Journal of Portfolio Management* will also bear witness to the relevance of the Adaptive Markets Hypothesis for financial markets and economics.

ENDNOTES

The author thanks Stephanie Hogue, Dmitry Repin, and Svetlana Sussman for helpful comments and discussion. Research support from the MIT Laboratory for Financial Engineering is gratefully acknowledged.

[1]Parts of this article include ideas and exposition from my published research. Where appropriate, I have modified passages to suit the current context without detailed citations and quotation marks so as to preserve continuity. Readers interested in the original sources may consult Lo [1997, 1999, 2002], Lo and MacKinlay [1999], and Lo and Repin [2002].

[2]Only when these axioms are satisfied is arbitrage ruled out. This was conjectured by Ramsey [1926] and proved rigorously by de Finetti [1937] and Savage [1954].

[3]For a less impressionistic and more detailed comparison of psychology and economics, see Rabin [1998, 2002].

[4]See, for example, Kendall [1953], Osborne [1959, 1962], Roberts [1959, 1967], Cowles [1960], Larson [1960], Working [1960], Alexander [1961, 1964], Granger and Morgenstern [1963], Mandelbrot [1963], Fama [1965], Fama and Blume [1966], and Cowles and Jones [1937].

[5]Simon's work is now receiving greater attention, thanks in part to the growing behavioral literature in economics and finance. See, for example, Simon [1982], Sargent [1993], Rubinstein [1998], Gigerenzer et al. [1999], Gigerenzer and Selten [2001], and Earl [2002].

[6]This important insight was forcefully illustrated by Damasio [1994] in his description of one of his patients, code-named Elliot, who underwent surgery to remove a brain tumor. Along with the tumor, part of his frontal lobe had to be removed as well, and after he recovered from the surgery, it was discovered that Elliot no longer possessed the ability to experience emotions of any kind. This absence of emotional response had a surprisingly profound effect on his day-to-day activities, as Damasio [1994, p. 36] describes:

> When the job called for interrupting an activity and turning to another, he might persist nonetheless, seemingly losing sight of his main goal. Or he might interrupt the activity he had engaged, to turn to something he found more captivating at that particular moment…. The flow of work was stopped. One might say that the particular step of the task at which Elliot balked was actually being carried out too well, and at the expense of the overall purpose. One might say that Elliot had become irrational concerning the larger frame of behavior.

Apparently, Elliot's inability to feel—his lack of emotional response—rendered him irrational from society's perspective.

[7] More recent research on preferences include Kahneman, Slovic, and Tversky [1982], Hogarth and Reder [1986], Gigerenzer and Murray [1987], Dawes [1988], Fishburn [1988], Keeney and Raiffa [1993], Plous [1993], Sargent [1993], Thaler [1993], Damasio [1994], Arrow et al. [1996], Laibson [1997], Picard [1997], Pinker [1997], and Rubinstein [1998]. Starmer [2000] provides an excellent review of this literature.

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