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Frontiers of Finance

Shift Happens

On a New Paradigm of the Markets as a Complex Adaptive System

Introduction

The tension in the air is as palpable as a high-stakes prize fight. In one corner, the finance professors—the proponents of stock market efficiency—argue that investors cannot outperform the market over time. In the opposing corner, the practitioners maintain that the market's gyrations defy the ivory tower logic of academia.

The battle armor for the professors: rational agents, random walk, and the efficient market hypothesis. Their "proof" includes the general failure of the chartists and the fact that most money managers cannot consistently outpace the market.

The weapons of the practitioners include the reality that some money managers do outperform the market over time, that investors often act "irrationally," and that the market can often be described in anthropomorphic terms—jubilant, downtrodden, excited, jittery.

Which is the truth? The answer is that both models are right and both are wrong. Indeed, capital markets display some of the characteristics of both market efficiency and "inefficiency": a lack of predictability and rapid information assimilation coexist with sudden shifts in prices and "group think." These characteristics are part and parcel of a newly articulated phenomenon—called a "complex adaptive system." Indeed, we believe that capital markets can best be understood as complex adaptive systems. The rest of this paper is dedicated to developing this assertion.

While the notion of capital markets as a complex adaptive system may be relatively new—even to studied finance professors—we believe this framework will be the accepted paradigm for describing capital markets within the next decade, superseding the current dogma. Shift happens.

Paradigm Shifts

Before delving into the heart of the case, it is worth outlining a backdrop for so-called "paradigm shifts." Thomas Kuhn laid out the best-known framework for this analysis in his seminal book, *The Structure of Scientific Revolutions* (1962). Kuhn's process allows us to break down the evolution of ideas into four parts. (See Table 1.) First, a theory is laid out to explain a phenomenon. Second, scientists start to "test" the theory by collecting empirical data. In the process, they find certain facts that run counter to the prevailing theory. Third, scientists—especially those that have a personal stake in the prevailing theory—"stretch" the old theory to accommodate the new findings, often choosing to dismiss or discount certain data. Finally, a new theory emerges that overtakes the old, offering better fidelity to the facts and greater predictive power.

Table 1
The Evolution of Ideas

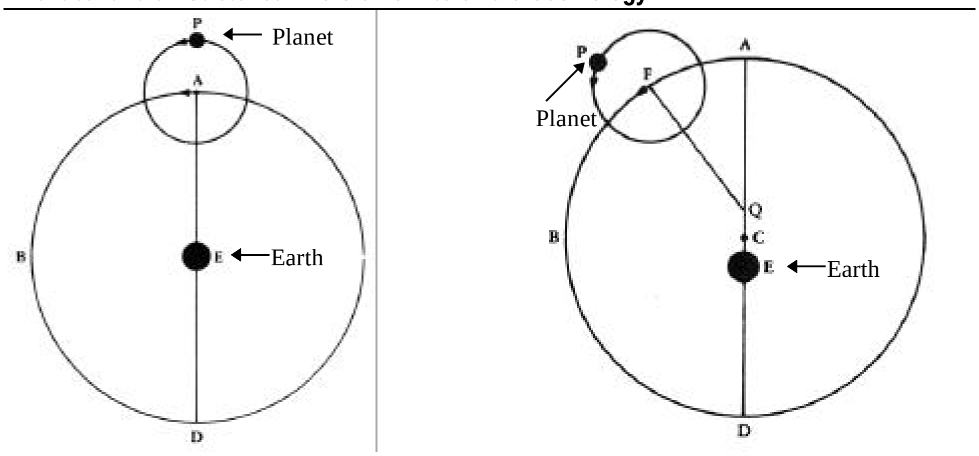
I	A theory is laid out in order to explain a phenomenon
II	Scientists test the theory and find facts that counter it
III	The original theory is "stretched" to accommodate new findings
IV	A new theory supersedes the old theory

A simple illustration of a paradigm shift comes from the evolution of human understanding of the celestial/terrestrial world. (See Table 2.) Aristotle posited that the universe was geocentric and that the celestial world was "perfect." The main implication was that orbits around the Earth were circles. As the learned men of the day studied planetary motion, they discovered that orbits were not exactly circular, but rather elliptical. Ptolemy, who lived roughly 500 years after Aristotle, documented these elliptical orbits, but rather than suggest celestial imperfection he created a system of circles-upon-circles. However, to accommodate his empirical findings, Ptolemy had to "stretch" his theory with slight modifications. (See Figure 1.) Finally, over 1,000 years later Copernicus, Kepler and Galileo, among others, introduced the heliocentric universe and put to rest celestial perfection, ushering in a new paradigm.[1]

Table 2
The Evolution of Ideas– Celestial/Terrestrial Changes

I	Theory laid out	Aristotle (~340 BC) proposes a geocentric universe with celestial perfec- the orbits of the planets and the sun are perfect circles
II	Theory tested	Astronomers observed that orbits are elliptical, not circular
III	Theory stretched	Ptolemy (~140 AD) introduces circles-upon-circles, hence accommodating elliptical observations but preserving celestial perfection
IV	New theory	Copernicus (~1543), Kepler (~1610) and Galileo (~1600) introduced a heliocentric universe, elliptical orbits and celestial imperfection, respec-

Figure 1
The Ideal and a "Stretched" Version of Ptolemaic Cosmology



Source: Ptolemy's *Altamost.*

Correspondence

With this process in mind, how do we know whether or not to take a new scientific theory seriously? Bernstein (1994) suggests a test he calls "correspondence," a term borrowed from physicist Niels Bohr. Correspondence has two parts. First, a new idea must explain why the old theory worked, while furthering the understanding of the phenomenon being studied. Second, the new theory should add some predictive value.

A ready example is the melding of classical, Newtonian physics with quantum theory. For centuries scientists used Newtonian physics—powerful as a result of its deterministic focus—to explain why an apple falls or planets orbit. However, despite the best efforts of scientists, classical physics offered an incomplete understanding of electrons. On the other hand, quantum theory, while not very helpful in everyday life, explains the counterintuitive notion that electrons can be understood both as waves *and* as particles. The classical model is a good first approximation

[1] See Appendix A for more details.

of reality, but the new model extends comprehension without undermining what is "known."

Our game plan is now clear. First, we will review the basics of the "old" view—capital market theory. Then, we will see whether or not the empirical studies of capital market behavior are completely consistent with this theory. In particular, we will search for evidence of "theory-stretch." Next, we will introduce the new paradigm—the world of complex adaptive systems—defining terms such as self-organized criticality and nonlinearity. Our goal is to judge whether or not these new models can better explain capital markets behavior—satisfying the practitioners—while showing why the old theory worked reasonably well—appeasing the ivory-tower types. Said differently, we will test the theory for correspondence. Finally, we will consider the *practical* implications for investors.

Classical Capital Market Theory

We develop the basics of capital market theory by exploring a few of its key principles. These issues cannot, however, be addressed without some comment on the foundation of most economic theory, including financial economics.

The bulk of economics is based on equilibrium systems: for example, a balance between supply and demand, risk and reward, price and quantity. Articulated by Alfred Marshall in the 1890s, this view stems from the idea that economics is a science akin to Newtonian physics, with an identifiable link between cause and effect and implied predictability. When the equilibrium system is hit by an exogenous shock, it absorbs the shock and returns to an equilibrium state.

This equilibrium perspective has associated irony and a significant practical implication. The irony is that the convenient, predictable science that economists hold as an ideal—nineteenth century physics—has been undermined by advances such as quantum theory, where indeterminacy is intrinsic. The equilibrium science that economists have mimicked has evolved; economics, by and large, has not.

The major implication is that many of the statistical tools used to understand capital market behavior can only be applied if equilibrium theory holds (Fama, 1963). If this theory does not describe reality, many of the conclusions drawn by financial economists may be misleading.

These observations are not meant to be an indictment of the founding fathers of modern finance. Indeed, their contributions have advanced our knowledge of markets by leaps and bounds. Rather, we urge both academics and practitioners to use equilibrium-based models with caution. Linear models may have important simplifying assumptions that do not jibe well with how the world actually works.

Theory Laid Out

Capital market theory, largely developed over the past 50 years, rests on a few key points. These include efficient markets, random walk, and rational agents. Our outline relies heavily on the structure laid out by Peters (1991). We will consider each element in turn, and outline its contribution to the theory:

- *Stock market efficiency* suggests that prices reflect all relevant information when that information is cheap and widely disseminated (a reasonable description of the U.S. stock market). As such, purchasing stocks is a zero net present value proposition; you will be compensated for the risk that you assume but no more, over time. Market efficiency does not say that stock prices are always "correct," but it does say that stock prices are not systematically mispriced. Market efficiency does not require the assumption of random walk—although it generally does—but a random walk does imply market efficiency.

- *Random walk*. A theory developed by Bachelier (1900) and Osborne (1964) and supported empirically by Kendall (1953), random walk suggests that security price changes are independent of one another. The premise is that since capital markets are comprised of lots of agents, current prices will reflect the information that is collectively known. Accordingly, changes in prices would come only from unexpected information that is, by definition, random. Random walk is an important assumption because it implies that the probability distribution of returns will be normal or near normal.

- *Rational agents* is an assumption that investors can assess and optimize risk/reward opportunities. Markowitz (1952), inspired by the work of John Burr Williams (1938), took an important step by linking the potential returns of a portfolio to its riskiness, as measured by the variance of returns. His theory explained that risk-adverse investors would "rationally" seek the highest return for a given level of risk. This idea is formally know as mean/variance efficiency. This model served as the basis of the Capital Asset Pricing Model (CAPM), developed simultaneously by Sharpe (1964) and Lintner (1965) and later modified by Black (1972). CAPM suggests a linear relationship between risk and return. This framework of investor behavior is based on equilibrium economics, a linear measure (beta), and rational agents. Importantly, the work of Markowitz and the CAPM also rely on the assumption of normally distributed returns, with finite variance.[2]

These key principles of capital markets theory have two important underlying assumptions and one significant predicted outcome. The first premise is that stock price returns can be treated as independent, identically distributed random variables, unleashing the use of traditional probability calculus—a powerful tool. The second assumption is that of rational agents—either on an individual or a collective basis. A predicted outcome of capital markets theory is modest trading activity and limited price fluctuations. These assumptions and anticipated outcomes should be matched against the empirical evidence to see if they fit.

Theory Tested

Testing started on most capital market theories as soon as the ink dried on the original research. However, there is an inherent difficulty in testing economic theory. Economists, unlike some other scientists, have no laboratory; their theories can only be evaluated on how they describe events of the past and how well they predict events in the future. Further, the amount of quality data is limited. For example, the Center for Research in Security Prices (CRSP) database—the primary source of detailed information on stocks and the stock market—goes back less than 80 years.

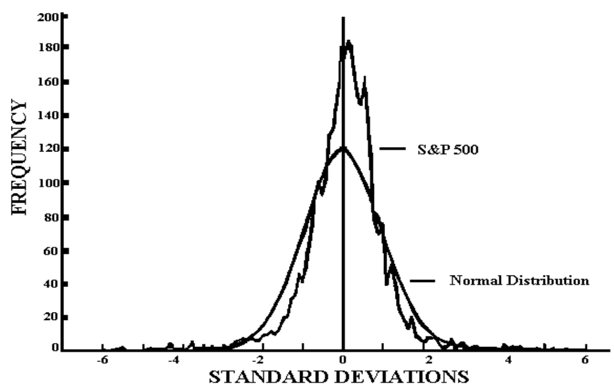
Of course, the difficulty of performing rigorous analysis has not prevented a steady flow of theories on how to "beat the market." As any practitioner will attest, most of these theories have little merit. Our goal here is not to consider these theories,

[2] The normal, or Gaussian, distribution is of great importance in science because of the powerful Central Limit Theorem (CLT). The CLT states that given a set of independent random variables with a given mean value and finite variance, the distribution is bell shaped, or normal. The CLT tells us it is safe to assume that any physical measurement that represents a series of independent variables is going to be normally distributed about its mean.

but rather to evaluate those tenets that serve as the bedrock of finance theory. We find that five of these significantly fall short:

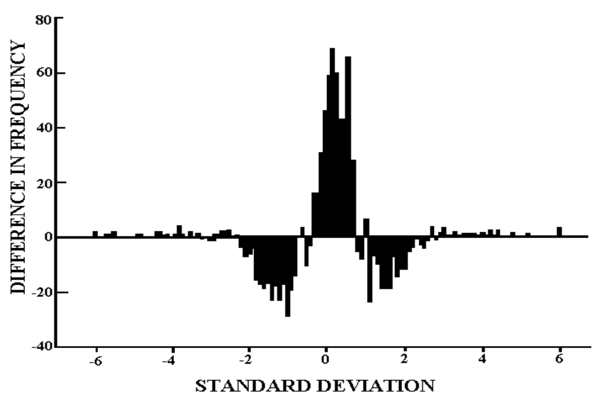
- *Stock market returns are not normal,* as capital market theory suggests. Rather, return distributions exhibit high kurtosis; the tails are fatter and the mean is higher than what is predicted by a normal distribution. In ordinary language this means that periods of relatively modest change are interspersed with higher-than-predicted changes (i.e., booms and crashes).[3] Figures 2 and 3 illustrates the point graphically. Non-normal distributions undermine the random walk and weaken the strength of the statistical tools available to evaluate market behavior.

Figure 2
Frequency Distribution of S&P 500 (January 1928–December 1989)
Five-Day Returns: Normal versus Actual



Source: *Chaos and Order in the Capital Markets*, Edgar Peters, 1991. Reprinted by permission of John Wiley & Sons, Inc.

Figure 3
Frequency Difference: Normal versus Actual Five-Day Returns



Source: *Chaos and Order in the Capital Markets*, Edgar Peters, 1991. Reprinted by permission of John Wiley & Sons, Inc.

[3] Biologists will see a parallel between these observations and the theory of punctuated equilibrium. The theory of punctuated equilibrium was articulated in 1972 by Stephen Jay Gould and Niles Eldridge. The basic case is that evolutionary changes are not gradual, but rather jerky. Long periods of statis are interrupted by abrupt and dramatic periods of change.

- *The random walk assertion is not supported by the data.* Campbell, Lo, and MacKinley (1997), after applying a battery of empirical tests, recently concluded that "financial asset returns are predictable to some degree." Furthermore, Peters—building on the work of Mandelbrot—suggests that there is a long memory component in capital markets. That is, return series are often both persistent and trend-reinforced. Non-normal returns and a lack of empirical support call into question the random walk assumption.[4]

- *Trading volume is higher and price changes greater than predicted.* Standard economic theory predicts low trading volume and limited price volatility. In reality, trading volume is active and—as indicated above—price changes come in greater size than the theory predicts (Shiller, 1981). The most obvious evidence of the latter point is the stock market crash of October 19, 1987, a day when the S&P 500 retreated 22.6%. Defending traditional capital market theory in the wake of the crash requires liberal interpretation of the widely taught creed.

- *Risk and reward are not linearly related via variance.* Fama and French (1992) provide a good summary of the empirical tests of CAPM as well as a detailed analysis for the 1963-1990 period. They conclude, simply: "Our tests do not support the most basic prediction of the SLB [Sharpe-Lintner-Black] model, that average returns are positively related to the market's." They did find that two factors—firm size and market-to-book value—explained returns during the measured period. However, Fama and French maintained a "rational asset-pricing framework," which means that they identified the factors associated with various returns and *assumed* that those returns were attributable to risk. While consistent with the theory that rational agents seek to maximize returns given risk, their conclusions are undermined if those same agents cannot, or do not, optimize the risk/reward trade-off.

- *Investors are not rational.* The case here rests on two points. The first is the growing body of evidence from decision-making theorists showing that humans make systematic judgment errors (Bazerman, 1986; Thaler, 1992). One of the best-documented illustrations is Prospect Theory, developed by Kahneman and Tversky, which shows that individual risk preferences are profoundly influenced by how information is presented. The second point, subtle yet central, is that humans generally operate using *inductive*, not deductive, processes to make economic decisions. As no individual has access to all information, judgments must be based on what that person "knows" as well as what that person *believes others to believe*. Such decisions are often generated using rules of thumb and suggest a fundamental indeterminacy in economics (Arthur, 1995). Asset prices are a good proxy for aggregate expectations. However, if enough agents adopt decision rules based on price activity—generated either consciously or randomly—the resulting price trend can be self-reinforcing.

Theory Stretched

A point that Kuhn makes forcefully is that scientists are slow to adopt new theories. It is understandably difficult for anyone to rapidly devalue a theory in which they have "invested" substantial resources. This is because of both the economic consequences of admitting relative ignorance and the emotional stress of acknow-

[4] However, it does not follow that technical analysis, at least how it is generally practiced, is valuable. Detecting the difference between a random series and a series with a persistent trend is nearly impossible with a simple stock price chart.

edging sunk costs as irrelevant. The natural reaction, then, is to modify the current theory as best as possible in order to accommodate reality. However, defenders of the faith can only put so many proverbial fingers in the dam. Eventually, the water gushes forth and the challenging theory gains widespread acceptance.

Here we review some of the reactions, and lack of reaction, to the evidence offered in the previous section:

- *Non-normal distributions*. Numerous studies of security returns have unveiled higher-than-expected means and fat tails—characteristics inconsistent with a normal distribution. However, most economists have been reticent to abandon the normal distribution assumption because it would invalidate the use of traditional probability calculus. Mandelbrot (1963) offers that capital market returns follow a stable Paretian[5] distribution, which exhibits the attributes empirically observed in markets. Cootner (1964), in his critique of Mandelbrot's article, noted that most statistical tools would be rendered "obsolete" and past econometric work "meaningless" if Mandelbrot were right. While willing to further explore Mandelbrot's theory, Cootner called for more evidence of its validity before "consigning centuries of work to the ash pile."

- *Noise traders.* Given that efficient markets and rational agents would lead to minimal trading volume, the theory of "noise" and "noise traders" was developed to explain the levels of real-life trading activity. Black (1986) described noise trading as "trading on noise as if it were information" even though "from an objective point they [noise traders] would be better off not trading." He notes that noise traders may be active because "they like to trade." Most striking about Black's paper is the introductory commentary. He writes that: "[noise theories] were all derived originally as a part of a broad effort to apply the logic behind the capital asset pricing model to . . . behavior that does not fit conventional notions of optimization." Admitted theory stretching.

- *Stock market crashes*. While price fluctuations are consistent with a random walk, the frequency and magnitude of such changes are greater than what is predicted by theory. The academic reaction to the October 1987 crash—the greatest single-day price change to occur since the academic theories were formalized—is revealing. When asked about the 1987 crash in a recent interview (Tanous, 1997), Eugene Fama, one of the fathers of efficient market theory, responded: "I think the crash in '87 was a mistake." Miller (1991), after enumerating some potential rational economic causes for the crash, recommends reading Mandelbrot—precisely the individual who argued that traditional capital market theory was conceptually flawed.

- *Rational agents and the world of behavior finance*. The broadest reaction to the behaviorists—those that argue that agent rationality should not be assumed in economics—is dismissal. The reasoning for this hand-wave generally comes in one of two varieties (DeBondt and Thaler, 1994). The first is that a collection of agents—with errors canceling out—creates a market similar to one in which agents are rational. This "as if" argument, generally attributed to Milton Friedman, appears reasonable under many circumstances but fails to explain certain anomalies,

[5] A stable Paretian, or Pareto-Levy, distribution has an undefined variance, unlike a normal distribution. The properties of these distributions were described by Levy in the 1920s based on the work of Pareto. Pareto found that the distribution of income was normal, except for the upper 3%, resulting in a fat tail. As in many cases of fat tails, it was discovered that feedback mechanisms caused these distribution outliers.

including the crash of 1987. The second argument is that introducing investor irrationally dilutes the theory. For example, Miller (1986) suggests that behavior finance is "*too* interesting and thereby distracts us from the pervasive market forces that should be our principal concern."

The established theory has significantly advanced our understanding of capital markets, but is approaching the limit of its usefulness. The introduction of a new theory, along with the requisite computational power to model it, may usher in a new era of understanding of capital market behavior.

The New Theory: Complex Adaptive Systems

Now we lay out the challenging theory: capital markets as complex adaptive systems. This model is more consistent with what is known in other sciences, such as physics and biology, and appears to be more descriptive of actual capital markets activity.

This section is broken into three parts. First, we provide a description of complex adaptive systems, identifying key properties and attributes. Next, we compare the results predicted by the new theory to actual market behavior. Finally, we check for correspondence.

Complex Adaptive Systems: A Definition

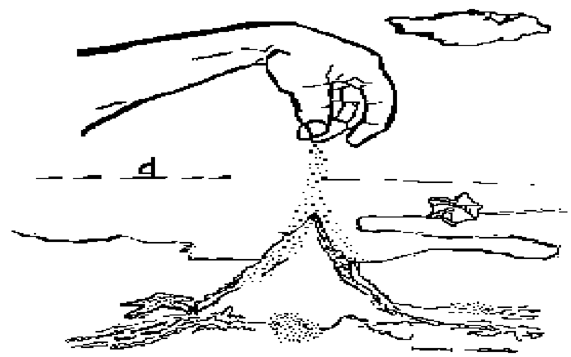
Put two people in a room and ask them to trade a commodity, and the result will not be particularly fascinating. Add a few more people to the room and the activity may pick up, but the interactions remain relatively uninteresting. The system is too static, too lifeless, to reflect what we see in the capital markets.

As more agents are added to the system, however, something remarkable happens: it transitions into a so-called "complex adaptive system," replete with new, life-like characteristics. In a tangible way, the system becomes more complex than the pieces that comprise it. Importantly, this transition—often called "self-organized criticality"—occurs *without design or help* from any outside agent. Rather, it is a direct function of the dynamic interactions among the agents in the system (Bak, 1996).[6]

Bak illustrates self-organized criticality with a sand pile. (See Figure 4.) Start to sprinkle sand on a flat surface and the grains settle pretty much where they fall; the process can be modeled with classical physics. After a modest pile is created the action picks up, with small sand slides. Once the pile is of sufficient size, the system becomes "out of balance," and little disturbances can cause full-fledged avalanches. These large changes cannot be understood by studying the individual grains. Rather, the system itself gains properties that must be considered separately from the individual pieces.

[6] Kauffman (1995) has theorized that a similar process explains the beginning of life.

Figure 4
Complex Adaptive System: Sand Pile



Drawing by Ms. Elaine Wiesenfield. Source: *How Nature Works*, Per Bak, 1996.

One absolutely central characteristic of a complex adaptive system is "critical points." That is, large changes occur as the result of cumulative small stimuli—just as large avalanches are precipitated by the accumulated weight of many sand grains. This implies that large fluctuations are *endogenous* to such a system. Critical points are a formal way of restating the old phrase "The straw that broke the camel's back." Seeking specific causes for even big-scale effects is often an exercise in futility.

A complex adaptive system can be said to exhibit a number of essential properties and mechanisms. We rely on the work of Holland (1995) in developing these points:

- *Aggregation.* Aggregation is the emergence of complex, large-scale behaviors from the aggregate interactions of many less complex agents. An example of this phenomenon is an ant colony. If you were to "interview" any single ant about what it does, you would hear a narrowly defined task or set of tasks. However, because of the interaction of all the ants, a functional and adaptive colony emerges. In capital markets language, the behavior of the market "emerges" from the interactions of investors.[7] This is what Adam Smith called the "invisible hand."

- *Adaptive schema.* Agents within a complex adaptive system take information from the environment, combine it with their own interaction with the environment, and derive schema, or decision rules (Gell-Mann, 1994). In turn, various schemata compete with one another based on their "fitness," with the most effective ones surviving. This process allows for adaptation, which explains the "adaptive" within the phrase "complex adaptive system." Individual trading rules and investment rules of thumb can be thought of as schemata in the capital markets.

- *Nonlinearity.* In a linear model, the value of the whole equals the total of the parts. In nonlinear systems, the aggregate behavior is more complicated than would be predicted by summing the parts. This point can be illustrated with a basic prey/predator model. Given some basic variables—predators and prey in a given area, the rate of interaction between the two and a predator "efficiency" measure—the predator/prey model produces the nonlinear outcome of feasts and

[7] This property is called "emergence" and is a defining characteristic of a complex adaptive system. The inability to fully explain emergent properties stems from the large number of nonlinear interactions.

famines. This is because the model is driven by the *product* of variables, not their *sum*. For the capital markets, this means that cause and effect may not be simplistically linked.

- *Feedback loops*. A feedback system is one in which the output of one iteration becomes the input of the next iteration. Feedback loops can amplify (positive feedback) or dampen (negative feedback) an effect. One example of positive feedback is the multiplier effect, taught in basic economics. Here, additional resources gained by one agent typically get passed on in some way to other agents, magnifying the impact of original stimulus. In the capital markets, an example of a feedback loop would be momentum investors using security prices changes as a buy/sell cue, allowing for self-reinforcing behavior. Another example is the "theory of reflexivity," developed by George Soros.[8]

We now have a framework that, while relatively new, is both consistent with advances made in other sciences and promising in its descriptive potential. It now must face the real test: explaining the facts.

Does the Theory Conform to Reality?

We have established both the basics of traditional capital market theory as well as the inconsistencies between the theory and reality. Now we can see if the new framework helps bridge the gap between the two:

- *Non-normal distributions*. Understanding the capital markets as complex adaptive systems would account for the high kurtosis seen in return distributions. In particular, periods of stability punctuated by rapid change, attributable to critical levels, is a characteristic of many complex adaptive systems, including tectonic plate activity, bee hives, and evolution. Hence, the observed return distributions, booms and crashes and "high" levels of trading activity would all be consistent—even predicted—by the new model.

- *Random walk—almost*. Trend persistence is found throughout nature, and should be no great surprise that it appears to some degree in capital markets. New statistical models, including fractal time series, may help analyze such trends. The main point, however, is that the price activity of the market, assuming it is a complex adaptive system, would be similar to a classic random walk. The new model, however, appears to do a better job of explaining persistence.

- *Homogeneous versus heterogeneous expectations*. The ability to relax the assumption of rational agents—and the associated assumption of risk/reward efficiency—also argues for the complex adaptive system model. Shifting from the mindset of economic agents as deductive decision-makers, viewed either singularly or collectively, to inductive decision makers is crucial. Under most circumstances, it is reasonable to assume that the collective, inductive judgments of agents will yield an asset price similar to "intrinsic value" when their errors are independent. However, if certain decision rules are able to gain footing ("buy when the price exceeds X"), the resulting nonindependence of errors can lead to self-reinforcing trends. The key here is that complex adaptive systems can explain the dynamics of the market without assuming that agents have homogeneous expectations.

[8] See Appendix B for more details.

- *Portfolio manager performance.* A complex adaptive system may offer a better descriptive model of the market, but offers little in the way of predictability beyond structural generalizations. In turn, the poor performance of active portfolio managers is consistent with the new model. That point made, it remains possible that certain investors—Warren Buffett and George Soros, for example—may be "hard-wired" to be successful investors. In this sense "hard-wired" suggests innate mental processes, fortified with practice, that allow for systematically superior security selection.

- *Artificial models simulate market action.* Researchers at the Santa Fe Institute have created an artificial stock market that mimics actual market behavior (Arthur et al., 1997). Their model provides agents with multiple "expectational models," allows the agents to discard poor performing rules in favor of better performing rules, and provides for a discernible "intrinsic value." Agents are assumed to have heterogeneous expectations. The model shows that when the agents replace their expectational models at a low rate, the classical capital market theory prevails. However, when models are explored more actively, the market transitions to a complex adaptive system and exhibits the features of real markets (trading activity, booms and crashes). The Santa Fe Institute model, while admittedly simple, illuminates a path for understanding of real capital market behavior.

This new theory of market behavior does a better job of explaining reality than the old model, but it does so at the expense of a difficult trade-off: by incorporating more realistic assumptions we lose the crispness of current economic models. This paradigm shift requires letting go of the determinate and accepting indeterminacy; trading equations with unique equilibrium solutions for models with multiple equilibria; looking to other fields of science for relevant metaphors.

The new model offers us a richer understanding of how markets work. It is also encouraging that there may be certain "rules" that govern all complex adaptive systems, meaning capital markets may have a lot in common with other natural systems.

Correspondence

The market as a complex adaptive system passes the test of correspondence. The first part of correspondence is an explanation of why the preceding theory worked. We see that in a number of instances the effective difference between the old and new theories is modest from a practical standpoint (e.g., the value of most technical analysis, predictability). However, this framework can be said to add to our understanding of capital markets theory by explaining certain results and phenomenon (crashes, trading activity).

The second component of correspondence relates to predictability. While the new theory does not offer predictability in an normative sense[9], the theory is of value in a descriptive sense. As quantitative models are further developed and refined, there may be hope for greater predictive power in the new framework.

The stage appears to be set for a paradigm shift. It is only a question of time. While some in the academic community have embraced some or all of this new understanding of markets, they remain a minority. The evidence supporting the complex adaptive system framework, however, is growing.

[9] Actually, at least one money management firm, the Prediction Company, does run money with these concepts.

Practical Investor Considerations

Now we step outside the world of theory and into the realm of the practical. What does this new paradigm mean for investors? How should investors change their behavior, if at all, to accommodate the complex adaptive system framework? Can old tools be applied to the new reality? Here are some thoughts:

- *The risk and reward link may not be clear.* Traditional finance theory assumes a correlation between risk and reward, with the debate surrounding how to correctly measure risk. In a complex adaptive system, however, risk and reward may not be so simplistically linked (Vaga, 1994). More specifically, Peters and Vaga have suggested that owning a stock that exhibits persistence may less risky than traditional theory suggests.[10]

- *Cause and effect thinking is dangerous.* Humans like to link effects with causes, and capital markets activities are no different. For example, politicians created numerous panels after the market crash in 1987 to identify its "cause." A nonlinear approach, however, suggests that large-scale changes can come from small-scale inputs. As a result, cause-and-effect thinking can be both simplistic and counterproductive.

- *Traditional discounted cash flow analysis remains valuable.* This is true for three reasons. First, discounted cash flow (DCF) spells out principles: the value of a financial asset is the present value of future cash flows discounted appropriately. Second, a DCF model remains an excellent framework for sorting out key investment issues. Finally, there is arguably no better available quantitative model than the DCF for crystallizing expectations impounded in stock prices. The main caveat to the use of a DCF framework is that investors need to remain aware that many factors play into expectations—including the investor's personal biases—that may not be easy to model.

- *Strategy in the new paradigm world.* As the economy evolves from one that is manufacturing based to one that is information based, microeconomics are changing as well (Arthur, 1996; Beinhocker, 1997). For example, some economists have argued that certain businesses enjoy increasing, not decreasing, returns on investment as a result of path dependence and technological lock-in. Investors in technology may have separate rules to play by, all steeped in the basics of complex adaptive systems.

Conclusions

The academics and the practitioners can now touch gloves in the middle of the ring with the knowledge that the "truth" lies somewhere between their polar views. The tie that binds the two camps is the new paradigm of markets as complex adaptive systems. Acceptance of this stance requires the modification of current thinking, but opens the door for a perspective that is supported by other areas of science and that spans the gap between current theory and reality.

[10] See Appendix C for more details.

Philip Anderson, a Nobel-prize-winning physicist, helps explain why the old theory is constraining:

> "Much of the real world is controlled as much by the 'tails' of distributions as be means or averages: by the exceptional, not the mean; by the catastrophe, not the steady drip; by the very rich, not the "middle class." We need to free ourselves from 'average' thinking."

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Appendix A

A Celestial Example

A simple illustration of a paradigm shift comes from human understanding of the heavens. (See Table 2.) Aristotle posited that the universe orbited around the earth. Moreover, he assumed that the sun and outer planets orbited the earth in perfect circles. Scientists found these notions so appealing that they engaged in mental gymnastics to preserve their place at the center of the universe.

Indeed, 500 years later, the Egyptian astronomer Ptolemy resorted to the convoluted idea of epicycles, or "circles-upon-circles," in which the outer planets orbited in a circle around an imaginary point that itself orbited the earth in a perfect circle. (See Figure 1.) In addition to fairly accurately describing elliptical orbits, Ptolemy's epicycles theory explained the phenomenon of "retrograde motion"—where certain planets reverse their direction across the earth's sky. However, to save the geocentric paradigm, Ptolemy had to stretch his theory with additional conjectures: a slightly off center earth, and the equant, another off-center imaginary point around which a planet orbited. Thus, the Ptolemaic scheme became less accurate as the centuries rolled by, and its parameters and constants had to continually revised by Arabic and Christian astronomers.

The inaccuracy of Ptolemaic system posed more than an abstract problem for scientists. After Julius Caesar adopted the Egyptian solar calendar, it became the clock of the Western world. However, after 16 centuries, the overly simple Julian system—with 365-day years and a leap year every fourth year—had accrued enough errors so that it was ahead by 10 days. As a result, the Pope, in 1514, asked Copernicus, a Polish clergyman and astronomer, to look into calendar reform. Copernicus solved the problems that had stymied Ptolemy and the millennia of astronomers who followed him, but his resulting heliocentric theory placed the Sun instead of the earth at the center of the universe. (See Figure 5.)

Figure 5
The Picture That Sparked the Copernican Revolution

Map of the Copernican universe by Thomas Digges.

A loyal priest, Copernicus refused to publish these heretical results until right before his death. Indeed, in breaking with the Ptolemaic tradition, the Copernican theory offended the Church and others by removing the earth from the center of the universe and the focus of God's concern.[11] The Church eventually sanctioned his theory implicitly when Pope Gregory XIII adopted the Gregorian calendar based on the new system in 1582. But it took many decades before the theory gained broad acceptance.

[11] It is worth noting that for all his heliocentric paradigm breaking, Copernicus still believed in circular orbits and celestial perfection. Kepler and Galileo shifted those respective paradigms.

Appendix B

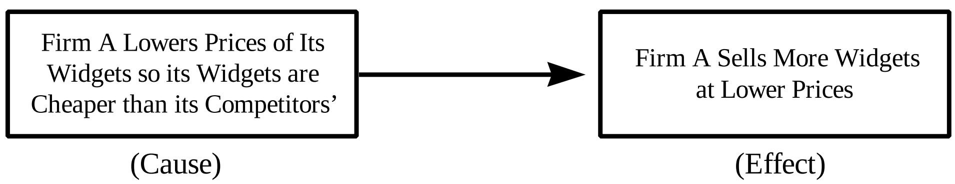
A Nonlinear Model: George Soros's Theory of Reflexivity

George Soros's phenomenal track record suggests that he has some secret weapon that allows him to beat the market. Indeed, he ascribes his success to a unique mental model of how the world works. This model dismisses classical economic theory as an elegant but irrelevant hypothetical construct with overly constrictive assumptions. To replace it, Soros has created his so-called Theory of Reflexivity that deals with the actual world of imperfect understanding, instead of the economist's world of perfect information. His nonlinear model—full of not-so-intuitive circular feedback loops—contrasts sharply with the linear model that the academic profession espouses and in which most investors believe.

Lines and Logic: The Standard Linear Model

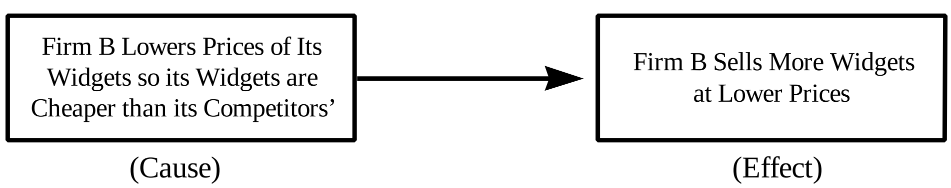
The shortest path between two points is a straight line, and the way the human brain operates is no exception. We humans tend to think linearly, linking causes to effects in order to generate logical chains that describe the world around us. For example, we may use the following cause-effect diagram to describe the results of a firm lowering its prices:

Figure 6
Linear Logic Chain



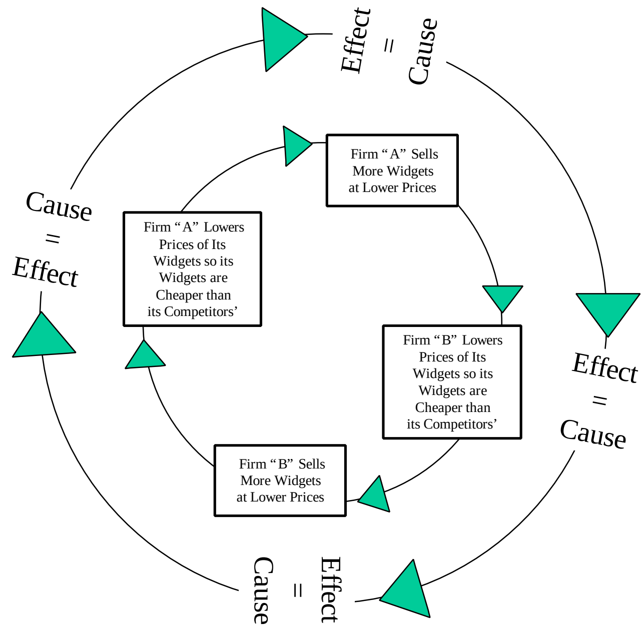
This linear thought fairly describes reality, but it is only a half truth. This is because there is another half to the story: game theory predicts that Firm B will react to stem the loss of its market share. (See Figure 7.)

Figure 7
Linear Logic Chain



Together, these half truths link together to form a whole—a vicious circle in which both firms continually lower prices to remain competitive, thus destroying the profitability of their industry.

Figure 8
A Nonlinear Feedback Loop: A Vicious Circle

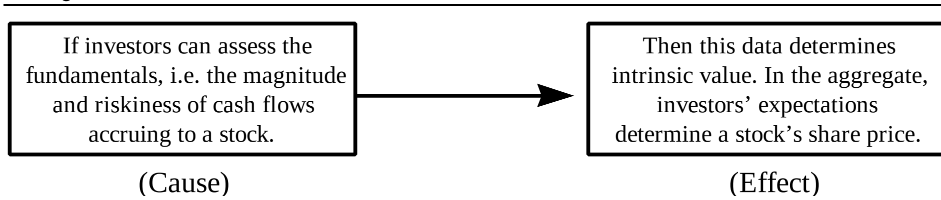


Moreover, this diagram also shows us that we have drawn a false dichotomy between cause and effect; any point on the circle is both an effect of the previous cause, and a cause of the next effect. Thus, like the "hallway" formed by two facing mirrors, each node on the circle is ultimately a self-referential function of itself. While this is a potentially damning error in traditional modeling—as anyone knows who has gotten a "circular reference" error on a spreadsheet—we must still deal with this issue to analyze a self-referential systems. Soros argues that the stock market is such a self-referential system, and his Theory of Reflexivity grapples with the consequences of this assertion.[12]

The Theory of Reflexivity

Following the archetype set by our previous example, Soros explains that the stock market can act as a self-referential circle comprised of two connected linear, logical chains. The first chain is the uncontroversial "cognitive function," whereby "reality is reflected in people's thinking." (See Figure 9.) Along with most economists, Soros believes that investors use all available information to assess the magnitude and riskiness of cash flows accruing to a security's owner. They then discount these cash flows to the present value, and buy or sell these securities in the open market accordingly.

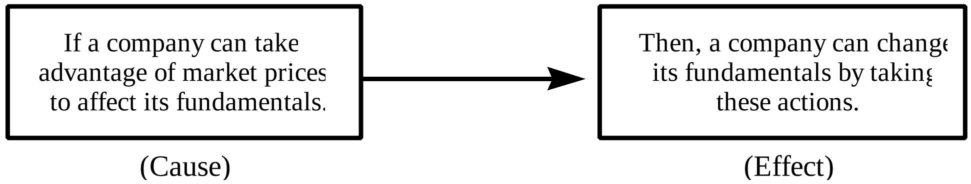
Figure 9
A Cognitive Function in the Stock Market



[12] Soros uses the invented term "reflexive" to refer to the self-referential nature of variables in his model.

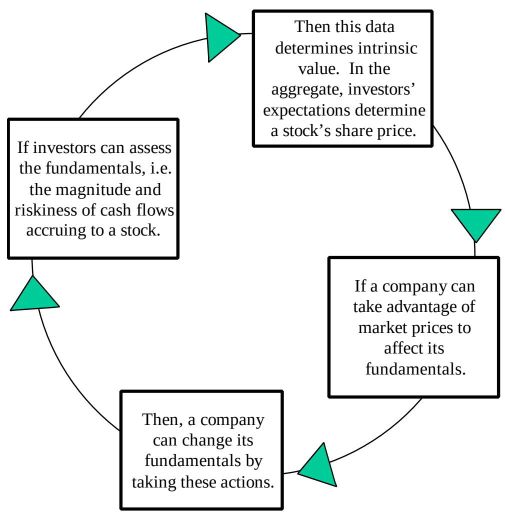
So far, this is standard textbook fare. However, Soros also believes that at certain times investor expectations—as quantified by a stock price—can affect the fundamentals. This is the second, and more controversial logical chain, which Soros terms the "participating function."

Figure 10
The Participating Function in the Stock Market



If we accept both of these logical chains, then we can link them together in a reflexive circle, as shown below.

Figure 11
A Reflexive Loop in the Stock Market



This reflexivity operates whenever the participating function operates. For example, a company can take advantage of its high market price by going back to the capital markets to raise money in a secondary equity offering. The company can then turn around and use that money to make an acquisition that increases a metric of financial performance, say, earnings per share or return on invested capital. This improvement in the company fundamentals pleases investors, who then bid up the company's share price. If the company repeats this cycle by then returning to the capital markets once more, it can enjoy the benefits of a "benign circle" that improves its fortunes by means of this reflexive loop.

Note that the reflexivity embedded in this model—which classical economics simply assumes away—has several important implications. First and foremost, people's expectations affect the very reality from which they infer those expectations. This feedback loop creates a fundamental uncertainty about reality, for investors' actions may change the company in which they are trying to invest. Second, reflexivity gives alert investors an opportunity to earn abnormal returns, with a long position in a benign reflexive loop and a short position in a vicious one.

Finally, reflexivity predicts more frequent booms and busts than what is suggested by the classical economic model. A conservative investor should thus be vigilant for reflexive situations to avoid getting burned. Moreover, we would note that the empirical evidence corresponds with the relatively frequent booms and busts predicted by this theory.

Appendix C

Hurst Exponents and Thoughts on Risk

Harold Edwin Hurst was a hydrologist who worked on the Aswan Dam project on the Nile River in the 1900s (Peters, 1991; Mandelbrot, 1977). He had a problem with reservoir control, and attempted to construct a model that would resolve the issue. His first assumption—and that of most hydrologists of the day—was that rainfall, and hence the influx of water, followed a random walk. However, the tool he developed, called the Hurst exponent, showed that the system followed a "biased random walk"—a discernible trend mixed with noise. In fact, Hurst found that most natural systems—temperatures, rainfall, and sunspots—are biased random walks.

Hurst laid out a generalization of Brownian motion, rescaled range (R/S) analysis, that could be applied to a broader class of time series. Hurst's analysis can distinguish between a random series and a nonrandom series, and hence has applicability for capital markets. The general equation is as follows:

$R/S = (k*n)^H$

where	R/S	= rescaled range (range/standard deviation)
	n	= number of observations
	k	= a constant
	H	= Hurst exponent

There are three possibilities for the value of H:

- $H = .5$ This is an *independent* series, or random walk.
- $0 < H < .5$ This is an *antipersistent* series, which means it is mean-reverting. This is, if increasing it is more likely to decrease in the next period and vice versa.
- $.5 < H < 1$ This is a *persistent* series, which means that increases are likely to be followed be additional increases. Often, the persistence effect lasts for a discernible cycle.

Bloomberg Financial Services calculates Hurst exponents for stocks and major indices. (Type "Ticker Symbol" "Equity" "KAOS" "space" "W" "Go") Following are Hurst exponents, calculated using weekly stock price closing over the past five years, for the top ten companies (ranked by market capitalization) in the S&P 500. (See Table 3.)

Table 3
Hurst Exponents for Selected Securities
weekly closings over past five years

Company (Ticker)	Hurst Exponent
General Electric (GE)	0.50
Exxon (XON)	0.55
Microsoft (MSFT)	0.53
Coca-Cola (KO)	0.77
Intel (INTC)	0.56
Merck (MRK)	0.69
Royal Dutch (RD)	0.63
International Business Machines (IBM)	0.54
Philip Morris (MO)	0.41
Procter & Gamble (PG)	0.57
S&P 500	0.59

Source: Bloomberg Financial Services.

It is interesting to see the range of Hurst exponents within this narrow slice of the S&P 500. General Electric stock, with an H of .50, appears to follow a random walk while Coca-Cola, with an H of .77, demonstrates strong persistence. Philip Morris returns are antipersistent. An important caveat: given the scarcity of inputs and potential explanations for the results, we would be hesitant to draw too many conclusions based on these data.

Peters has suggested that higher H values mean *less risk* because there is less noise in the data. This is in contrast to the standard finance theory that links risk with variance.

Risk measurement remains an enigmatic issue. While the Hurst exponent may not be the solution to the problem of risk quantification, it may prove to be a step in the right direction.

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