REVISITING MARKET EFFICIENCY: THE STOCK MARKET AS A COMPLEX ADAPTIVE SYSTEM

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It is time to shift the emphasis of the debate about market efficiency. Most academics and practitioners agree that markets are efficient by a reasonable operational criterion: there is no systematic way to exploit opportunities for superior gains. But we need to reorient the discussion to *how* this operational efficiency arises. The crux of the debate boils down to whether we should consider investors to be rational, well informed, and homogeneous—the backbone of standard capital markets theory—or potentially irrational, operating with incomplete information, and relying on varying decision rules. The latter characteristics are part and parcel of a relatively newly articulated phenomenon that researchers at the Santa Fe Institute and elsewhere call complex adaptive systems.

Why should corporate managers care about how market efficiency arises? In truth, executives can make many corporate finance decisions independent of the means of market efficiency. But if complex adaptive systems do a better job explaining how markets work, there are critical implications for areas such as risk management and investor communications.

Take, for example, the earnings expectations game.[1] In a complex adaptive system, the sum is greater than the parts. So it is not possible to understand the stock market by paying attention to individual analysts. Managers who place a disproportionate focus on the perceived desires of these analysts may be managing to the wrong metrics—and ultimately destroying shareholder value. A better appreciation for how markets work will shift management attention away from individual analysts to the market itself, thus capturing the aggregation of many diverse views.

Standard capital markets theory still has a lot to recommend it.[2] The theory maintains that a company's stock price represents an unbiased estimate of its intrinsic value, and that investors cannot develop trading rules that earn "excess" returns over time. From a practical standpoint, these predictions closely mirror the realities of today's markets. Year after year, the vast majority of professional money managers underperform the broad market averages. So few are the investors who consistently outperform the averages that people like Warren Buffett have assumed near-legendary status.

1. See "Just Say No to Wall Street: Putting A Stop to the Earnings Game" by Joseph Fuller and Michael C. Jensen in this issue.

2. For an excellent survey of the accomplishments of market efficiency theory, see Ray Ball, "The Theory of Stock Market Efficiency: Accomplishments and Limitations," in *The New Corporate Finance: Where Theory Meets Practice*, 3rd edition, edited by Donald H. Chew (New York: McGraw-Hill, 2001), pp. 20-33.

The efficient markets hypothesis and its close counterpart the random walk theory have been fixtures on the financial economics scene for well over 30 years. But the theories make predictions that do not match the empirical data.[3] Financial researchers have documented several anomalies that run counter to market efficiency. The theory also rests on the assumption of rational, well-informed investors—an assumption that is shaky at best. And while price changes are roughly consistent with a random walk, price fluctuations come in greater size than the theory predicts. The obvious case in point is the stock market crash of October 19, 1987, a day the S&P 500 plummeted 22.6%. Such return outliers are crucial for executives trying to manage risk.

The goal of this paper is to explore whether markets are, in fact, better understood as complex adaptive systems. I follow roughly the approach outlined by Thomas Kuhn in his seminal book, *The Structure of Scientific Revolutions*, which attempts to explain "paradigm shifts." A paradigm shift is an evolution in a model or theory. Kuhn's process allows us to break down the evolution of ideas into four parts. First, a theory is laid out to explain a phenomenon. In our case, the starting point is standard capital markets theory and the efficient markets hypothesis, which together seek to explain market behavior. Second, researchers test the theory by collecting empirical data, and eventually find facts that are inconsistent with the prevailing theory. The third phase involves "stretching" the old theory—especially important for those who have a personal stake in the prevailing theory—to accommodate the new findings. I will describe some of these anomalous findings and provide some evidence of theory stretching. Finally, a new theory emerges that overtakes the old, offering greater fidelity to the facts and greater predictive power. Complex adaptive systems may provide such a theory. The new model offers a richer understanding of how markets work, and shows how the market shares properties and characteristics with other complex adaptive systems. At the close of this article, I discuss the *practical* implications of this new theory for managers and investors.

STANDARD CAPITAL MARKETS THEORY

The bulk of economics is based on equilibrium systems—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 an equilibrium system is hit by an "exogenous shock," such as news of a major default or a surprise interest rate cut (or hike) by the Fed, the system absorbs the shock and quickly returns to an equilibrium state.

The irony of this equilibrium perspective is that the convenient, predictable science that economists tacitly hold as an ideal—namely, 19th-century physics—has been subsumed by advances such as quantum theory, where "indeterminacy" is commonplace. Most systems, in nature and in business, are not in equilibrium but rather in constant flux. Classical physics offers a good first approximation of reality, but quantum physics is more broadly applicable, while still accommodating what is already "known." The equilibrium science that economists have mimicked has evolved; economics, by and large, has not.[4]

Capital markets theory, largely developed over the past 50 years, still rests on a few key assumptions, primarily efficient markets and investor rationality. We consider both in turn.

- *Stock market efficiency* suggests that stock prices incorporate all relevant information when that information is readily available and widely disseminated (a reasonable description of the U.S. stock market), which implies that there is no systematic way to exploit trading opportunities and achieve superior results. 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.[5] Market efficiency does not say that stock prices are always "correct," but it does say that stock prices are not mispriced in any kind of "systematic" or predictable way. The random walk theory, which is related to the efficient markets hypothesis, holds that security price changes are independent of one another.

3. For a recent summary of the empirical features that economic theory has difficulty explaining, see John Y. Campbell, "Asset Pricing at the Millennium," *The Journal of Finance*, Vol. 55 (2000), pp. 1515-1567.

4. For a particularly forceful elaboration of this point, see Philip Mirowski, *More Heat than Light* (Cambridge: Cambridge University Press, 1989).

5. Sandy Grossman and Joe Stiglitz noted the following paradox about efficient markets: they pointed out that if markets were *completely* efficient, there could be no return earned by information gathering, and hence no one would trade. Thus, in practice, there must be "sufficient profit opportunities, i.e., inefficiencies, to compensate investors for the cost of trading and information-gathering." See Sanford J. Grossman and Joseph E. Stiglitz, "On the Impossibility of Informationally Efficient Markets," *American Economic Review*, Vol. 70 (1980), pp. 393-408.

Accordingly, changes in prices come only as a result of the arrival of unexpected information that is, by definition, random.

One predicted outcome of the efficient markets hypothesis is modest trading activity and limited price fluctuations.[6] As investors receive information and agree on its meaning, prices can adjust without substantial trading activity. Another assumption is that investors can treat expected stock price returns as independent, identically distributed variables—unleashing probability calculus. Often, model builders assume that stock price changes are normally, or log normally, distributed.

- *Rational investors* are people who can quickly and accurately assess and optimize risk/reward outcomes. They are constantly seeking profit opportunities, and it is the very efforts of such investors to make money that lead to market efficiency. This framework of investor behavior is reflected in the Capital Asset Pricing Model (CAPM), which suggests a linear relationship between risk and return. In other words, rational investors seek the highest return for a given level of risk.

Do we need *all* investors to be rational profit-seekers? Not necessarily. Joel Stern has used the metaphor of the "lead steer" to explain why the market appears to follow an economic model even if very few investors do so. To paraphrase Stern, "If you want to know where a herd of cattle is heading, you need not interview every steer in the herd, just the lead steer." The basic idea is that there is a relatively small group of super-smart investors who *do* understand the *economic model* (as opposed to the conventional accounting model) of the firm, in which value is driven by expected changes in operating cash flow (as opposed to EPS). And it is these lead steers who are setting prices at the margin. Hence, companies need not worry about the typical investor because the investors at the margin—the lead steers—ensure that prices, on average, are set correctly.

The lead steer metaphor represents a centralized mindset: all you need are a few smart investors to ensure that markets are efficient. As we will see, however, there is no need to assume the presence of "leaders" to arrive at market efficiency.

Classical Capital Markets Theory Tested

Testing began on the efficient markets hypothesis 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 be evaluated only on their ability to "explain" past events and predict future ones. Another potential problem is the availability of quality data. Researchers in finance have the Center for Research in Security Prices database—the primary source of detailed information on stocks and the stock market—which has comprehensive data going back 80 years.

In general, there are four areas where the classic theory significantly falls short:

- *Stock market returns are not normal*, as capital markets theory suggests. Rather, return distributions exhibit high *kurtosis*; that is, the "tails" of the distribution are "fatter" and the mean is higher than predicted by a normal distribution. In ordinary language, this means that periods of relatively modest change are interspersed with higher-than-predicted changes—namely, booms and crashes.[7] Figures 1 and 2 illustrate the point graphically.

The observation that stock price returns do not follow normal distributions is not new. As Eugene Fama, one of the fathers of efficient markets theory, wrote back in 1965:

> *If the population of price changes is strictly normal, on average for any stock…an observation more than five standard deviations from the mean should be observed about once every 7,000 years. In fact such observations seem to occur about once every three to four years.*[8]

The 22.6% stock market decline of October 19, 1987 was one of these fat-tailed observations. In a world of normal distributions, the probability of a move as large as the crash was so remote as to be effectively impossible.[9] The academic reaction to the crash was revealing. When asked about the 1987 crash in a recent interview, Fama responded: "I think the crash in '87 was a mistake." Merton Miller offered an explanation

6. See Fischer Black's famous article, "Noise," *Journal of Finance*, Vol. 41 (1986). In that article, Black said that trading is the result of people with different beliefs that ultimately derive from different information.

7. Biologists will see a parallel between these observations and the theory of punctuated equilibrium. Stephen Jay Gould and Niles Eldredge articulated the theory of punctuated equilibrium in 1972. The basic case is that evolutionary changes are jerky rather than gradual. Long periods of stasis are interrupted by abrupt and dramatic periods of change.

8. Eugene Fama, "The Behavior of Stock Prices," *Journal of Business*, January 1965.

9. See Jens Carsten Jackwerth and Mark Rubinstein, "Recovering Probability Distributions from Option Prices," *The Journal of Finance*, Vol. 51 (1996), p. 1612.

FIGURE 1
FREQUENCY DISTRIBUTION OF S&P 500 FIVE-DAY RETURNS: NORMAL VERSUS ACTUAL (JANUARY 1968–FEBRUARY 2002)

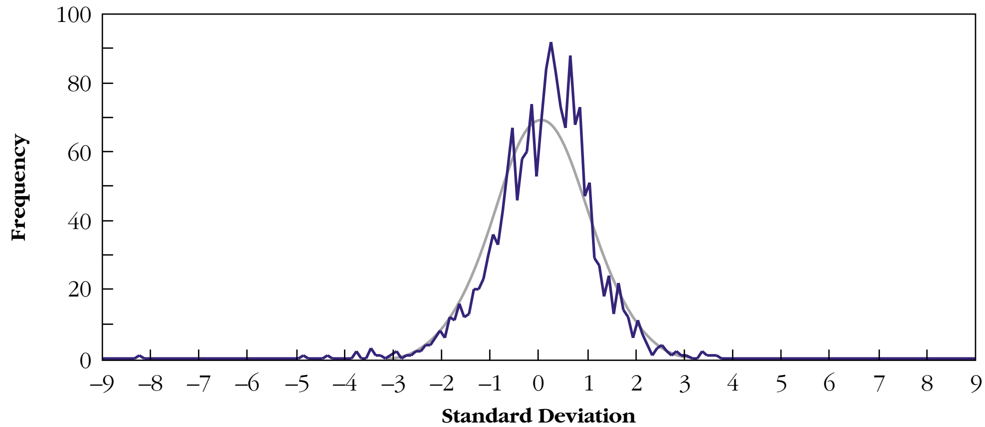
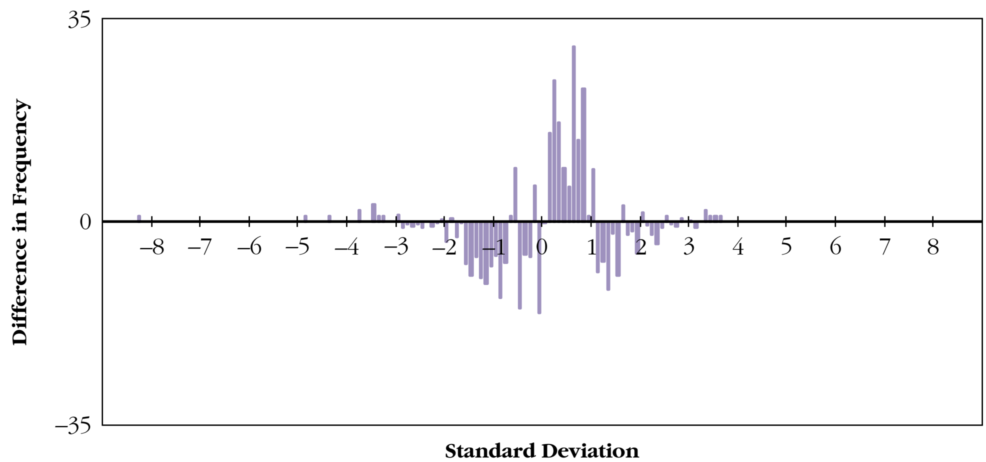


FIGURE 2
FREQUENCY DIFFERENCE: NORMAL VERSUS ACTUAL FIVE-DAY RETURNS (JANUARY 1968–FEBRUARY 2002)



for the crash consistent with investor rationality—but then rather tellingly went on to cite the research of Benoit Mandelbrot, a mathematician who as early as the 1960s pointed out that stock price volatility was too great to justify use of a normal distribution.[10]

That the academic community and investment community so frequently talk about events five or more standard deviations from the mean should be a sufficient indication that the widely used statistical measures are inappropriate for these types of distributions. Yet the assumption of normal distributions persists.

■ *The random walk assertion is not supported by the data.* John Campbell, Andrew Lo, and Craig MacKinlay, after applying a battery of empirical tests, concluded, "financial asset returns are predictable to some degree."[11] Furthermore, other finance researchers—building on the work of Mandelbrot—have suggested that there is a long-term memory component in capital markets. That is, return series are often both persistent and trend-reinforced.

■ *Risk and reward are not linearly related.* In their much-cited 1992 survey of the empirical tests of the CAPM (which included their own analysis for the period 1963-1990) that appeared in the *Journal of Finance*, Eugene Fama and Kenneth French concluded that the "tests do not support the most basic prediction of the SLB [Sharpe-Lintner-Black]

10. See Merton H. Miller, *Financial Innovations and Market Volatility* (Cambridge, MA: Blackwell Publishers, 1991), pp. 100-103. Miller refers to Benoit B. Mandelbrot, "The Variation of Certain Speculative Prices," in *The Random Character of Stock Market Prices*, edited by Paul Cootner (Cambridge, MA: MIT Press, 1964). Mandelbrot's paper was originally published in 1963.

11. Campbell, J.Y., Lo, A.W., MacKinlay, A.C., *The Econometrics of Financial Markets* (Princeton, NJ: Princeton University Press, 1997), p. 80.

model, that average returns are positively related to the market's."

Fama and French also reported that two other non-CAPM factors—firm size and market-to-book value—were systematically correlated with stock returns during the measured period. However, Fama and French maintained a "rational asset-pricing framework," which means they identified factors associated with various returns and *assumed* that those returns were attributable to risk.

■ *Investors are not rational*. The case here rests on several points. The first is the growing body of evidence from decision theorists showing that people make systematic judgment errors.[12] One of the best-documented illustrations is "prospect theory," which shows that individual risk preferences are profoundly influenced by how information is presented or "packaged."[13] For example, investors act in a risk-averse way when making choices between risky outcomes, conflicting with the "rational" behavior predicted by expected utility theory.

Second, investors trade more than the theory predicts. In order to explain the real-life trading activity, Fischer Black developed the theory of "noise" and "noise traders." Black describes 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." Most striking is Black's introductory comment that "[noise theories] were all derived originally as 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."[14]

The final point is that people generally operate using *inductive*, not deductive, processes to make economic decisions. Since no individual has access to all information, investors must base their judgments not only on what they "know," but on what they think *others believe*. The fact that investors make such decisions using rules of thumb suggests a fundamental indeterminacy in economics.[15] 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.

Despite its apparent shortcomings, the established theory *has* significantly advanced our understanding of capital markets. But is it 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. But a new theory must not only explain why the old theory worked, it must add predictive power.

THE STOCK MARKET AS A COMPLEX ADAPTIVE SYSTEM

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. First, we provide a description of complex adaptive systems, identifying their key properties and attributes. Next, we compare the new theory's predictions to actual market behavior. Finally, we check to see if the theory adds to our understanding of markets, while preserving the power of classic markets theory.

A New Model of Investor Interaction

Put two people in a room and ask them to trade a commodity, and not much happens. 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. But, as we add more agents to the system, something remarkable happens: it turns into a so-called "complex adaptive system," replete with new, lifelike characteristics. In a tangible way, the system becomes more complex than the pieces that it comprises. 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.[16]

12. See Max H. Bazerman, *Judgment in Managerial Decision Making* (New York: John Wiley & Sons, 1986); also Richard H. Thaler, *The Winner's Curse: Paradoxes and Anomalies of Economic Life* (New York: Free Press, 1992).

13. See Daniel Kahneman and Amos Tversky, "Prospect Theory: An Analysis of Decision Under Risk," *Econometrica*, Vol. 47 (1979), pp. 263-291.

14. See Black (1986), cited earlier.

15. W. Brian Arthur, "Complexity in Economics and Financial Markets," *Complexity*, Vol. 1 (1995), pp. 20-25.

16. For a discussion of self-organized criticality, see Per Bak, *How Nature Works* (New York: Springer-Verlag New York, 1996). In fact, theoretical biologist Stuart Kauffman has theorized that a similar process explains the beginning of life. See Stuart Kauffman, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* (Oxford: Oxford University Press, 1995).

Physicist Per Bak uses a sand pile to illustrate self-organized criticality. 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. We cannot understand these large changes by studying the individual grains. Rather, the system itself gains properties that we must consider separately from the individual pieces.

A central characteristic of a complex adaptive system is "critical points." That is, large changes occur as the result of the accumulation of small stimuli—just as the accumulated weight of many sand grains precipitates large avalanches. This implies that large fluctuations are *endogenous* to such a system. Critical points are a formal way to express the concept of "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 exhibits a number of essential properties and mechanisms.[17]

Aggregation. Aggregation is the emergence of complex, large-scale behaviors from the collective 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.[18] This is what Adam Smith called the "invisible hand."

Adaptive decision rules. Agents within a complex adaptive system take information from the environment, combine it with their own interaction with the environment, and derive decision rules.[19] In turn, various decision rules compete with one another based on their "fitness," with the most effective rules surviving. This process allows for adaptation, which explains the "adaptive" within the phrase "complex adaptive system." We can consider individual trading rules and investment rules of thumb as decision rules in the capital markets. Notably, the concept of adaptive decision rules is consistent with the disappearance of "anomalies." Given that investors seek such profit opportunities and refine their decision rules to compete them away, anomalies "carry with them the seeds of their own decay."[20]

Nonlinearity. In a linear model, the value of the whole equals the sum of the parts. In nonlinear systems, the aggregate behavior is more complicated than would be predicted by totaling 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 famines. This is because there is an interaction effect—the variables ebb and flow together and create booms and busts. For the capital markets, this means that cause and effect may not be simplistically linked but may instead interact to produce exaggerated outcomes.

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 are typically passed on in some way to other agents, magnifying the impact of the original stimulus. In the capital markets, an example of a feedback loop would be the practice of "momentum" investors, who use security price changes as a buy/sell cue, allowing for self-reinforcing behavior.

Does the Theory Conform to Reality?

We now have a framework that, while relatively new, is both consistent with advances made in other sciences and promising in its descriptive potential. But it must face the real test: explaining the facts. We have established both the basics of traditional capital markets theory as well as some inconsistencies between that theory and reality. Now we can see if the new framework helps bridge the gap between the two.

17. The rest of this section relies on the work of John H. Holland, *Hidden Order: How Adaptation Builds Complexity* (Reading, MA: Helix Books, 1995).

18. 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.

19. For a more detailed discussion of evolving decisions rules, see Murray Gell-Mann, *The Quark and the Jaguar* (New York: W.H. Freeman and Company, 1994).

20. Merton Miller, "The History of Finance: An Eyewitness Account," *Journal of Applied Corporate Finance*, Vol. 13 (Summer 2000).

Non-normal distributions. Understanding the capital markets as complex adaptive systems would account for the high kurtosis ("fat tails") seen in return distributions. In particular, periods of stability punctuated by rapid change, attributable to critical levels, is a characteristic of many complex systems, including tectonic plate activity, beehives, 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 it should be no great surprise that it appears to some degree in capital markets. New statistical models 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, would appear to do a better job of explaining persistence in returns to the extent that such persistence exists.

Homogeneous versus heterogeneous expectations. The ability to relax the assumption of rational investors—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 singly 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 unrelated to each other. However, if certain decision rules are able to gain footing, the resulting non-independence of errors can lead to self-reinforcing trends.[21] This reduction in decision-rule diversity offers important insight into stock market instability. The key here is that complex adaptive systems can explain the dynamics of the market without assuming that investors have homogeneous expectations.

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. The poor performance of active portfolio managers is consistent with the new model as well as with market efficiency. That point made, it remains possible under either theory that certain investors—Warren Buffett and Legg Mason's Bill Miller, 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.[22] Their model provides agents with multiple "expectational models," allows the agents to discard poorly 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 markets theory prevails. However, when new models are adopted more actively, the market turns into 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 actual capital markets behavior.[23]

The decentralized approach inherent in complex adaptive systems can feel very unsettling. Consider, for example, computer scientist Mitch Resnick's observations about the behavior of flocks of birds:

> *Most people assume that birds play a game of follow-the-leader: the bird at the front of the flock leads, and the others follow. But that's not so. In fact, most bird flocks don't have leaders at all. There is no special "leader bird." Rather, the flock is an example of what some people call "self-organization." Each bird in the flock follows a set of simple rules, reacting to the birds nearby it. Orderly flock patterns arise from these simple, local interactions. The bird in the front is not a leader in any meaningful sense—it just happens to end up there. The flock is organized without an organizer, coordinated without a coordinator.* [24]

21. See Jack L. Treynor, "Market Efficiency and the Bean Jar Experiment," *Financial Analysts Journal*, May-June 1987.

22. W. Brian Arthur, et al., "Asset Pricing Under Endogenous Expectations in an Artificial Stock Market," in *The Economy as an Evolving Complex System II*, edited by W.B. Arthur, S.N. Durlaf, and D.A. Lane (Reading, MA: Addison-Wesley, 1997).

23. For a more recent discussion, see Blake LeBaron, "Volatility Magnification and Persistence in an Agent Based Financial Market," Working Paper, Brandeis University, March 2001.

24. Mitchel Resnick, *Turtles, Termites and Traffic Jams* (Cambridge, MA: MIT Press, 1994), p. 3.

Order, then, is not always the result of leadership, but can arise from the dynamic interaction of agents employing relatively simple decision rules. In a 1993 study, Dan Gode and Shyam Sunder tested this possibility by creating markets in which traders used simple, and not necessarily realistic, decision rules to submit their bids and offers. The study found that markets were *still* remarkably efficient; in other words, even dumb agents achieve smart results. In their own words:

> *Allocative efficiency of a double auction market derives largely from its structure, independent of traders' motivation, intelligence, or learning. Adam Smith's invisible hand may be more powerful than some may have thought; it can generate aggregate rationality not only from individual rationality but also from individual irrationality.*

These findings stand in stark contrast to the lead steer metaphor. Most people feel more comfortable with the notion that prices are set by smart investors. But there is growing evidence that the aggregation of many investors is sufficient to create a well-functioning market.

While the theory of the market as a complex adaptive system arguably does a better job of explaining reality (crashes, trading activity) than the old model, it does so at the expense of a difficult trade-off: by incorporating more realistic—albeit still simple—assumptions we lose the crispness of current economic models. This paradigm shift requires letting go of the determinate and accepting indeterminacy; substituting equations with unique equilibrium solutions for models with multiple equilibria; looking to other fields of science for relevant metaphors.

PRACTICAL CONSIDERATIONS

But even if capital markets have a lot in common with other natural systems, what does this new paradigm mean for investors and corporate practitioners? How should they 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 linear relation 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.[25] The fact that the tails of empirical distributions are fatter than predicted by most models is essential to consider in risk management, where extreme outcomes can undermine the most brilliant economic models (witness the case of Long-Term Capital Management).

What are the practical implications? For most corporate investment decisions, the Capital Asset Pricing Model is still probably the best available estimate of investment risk. But managers must be aware that their stock price may be subject to volatility swings beyond what the standard theory suggests.

Don't listen to agents, listen to the market. Most managers try to allocate capital so as to create shareholder value. However, when faced with significant decisions they often trust the counsel of select individuals (i.e., investment bankers and analysts) in favor of reviewing empirical market studies. Complex adaptive systems show us that the market is smarter than the individual. Most studies in financial economics are at the market level, and hence capture the benefit of aggregation. Managers that weight the advice of experts over the evidence of the market can make poor decisions.

Look for diversity breakdowns. Many corporate managers view the stock market with some misgiving. On balance, this skepticism is unfounded—markets appear to function well when there is a diversity of decision rules and agent errors are independent.[26] However, if too many investors either mimic one another or don't participate, then markets can become fragile, leading to substantial volatility. Managers should look for opinion extremes—times when investors are all acting the same. Potentially armed with better information, managers may be able to take action by buying or selling securities in order to enhance value. At a minimum, these occasions require a sharp focus on investor communication.

Cause and effect thinking is futile if not dangerous. People like to link effects with causes, and capital market activities are no different. For example, politicians created numerous panels after the 1987 market crash in a futile effort to

25. Tonis Vaga, *Profiting From Chaos* (New York: McGraw Hill, 1994).

26. Norman L. Johnson, "Diversity in Decentralized Systems: Enabling Self-Organizing Solutions, *LANL*, LA-UR-99-6281, 1999.

identify its "cause."[27] 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, particularly when a "quick fix" ends up doing more harm than good. To the extent that the complex adaptive system theory reinforces the notion that a random disturbance can sometimes have an enormous effect, and restrains the natural inclination to impose a solution, it may be a positive step forward.

Traditional discounted cash flow analysis remains the key to value. This is true for three reasons. First, discounted cash flow (DCF) spells out first 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 DCF for crystallizing expectations impounded in stock prices.[28]

CONCLUSIONS

In a widely cited 1953 paper, Milton Friedman pointed out that the plausibility of a model's assumptions is not as important as the accuracy of its predictions.[29] We argue that standard capital markets theory provides good predictions *for the most part.* But there are some important exceptions. For example, asset price changes do not conform to normal distributions, the evidence in support of CAPM is ambiguous, and trading activity is much greater than the theory predicts.

Over the past few decades, researchers have defined some of the prime properties and characteristics of complex adaptive systems. These systems are present throughout nature, and their general features appear to be a good description of how capital markets work. Importantly, complex adaptive systems predict stock price change distributions similar to what we see empirically, while showing why it is that markets are so hard for investors to beat. Further, the underlying assumptions behind complex adaptive systems are at once simple yet do not require restrictive assumptions about investor rationality or lead steers.

From a practical standpoint, managers who subscribe to standard capital markets theory and operate on the premise of stock market efficiency will probably not go too far astray. However, complex adaptive systems may provide a useful perspective in areas like risk management and investor communication.

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27. See Miller (1991), cited earlier.
28. For extensive discussion of this argument, see Alfred Rappaport and Michael J. Mauboussin, *Expectations Investing* (Boston: Harvard Business School Press, 2001).
29. Milton Friedman, *Essays in Positive Economics* (Chicago: The University of Chicago Press, 1953).

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