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Self organizing evolution in financial markets and elsewhere

Introduction

InfoWar concerns the ongoing battle for control of information in our society. With the advent of the internet and genetic engineering this battle will become even more intense. We are on the verge of creating a network of complex information processing organisms that are difficult even to imagine. This movement toward ever-increasing complexity and information processing is driven by the same inexorable self-organizing process that has created the rich living ecosystem and human culture that we take for granted. The remarkable fact is that this complex order has arisen from a state that we believe was originally utterly disordered, through a spontaneous process of automatic design that takes place without conscious direction. As we enter the future information age and this process of self-organizing evolution overwhelms us, it would be nice to at least have a glimmer of understanding about its underlying principles. Unfortunately, we still have no good theory to guide us.

In this discussion I will attempt to impart a bit of my limited insight into the workings of self-organization, using evolution in financial markets as the main example. My thesis is that self-organizing evolution, broadly defined, is a universal and ubiquitous phenomenon, extending well beyond biology, that pops up and spontaneously generates complex structures whenever an appropriate medium is present. This medium can be a primordial soup, a cell, the metabolism of a vertebrate, the human brain, commerce in a stable society, or the internet. There is much in common among the diverse mechanisms that generate order in these different environments. Perhaps more optimistically, there is one common mechanism with many situation-dependent variations. This is an old idea, going at least as far back as Herbert Spencer.[1]

Global Electronic Financial Markets

The struggles of society are increasingly focused on the ability to acquire, manipulate, and make decisions based on electronic information. Nowhere is this more apparent than in the global financial markets. Money is now purely electronic. Whether you are a billionaire is measured by the state of a few arbitrary pieces of silicon. This representation of money has evolved to facilitate a rapid-fire commerce that allows trillions of dollars in transactions every day, more than 50 times the daily gross national product of the world. This may or may not make our lives better, but the fact is that it has become an ecosystem in and of itself–an integral organ of society performing a vital function. This ecosystem evolves rapidly, its course at most weakly determined by individual governments, banks, or corporations.

The ecosystem of global finance is made up of hundreds of thousands of different agents employing a variety of diverse strategies. Each agent has the same goal: maximize profits. To achieve this each agent processes information in order to make decisions about what and when to buy or sell. This is a highly Darwinian environment; each year many firms go out of business because of their failure to play this game well. This selection pressure is driving a conversion of information storage and processing from paper and people to electrons and computers. The improvement in speed, reliability, and capacity is many orders of magnitude, which facilitates a more complex decision-making process. At this point computers are used mainly to assist human decision making. There is, however, an incipient trend to let computers actually *make* decisions on their own.

Prediction Company, of which I am one of the founders, is on the forefront of this trend. Over a seven year period we have assembled a comprehensive 50 gigabyte database containing almost all the publicly available information on American stocks. This includes every transaction and price quotation on stocks and stock options for the preceding ten years, as well as accounting reports, and filings with the Securities and Exchange Commission. We use computers to analyze this information, searching for patterns of temporal behavior that occur predictably and repeatedly. The aggregate of these patterns is then used to build models to predict future price movements. They are installed as programs running in a fault-tolerant realtime environment where every transaction and quote is processed. Our computers monitor about 2000 stocks, updating their forecasts every minute. When they detect the appropriate conditions they send a buy or sell order to the proper stock exchange; the orders are received and processed within a matter of seconds. Our profits or losses, which are continuously tabulated throughout the day, can change dramatically in a matter of minutes. Humans write the software that formulates and runs the models, and monitor the trading system to deal with exceptional conditions, such as failures of the data feeds. Other than this the system is completely automatic.

A Model for Evolution in Finance

To give an illustration of a situation where evolution can be described by a mathematical model, I will give a brief summary of a theory of financial markets that I have been developing.[2] This theory is based at the lowest level on dynamics–in this case a simple rule that relates the behavior of people to prices. This makes it possible to see how the different strategies that traders use interact with each other. If an old strategy dies out, or a new strategy emerges, one can compute how this will affect the pool of pre-existing strategies. In general, each strategy depends on other strategies for its existence. Thus on one hand each strategy is competing, but on the other it is in a cooperative relationship. This is analogous to an ecology in a biological system. The net result is a self-organized, collective decision making process that plays a significant role in setting the goals of society. Hopefully wading through a few of the details of financial systems will make the general principles clearer. At the broader level, this simple model of finance illustrates how little is required to create an evolving, self-organizing system.

A Nonequilibrium Theory of Supply and Demand

The classical approach to economics is based on the laws of supply and demand. This idea can be briefly summarized as follows: For any good or service, supply and demand vary depending on the price. As the price increases demand goes down and supply goes up. In a competitive market prices should be set where supply equals demand. The condition where supply and demand are equal is called "equilibrium."

This is a very nice idea. However, it has become increasingly clear that it doesn't describe real financial markets very well. Based on this theory, one would expect prices to change rather slowly, and only in response to new information. In fact, large swings in prices can occur rapidly and seemingly spontaneously. In many cases, such as the stock market crash of 1987, large shifts in price occur without any apparent external cause. Of course, prices are also affected by news, but often the internal dynamics of the market seem to be at least as important.

There are many ideas about what is wrong with the usual equilibrium formulation of supply and demand. As developed in the emerging discipline of behavioral economics[3], most of these ideas center on the myriad ways in which people are less than rational. Supply and demand are moving targets that depend on mass psychology. In a modern market there is lots of information, far more than any individual can fully process. The interpretation of this information is problematic, because the response of the market depends on how everyone else will perceive it. Understanding this would require a predictive theory of mass psychology– something that is not in the possession of the average trader. (Furthermore, if the average trader did have such a theory, the theory would need to take this into account, which may be fundamentally impossible.) Decisions in financial markets must be made quickly. Furthermore, many commonly used trading strategies are not rational. People are not very good at statistics. Fads, trends, and mass hysteria may drive the price far from equilibrium. Price movements depend on both perception and psychology, and ultimately, buying and selling is done by people, who are subject to all the irrationality that characterizes human beings.

George Soros has stated a principle of "market reflexivity"[4]. His idea is that on one hand buy and sell decisions are based on expectations about future prices, but on the other, future prices are contingent on present buy and sell decisions. Market prices are the aggregate result of trading activity, at the same time that trading activity is determined by individual perceptions of the market. Thus market prices fluctuate dynamically as people attempt to guess what the market is going to do and trade accordingly.

I have modified Soros' idea slightly and cast the result in mathematical terms. The principle is even simpler: Buying tends to drive the price up and selling tends to drive it down. This is a rule that no trader will dispute. All that is assumed is that, if at any given moment there are more buyers than sellers, the price will tend to go up. Similarly, if there are more sellers than buyers, it will tend to go down. The larger the imbalance, the faster the price moves. Note that this is a lot like supply and demand, but weaker. There is no assumption of equilibrium. It is not necessary to state where the price will end up, but only which way it will go when it is out of balance, and how fast it will move. Another big advantage is that it is relatively easy to measure the price response to a trade, so the theory is easy to verify based on readily obtainable data. Indeed, when one looks at transactions, the basic observation is apparent: The larger the trade, the bigger the resulting price movement.

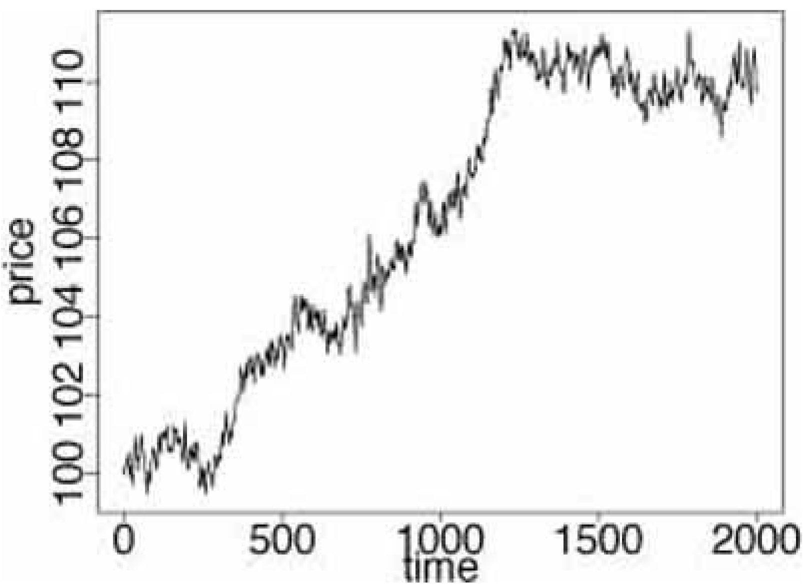
From this point of view the market can be regarded as a global casino. The game is to anticipate what the other players are going to do. If you think the majority of the other players are going to buy, you try to buy first. Their buying will cause the price to rise, and you will make a profit. Of course, if you are wrong and they sell, you will be subjected to a loss. Many traders regard markets in just this way. For example, in his book George Soros keeps a diary of his trading decisions during 1986, and gives a clear account of the manner in which he anticipates the mass psychology of other traders. (This has been difficult for others to replicate).

Trend Followers and Value Investors

Most traders follow more systematic strategies. The simplest can be categorized based on the response to changes in price. One major group, of which the American investor Warren Buffet provides an example, is value investors. Value investors attempt to determine what things are really worth. They look for situations where prices are out of line with they estimate to be the "true value" and place their bets accordingly. Another major group is trend followers. They believe that prices tend to keep moving in the same direction. When prices start to trend upward they buy, and when they start to trend downward they sell.

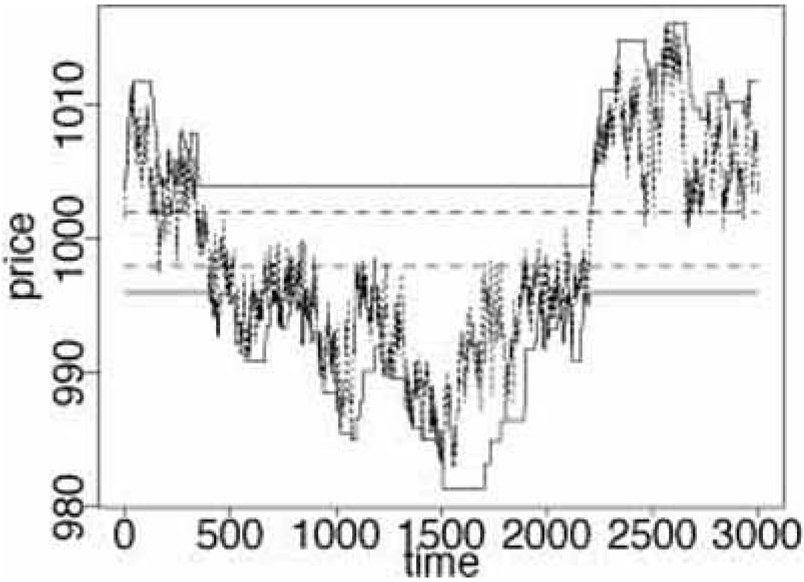
Actually the situation is more complicated than this. Determining the true value is not easy, and trend rules can be quite complicated. A given trader may be a trend follower in some situations and a value investor in others. And there are a host of other strategies, ranging from arbitrage to astrology. Nonetheless, these are common strategies that are used throughout the world. They form a good basis for discussion because they are easy to understand and easy to study within the model.

According to the classic dogma of economics markets should be "efficient". Price movements should be unpredictable based on public information. Prices should vary only in response to external information; except for inside information, any variations in price should be random. Under the alternative theory discussed here, however, if traders form well-defined groups, the characteristic behavior of the group can induce patterns in price movements. Trend followers, for example, will tend to buy when the price is going up. This will in turn cause more buying, which will cause the price to go up further. Thus, if there are enough trend followers they generate a self-fulfilling prophesy: Trend followers cause trends. This is illustrated in the simulation shown in Figure 1. The net of buying and selling is computed by simulating a mixture of different trend-following strategies, with random noise added. The random noise can be thought of as representing the aggregate of all the unpredictable external information that might influence the market, such as news events. For this simulation the noise level is set unrealistically low in order to make the deterministic component of the dynamics more apparent.



A simulation of price vs. time for a population of trend followers, with noise added to simulate unpredictable outside events that influence the markets. A random fluctuation at time 300 causes the trend followers to start buying, which makes them push the price upward, creating a trend. They continue buying until roughly time 1200, at which point the trend stops.

Figure 2 shows what happens when value investors are added to the mix. To make things simple, we assume that all the value investors believe the correct value is 1000 units. As long as the price stays within a band around 1000, they stay out of the market. When the price moves away from 1000, they make a bet that it will come back. For example, if the price is low they buy. But when they buy, they give the price a kick that tends to drive it back up. Thus, they tend to keep the price near what they consider to be the true value. We see how, even without assuming equilibrium, commonalities in perception provide a weak "force" that keeps the price close to a given level. The invisible hand of Adam Smith thus comes into view.



A simulation of a population consisting of value investors and trend followers. The price is the finely dashed jagged curve. The value investors all perceive a common true value of 1000. Once the price moves out of the channel they buy or sell accordingly. Different investors have different thresholds; the solid line shows where value investors are entering the market at any given time, and the dashed solid line shows where they exit the market. The trend followers tend to drive the price out of the channel, creating opportunities for value investors.

By causing trends, the trend followers make the price move away from the true value faster than it otherwise would. This is evident in Figure 2 at about time 2300, where a strong trend causes the price to rapidly move from undervalued to overvalued. Trend followers "feed" value investors. Without trends, the price would spend more time around the true value, and there would be fewer opportunities for value investors. This in turn might make the price more prone to wandering, since the market would not be able to support as many value investors. This begins to illustrate the complexity of the interactions in financial ecologies: By themselves, trend followers tend to destabilize the market, but in concert with value investors, they may actually contribute to its stability (this needs further study).

If there were a continuum of different strategies, with no clumping together of traders to particular strategies, the patterns of trading would blur together and they would tend to cancel each other out. But if there are distinct groups of traders, then each group will tend to trade at different times. Patterns occur when a particular group becomes more active while the others are less active.

Food Chains

There is an analogy between the interaction of different types of traders in a financial ecology and a food chain in a biological ecology. At one end of the food chain are "customers" who want insurance, such as a farmer who needs to lock in the price of wheat, or an automobile manufacturer who uses parts manufactured in a different country and doesn't want the risk of currency fluctuations. To eliminate these risks they buy future or forward contracts which guarantee a given price some time in the future. Their broker buys this from a market maker, who provides liquidity by always being willing to either buy or sell. The broker gets a commission, and the market maker tries to make a profit from the spread, i.e. buying at a slightly lower price and selling at a slightly higher price. The market maker turns around and unloads this on a speculator, who has a directional view and is willing to take on the risk over a longer term. In return for taking on risk, speculators tend to profit from customers. For providing liquidity (and taking on short term risk), market makers tend to profit from everyone. Each group needs the other.

Evolution and Efficiency

Markets evolve with time. This occurs in many ways. As the global economy grows there is more trading and there are more market participants. With the accumulation of knowledge and experience, strategies diversify and become more complex. With new technologies, such as computers, there is a greater ability to make transactions and process information. Increased computational capabilities and improved understanding of risk stimulate the introduction of new financial instruments, such as futures and options. This in turn alters the price dynamics, which affects the profitability of pre-existing strategies.

One of the long-standing and prevalent assumptions in economics is that markets are efficient. Roughly speaking this means that if one finds a strategy that makes money, after a short period of time others will also discover it, and their trading will cause the original strategy to cease to make money. One of the nice features of the theory I have outlined here is that it becomes possible to find out under what circumstances this is true. The answer that emerges is that efficiency is not always guaranteed. For example, suppose you discover a way to detect the beginning of an upward trend. To exploit this discovery, you buy when you think the trend is about to start. This causes the price to rise a bit sooner than it would have without you. But the trend followers are waiting for just such a price rise to buy, and they buy even more. As a result of your additional trading, the trend starts earlier and is stronger; the pattern is *enhanced* rather than diminished.

In general what is apparent is that efficiency is only part of the story. As traders change their strategies in response to finding better profit making opportunities, temporal patterns evolve but do not necessarily disappear. For example, when exploiting a trend as discussed above, there is an advantage to going first. The trader who buys first will make the most profits (providing he or she exits at the appropriate time), and the traders who take their positions last will lose. Thus, since traders are motivated to make a profit, the original pattern will tend to extend and evolve toward earlier times as more traders get involved trying to exploit it. This drive to be the early bird is one of the forces behind the increased automation and processing of information by computers.

In most cases the only way to be sure that one has discovered a true pattern rather than a fluke is through statistical analysis. This puts a limit on the rate at which markets can become efficient. Even very successful trading systems generally require several years to accumulate a long enough track record for one to know with confidence that the profits are due to skill rather than luck. As a result, one can expect that, when it occurs, the progression to market efficiency proceeds on a timescale that is measured in years.

One of the most interesting questions about market evolution concerns the trend toward greater complexity. It appears that markets have tended to become more complex through time. There has been a general increase in the number of market participants, and more recently, a growing reliance on more complex strategies that require computers. Can this be understood from a theory? I cannot show (yet) that the theory discussed here predicts this. However, it is fairly simple to show something that suggests that it may be the case. In particular, there always exists a strategy that will outperform all other strategies. This is the strategy that knows about all the other strategies. Since this strategy can anticipate the aggregate buying and selling of all the participants better than any other strategy, it can make the best forecast of future price movements, and is the most profitable strategy. Since it has to know about all other strategies, it is also more complex than any other strategy. Providing this strategy (or some approximation of it) can be repeatedly discovered, there will be a progression toward greater complexity, as at each stage the population of strategies becomes more complex. There are of course complications. For example, every time a new strategy enters it may drive previously good strategies to extinction by turning them into losing strategies. Nonetheless, this hint of an explanation of the progression toward greater complexity is exciting because this has been a long standing mystery for evolution in general. (Some biologists, such as Stephen Gould, deny that such a trend even exists at all).

What is the Social Function of Financial Markets?

There are many factors that motivate people to do what they do: Among them are sex, ideology, fame, and the need for respect and affection. But there is no doubt that one of the most important is money. As a baseline we all want to survive, which requires a fundamental level of economic well being. And most people want more than that. Financial markets perform the function of setting prices. This determines what things are worth, which in turn affects people's goals and activities. If the price of pork bellies is high, more people will grow pigs. If the stock of an automobile company performs well, more people will buy it, and the company will have the option to invest, employ more workers, and produce more automobiles. When prices rise it implies that, for whatever reason, society has decided that the associated goods and the activities required to produce them are valuable.

The beauty of the way financial ecologies work is that price setting happens spontaneously, without high-level, top-down conscious direction. Although the process of price-setting can be flawed, sometimes generating insane behaviors such as boom-bust cycles, it seems to work better than alternatives, such as centralized price fixing. It is a bottom-up, self-organizing process: Individual agents compete to maximize their own objectives; in the course of processing information and making decisions a price emerges from their collective activity. Markets evolve more or less incrementally from more primitive antecedents. Competition at one level results in collective self-organization at the next level. This is not peculiar to financial markets, but rather a universal evolutionary principle that plays itself out on many different stages.

In saying this I am by no means promoting a laissez-faire ideology. Trial and error has shown that governments have an important role in setting and enforcing the basic rules of commerce, providing social stability, and regulating practices that stifle competition. Monopolies were prohibited by the most ancient laws of China, India, and Babylonia. The law for regulating markets has co-evolved along with the markets themselves, and the history of the world economy is littered with failed experiments. In general one should be wary of simplistic interpretations and extrapolations of evolution from one context to another. For example, in the latter part of the 19th century Social Darwinists took a good idea–that societies evolve like biological systems–and used what has now been shown to be a misunderstanding of biological evolution to argue for a lot of bad ideas–like racism.

Universal Principles

The main message that I hope will emerge from this model of financial ecologies to generalize for other evolutionary contexts is that it doesn't take much to get a self-organizing evolutionary process going. The basic elements of the model for finance discussed above are:

— A selection mechanism.

— Dynamics that couple different strategies together and make them depend on each other for selection.

— A mechanism for implementing strategies. This necessarily involves the storage and use of information.

Each strategy operates locally, and selection operates locally. But the dynamics couple the strategies together, because their selection value (in this case their profits) depends on that of other strategies. The result is a local process that is driven from the bottom up, yet has emergent global behaviors.

The Immune System and Other Microcosms of Evolution

One of the most fascinating aspects of evolution is that a given complex evolving system may be composed of many different evolving subsystems. This is particularly clear in societies where the economy, the government, the military-industrial complex, organized crime, or religion, are all entities unto themselves with their own self-perpetuating evolutionary survival strategies. Evolution is also used in many different contexts *within* biological organisms.

When I first heard the term "InfoWar," the immune system immediately came to mind. In an analogy between your body and society, the immune system plays the role of the military-industrial complex. It protects you from invaders, in this case making sure that you are really entirely yourself. The process of distinguishing self from other is indeed information-intensive. There are an enormous number of possible distinguishable chemical configurations, and the difficulty of distinguishing those that are you from those that are not has been likened to the problem of recognizing a single face out of a billion possibilities.

The immune system is a microcosm of internal Darwinism. B-cells are factories for producing antibodies that serve as flags to label invaders so that killer cells can then remove them. When a chemical configuration is recognized as foreign, the B cells that match them are selected and stimulated to reproduce. The mechanism for achieving this is overtly Darwinistic. To guarantee a good match, when the B cells reproduce, a hypermutation gene is switched on. This gene makes the replication of the part of the DNA that controls the receptors for identifying invaders unusually sloppy, so that mutations occur at an amplified rate. These mutations make sure that the large space of chemical configurations is thoroughly covered. An entire evolutionary selection process takes place over the course of only a few days. The cells that provide the best match to the invader are allowed to reproduce quickly, so that their genetic line is amplified, while those that do not are suppressed. After a couple of days, assuming the process is successful, there are a large number of cells producing antibodies that closely match those of the invader.

Once all the invaders have been properly identified and tagged killer cells can find them and remove them. For example, consider a tumor, which is just a distortion of you that is trying to take you over. Figure 3a shows a killer cell that has just finished drilling holes in a (much larger) tumor; figure 3b shows the remnants of this tumor after the holes have caused it to explode, with the victorious killer cell triumphantly remaining.

As we see, your body uses survival of the fittest as part of its tool kit to keep you alive and protect you from invaders. It grows a crop of useful cells through random variation and its own internal version of natural selection. The process of making the identification that results in selection is highly complex, involving several types of cells and a multitude of regulatory molecules that act like the switching elements in a computer. It is a high stakes game in which the victor lives and the loser dies. It is an ongoing "InfoWar" that is happening inside your body all the time.

The Internet and Beyond

While I have argued that "InfoWar" is nothing new, with the rapid development of computer technology and the advent of the internet there is a qualitative change in the ability of society to process information. There is an impending identity crisis for homo sapiens, as our monopoly on high-level consciousness is threatened by possible self-organizing behaviors of our own cyber-creations.[5] roughly 2025 the raw processing power of a single computer will rival that of the human brain. The bulk of the traffic on the information highway of the future is likely to be computers communicating with each other. While the possibility of the emergence of consciousness in such a network is still hotly debated, many of us have no doubt that it will happen. The possibilities for the evolution of new conscious organisms are further expanded by the soon to be completed sequencing of the human genome and the rapidly developing industry of genetic engineering. We will evolve into something beyond human. The resulting hybrid cyber/organic super-conscious society of the future is difficult to imagine.

Regardless of the precise form of these information-based organisms of the future, certain basic principles seem clear. A simple extrapolation from present examples, including ecosystems, financial markets, or the immune system, suggests that competition and selection will continue to be the organizing principle. Order and structure will emerge spontaneously, and complexity will tend to increase. The struggle for more and better information, and ever-enhanced information processing and decision-making will be central. The goal will be both information for its own sake and information for its ability to capture and control physical resources. "InfoWar" will become even more important in the future than it has been in the past.

[1] Herbert Spencer, *Structure, function, and evolution*, Charles Scribner's Sons, New York 1971 (a collection of essays originally published between 1862 and 1893).

[2] J.D. Farmer, *Market force, ecology, and evolution*, in preparation.

[3] Richard H. Thaler, *An introduction to behavioral finance*, 1996 preprint.

[4] George Soros, *The alchemy of finance*, John Wiley and Sons, 1987.

[5] J.D.Farmer and A. d'A. Belin, "Artificial life: The coming evolution", in "Artificial Life II", eds. C. Langton, C. Taylor, J.D. Farmer, and S. Rasmussen, Santa Fe Institute "Lectures in the Sciences of Complexity" Series, Addison-Wesley (1991) pp. 815-840.