Money is Funny, or Why Finance is Too Complex for Physics

Arriving at the Laws of Finance

JOHN L. CASTI

John L. Casti received his Ph.D. in mathematics under Richard Bellman at the University of Southern California in 1970. He worked at the RAND Corporation in Santa Monica, CA, and served on the faculties of the University of Arizona, NYU, and Princeton before becoming one of the first members of the research staff at the International Institute for Applied Systems Analysis (IIASA) in Vienna, Austria. In 1986 he left IIASA to take up his current post as a Professor of Operations Research and System Theory at the Technical University of Vienna. He is also a resident member of the Sante Fe Institute in Santa Fe, New Mexico. In addition to numerous technical articles and a number of research monographs, Professor Casti is the author of several volumes of trade science, including Paradigm Lost, Searching for Certainty, Complexification, *and* Would-be Worlds.

Virtually all conventional theoretical models of economic phenomena and, perforce, all mainline academic models of finance, rest upon a metaphor drawn from classical physics. The dialogue presented here shows why such mathematical and computational pictures of the world of finance—including even the newest metaphors from modern physics involving such things as chaotic processes—are forever doomed to fail as valid portrayals of the way real investors behave and the way real financial markets operate. The conclusion emerging from these deliberations is that financial modelers would be far better off consulting a biology book than a physics text for their metaphorical inspirations—finance is just too complex for physics.

THE SCENE

Event: The annual meeting of the Transworld Society for Science, Truth, and Beauty in Modeling

Date: Sometime in the very near future

Setting: A panel discussion on "Mathematical and Computer Modeling of Economic and Financial Processes—Science or Alchemy?"

Theme: Is physics a suitable metaphor upon which to base models aimed at explaining and/or predicting the behavior of price movements on speculative markets?

DRAMATIS PERSONAE

Prof. Ransom ("Randy") Walker: guru of mainline academic finance and devotee of efficient markets and rational expectations; renegade theoretical physicist turned financial analyst

Mr. D. O. W. Jones: representative from the Association of International Investment Fund Managers; training in philosophy, with an MBA in finance

Prof. Max U. Till: Viennese-born and educated behavioral psychologist; well known for his experimental work on the identification of how real people make real financial decisions in real market environments

Col. Hy R. Fees: big-time stocks-and-commodities broker; a man with no formal academic training whatsoever, but an expert in making "the right connections" (and lots of money)

Dame Bea Wright: avant-garde systems thinker, modeler, intellectual gadfly and genera! iconoclast; originally trained as a mathematician and computer scientist, but now working as a theoretical biologist and philosopher of science

Panel Moderator

THE PANEL DISCUSSION

Moderator: Near the end of the Second Epilogue of *War and Peace,* Tolstoy remarks that, "Only by taking an infinitesimally small unit for observation (the differential of history, that is, the individual tendencies of men) and attaining to the art of integrating them (that is, finding the sum of these infinitesimals) can we hope to arrive at the laws of history." Of course, in writing this passage Tolstoy was merely echoing the scientific attitude of his day, one anchored firmly in the clockwork picture of the progression of worldly affairs bequeathed to us by Newton, and enshrined in Newton's famous laws of motion governing the behavior of material bodies. But to my eye it looks as if by substituting the word "finance" for "history," Tolstoy's statement would serve equally well as a research manifesto for the mathematical and computer modeling branch of the academic finance community. Perhaps Professor Walker would care to open our discussion by commenting on this?

Prof. Walker: I don't think any of us here would deny that all economic activity ultimately rests on the "individual tendencies of men," to use the phrase from Tolstoy's elegant formulation. And it is certainly a truism that the sum total of all these individual decisions and actions is exactly what ends up determining the price of a share of stock or a barrel of oil. But financial modelers have come a long way since the time of Newton—and since the time of Tolstoy, too, for that matter.

In the 1960s financial theorists discovered earlier work by the Frenchman Louis Bachelier, who around the turn of the century was the first to study mathematically the properties of price changes of a speculative commodity. Bachelier's ideas led to what we now call the "random walk hypothesis." This is the claim that price changes for any commodity fluctuate randomly. As a result, theorists claim that a history of such price information cannot serve as the basis for any kind of trading scheme, or rule, that can consistently outperform the market as a whole, measured by, say, something like the S&P 500 index of stock prices on the New York exchanges. "Souping up" the random-walk theory by adding the notion of an "efficient market," essentially a behavioral assumption about the way investors make decisions, modern financial theorists have strengthened Bachelier's ideas into the so-called *efficient markets hypothesis* (*EMH*). Put simply, the EMH states that no publicly available information of any kind can form the basis for a trading rule that will regularly beat the market over a long period of time.

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Moderator: But doesn't the EMH rest on assumptions that are just translations into financial terms of many of the very same assumptions underlying the Newtonian models of how material objects like planets and billiard balls behave?

Prof. Walker: Speaking as a former physicist, I can hardly deny that. The hypothesis of market efficiency is basically an equilibrium assumption, saying that investors behave so that any imbalance in supply and demand generated by new information coming into the market is immediately counteracted. This kind of negative feedback effect then acts to generate price movements that tend to push prices toward a single, global, stable equilibrium level at which both buyers and sellers are satisfied. And such a single, stable equilibrium is definitely a central aspect of the Newtonian picture of the movement of material bodies.

Furthermore, the EMH assumes that all investors act in a purely rational manner on the basis of their expectations of future prices. More specifically, the assumption is that each investor forms an estimate of tomorrow's price and then acts today so as to maximize his or her expected marginal return. So, speaking loosely, you might say that the rational expectations assumption is a finance-world version of the principle of minimal energy governing the behavior of a system of Newtonian particles.

And, of course, the essence of the whole EMH idea is that finance is not a historical process, in the sense that the particular path taken in arriving at today's price has no influence whatsoever on what will happen tomorrow—just like tomorrow's position of the Moon is determined only by where it is today and not how it came to be in this location. So if you want to think that these features of the EMH suggest a kind of physics-envy on the part of academic finance theorists, you have my blessing. After all, why shouldn't we base our models on those of physics? They are by far the most well-developed, coherent, and successful set of theories we humans have ever created for describing in scientific terms the way the world seems to work.

Mr. Jones: Maybe these theories do a good job of describing the worlds of black holes, planets, quarks, and billiard balls. But if you'll pardon the neologism, those Newtonian notions don't seem to fit my world of *Realfinanz,* at all. In this world I see as much irrationality and "group-think" as I do cool, calculated, rational behavior. Personally, I think this rational expectations business is a lot of abstract "it in the sky" invented by you professors of finance to debate at academic conventions and write scholarly articles about.

I don't think it makes one bit of contact with the way things actually work on the floor of the exchange.

Col. Fees: Hrumph! Hrumph! I dare say old boy I'm forced to agree with you. Some of my clients are real boffins, frightfully good chaps with numbers, formulas, and that sort of thing. And some of them have told me about various stock market anomalies, things like the Value Line enigma, the low price/earnings effect and the small-firms phenomenon, each of which certainly seems to put the lie to the EMH. Why, one of my American clients even says he can forecast the long-term movement of the market using the outcome of their Super Bowl football game, whatever that is. Some sort of American rugby I gather, not real football at all. The fellow's slightly barmy, if you ask me. Nevertheless, he swears that this Super Bowl indicator works more than 90 percent of the time. But even if it doesn't, I can hardly think of a more irrational scheme for betting, err… I mean investing, on the market. How can football scores have anything to do with stock prices? Sounds like a lot of claptrap to me. Complete rubbish!

Moderator: Hmm, yes. Ah… thank you very much, Colonel Fees. Let me shift the discussion for a moment to one of the most exciting new scientific ideas to hit the world of theoretical finance since the random-walk theory. Of course, I'm referring to the claim that price changes follow what the mathematicians call a "chaotic" rule. A lot of edge-of-the-frontier financial thinkers currently seem to believe that there really do exist definite rules, or recipes, according to which price histories are generated in a fixed, even deterministic way. But the problem is that whatever the precise form of these rules may be, the result of applying such a rule to past prices leads to a chaotic, "incompressible" sequence of numbers. So, although a definite rule for price changes may indeed exist, we could never hope to make use of it in any practical way to predict the future course of price movements.

Mr. Jones: Why not? If we know the rule, then it should be straightforward to employ it to calculate what the markets will be doing next.

A lot of edge-of-the-frontier financial thinkers currently seem to believe that there really do exist definite rules, or recipes, according to which price histories are generated in a fixed, even deterministic way.

Moderator: The reason why such a chaotic rule cannot be applied to past price changes in order to predict future ones is that the outcome of following such a rule is pathologically sensitive to any errors we make in measuring the past price information or in carrying out the computations called for by the rule. In the language of physics, this kind of prescription for price changes is unstable in the worst possible way. So even if we knew the exact form of the rule (which we most assuredly do not), since data are almost always known imprecisely and computations are carried out only to a fixed degree of precision, the predictions obtained from following this kind of chaotic rule rapidly degenerate to meaningless nonsense. Ironically, this unpredictability of price changes is just what the random-walk theory claims, too-but for very different reasons. However, even if there is some magical chaotic rule that really is the one true mechanism by which market prices fluctuate, I still wonder how it fits in with the deeper issue of whether physics—classical or chaotic—is a suitable metaphor upon which to build valid models of the behavior of financial markets. I know that Dame Wright holds some rather definite views on this matter.

Dame Wright: Indeed. To mathematically represent price changes with a model displaying chaotic behavior, thereby thinking you're making progress in financial modeling, is like thinking you're making progress in getting to the Moon by going out into your garden and climbing a tree. Both show the same singular lack of understanding of the basic nature of the problem.

Chaotic dynamical processes depart in no essential way from the Newtonian paradigm of a clockwork universe. Their only novel feature, and the source of all the recent brouhaha about "chaos" in the popular and scientific press, is that they display a new type of long-run behavior quite unlike that shown by more traditional dynamical processes. Classical Newtonian systems have two types of long-run behavior: (1) an equilibrium point of the type a marble rolling around inside a soup bowl ends up at, or (2) a periodic orbit like the path the Earth takes in its annual tour around the Sun.

In addition to these classical types of "attractors," which were known even in Newton's time, chaotic processes can show a third type of long-run behavior called a "strange attractor." Instead of being points or closed orbits, strange attractors look a lot like a bowlful of spaghetti. This means that small, perhaps unmeasurable—or even unknowable—disturbances to the system can push the system trajectory from moving along one strand of spaghetti to motion along another. And in this way the process goes off onto an entirely different course of behavior. As our moderator already mentioned, it's this almost pathological type of sensitivity to disturbances that gives rise to the great difficulties we have in predicting what a chaotic system will do next. But the underlying framework is still resolutely Newtonian—and in exactly the sense we spoke of earlier. All that's been added to Newton's picture is this third type of attractor.

Prof. Walker: Perhaps Dame Wright would care to enlighten us by spelling out just what she thinks a proper, 21st-century non-Newtonian framework for modeling financial processes should look like?

Dame Wright: I'm glad you asked that question, Professor Walker. Earlier you told us that EMH-oriented financial theorists regard finance as a nonhistorical science. I often wonder how professors of finance can make such statements with a straight face. It doesn't take much by way of deep analysis of the literature or detailed study of the behavior of actual markets to see that this can't possibly be the case. Future price changes are dramatically affected by the particular path a market has taken in getting to its present level. For example, if the S&P 500 index stands at 370 today, it's ludicrous to think that tomorrow's level doesn't depend in crucially important ways on exactly what path events took leading up to the index being at this level. I think anyone with even a modicum of street smarts will tell you that if the 370 level is reached in a climate of steadily rising interest rates and unemployment; that's a totally different story than seeing the index at 370 against a background of declining interest rates and increasing consumer confidence. The big runup in stock prices in early 1991 following the Gulf War is a perfect example illustrating the point. Of course, EMH advocates have constructed many devious schemes to try to circumvent this glaring deficiency in their financial *Weltanschauung.* But you can't sweep the dirt under the rug forever. Eventually you've got to toss it into the trash barrel. And that means creating a modeling paradigm that's specifically designed for the peculiarities of financial markets and human beings, not billiard balls and planets. So the first feature a non-Newtonian modeling paradigm for finance should display is some kind of provision for path-dependence in its descriptive framework.

Mr. Jones: But what about things like market crashes, tulip manias, and all the other situations in which rapid, discontinuous shifts in prices occur? Don't you think something like the chaos-type models might be the best way to account scientifically for these kinds of booms and busts?

Dame Wright: Not necessarily. Any dynamical process, chaotic or otherwise, that admits both stable and unstable long-run behaviors can give rise to such rapid, jerky kinds of shifts under appropriate circumstances. And, in fact, if you give me a set of price changes, I'll give you back an infinite set of rules (i.e., models), all of which will reproduce your price history exactly. Good models of reality give us genuine *insight* into that reality, not just good agreement with what's been observed. And the business of science is knowing the why of things, not just the what or even the when. So any type of recipe for price movements that merely agrees with observed past price histories is very far from being a "good" model, at least in a scientific sense.

This means that choices are made so that we tend toward an equilibrium state in which equal margins of satisfaction come from each possible activity. This is the principle of maximal marginal utility.

Prof. Walker: But, but.

Dame Wright: Please allow me to finish. I'm not saying that these chaos-based models are necessarily on the wrong track; I'm saying simply that they don't as yet make explicit provision for the sort of *explanatory* features that a good mathematical reflection of market reality should display. Or, at least, what a model should contain if it's to give us any genuine insight into what's happening in these markets and why. For example, not only are the current models inherently nonhistorical, they are also pitifully inadequate when it comes to their built-in assumptions about the psychology of market participants, as both Mr. Jones and Col. Fees have already mentioned in connection with the rational expectations fairy tale.

Moderator: You've raised a vitally important point regarding the way real-life investors behave when faced with real financial decisions. Professor Till is well known for his ingenious experiments aimed at determining just exactly how these real investors do in fact behave when hard cash is on the line. Could you please tell us about some of your findings, Professor?

Prof. Till: Ja. It is my pleasure. We have built a mini-exchange in our laboratory mit students playing on this market with real money. What we have discovered is that speculative "bubbles" come always, even when traders know the market price is far above the fundamental stock value. These bubbles, they are caused by inexperienced and over-eager traders. When we try to remove these bubbles by adding futures trading, margin buying, short selling and rules to stop trading when the market falls by a certain amount-what the press calls "circuit breakers"—we find that only futures trading reduces the size and duration of these bubbles. It is funny that circuit-breaker rules actually make these bubbles bigger and last longer-before the big crash.

Col. Fees: Jolly good, Professor. Maybe your results will convince the SEC and other market meddlers that the brokers were right after all, and that these circuit-breaker rules only make markets more volatile, not less.

Mr. Jones: Tell us, Professor, what have you discovered about the behavior patterns of individual traders?

Prof. Till: We have discovered that traders get carried away in rising markets, bidding prices up instead of buying on fundamentals like price/earnings ratios or expected dividends.

We also made a very important empirical discovery. We discovered that individuals do not maximize utility in the way economists think. Standard theory tells us that an individual makes choices to maximize marginal utility. This means that choices are made so that we tend toward an equilibrium state in which equal margins of satisfaction come from each possible activity. This is the principle of maximal marginal utility. We find this assumption is completely wrong.

Our experiments show that traders tend to maximize *average* utility, not marginal. What this means is that they use a nonstandard formula to discount time. Standard theory says time is discounted at a constant rate; we find that time is discounted at a *hyperbolic* rate. So rewards not only take on different values at different times in the future, they lose value at different rates too. This kind of discounting predicts that traders will initially act rationally; but eventually they will fail to do so.

Mr. Jones: But why would traders follow such a discounting rule? It seems that by doing this they are acting against their own selfish interests, giving up gains that they could have received through maximizing marginal returns in favor of the lower returns they get from this hyperbolic discounting scheme, which maximizes only their average utility.

Prof. Till: Ja. This is the key question. Hyperbolic discounting is nonoptimal—maybe! The problem is with how you measure what is optimal. We think that the solution is that it is much easier to calculate average utility than marginal. So we believe that although marginals are needed for truly rational behavior, they are hard to compute. Most people lack the information and analytical power to compute them reliably. Also, these marginals, they are very unstable; a small mistake in the data or in the computation, it leads to a big error in the end result. So we think that over the millennia evolution has favored the computation of average utility, not marginal. This means that investors, they do not act like rational expectations theory says.

Moderator: So would you conclude, Professor, that another crucially important feature that a new framework for financial modeling should incorporate is some replacement for the rational expectations hypothesis?

Prof. Till: Jawohl! What we need is some new way to represent how traders really form expectations of the future.

Dame Wright: Perhaps a helpful way to think about this matter is to say we need to inject a form of self-reference into the paradigm for finance. I think even Professor Walker would agree that every trader has some kind of internal mental model of both the market and himself, which he runs on a time scale faster than real time in order to generate his individual expectation for the future. Our non-Newtonian view of financial markets should explicitly incorporate these self-referential models somehow, as well as include learning procedures by which these models get updated. The rational expectations hypothesis neatly does away with this problem by the crude expedient of just assuming that all traders use the same maximal-marginal-return model for the future and, moreover, that the model is never updated. But we know that not everyone has the same attitudes toward risk, nor do people fail to learn from past experience. So again we find the conventional wisdom of the EMH being more of an academic fantasy than an account of how the players act in any real financial market.

Somehow it seems as if the physics-based frameworks are just too simple, in Einstein's sense, for the real world of finance.

Prof. Walker: Naturally, we always simplify real-life situations for the sake of arriving at a formulation of the problem that we can work with. It would be totally impractical, if not impossible, for our models to account explicitly for every trader's personal picture of the market and himself. Scientific theories and models are always simplifications of the real thing. And the rational expectations hypothesis is just such a simplification.

Dame Wright: I think it was Einstein who once remarked, "A theory should be as simple as possible-but no simpler." By this, I think what he meant was that what separates a good theory from a bad one lies in the choice of the features of the real situation to include in the theory and what aspects to leave out. In my opinion, the traditional EMH-based models of financial markets, including the ones based on chaotic dynamics, end up throwing out the baby with the bathwater.

Moderator: Well, I see our time is running short. So I'm afraid I'll have to bring this very thought-provoking discussion to a close. But before doing so, let me try to summarize what's been said here today.

My sense of the discussion is that the conventional physics-based paradigm for modeling the price changes on speculative markets is in deep trouble, epistemologically speaking at least. Some radically new framework, or paradigm, seems to be called for that would, at the bare minimum, incorporate the following features: (1) positive (i.e., deviation-amplifying) feedbacks, thereby admitting the possibility of processes having both stable and unstable modes of long-run behaviors, (2) path-dependence of price changes, (3) new behavioral assumptions replacing the notion of strict rationality, and (4) the self-referential, anticipatory models of individual traders.

When I look at this list of desiderata, I can't help thinking that what we're talking about here is a modeling metaphor that's a lot closer to something we might see in a biology book than what's on offer between the covers of a physics text—classical or modern. Somehow it seems as if the physics-based frameworks are just too simple, in Einstein's sense, for the real world of finance. If we're ever going to get a scientific handle on the ways of financial markets, let alone on the larger universe of social and behavioral phenomena, it looks as if we'll be forced to move away from the realm of the simple systems of physics and confront complex systems head-on. From what we've heard from the panel today, finance is just too complex for physics.

Now let me thank the participants for taking time today to give us their views on this fascinating topic. Perhaps we can continue this discussion at next year's TSSTBM meeting. Hopefully, by then some of today's discussants, or even some of you in the audience, may have new ideas and research results to share with us about how to deal with the complexities of finance. So until then, I wish you all the best of luck in your individual gropings and copings with complexity—wherever and whenever you stumble over it!