Real Options 'in' Economic Systems: A Proposed Resolution to Problems in Modern Market and Neo-Classical Economic Theory

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Abstract: **"**I contend that rational expectations theory totally misinterprets how financial markets operate. Although rational expectations theory is no longer taken seriously outside academic circles, the idea that financial markets are self-correcting and tend towards equilibrium remains the prevailing paradigm on which the various synthetic instruments and valuation models which have come to play such a dominant role in financial markets are based. I contend that the prevailing paradigm is false and urgently needs to be replaced." (Soros, 2008:**6**)

This conceptual paper will take on the Soros challenge, using the concepts and methodologies of "real options *in* economic systems" and adding fresh thinking about data sources and the meaning of risk. It will examine the shortcomings and fallacies associated with modern portfolio and capital market theory and neo-classical economics and ask many disquieting questions. General solutions, based in real options thinking for systems design, will be proposed and extended to the outer edge of global economic systems as found in the underground economies of the developing world.

Dedicated to Dr. Richard de Neufville, whose work in real options 'in' engineering systems has opened new vistas for economic systems model design

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1.0 Introduction

This conceptual paper revisits the challenges faced by economic systems in the early 21st century. It identifies a potential source of dysfunction, found in the tenets of modern portfolio theory as grounded in neo-classical economics, and asks discomforting questions that prove just how dysfunctional these tenets may be. It suggests applications of real options 'in' economic systems as a way forward and proposes fresh insights drawn from computer science/complexity theory that could be used to populate real options models. It concludes with avenues for future research and application.

Since the subject under consideration is vast and has received decades of attention, research, data-gathering, practical application, and so forth, the intent of this paper is not to offer an encyclopedic, point-by-point review and refutation of modern portfolio theory or the underlying economics. Nor is it to propose fully-formed quantitative models that correct the deficiencies of the current models. Its purpose is, rather, to highlight certain salient areas of theoretical weakness, indicate that a range of market participants also consider these to be weaknesses, and offer suggestions for thought and further research.

2.0 Summary Problem Statement

The "Great Collapse of 2008" emphatically illustrates the complexity, interdependence, and risk of modern economic systems. A wide array of cogent reasons for this latest crisis has been offered. However, there may be one fatal flaw in the "state of the system" that goes unnoticed because it is at such a fundamental level and is generally considered beyond question. I suggest that flaw is the failure of modern portfolio theory, grounded in linear, deterministic neo-classical economics, to provide the proper foundation for financial problem solving and decision making, given the actual state of the system.

3.0 State of the System

State of the system: Global, national, and local economic systems are marked by increased complexity and turbulence, creating increased, and different, sources of risk. We discuss in more detail some of the attributes of the state of the system that are having a profound effect on the ongoing viability of modern portfolio theory and neo-classical economics.

3.1 The exponential growth of market and transaction complexity. Increasingly sophisticated investment vehicles, enhanced computer-based trading and desk-top trading, 24x7 markets, global currency flows, Internet collaboration, consolidating exchanges and exchanges that operate as public companies – these all have profound effects on the traditional functions of markets. However, while traders build innovative algorithmic models to describe and manipulate new market functions, the fundamental financial theory on which they are built remains the same.

3.2 The increased presence of governmental and regulatory influence over every area of life. Organizations are expending massive amounts of time and resources to adapt to and mitigate the requirements of government and regulatory bodies, world-wide. Tax rules and other regulations and laws continue to burgeon. Government acquires massive new sources of debt with no economically viable source of cash inflow to sustain them. And fearful citizens call for even more draconian government oversight. Yet, none of our market decision models make more than a passing effort to include the effects of government on value – a "risk-free" rate, rates of inflation, a nebulous factor called "systematic risk."

3.3 The exponential growth of global data and information that must be considered and processed on a practically real-time basis. Information systems and brilliant programming are taking the place of human interface in order to support warp-speed market decisions in a "data smog" environment. But these systems are only as good as the models used to process and manipulate the data flowing into them.

3.4 The explosion of operating and financial complexity in economic systems worldwide. Industry and cross-industry consolidation, globalization, and new and exotic markets, industries and products requires an increasingly broad range of organizational and transaction structures, many of which are highly complex. Market participants must address such complexity in meaningful and accurate ways. While they build increasingly opaque and complex models to do so, they continue to use model assumptions that may no longer be capable of handling the task.

3.5 The influence of intangible assets on organizational structure, growth, complexity and value. As market attention has shifted toward intangible assets and away from tangible ones as the source of firm value, market participants face a dilemma. They must devise methods of measuring and managing the influence of such assets on the organization and its benefit streams, as well as quantify their influence on organizational projects and costs of capital. Yet, most of these assets are neither separable nor transferable, two attributes necessary for resource measurement and management.

3.6 The heightened potential of unforeseen and/or unforeseeable random acts of violence, or systemic surprises (i.e., Black Swans) that disrupt economic systems on a global scale. Prior to the Great Collapse of 2008, this topic was considered an outlier by most sophisticated academics/practitioners and all lay people. Post-collapse, it has become a central concern.

New sources of risk, such as these, create new sets of questions: Do modern economic systems actually function in the ways that are commonly described in the traditional literature? If they do not, how should we describe them? Can modern economic systems afford to view risk and complexity in the traditional way? Should portfolio/market/economic theory and quantitative finance more explicitly reflect the dynamism, complexity and risk inherent in system and organizational resources and activities?

To begin to answer such questions, we will first revisit some of the fundamental concepts that may be standing in the way of progress. We will then ask further questions before proposing a solution.

4.0 Revisiting the Fundamentals: Quantitative Analysis

There are three areas of quantitative analysis that appear to be the source of much poor theory and practice – statistics, economics, and behavioral finance. Each is a valuable discipline that has often been misused and/or misunderstood. The following subsections present uncomfortable challenges to the everyday practice and interpretation of statistics, neo-classical economics, and behavioral finance. It closely examines certain dysfunctions in our use of quantitative analysis that affect the way in which economic/market theory is built and used and market decisions are made.

4.1 Statistics is not mathematics. Statistical analysis is the underlying quantitative tool by which most research into and discussion of economic systems is performed. It appears, however, that, while many or most participants in economic systems utilize statistics to discuss, describe, and quantify market information and activities, they do so by rote, without a clear understanding of its strengths and shortcomings. We tend to attribute to statistics the aura of objective fact, when its statements and conclusions more closely belong to the category of subjective judgment. This may lead to insufficient, false, or harmful conclusions, decisions, and initiatives.

The formulation and use of statistics is not strictly mathematical, though it employs cardinal numbers in equations that appear mathematical. Mathematics is the "[s]cience of structure, order, and relation that has evolved from counting, measuring, and describing the shapes of objects. It deals with logical reasoning and quantitative calculation, . . . [and includes among its] principal branches . . . algebra, analysis, arithmetic, combinatorics, Euclidean and non-Euclidean geometries, game theory, number theory, numerical analysis, optimization, probability, set theory, statistics, topology, and trigonometry." (Encyclopedia Britannica)

Statistics, while listed above as a branch of mathematics, differs from other branches in that it is the probabilistic study of relationships between data sets and among the data in a set. It is based, not on measurement of specific data, but on the gathering, description, and comparison of ranges of data (populations and samples). The results of statistical analysis are not solutions. They are pictures of the probabilities of certain relationships occurring in a hypothesized manner within a specified range or ranges. Thus, statistical analysis embeds uncertainty, variability, and subjective judgment.

We cannot manipulate statistical equations in the same manner as we manipulate mathematical ones without the danger of losing the sense of the relationships they describe. However, we can manipulate the data inputs in statistical analyses in ways that misrepresent reality and mislead the user, while appearing to remain tightly within the given statistical parameters. Using statistics, we gain general understandings, rather than build irrefutable conclusions.

4.2 Economics is neither mathematics nor a natural science. Neo-classical economics is generally assumed to be the only correct approach to economic analysis. Its assumptions are taught and adhered to universally in business schools and other market-related educational venues. In fact, it is commonly attributed with the status of a pure science and discussed/utilized as such.

Yet, increased global upheaval and volatility should call into question many of the tenets of neo-classical economics, including its status as a science. Decades ago, the Austrian School of economics asked questions we should be asking today. This school of economic thought was, and is, more realistic and more progressive than its better-known, universally accepted counterpart. I suggest that the economic context for real options thinking and analysis is found with the Austrians. We will, therefore, quote them at length where relevant to this paper's goals.

With regards to economics as a science or a form of mathematics, Ludwig von Mises wrote (von Mises, 1949: **55-56**, **118, 92, 105**),

> There are, in the field of economics, no constant relations, and consequently no measurement is possible. If a statistician determines that a rise of 10 per cent in the supply of potatoes in Atlantis at a definite time was followed by a fall of 8 per cent in the price, he does not establish anything about what happened or may happen with a change in the supply of potatoes in another country or at another time. He has not 'measured' the 'elasticity of demand' of potatoes. He has established a unique and individual historical fact. . . . The impracticability of measurement is not due to the lack of technical methods for the establishment of measure. It is due to the absence of constant relations. . . . Economics is . . . . not quantitative and does not measure because there are no constants. Statistical figures referring to economic events are historical data. They tell us what happened in a nonrepeatable historical case. . . .
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> . . . The fundamental deficiency implied in every quantitative approach to economic problems consists in the neglect of the fact that there are no constant relations between what are called economic dimensions. There is neither constancy nor continuity in the valuations and in the formation of exchange ratios between various commodities. Every new datum brings about a reshuffling of the whole price structure. . . .
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> . . . [Furthermore] praxeology [the science of human action] does not deal with the external world, but with man's conduct with regard to it. Praxeological reality is not the physical universe, but man's conscious reaction to the given state of the universe. Economics is not about things and tangible material objects; it is about men, their meanings and actions. Goods, commodities, and wealth and all the other notions of conduct are not elements of nature; they are elements of human meaning and conduct. . . . [F]rom the human point of view action is the ultimate thing. . . [M]an chooses and acts and . . . we are at a loss to use the methods of the natural sciences for answering the question why he acts this way and not otherwise. . . .

> . . . Natural science does not render the future predictable. It makes it possible to foretell the results to be obtained by definite actions. But it leaves impredictable two spheres: that of insufficiently known natural phenomena and that of human acts of choice. Our ignorance with regard to these two spheres taints all human actions with uncertainty . . . The most that can be attained with regard to reality is probability." (von Mises, 1949: **92, 105**)

Frederick von Hayek, writing on the same topic in his 1974 Nobel Memorial Lecture, "The Pretense of Knowledge," states:

> [Economists attempt to] . . . imitate as closely as possible the procedures of the brilliantly successful physical sciences. . . . Unlike the position that exists in the physical sciences, in economics and other disciplines that deal with essentially complex phenomena, the aspects of the events may be accounted for about which we can get quantitative data are necessarily limited and **may not include the important ones**. [emphasis added] While in the physical sciences it is generally assumed, probably with good reason, that any important factor which determines the observed events will itself be directly observable and measurable, in the study of such complex phenomena as the market, which depend on the actions of many individuals, all the circumstances which will determine the outcome of a process . . . will hardly ever be fully known or measurable. And while in the physical sciences the investigator will be able to measure what, on the basis of a *prima facie* theory, he thinks important, in the social sciences often that is treated as important which happens to be accessible to measurement. This is sometimes carried to the point where it is demanded that our theories must be formulated in such terms that they refer only to measurable magnitudes. . .
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> . . . We know: of course, with regard to the market and similar social structures, a great many facts which we cannot measure and on which indeed we have only some very imprecise and general information. And because the effects of these facts in any particular instance cannot be confirmed by quantitative evidence, they are simply disregarded by those sworn to admit only what they regard as scientific evidence. They thereupon happily proceed on the fiction that the factors which they can measure are the only ones that are relevant. . . .
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> . . . In some fields, particularly where problems of a similar kind arise in the physical sciences, the difficulties can be overcome by using, instead of specific information about the individual elements, data about the relative frequency, or the probability, of the occurrence of the various distinctive properties of the elements. But this is true only where we have to deal with . . . 'phenomena of unorganized complexity,' in contrast to those 'phenomena of organized complexity' with which we have to deal in the social sciences. Organized complexity here means that the character of the structures showing it depends not only on the properties of the individual elements of which they are composed, and the relative frequency with which they occur, but also on the manner in which the individual elements are connected with each other. In the explanation of the working of such structures we can for this reason not replace the information about the individual elements by statistical information, but require full information about each element if from our theory we are to derive specific predictions about individual events. Without such specific information about the individual elements we shall be confined to . . . mere pattern predictions – predictions of some of the general attributes of the

> structures that will form themselves, but not containing specific statements about the individual elements of which the structures will be made up. (von Hayek, 1974)

In summary, the two critical disciplines underlying the theory and practice of quantitative finance are currently misunderstood, and, therefore, misused. This must be kept in mind as we challenge traditional approaches and suggest new ones.

5.0 Revisiting Fundamentals: Behavioral Finance

Behavioral finance has identified and described a series of fallacies in human reasoning that affect financial (and other) decision making, thereby contributing key insights into the psychologies that govern economic systems. These valuable insights, however, are positioned within the traditional neo-classical economics and finance context. The realities of 21st century economic systems require more radical views. Since these radical views also are a better fit with real options concepts, we present three sets at some length, supported by extensive quotes.

5.1 Soros. In *The New Paradigm for Financial Markets: The Credit Crisis of 2008 and What It Means*, George Soros, currency speculator, investor, businessman, philanthropist, and political activist, discusses the limitations of neo-classical financial theory, behavioral finance, and models for modern economic systems. He states:

> I contend that rational expectations theory totally misinterprets how financial markets operate. Although rational expectations theory is no longer taken seriously outside academic circles, the idea that financial markets are self-correcting and tend towards equilibrium remains the prevailing paradigm on which the various synthetic instruments and valuation models which have come to play such a dominant role in financial markets are based. I contend that the prevailing paradigm is false and urgently needs to be replaced. (Soros, 2008: **6**)

This brief book, based on a long and successful career spent in some of the most risky arenas in the global financial markets, deserves serious consideration though it is not strictly academic in nature or construction. The following sub-sections paraphrase and quote its key propositions.

5.2.1 Fallibility. The concept of fallibility is fundamental to Soros' central argument. He states: (Soros, 2008: **26**)

> People are participants, not just observers, and the knowledge they can acquire is not sufficient to guide them in their actions. They cannot base their decisions on knowledge alone. . . . . The capacity of the human brain to process information is limited, whereas the amount of information that needs to be processed is practically infinite. The mind is obliged to reduce the available information to manageable proportions by using various techniques – generalizations, similes, metaphors, habits, rituals, and other routines. These techniques distort the underlying information but take on an existence of their own, further complicating reality and the task of understanding it.

5.2.2 Reflexivity. Soros identifies what he believes is the key to the failure of traditional financial theory to reflect and quantify market realities and terms it "reflexivity." (Soros, 2008: **7-8, 31**)

> . . . [S]ocial events have a different structure from natural phenomena. In natural phenomena there is a causal chain that links one set of facts directly with the next. In human affairs the course of events is more complicated. Not only facts are involved but also the participants' views and the interplay between them enter into the causal chain. There is a two-way connection between the facts and opinions prevailing at any moment in time: on the one hand, participants seek to understand the situation (which includes both facts and opinions); on the other, they seek to influence the situation (which again includes both facts and opinions). The interplay between the cognitive and manipulative functions intrudes into the causal chain so that the chain does not lead directly from one set of facts to the next but reflects and affects the participants' views. Since those views do not correspond to the facts, they introduce an element of uncertainty into the course of events that is absent from natural phenomena. That element of uncertainty affects both the facts and the participants' views. . . . **Reflexivity . . . [describes] a two-way connection between the participants' thinking and the situation in which they participate.** [emphasis added]

> . . . Reflexivity bears some resemblance to Werner Heisenberg's uncertainty principle in quantum physics, but there is one important difference: quantum physics deals with phenomena that do not have thinking participants. Heisenberg's discovery of the uncertainty principle did not change the behavior of quantum particles or waves one iota, but the recognition of reflexivity may alter human behavior.

5.2 Taleb. Dr. Nassim Taleb, an academic and former mathematical trader, catalogues a series of fallacies and errors in judgment, described following, that extend far beyond traditional behavioral finance. I suggest we cannot build accurate models of economic systems without taking these into account.

5.2.1 "Black Swans" and Black Swan blindness. A Black Swan is an event with three attributes: a) it lies "outside the realm of regular expectations and nothing in the past can convincingly point to its possibility;" b) it "carries extreme impact;" c) "in spite of its outlier status, human nature makes us concoct explanations for its occurrence *after* the fact, making it explainable and predictable. . . . Black Swan logic makes *what you don't know* far more relevant than what you do know." (Taleb, 2007: **xvii, xviii, xix**)

Black Swans exist and occur more frequently than we believe. The Great Collapse of 2008 is one. Yet most or all financial and economic models in current use consider the probability of the occurrence of a Black Swan to be once in 10,000 years. We exhibit blindness to the Black Swan because: (Taleb, 2007: **50, 89, 8**)

> We focus on preselected segments of the seen and generalize from it to the unseen – the error of confirmation. . . . We fool ourselves with stories that cater to our Platonic thirst for distinct patterns – the narrative fallacy. . . . We behave as if the Black Swan does not exist – human nature is not programmed for Black Swans [even though] . . . nonlinear relationships in life are ubiquitous. . . . What we see is not necessarily all that is there. History hides Black Swans from us and gives us a mistaken idea about the odds of these events – this is the distortion of silent evidence. . . . We 'tunnel' – that is, we focus on a few well-defined sources of uncertainty, on too specific a list of Black Swans (at the expense of others that do not easily come to mind). . . .
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> [In addition, we are subject to the "Triplet of Opacity."] History is opaque. You see what comes out, not the script that produces events . . . The human mind suffers from three ailments as it comes into contact with history . . . They are: a) the illusion of understanding, or how everyone thinks he knows what is going on in a world that is more complicated (or random) than they realize; b) the retrospective distortion, or how we assess matters only after the fact, as if they were in a rearview mirror (history seems clearer and more organized in history books than in empirical reality); and c) the overvaluation of factual information and the handicap of authoritative and learned people, particularly when they create categories – when they 'Platonify.'

5.2.2 Misperceptions of uncertainty (randomness). There are two types of uncertainty (randomness), e.g. non-scalable and scalable. We tend to confuse them and to consider all uncertainty (randomness) we encounter in finance and economics as Type 1, when, in reality, it is always Type 2. Our quantitative analysis, thus, is misdirected and provides unrealistic results.

Type 1 randomness (non-scalable) Taleb calls *Mediocristan* and describes it as a "utopian province" in which, "[w]hen your sample is large, no single instance will significantly change the aggregate or total." In Mediocristan, what you can know from the data grows as rapidly as the supply of information. Its concerns are focused on physical quantities such as weight, height, calorie consumption, gambling profits, and mortality rates.

Type 2 randomness (scalable) Taleb calls *Extremistan* and describes it as the realm of social matters, in which "inequalities are such that one single observation can disproportionately impact the aggregate, or the total." In *Extremistan*, knowledge grows slowly and erratically at no given rate. Its concerns are focused on informational quantities such as academic citations, wealth, company size, populations of cities, financial markets, commodity prices, economic data. (Taleb, 2007: **32-35**)

5.2.3 "The scandal of prediction." Human beings are prone to "epistemic arrogance, [e.g.,] . . . hubris concerning the limits of our knowledge." This, in turn, affects our ability to make accurate forecasts. The following is a classic example of this shortcoming.

> The most interesting test of how academic methods fare in the real world was run by Spyros Makridakis, who spent part of his career managing competitions between forecasters who practice a 'scientific method' called econometrics – an approach that combines economic theory with statistical measurements. Simply put, he made people forecast *in real life* and then he judged their accuracy. This led to the series of 'M-Competitions' he ran, with assistance from Michele Hibon, of which M3 was the third and most recent one, completed in 1999. Makridiakis and Hibon reached the sad conclusions that 'statistically sophisticated or complex methods do not necessarily provide more accurate forecasts than simpler ones.' . . . [They were also] to find out that the strong empirical evidence of their studies has been ignored by theoretical statisticians. . . . 'Instead, [statisticians] have concentrated their efforts in building more sophisticated models without regard to the ability of such models to more accurately predict real-life data,' Makridiakis and Hibon write. (Taleb, 2007: **154-155**)

5.1.4 "The ludic fallacy." We use games to test reality and to discuss both chance and human response to risk when games and reality exhibit widely divergent types of uncertainty and randomness.

> [Gambling is] sterilized and domesticated uncertainty . . . The casino is the only human venture . . . where the probabilities are known, Gaussian (i.e. bell-curve), and almost computable. . . . Yet we automatically, spontaneously associate chance with these Platonified games. . . . In real life you do not know the odds; you need to discover them, and the sources of uncertainty are not defined. . . . Furthermore, assuming chance has anything to do with mathematics, what little mathematization we can do in the real world does not assume the mild randomness represented by the bell curve, but rather scalable wild randomness. What can be mathematicized is usually not Gaussian, but Mandelbrotian.
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> Now, go read any of the classical thinkers who had something practical to say about the subject of chance, such as Cicero, and you find something different: a notion of probability that remains fuzzy throughout, as it needs to be, since such fuzziness is the very nature of uncertainty. Probability is a liberal art; it is the child of skepticism, not a tool for people with calculators on their belts to satisfy their desire to produce fancy calculations and certainties. (Taleb, 2007: **127-128**)

5.3 Black. Data mining is a common topic within behavioral finance. Dr. Fischer Black takes the radical position that not only does data mining occur from time to time but that it is pervasive and taints much or all of the data used in market decision models and academic studies. (Black, 1993: **9**)

> When a researcher tries many ways to do a study, including various combinations of explanatory factors, various periods, and various models, we often say he is 'data mining.' If he reports only the more successful runs, we have a hard time interpreting any statistical analysis he does. We worry that he selected from the many models tried only the ones that seem to support his conclusions. With enough data mining, all the results that seem significant could be just accidental. . . .
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> Data mining is not limited to single research studies. . . . Data mining is most severe when many people are studying related problems.
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> Even when each person chooses his problem independently of the others, only a small fraction of research efforts result in published papers. By its nature, research involves many false starts and blind alleys. The results that lead to published papers are likely to be the most unusual or striking ones. But this means that any statistical tests of significance will be gravely biased.
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> The problem is worse when people build on one another's work. Each decides on a model closely related to the models others use, learns from the others' blind alleys, and may even work with mostly the same data. Thus in the real world of research, conventional tests of significance seem almost worthless.
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> In particular, most of the so-called anomalies that have plagued the literature on investments seem likely to be the result of data mining. We have literally thousands of researchers looking for profit opportunities in securities. They are all looking at roughly the same data.

Such direct challenges to traditional views of market/investor behavior indicate a need to reassess the effectiveness of extant theory and analysis. While human behavior will remain the same, real options models have the potential for incorporating a broader range of nuances and addressing the kinds of critical fallacies proposed by Soros, Taleb, and Black.

6.0 Revisiting the Fundamentals: Market Theory

This section reviews the basic market theory with the intent of providing a vehicle for disquieting questions, rather than a rehash of common knowledge. A common concept is described, followed by a set of questions that challenge it.

6.1 Market Theory. The "Market" is a term that covers a wide range of theoretical and actual economic systems. Commonly-described market attributes include:

> A "complete" market is one in which all trades can be made using available securities. An "incomplete" market is one in which some trades cannot be made using available securities. Market prices are determined by real people making real trades. Market equilibrium is the state in which all investors have chosen some combination of a market portfolio plus borrowing or lending and face only one source of risk – the performance of the market as a whole. The market portfolio should contain all forms of capital – human, intangible, tangible, and financial. But it does not because it is still too difficult to value anything but tangible and financial capital. (Sharpe, 2004 website) (Nelson, 2005: **27-28**)

Von Mises adds: "The forces determining the – continually changing – state of the market are the value judgments of these individuals and their actions as directed by these value judgments. The state of the market at any instant is the price structure, i.e. the totality of the exchange ratios as established by the interaction of those eager to buy and those eager to sell." (von Mises, 1949: **258-259**)

The markets, thus described, are composed of many classes and sub-classes of agents (market participants), all of which are providing information, making decisions and taking actions that affect market prices. These agents invest in complex quantitative models and information systems to help them scan the globe for opportunities to achieve *alpha* (excess returns) and invest wherever their strategies, research, cultural outlook, and instincts take them.. This means that computers and the algorithms they apply become yet one more form of "agent" influencing market movements.

6.1.1 Markets are efficient. An efficient market is one in which ". . . there are large numbers of rational, profit-maximizers actively competing, with each trying to predict future market values of individual securities, and where important current information is almost freely available to all participants. In an efficient market, competition among the many intelligent participants leads to a situation where, at any point in time, actual prices of individual securities already reflect the effects of information based both on events that have already occurred and on events which, as of now, the market expects to take place in the future. In other words, in an efficient market at any point in time the actual price of a security will be a good estimate of its intrinsic value" (Fama, 1965). (Nelson, 2005: **27-28**)

The following assumptions provide the base for efficient market theory: (a) The information supplied to the market is random and the timing of information supply is independent and random; (b) market participants are profit maximizing and independent of each other; (c) market participants adjust their pricing estimates instantaneously or rapidly to the receipt of new information; (d) such adjustments are unbiased, although they may not correctly reflect the value of the underlying assets; (e) prices embed estimates of both the riskiness of the underlying asset and its value.

To support efficiency, a well-functioning market has four key attributes: 1) accurate and timely information on the price and volume of past transactions and current supply and demand for securities; 2) The ability for investors to buy and sell rapidly at a known price, with prices that are stable from one transaction to the next, barring news that might affect price continuity; 3) informational efficiency that allows prices to adjust quickly to new information; 4) internal efficiency that keep transaction costs low. It is assumed that the ever-increasing insertion of sophisticated, globally-networked information systems into market activities ensures market efficiency.

In contrast, the Austrians describe market efficiency as follows: (Rizzo et al, 1979: **71, 90**)

> Efficiency exists only in relation to certain ends or objectives. . . . Let us take a given individual. Since his own ends are clearly given and he acts to pursue them, surely at least *his* actions can be considered efficient? But no, they may not, for in order for him to act efficiently, he would have to possess perfect knowledge – perfect knowledge of the best technology, of future actions and reactions by other people, and of future natural events. But since no one can ever have perfect knowledge of the future, no one's actions can be called 'efficient.' We live in a world of uncertainty. Efficiency is therefore a chimera.
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> Put another way, action is a learning process. As the individual acts to achieve his ends, he learns and becomes more proficient about how to pursue them. But in that case, of course, his actions cannot have been efficient from the start – or even from the end – of his actions, since perfect knowledge is never achieved, and there is always more to learn.

6.1.1 – Q1. At what point does the exponential growth of real-time information availability and the equal growth in the speed at which transactions can and do take place on a global basis reduce or negate market efficiency and produce unmanageable increases in market noise and, thus, the effects of reflexivity?

6.1.1. – Q2. If the Austrians are right about efficiency, are markets, therefore, "learning systems" rather than machines characterized by "weak form" or "strong form" efficiency? How should this affect market models?

6.1.2 Markets are self-correcting and maintain a continuous state of equilibrium. Thus, market prices properly reflect the values of the underlying assets they represent. Contemporary market theory holds that, while individual agents may violate rational expectations theory and make mistakes, all agents still operate from the same set of assumptions and relationships (i.e., model) and individual deviations from the model will end up converging back to it over time. Yet this view of market equilibrium may not represent reality.

> The forces determining the – continually changing – state of the market are the value judgments of these individuals and their actions as directed by these value judgments. The state of the market at any instant is the price structure, i.e. the totality of the exchange ratios as established by the interaction of those eager to buy and those eager to sell. (von Mises, 1949: **258-259**)

> [F]inancial markets are always wrong in the sense that they operate with a prevailing bias, but in the normal course of events they tend to correct their own excesses. Occasionally, the prevailing bias can actually validate itself by influencing not only market prices but also the so-called fundamentals that market prices are supposed to reflect. (Soros, 2008: **57**)

6.1.2 – Q1. Does market equilibrium, as described in modern finance, exist? How does the notion of continuous change affect the concept of market equilibrium?

6.1.2 – Q2. What if market biases do, in fact, influence the fundamentals that market prices are supposed to reflect? What, then, do market prices represent? How could we more accurately describe the relationship between price and value?

6.1.3 Markets seek and maintain equilibrium by wringing uncertainty out of the system. Again, the Austrians call this concept into question.

> *Uncertainty* conveys the suggestion that there is a determinate future preexisting choice and independent of it, needing only to be found out. If this were all, what meaning could be found in choice, what peculiar mechanism of error and ignorance would destiny be using in mockery of human effort, to bring about its preordained results? It seems plain that if the future merely waits to be revealed, the business of choice is merely a response to signals . . . History is not predetermined, merely waiting to be discovered. Rather, history is continuously *originated* by the pattern and sequence of human choice. (Rizzo et al, 1979: **27, 34**)

> **Profit exists only in a world of uncertainty and disequilibrium.** [emphasis added] (Rizzo et al, 1979: **10**).

6.1.3 – Q1. If we build deterministic models of market functions based on deterministic expectations and then execute those routinely using computers, are the outputs of such models a blatant contradiction to the very essence of human choice and of the continuously originating market environment?

6.1.3 – Q2. If “Profit exists only in a world of uncertainty and disequilibrium,” what roles do risk aversion, risk avoidance and risk mitigation actually play in the investment decision process? How do we model uncertainty and disequilibrium quantitatively?

6.1.4 Markets are populated by "Markowitzian" investors who are governed by rational expectations and risk aversion. In his 1952 paper, "Portfolio Selection," published in the *Journal of Finance,* Dr. Harry Markowitz, Nobel Laureate, developed a set of theories about the functioning of the capital markets that provide the fundamental base for modern portfolio theory. Modern portfolio theory assumes the following about investor behavior: (a) Investment opportunities are viewed by investors as probabilistic distributions of expected returns over a given investment horizon; (b) investors seeks to maximize their expected utility over a given investment horizon and their utility curves exhibit the effects of the diminishing marginal returns of wealth; (c) investors will take on increased risk only if compensated by higher expected returns; (d) risk is defined by investors as the variability of actual returns in relationship to a mean expected return. The variances and covariances of all asset returns are known, as are their expected returns; (e) investors only consider the risk/return attributes of an investment when making decisions. They are indifferent to other characteristics of the distribution of returns, such as its skew or kurtosis.

In addition, investors are governed by rational expectations, i.e. that they take all available information into account in forming expectations. Such expectations may turn out to be incorrect, but they will not deviate systematically from market equilibrium results. Investors also make rational choices, i.e. they choose the best action possible within the stable preference functions and constraints available to them.

Yet these assumptions may not reflect reality. For example,

> Participants are supposed to choose between alternatives in accordance with their scale of preferences. The unspoken assumption is that the participants *know* what those preferences and alternatives are. . . . [T]his assumption is untenable. . . . Nowhere is the role of expectations more clearly visible than in financial markets. Buy and sell decisions are based on expectations about future prices, and future prices, in turn, are contingent on present buy and sell decisions. . . . Anyone who trades in the markets where prices are continuously changing knows that participants are very much influenced by market developments. Rising prices often attract buyers and visa versa. . . . [S]uch trends are the rule rather than the exception. . . . Participants act not on the basis of their best interests but on their *perception* of their best interests and the two are not identical. (Soros, 2008: **54-56**)

6.1.4 – Q. Given that actual investors make decisions based on widely divergent goals, strategies, and concepts of risk, and under market bias influences and information asymmetry, can we be comfortable with Markowitz and neo-classical economics investor assumptions? If we are not, what could we substitute that would be meaningful?

6.2 Modern Portfolio Theory. Modern portfolio theory states that investors have the objective of selecting an *efficient portfolio* of assets, e.g. one that provides the highest expected return for their selected level of risk. Another way of stating this is that rational investors will diversify the assets they hold in their portfolios to optimize portfolio returns and lower/minimize risk. Based on this general investor strategy, risky assets within the portfolios can be priced. Both asset and portfolio returns are random variables that can be analyzed by statistics. Again, variability, or volatility, around a mean is the measure of risk and the measure of return is future (expected) returns. Asset-specific (unsystematic) risk is eliminated from portfolios using diversification. The risk that remains is termed *systematic risk*, or, the risk generated by and associated with the market itself. To measure portfolio performance, analysts depend on market systems being in equilibrium and investor behavior following these and related rules and assumptions.

If, however, market systems and investors do not behave as the classical models predict, our models may play us false. The following discussion regarding deficiencies in traditional performance metrics due to the difference between market realities and classical models highlights such a problem.

> [A]nother possible reason for the lack of impact of traditional performance measures for alternative investments is the fact that such measures are static, and do not capture the dynamic and predictive nature of active investment strategies. Specifically, measures such as alpha, beta, tracking error, and the information ratio are all functions of parameters of the portfolio-return and benchmark-return distributions at a single point in time, e.g., expected returns, covariances, and variances. None of these measures involves the relation between returns at *multiple points in time*, yet such multi-point statistics are often the central focus of active investment strategies." (Lo, 2007: **1**)

6.2 – Q1. Does portfolio diversification truly mitigate all risk except systematic risk? Is it possible to add increasingly risky assets to a portfolio to a level at which the portfolio becomes unstable or takes on the risk attributes of its riskiest assets?

6.2 – Q2. How might we incorporate concepts of real options into portfolio design, thereby incorporating multiple points in time and non-linearity?

6.3 Valuation Theory. There are three baseline approaches to valuing investment assets – Cost, Market, and Income. The one most directly tied to modern portfolio theory is the Income Approach. Simplistically, this approach involves discounting the net benefit stream generated by an asset over a given forecast period and then for a terminal period, using a discount rate (also called cost of capital or rate of return) specific to that asset.

The discount rate is commonly considered a means by which to express the riskiness of the subject asset. The traditional definition of risk in this context equates risk with uncertainty, as follows: risk is the "degree of uncertainty (or lack thereof) of achieving future expectations at the times and in the amounts expected. . . . Inasmuch as uncertainty is within the mind of each individual investor, we cannot measure the risk directly. Consequently, participants in the financial markets have developed ways of measuring factors that investors normally would consider in their effort to incorporate risk into their required rate of return." (Pratt & Grabowski, 2008: **40**) Modern portfolio theory provides the underlying principles used to measure such factors and develop costs of capital.

Even in today's tempestuous post-Great Collapse markets, valuation analysts continue to use the traditional methodologies of developing discount rates, adjusting them slightly for estimated changes in risk premia. The argument supporting this choice is that the underlying data includes data gathered from the Great Depression and/or other consequential Black Swans such as Black Tuesday, 1987. Therefore, it already contains adjustments for massive market corrections.

6.3 – Q1. If the fundamental assumptions underlying estimates of value are flawed, how good or useful will such valuations be? For example: Are risk and uncertainty equivalent? Is there really such a thing as a risk-free rate and should we re-think the ways in which we use it, based on what it may actually represent? Does Beta quantify systematic risk or something else? Can we learn more from the Capital Asset Pricing Model and use it more realistically than it is currently being used, or does it need to be replaced with a model capable of describing a dynamic, non-linear environment?

6.4 Time theory. Market, portfolio, and valuation theory are based on a concept of static market equilibrium, in which a form of time is taken into consideration under the rubric of "discounting to present value" or calculating a "future value." However, time, in this sense, is one-dimensional, linear, and deterministic. The focus of such analyses is on comparison of steady states rather than processes of change. Once again, the Austrian economists challenge this view:

> The notion of time is so primitive and basic an element in man's experience that its neglect by much economic theory constitutes an incredible puzzle. This puzzle is attributable, perhaps, to the almost irresistible lure of formalism – particularly one that cannot adequately handle time. The twin goals of manageability and formalism, then, have transformed the crucial questions that economists ask. So, if we are not careful, the

> question of time is not one which can even be asked. To consider the role of time in economic life, therefore, often requires that we step outside of the conventional models . . . Time, as we shall see, is so intimately connected with every aspect of economic theory that it is only a heroic artificiality that has kept it form occupying center stage. (Rizzo et al, 1979: **1**)
>
> . . .[W]aiting for value over time [i]s a scarce factor of production whose rationing by the interest rate is quite in accord with the logic of a price system. Waiting cannot be measured in purely physical terms, and the amount of it required in a physically specified production process does depend partly on its own price. . . . [However,] interpreting capital abstractly, as waiting, helps to clear up bothersome paradoxes. . . It gives intelligible meaning to such familiar phrases as 'interest on capital,' 'the cost of capital,' 'the capital market' . . . It brings the interest rate within the purview of ordinary theories of supply and demand and of functional income distribution. . . . It helps show what sort of opportunity cost the interest rate measures." (Rizzo et al, 1979: **192, 193, 194**)

As we confront these two divergent views of economic systems and related theory, one static, the other dynamic, we must ask: A*t the end of the day, if many of the assumptions underlying current market concepts are flawed, or out of touch with reality, are we able to use them to model markets and market returns with any accuracy? If we are not, what approach could we use to improve our models?* We suggest that, while real options analysis was conceived out of traditional financial theory and neo-classical economics, it may be able to resolve at least some of these questions.

7.0 Capturing the Value of Uncertainty and Flexibility in Dynamic Systems

Options thinking (e.g. placing a value on uncertainty and flexibility) has played a role throughout time in the world of commerce. It has " . . . a much richer history than is shown in the conventional literature. Forward contracts seem to date all the way back to Mesopotamian clay tablets dating all the way back to 1750 B.C. Gelderblom and Jonker (2003) show that Amsterdam grain dealers had used options and forwards already in 1550. In the late 800s and the early 1900s, there were active option markets in London and New York as well as in Paris and several other European exchanges. Markets, it seems, were active and extremely sophisticated option markets in 1870. . . . There was even active option arbitrage trading taking place between some of these markets. (Haug & Taleb, 2009: **4**)

Options thinking involves implicit consideration of non-linear, non-deterministic, dynamic relationships, change (rather than steady state equilibrium), and the role of time in investment value. With the advent of real options, these considerations have become increasingly explicit.

7.1 Financial Options. Financial options – market-traded contracts granting the buyer the right but not the obligation to exercise the contract terms within a given time – are a form of investment whose value is derived from the value of an underlying asset, in this case, equity securities. The work of economists Robert Merton and Myron Scholes in the early 1970s is generally credited with the explosion of the use of derivatives in modern capital markets. The Black-Scholes-Merton options pricing model is universally used in academic research, business schools, and CFA (and other) training programs, although it is questionable whether it is used by options traders. Valuation analysts also use it in appraising certain balance sheet assets.

The Black-Scholes-Merton pricing model is based on strong assumptions much like those for the CAPM: (a) It is possible to borrow and lend cash at a known constant, the risk-free interest rate; (b) there are no transaction costs; (c) the underlying securities do not pay dividends; (d) all underlying securities are perfectly divisible; (e) equity prices follow a continuous-time stochastic process, under geometric Brownian motion, exhibiting constant volatility and drift; (f) there are no restrictions on short selling. Model variables are: the price of the underlying security; the exercise price of the option; the expiration period; the volatility and drift of the underlying stock price; and the risk-free rate. While this model can be expanded to include changes of drift, volatility, expiration periods and dividend payouts, it remains fundamentally linear and deterministic.

7.2 Real Options. The introduction of options pricing theory into the non-linear, non-deterministic world of "real" assets (v. financial assets) and business investments created the rich field of real option theory and practice. This field has experienced over thirty years of innovation with regards to modifying the linear, deterministic world of capital market theory to fit the realities of business choices and investing. As widely discussed in finance and real options literature, real options analysis faces some noteworthy challenges, as follows: (Nelson, 2005: **18-21**. quoted and paraphrased)

7.2.1 Various parties in a specific transaction/project use different languages and thought processes to develop model inputs and evaluate model outputs. Examples are:

7.2.1.a. Real options are driven by value creation while finance and engineering are driven by risk management, creating difficulties in discussing and developing inputs.

7.2.1.b.Corporations are measured by the markets on predictable growth, while real options analysis estimates value under uncertainty, i.e. the value of strategic flexibility. This means that the client (investor, market) will be looking for one kind of data and value estimate while the supplier (RO analyst) will be providing another.

7.2.1.c.Currently, corporations are tracking performance in excruciating detail on a virtually real-time basis, but not within a strategic context. Real options practice is strategic and should be assessed in that context.

7.2.1.d. Real options analysis is not positioned within the context of normal capital budgeting language, such as IRR and PBP. This creates an aura of inaccessibility for both the analysis and results.

7.2.2 Valuation of the underlying asset is difficult. It is difficult or impossible to replicate the underlying asset for real options analysis by using a market portfolio for such reasons as:

7.2.2.a. It is difficult to develop appropriate estimates of the net present value of cash flows of the underlying assets. Examples: Assets that currently produces little or no cash flow; the changing nature of an organization's weighted average cost of capital (WACC) over time; difficulties in estimating an asset's economic life; forecast errors in estimating future cash flows, due to uncertainty, riskiness, and project complexity; no unambiguous cash flows that can be assigned to a project; diversification, interdependencies, synergies that are hard to identify or quantify but affect value; no means to measure intangible factors, which are often mission critical.

7.2.2.b. It is difficult to develop an appropriate and defensible rate by which to discount the expected cash flows of the underlying asset for the base case. This requires subjective assessment of various risk factors (maturity risk, inflation risk, size risk, non-marketability risk, and so forth) and invites massaging to suitable levels.

7.2.3 Capturing the volatility (risk) of projects is difficult. For example, the risk profiles for the organization and project or asset may differ from each other and also from original estimates over time.

7.2.4 It is difficult to determine how to modify traditional theoretical assumptions to fit real options settings and/or fit real options analysis to traditional theoretical assumptions. The underlying assets of real options do not follow prescribed stochastic processes required for traditional financial options theory to operate. In addition, the theoretical assumptions fundamental to portfolio and options theory are all violated by real options, e.g. 100%

marketability, tradability, infinite borrowing and lending, no taxes, no transaction costs, a perfectly risk-free asset, an arbitrage-free portfolio.

Are these challenges insurmountable? No, they are not. However, overcoming them will require real options researchers and practitioners to continue to push the limits of financial theory or invent new theory. They will have to step outside of comfortable paradigms and learn more effective ways of discussing and presenting their valuable insights. It would be quite appropriate for them to adopt the Austrian School of economics as their contextual platform, leaving neo-classical economics far behind. Simply retrofitting real options analysis to fit the current finance and economics paradigms will not get us where we need to go.

Has this process of enriching and expanding real options theory and practice and pushing the limits of current finance and economics begun? Yes, it has. For example, Drs. Hans Smit and Lenos Trigeorgis, have made a notable contribution by wedding strategic management with corporate finance, using game theory and corporate real options. Smit and Trigeorgis quantify firm total value creation (termed "expanded/strategic" NPV) by summing direct (passive) NPV with the present value of growth options under uncertainty and the value of strategic competition [*Expanded (strategic) NPV = (passive) NPV + flexibility (option) value + strategic (game theoretic) value*]. Their approach allows management to identify and value competitive strategies and strategic moves and manage the firm's portfolio of options as both "an internal value-optimization problem under uncertainty, [and] a strategic game against competitors." (Smit & Trigeorgis, 2004: **87**). This leads us deep into the real world of dynamic markets, firms as ever-changing portfolios of options, and non-equilibrium concepts such as information asymmetry, time and choice (strategy) as value-drivers, and so forth. Smit and Trigeorgis challenge and expand traditional thinking regarding the fit and management of firms within their market/competitive contexts.

Dr. Trigeorgis has also begun to work on problems in human capital strategy using real options theory. Human capital valuation is a mission-critical area that is still virtually uncharted territory, other than the common and incorrect equating of human capital value with its cost. But, something still is missing in the journey toward modeling market systems, including the firm, effectively. This is where we look to real options 'in' engineering systems for an answer.

7.3 Real Options 'in' Engineering Systems. Real options 'in' engineering systems (ROiEnS), the creation of Dr. Richard de Neufville and the ongoing research of his students, has allowed us to move away from linear, path-dependent, and deterministic models entirely and address some of the weaknesses in real options analysis we have already discussed. In addition, real options 'in' engineering systems can be extended to economic systems to model not just market, industry, or firm systems at the macro level but firm, project and portfolio systems design at the micro level. This breakthrough could provide the foundation for new theory regarding the capital markets as dynamic economic systems.

Therefore, we will first review ROiEnS briefly and then apply it to economic systems. To simplify the remainder of our discussion, we will use the acronym ROiEnS for real options 'in' engineering systems and ROiEcS for real options 'in' economic systems.

7.3.1 Basic structure of ROiEnS. Unlike its predecessors that construct a sense of change by layering up successive static equilibria, ROiEnS is based in the concept of dynamic equilibrium. Thus, it is quite distinct from real options, as commonly practiced. The following lengthy quote provides an overview of the basic structure of ROiEnS. We draw on the work of

Tao Wang, whose doctoral dissertation provided a preliminary operating model of ROiEnS using stochastic mixed-integer programming. (von Helfenstein, 2008: **17-19**)

> The design of physical systems, such as large-scale engineering systems, involves identifying and incorporating a vast array of technical constraints (real options "in" the system) that are highly interdependent and path dependent, conditions that are not traditionally considered in calculating the real options value "on" firm projects. An example of such path dependency is the manner in which the power generating capacity of a downstream dam changes when an upstream dam is built. [Wang, 2005: 20]
>
> Traditional deterministic engineering systems design makes use of projected expected values of uncertain parameters, passive recognition of such uncertainties, and a focus on economies of scale. Dynamic engineering systems design of the sort proposed by Wang and de Neufville, considers "sequences of probability functions at multiple points in time," proactive management of the uncertainties, and foci other than economies of scale. [Wang, 2005: 22, 23] More provocatively, Wang also mentions the need to consider "social stochasticity," i.e. the economic and social consequences and uncertainties surrounding large-scale engineering project design, since "[a]ny technical systems are to serve human's needs." [Wang, 2005: 38]
>
> The following describes the context in which dynamic engineering systems design has become a necessity: "Engineering systems are increasing in size, scope, and complexity as a result of globalization, new technological capabilities, rising consumer expectations, and increasing social requirements. Engineering systems present difficult design problems and require different problem solving frameworks than those of the traditional engineering science paradigm: in particular, a more integrative approach in which engineering system professionals view technological systems as part of a larger whole. Though engineering systems are very varied, they often display similar behaviors. New approaches, frameworks, and theories need to be developed to understand better engineering systems behavior and design." [Roos, 1998 from Wang, 2005: 29] Thus, engineering systems design and implementation require the consideration of high degrees of complexity and uncertainty, neither of which is properly captured using traditional, deterministic methodologies. Wang suggests a layered real options model that can address these challenges effectively. . . .
>
> . . . The reason why real options "in" projects are of special interest to the study of engineering systems is that large-scale engineering projects share three major features that are particularly amenable to real options analysis. "They:
>
> - Last a long time, which means they need to be designed with the demands of a distant future in mind;
> - Often exhibit economies of scale, which motivates particularly large construction;
> - Yet have highly uncertain future requirements, since forecasts of the distant future are typically wrong.
>
> "This context defines the desirability of creating designs that can be easily adjusted over time to meet the actual needs as they develop." [Roos, 2004 in Wang, 2005: 107] Only

some form of real options analysis could capture and quantify the flexibility required by such systems.

7.3.2 Modeling RoiEnS. ROiEnS contends with the same set of "garbage in – garbage out" data issues and human fallacies and biases as all other models. What is appealing about its approach is that it incorporates the flexibility of the real options problem structure into a three-stage "design" space endogenous to the system under consideration. In this way, the analyst can use his imagination and logic to sort through large sets of path-dependent variables to identify those most relevant and useful to the system and build systems designs from the "inside out."

> . . . [T]he distinction between real options "on" systems (as traditionally computed) and real options "in" systems must be understood. Real options "on" systems "treat the technology as a black box," i.e. offer no consideration of or insight into the inner workings of the systems/projects they are valuing. [Wang, 2005: 106] Real options "in" systems consider the inner workings of system/project design to identify and provide flexibility (i.e., options) from the inside out. (von Helfenstein, 2008: **18**)

The following is a simplified description of the three-stage design model suggested by Wang. (von Helfenstein, 2008: **19-21**)

> The top layer of Wang's approach is a screening model that answers the question: Which of the many options that present themselves in an engineering system are "most important and justify the resources for further study? The engineering system he uses as his test case is a dam building (i.e., water resources planning) project.
>
> "The screening model is established to screen out the most important variables and interesting real options (flexibility). The screening model is a simplified, conceptual, low-fidelity model for the system. Without losing the most important issues, it can be easily run many times to explore an issue, while the full, complete high-fidelity model is hard to establish and costly to run many times. From another perspective . . . we can think of it as the first step of a process to reduce the design space of the system." [Wang, 2005: 138] The screening model involves simplifying assumptions such as allowing all sub-projects to be built at once and removing the stochasticity from all variables being explored (in this case, water flow and the price of electricity). If an important aspect of the project has been simplified in this manner, it should be studied in depth later, after the screening model is complete. In cases in which feedback exists in the system, the screening model must take it into account in order to ensure accurate results.
>
> The screening model uses non-linear programming to perform sensitivity analysis on key system parameters. Once optimal designs have been identified for each set of parameters, they are reviewed and compared for real options that are both "good" for all sets and also conducive to optimal value creation.

The next layer in the overall model is a high-fidelity simulation model, through which the selected candidate designs are put. "Its main purpose is to examine, under technical and economic uncertainties, the robustness and reliability of the designs, as well as their expected benefits. . . . This process leads to refinement of the designs identified by the screening model." [Wang, 2005: 140] Standard water resource planning simulations use historical records to simulate stochastic variation in water flows. Wang's model simulates both water flow and economic uncertainties in order to fully understand the role economies of scale should play, or not play, in the final design.

Once the most promising real options in the project design have been identified, these options must be valued so that a primary strategy and related contingent strategies may be set. Wang suggests "recasting [a standard binomial lattice] in the form of a stochastic mixed-integer programming model [in which the binomial tree is maximized] subject to constraints consisting of 0-1 integer variables representing the exercise of the options (=0 if not exercised, =1 if exercised." [Wang, 2005: 141, 142] "[S]uch reformulation empowers analysis of complex path-dependent real options 'in' projects for engineering systems.

"Technical constraints in the screening model are modified in the real options timing model. Since the screening and simulation models have identified the configuration of design parameters, these are no longer treated as design variables. On the other hand, the timing model relaxes the assumption of the screening model that the projects are built together all at once. It decides the possible sequence of the construction of each project in the most satisfactory designs for the actual evolution of the uncertain future." [Wang, 2005: 152]

To assist those readers who do not have an expertise in the kinds of programming used in this analysis, Wang provides the following descriptions: "Mathematical programming studies the mathematical properties of maximizing or minimizing problems, formulates real world problems using mathematical terms, develops and implements algorithms to solve the problems. Sometimes mathematical programming is mentioned as optimization or operations research. . . . Stochastic programming is the method for modeling optimization problems that involve uncertainty. . . . In stochastic programming, some data are random, whereas various parts of the problem can be modeled as linear, non-linear, or dynamic programming. . . . A mixed integer programming problem is the same as the linear or non-linear problem except that some of the variables are restricted to take integer values while other variables are continuous." [Wang, 2005: 39, 40, 41, 42] One deficiency of stochastic mixed-integer programming is that it is difficult to tell if the result is a global or a local optimum. However, Wang maintains that the solution provided by this computational methodology, while it may be a local rather than a global one, is superior to the solutions offered by traditional methodologies or human intuition. In addition, once the problem is programmed, it can be executed easily and rapidly on an ordinary laptop computer.

Rather than using increasingly complex mathematical models to attempt to capture system complexity and path dependencies, this approach suggests using sophisticated computer modeling techniques to simplify the design space throughout the analysis process, making it more transparent with each successive layer. In addition, this approach does not tie system analysis and design to specific stochastic models but allows for flexibility.

If we accept the assumption that engineering systems and economic systems have much in common and are therefore mutually amenable to this approach, it appears that some or all of the quantitative shortcomings that plague modern capital market theory and practice could be overcome. The basic structure of these theories might remain the same, but the assumptions, modeling, and insights would take place very differently.

7.4 Real Options 'in' Economic Systems. As we contemplate applying ROiEnS to problems in market systems and the related theory, we must ask ourselves whether the engineering systems it currently addresses are remotely like the capital markets in terms of complexity, dynamics and reach. Perhaps the design of airport systems, a current application of ROiEnS, will provide an answer.

While we do not have the expertise to address the specifics of airport systems design at a granular level, at a macro level we suggest they are as complex an engineering system and nested set of microcosmic economic systems as can be imagined. They include a breadth of stakeholders and systems participants with competing needs and requirements that may equal or exceed that of the capital markets. Industries, firms, individual investors, and the public must be taken into consideration. The intrusive effect of government/regulatory "risk" pervades airport functionality as it does that of the capital markets. Both are airports and capital markets are dynamic, open systems, presenting complex, path-dependent problem sets. Both problems sets bounded, not infinite. It, thus, seems logical that a real options model that can be applied to the former may also be usefully applied to the latter.

To more closely examine the application of ROiEnS to economic systems, we will review several of the issues and questions posed in earlier sections of this paper. Our first task, however, is to define economic systems and, then, markets as economic systems.

7.4.1 Economic systems. Economic systems can be defined as follows. (von Helfenstein, 2008: **22-23**)

> As with engineering systems, economic systems come in many sizes and forms. They can be as large as the global marketplace, a national economy, an industry, or a firm. They can be as small as a family unit, though no smaller since any system requires more than one agent to exist. Similar to other systems, economic systems are governed by explicit and implicit rules that affect all agents within the system in varying ways. The kinds and combinations of rules in a particular economic system allow it to be put into general system categories such "capitalism," "market," "oligopoly," or "start-up." As with engineering systems, discussion and management of economic systems requires consideration of "social stochasticity," i.e. the social consequences and uncertainties surrounding decisions and initiatives.
>
> Economic systems are open, complex, and adaptive – living. If they are not, they may be kept on life support but eventually they will die (as in the demise of the Iron Curtain) or rupture open in an unmanageable chaos of birthing (as with the hyper-capitalism being born out of that closed system, the People's Republic of China). Why? Because economic systems are created by and built upon open, complex, adaptive, living biological systems called human beings and life must beget life.

7.4.2 Markets as economic systems. While the following description (von Helfenstein, 2008: **29**-30) was originally intended to describe firms as economic systems, it is equally relevant to markets as economic systems.

> The [market] . . . exhibits all the attributes of a complex adaptive system. (1) It is a network of many agents acting in parallel, in an environment produced by the interactions of all agents on each other, and in which system control is highly dispersed. (2) It has many levels of organization, with agents at one level serving as building blocks for agents at a higher level, and in which the system is constantly revising and rearranging building blocks as it adapts and gains experience. (3) It anticipates the future by constantly making predictions based on its internal models of the world, its implicit and explicit assumptions of the way things are within the system. (4) It has many niches being exploited by agents adapted to fill each niche. The very act of filling a niche opens up more niches, creates new opportunities. Therefore, the [market] is never in equilibrium because it is always unfolding, always in transition. . . .
>
> . . . As an open, complex, adaptive system, the [market] maintains a state of homeostasis – one of the most remarkable and typical properties of highly complex open systems. A homeostatic system maintains its structure and functions by means of a multiplicity of

> dynamic equilibriums rigorously controlled by interdependent regulation mechanisms. Such a system reacts to every change in the environment, or to every random disturbance, through a series of modifications of equal size and opposite direction to those that created the disturbance. The goal of these modifications is to maintain the internal balances. In a sense, the [market] as an open system in homeostasis will be in a state of 100% information and risk . . . This state corresponds to Dr. Stephen Wolfram's complexity theoretic universality class IV, the edge of chaos, the state in which "[o]rder and chaos intertwine in a complex, ever-changing dance of submicroscopic arms and fractal filaments' and life originates." (Nelson, 2005: 35-36)

7.4.3 Applications of ROiEnS to economic systems. We have demonstrated that dynamic engineering and economic systems have much in common and that traditional static system models and design methods may no longer be useful. Since applications of ROiEnS to economic systems are still at the conceptual level, we will suggest a number of potential applications that could address some of the questions we posed in Sections 4-6 of this paper.

7.4.3.a Reflexivity. We do not want to use ROiEcS to exclude the effects of reflexivity from market models but, rather, to include them and examine the ways in which reflexivity needs to be described and addressed in market model design. This notion may not be possible to implement due to path dependencies and circularities, but it would be well worth further research since ROiEnS is capable of handling design problems with path dependencies.

7.4.3.b Black Swans. While current market models have no means by which to include the existence or impact of Black Swans, the ROiEcS three-layered design space may be able to do so. Black Swans could be simulated and their impact considered a critical element of all market systems model design.

7.4.3.c Efficient market theory. Perhaps, using ROiEcS, market model design might become capable of considering a range of information efficiencies (including a complete lack of efficiency) drawn from the level of firms or industries, as well as or instead of, from the global market. This might provide richer insights into portfolio/market risk.

7.4.3.d Market equilibrium and rational expectations. ROiEcS may allow us to represent dynamic equilibrium or disequilibrium rather than static equilibrium; open up ways to describe the pattern and sequence of human choice rather than viewing choice as a mere "response to signals;" and enable us to explore the role of imagination v. predetermined expectations as model inputs.

7.4.3.d Modern portfolio theory. Perhaps further research using ROiEcS will open the door for us to successfully relax the strong assumptions of modern portfolio theory; reconsider (and possibly reconfigure) the use of diversification in portfolio design, based on fresh insights into risk and return; and build better investment performance metrics.

7.4.3.e Pricing models, and valuation. Could ROiEcS be used to develop richer, more realistic pricing models? Would this, then, allows investors to more accurately integrate price with value? It seems that if ROiES can be used successfully for market, firm, and portfolio model design, it could also be used for asset pricing and valuation models.

7.4.3.f The role of time. If ROiEcS were to be used to create next generation models for markets, portfolio management, and even cost of capital estimates, the capabilities of the suggested programming tools would allow for a richer investigation into and representation of the effects of time on value.

Whether such applications of ROiEnS to market economic systems are realistic or possible to implement remain to be discovered through further research and design. However, one critical input is deficient and/or lacking for ROiEnS or any other effort to build new models of dynamic economic systems. It is raw data. The data from which we currently develop estimates of individual firm risk and value is not optimal for our common models and will not be sufficient for the proposed new ones. Sub-corporate finance attempts to address this deficiency.

8.0 Sub-Corporate Finance

During a project focused on bringing capital market concepts to the "market" of network-centric warfare, it became clear that complexity theory could be applied to finance in a way that would provide more transparency regarding the value of organizational processes, intangible and knowledge assets, and the organization itself. Since the resulting data and related analyses would be developed from within (i.e., endogenous to) the organization, rather than by reference to exogenous entities and forces, I called it sub-corporate finance.

Concepts of sub-corporate finance are still in their infancy. Its core proposition was developed in the early 1990s by Dr. Valery Kanevsky (mathematics) and Dr. Tom Housel (computer science) to solve a practical problem in valuation, e.g. the inability to assign "value," or benefit streams, to processes within the organizational structure, making organizational design and process reengineering difficult or impossible. Simplistically, the core proposition states:

1. Organizational human capital and information technology take inputs and change them into outputs through core processes. The value added to the organization by core processes is proportionate to the amount of change required to produce process outputs. Therefore, if we can identify a common unit of measure by which to count the amount of change required to produce process outputs we will also be able to quantify the value added to the organization by process outputs by assigning benefit streams to such units.

2. Complexity theory establishes a relationship of proportionality between units of change, units of complexity, and information bits. Since information bits can theoretically be observed and counted, we can use bits or their reasonable proxy as the common unit by which to measure the change required to produce process outputs.

While the details of how these units of change are determined are not pertinent to this paper and while operationalization of the core concepts has not yet been successfully achieved, the data required to populate sub-corporate finance models is abundant and readily accessible, making the insights it provides amenable to empirical testing. Sub-corporate finance allows us to propose certain important revisions to modern portfolio theory that may assist ROiEcS in the tasks previously assigned to it.

8.1 Fundamentals of sub-corporate finance. Ludwig von Mises states, "Human action is purposeful behavior. Or we may say: Action is will put into operation and transformed into an agency, is aiming at ends and goals, is the ego's meaningful response to stimuli and to the conditions of its environment, is a person's conscious adjustment to the state of the universe that determines his life." (von Mises, 1949: **11**) Another way of stating this is that the universal activity of humans is changing "inputs" into "outputs." This is true of investing as well as all other human activities.

Complexity theory indicates that change creates Kolmogorov Complexity (and its equivalent, information), where Kolmogorov Complexity is the universal product, a universal measure of changes in the form of matter, and a universal property of matter as well (Housel and Kanevsky, 1998).

Entropy is the term that describes the reduction of energy to a state of maximum disorder in which each individual movement (activity) is neutralized by statistical laws. Left to itself, an isolated system tends toward a state of maximum disorder, i.e. higher probability. Boltzmann stated, "In an isolated system, the system will evolve to its most probable state, that is, the one with the most homogeneous probability distribution," (e.g. the Law of Large Numbers). In a state of homogeneity (or, highest entropy or uncertainty), we have no indication at all to assume that one state is more probable than another.

Information is a probabilistic measure of reduction in uncertainty (entropy). The following formula, developed by Claude Shannon, expresses the probabilistic relationship between entropy and information, for all possible states 1 . . . *n* :

$$\mathrm{H}(x) = -\sum_{i=1}^{n} p(i)\log_2 p(i)$$

Where:

H	=	Entropy
x	=	A discrete random event
p	=	Probability distribution
i	=	Outcome

H is maximized if all states are equi-probable (a state of homogeneity), since when there is no pattern, there is no information and entropy and information are opposites. H is 0 if $p(i) = 1$, since the system is in a state of maximum certainty or complete information.

Randomness, entropy, probability, and uncertainty are equivalent terms. Their opposites are pattern, complexity, information, and certainty, which are also equivalent terms.

Since the most basic activity of humans, technology, organizations, and industries is change, economic systems of all kinds can be viewed as open systems that can: (1) Exchange raw inputs (substance, information, or energy) with the environment; and (2) change the structure of raw inputs into outputs (final products/services). This structural change is described in terms of the way process "*P*" structures input "*a*" to be output "*b*." It creates a series of proportionalities in which the ΔE (change in entropy, uncertainty) ≈ $K(y|x)$ (conditional Kolmogorov complexity) ≈ bits ≈ common units of process change.

Sub-corporate finance chooses to define "common units of process change" in terms of the knowledge assets of the company and notates them K_μ. The K_μ related to process *P* are the value added by *P* and, because they are common to all processes in all organizations, they can be monetized.

In investing activities, we could call process *P* a "transaction" that structures input *Asset A* into output *Asset B*. The structural change that occurs during a transaction *T* involves a change in uncertainty (entropy, Kolmogorov complexity) as *Asset A* undergoes a state transformation to become *Asset B*. The monetization of this change in uncertainty from *Asset A* to A*sset B* is what we commonly call "return on investment." It is also the value added by transaction *T*.

If we look at traditional concepts of risk and return from the perspective of complexity theory, *risk* is no longer equivalent to uncertainty. It becomes a descriptor for the *change in uncertainty* ($\Delta\Phi$) related to the state transformation of *Asset A* into *Asset B* via *T*. As such, it is a rate and is composed of two elements: (1) *volatility*, the magnitude of change in uncertainty; and (2) *growth, or, drift*, the direction of change in uncertainty. Using this way of thinking, an expected return (i.e., expected $\Delta\Phi$) for the state transformation of *Asset A* into *Asset B* via *T* becomes the benchmark against which to assess and match risk (i.e., actual $\Delta\Phi$).

This decoupling of risk and uncertainty is helpful because it makes sense out of what we already know about them, e.g. that the band of uncertainty (probability, randomness) regarding *T* outputs increases over time, while the level of risk estimated for the underlying asset may remain the same throughout the period.

If we apply the proportionalities we just described, and we agree that risk is the actual change in uncertainty ($\Delta\Phi$), risk and K_μ are also proportionate to each other. This implies that measuring the process outputs of the organization in common units, K_μ, is equivalent to measuring the risk of the organization, linking risk measurement *directly* to the knowledge assets of the organization. Extending this thought further may provide beneficial insights into organizational value, perhaps relieving us of dependence on educated guesswork using exogenous benchmarks and variables. It might also more properly represent the reasoning of investors in the markets. Finally, if we could populate a ROiEcS model with better quality data that was abundant, accessible, and tied risk to the "genes" of the firm, we might have some helpful avenues from which to improve our thinking about economic systems.

9.0 The Obstacle of Computational Complexity

Computational complexity is a very real obstacle to the further exploration and proposed utilization of ROiEcS.

> The question we must ask ourselves again is whether it is preferable to make increasingly complex, sequential, and subjective adjustments to various traditional model variables in order to attempt to capture market, portfolio, and firm complexity or to explore and build complex computational models that can be run on an average laptop computer and embed the ability to investigate the effects of all variables simultaneously. The former eventually leads us so deeply into a maze of informed professional judgment that we lose all sense of reality concerning the specific economic system we are creating or evaluating. The latter, while requiring the use of informed professional judgment in structuring the rules by which the programming models are built, might allow us to explore large design/valuation spaces while minimizing the role of subjectivity and/or speculation.
>
> Simple, deterministic computations built on convoluted estimates and opinions, or complex, dynamic computations built on simple rules and judgment calls? That may be the choice facing us in this matter. (von Helfenstein, 2008: **34**)

10.0 Where do we go from here and why does it matter?

ROiEcS could provide a way of thinking and a method of quantitative analysis that could change how we build portfolios, invest, create investment vehicles, assess the value of investments. It is not a magic bullet, any more than real options *on* projects is. Its use involves a willingness to rethink market relationships at a fundamental level and step out of comfort zones. We would be required to consider the influence of time, imagination, intangible assets and synergies in our valuations and our choice-making. The exciting part is that ROiEcS appears to be up to the task, where familiar theory, approaches and methods have us locked into a closed, linear, deterministic, time-free box.

There may be other theoretical and mathematical models and approaches that would work as well. However, real options analysis is one that so nicely configures with the way human beings think about the world. This, alone, puts ROiEcS far in advance of approaches that require highly specialized education and training. Utilizing data from deep within the economic system of the firm, grounded in its intangible assets, and thinking of risk in a new way might also beneficially enhance the use of ROiEcS.

10.1 What needs to be done? Much. (a) A great deal of rigorous empirical research must be performed. There is an abundance of data at all levels of the economic systems that must be investigated and analyzed. (b) The real options frameworks by which to structure the problem must be developed, along with any new theory necessary to support it. (c) Programming models need to be built. The level of programming sophistication available in universities and on “The Street” is enormous. So, the talent is there. (d) Other forms of modeling and analysis also need to be considered, such as agent-based modeling and the use of evolutionary algorithms.

10.2 Why does it matter? As a part of the research underlying this paper, we investigated two extreme edges of the global economic system: a) the causes and proposed cures of poverty in the developing world; and, b) the causes of the collapse of complex societies throughout history.

There are markets in the developing world, and entrepreneurs seeking profits at the micro level. So much entrepreneurial potential and underground wealth remains unlocked. Yet, it seems as though the society and economic systems that have provided the basis for the greatest wellbeing for the broadest citizenry in history are about to collapse. In addition, for a century or more, the West has tried its own formulas on developing nations. Those formulas have been based on concepts of equilibrium, neo-classical economics, and financial theory that do not fit the cultures, complexity, chaos, and dynamism of the hidden markets in these nations. Our policies, our theories, and our money have not worked there.

We must step outside of our comfortable paradigms to listen and learn. While real options analysis is just a humble tool to be used in the service of commerce, it is also a tool that requires listening and learning, a different way of approaching familiar problems. ROiEnS was developed with an eye toward what it calls "social stochasticity," or the social effects of engineering projects. Why could its application to economic systems not only help restructure economic/capital market theory in the developed world to make it more sustainable but also provide a tool to help unlock the mystery of capital for marginalized people elsewhere?

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References – Of Special Note

The following white paper and debate, found on a website populated by the thinking of some of the most innovative minds around the globe, indicate the importance of the issues and concepts I have discussed herein. The progress of the Economic Manhattan Project should be followed by the finance community as a part of its ongoing research initiatives.

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